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Call for Papers

The 1981 International Seminar of the International Society of Air Safety Investigators will be held at the Hyatt Regency Hotel in Washington, D.C.
September 29 - October 1, 1981

The theme of the seminar will be:
"Investigation Techniques:
Back to the Basics"
(Presentations on other topics will be considered)

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

Ira J. Rimson
4507 Wakefield Drive
Annandale, VA 22003
Phone: (703) 978-2944

Abstracts must be received by April 30, 1981.
Final papers will be required by August 15, 1981.

The Jerome F. Lederer Award

The award is given for outstanding contributions to technical excellence in accident investigation. Not more than one award will be made annually and presentation is at the ISASI Seminar. The recipient is selected by an ISASI Board of Award.

Any ISASI member may submit a nomination for this award. It must be sent to the Chairman of the Board of Award not later than 15 May 1981, and must include a statement describing why the nominee should be considered. This statement should be sufficiently descriptive to justify the selection but no more than one typewritten page in length.

This award is one of the most significant honors an accident investigator can receive, and so considerable care is given in determining the recipient. Each ISASI member should thoughtfully review his or her association with professional investigators, and submit a nomination when they can identify someone who has really been outstanding in increasing the technical quality of investigation.

Mail to: **David S. Hall**
Chairman, Board of Award, ISASI
8202 E. Vista
Scottsdale, AZ 85253

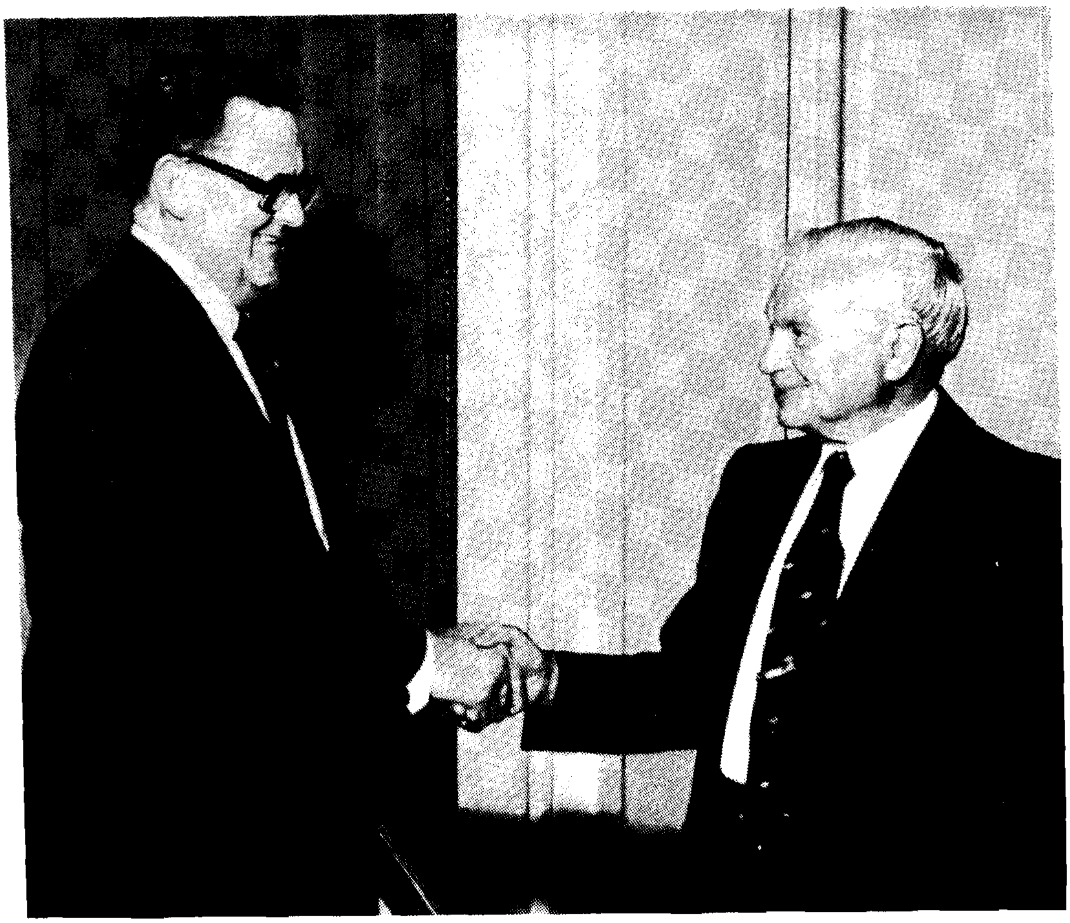
THE JEROME F. LEDERER AWARD

1980
presented to

JOHN GILBERT BOULDING, MBE

for

Outstanding Contributions to Technical Excellence in Accident Investigation



Mr. Boulding has completed nearly 40 years of service with British Airways, much of which has been devoted to accident investigation and prevention. He has achieved a remarkable span of experience in accident investigation covering all types of civil transport aircraft, and he has become one of the world's most respected airline accident investigators.

As Chief Air Safety Investigator - an appointment which he has held since 1966 - he leads a team of investigators who cover all aircraft types operated by British Airways. He is an exceptionally successful investigator whose skill, determination, imagination, and persistence have invariably brought forth the cause of accidents and, more importantly, brought about the changes necessary to improve safety.

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

President-elect John McDonald discusses "problem-solving"

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Recent Observations Of Volcanic Ash In Oil Sump Spectrographic Analysis

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From the time that Mount Saint Helens first erupted, we have received a flood of information about the ash that was produced. Some of this information has been rather confusing and not a little bit conflicting. However, in nearly every report there has been one common phrase: "The ash is highly abrasive."

Sometime after the first eruptions, I received a small amount of the ash sealed in a plastic package. Since the plastic was transparent, I was able to look at it and shake it, but I never unsealed the package so that I could touch the ash. Looking at it, it appeared to be a dark talcum powder and it even flowed like a talcum powder would. Nothing from its appearance or action gave a hint to its true abrasiveness.

Sometime later we obtained a bigger sample of the ash in a glass jar. At this time I was able to actually feel it. When I rubbed a small quantity between my finger tips I finally understood what the earlier reports meant by the word "abrasive."

Now the real possibilities of internal damage to aircraft engines became a major concern to me. In order to have you understand my concern, I have provided each of you with a small sample of the ash in the jar in front of you. If you have not felt it before, I suggest you take a little out of the jar, but be very careful because it is a dust, and feel the abrasiveness.

Any time I think of internal wear in an engine, I immediately think of the benefits of spectrographic oil analysis. This started me wondering—what have been the results of oil analyses on engines exposed to the ash? We thought that the members of ISASI would be interested also.

Since spectrographic oil analysis is still not a universally understood procedure, I think it would be well first to give you an explanation of the procedure. To do this I have obtained a few slides from a large oil lab named Wear Check. Another lab, Analysts, Incorporated, have sent their Regional Sales Manager, Gordon Brindley, who will be available following the presentation to answer any of your questions.

First, I would like to give you a very brief history of spectrographic oil analysis. We commonly refer to it as S.O.A. Some companies refer to it as S.O.A.P., Spectrographic Oil Analysis Program. We use all kinds of abbreviations. For our purposes today, I like the term "SOAP." Spectrographic oil analysis really got started in the early '40s when the United States railroads started to go to electro-diesel engines, particularly the Rio Grand Railroad. When that railroad put the electro-diesel on its line, it started to have a lot of problems with bearing failures. Ray McBride, an engineer with the railroad, began experimenting to find ways to prevent the bearing failures. Working with the different metal alloys from the bearings, he wanted to track the rate at which the bearings were wearing. Hopefully, this could forecast the time of failure so that the item could be replaced prior to that. The main piece of equipment was a spectrometer which could identify different metallic elements in a sample of oil by burning it. McBride correctly assumed that since the metal worn from the bearing must still be floating around in the engine crank case oil, by burning a sample of that oil he could identify and quantify those metals. It worked. This was back in 1947. By 1952 over 50 railroads were on a continuous sampling program. The news of the success spread rapidly and very shortly the military picked it up. I think it all started with the United States Navy. I recall in 1963 standing in Navy New York Operations to file a flight plan. As I was filling out the necessary forms, I heard the dispatcher talking to the Flight Operations Officer, reporting that he had just received a call from Base Maintenance. Maintenance had asked that a certain twin-engine airplane be kept on the ground. They had just received a call from their oil lab and were told that the number 2 engine on that aircraft was expected to fail in the next couple of flight hours due to a bearing burning out. The Operations Officer looked at the flight status board and very sadly said, "That's too bad; it's already been out for an hour and a half." It was too late. By the time I finished filling out the flight plan, there was a call from the control tower notifying operations that the airplane in question was returned to base with number 2 feathered. Later I found out it was a bearing failure exactly as forecast. I was impressed. I have been impressed ever since with what spectrographic oil analysis can do. With that background, let me give you a quick rundown on the spectrographic oil analysis program.

Preventive maintenance in the aviation industry is very important, not only because maintenance lowers costs and equipment last longer, but most important, the safety factor is increased. The A&P Mechanic needs all the tools and knowledge available when making the decision to sign off the engine logbook as AIRWORTHY. Of all the tools available to him, a good SOAP program can provide more advance warning of impending problems than any other single tool when used in conjunction with proper inspection procedures.

The concept is simple: WEAR CAUSES PARTICLES; THESE PARTICLES CAN BE SEEN AND THEY CAN BE IDENTIFIED. When "Wear Metal" is mentioned, the first vision that comes to mind is that of shiny, visible metal that is sometimes seen in the oil screen or in the paper elements of a filter cut open for inspection. This size metal is generated after the wear problem is in its well advanced stages. The size particles trapped by the screen are in the 5,000 to 7,000 micron range. Oil analysis "tracks" the metallic wear rates by measuring the metal produced as small as 2-3 microns, which is the size of bacteria.

Let's look further at the basics. The most common causes of premature engine overhaul or failure are of the progressive damage type. In other words, they don't fail instantly as in fatigue failures. The wear pattern is accelerated gradually by one of the three factors that wear an engine out: corrosion, abrasion and scuffing. These three items, with the exception of a rare design problem, are generally caused by contamination of some sort created largely by engine operations which create damaging elements such as carbon, water, acid, partially burned fuel, varnishes and lacquer. Contamination unchecked causes damage with the major cause of aircraft engine damage being dirt. Plain simple dirt—not only the most common element on Earth (Silicon) but also the most damaging. Approximately 44% of all engines overhauled or topped prematurely are worn out or failed by direct ingestion through the air intake system. Studies by AVCO Lycoming, reprinted from a bulletin, show an engine can be ruined to the point of overhaul by only one tablespoonful of dirt.

Wear problems, of course, are not confined to the cylinder area but spread, creating excessive metal wear throughout the engine. If we knew this wear was occurring and could identify the contaminants, we could find the problem and stop it in its minor stages, therefore preventing failure and greatly increasing the safety factor. That's where SOAP exhibits its value as a predictive maintenance tool. SOAP monitors the rate of metallic wear and establishes trends for each engine. The problems are evidenced by changes in these trends. Each engine has its own "wear pattern" with no two engines being exactly alike, even though they may be on the same aircraft and manufactured at the same time.

All normally operating engines go through their life following the same general pattern. In the first stages or break-in period of the engine's life, exposed metals, those that wear against other parts, exhibit higher rates of wear as a result of "wearing down" the honing marks, flashing and other "rough" areas of the new engine. Wear decreases as engine hours increase until the engine is completely broken in. Then wear rates level off and continue at a "baseline" rate until the final hours of an engine's life. At that point we see a steady increase in the wear rates because clearances have increased to where "slap" of the parts breaks through the oil film. Analysis should then be increased to every 50 hours until the need to overhaul is evident. This "Bath Tub" curve is characteristic of the engine life wear pattern we want to occur. Oil analysis is the monitoring device used to let us know when the pattern changes when it shouldn't.

An example uses Iron to demonstrate the metal wear, and Silicon to show dirt, representing the abrasive catalyst that caused the change. The iron line will exhibit the desired wear pattern until midpoint in engine life, at which time the Silicon level increases as a result of air filter failure. Silicon, being an abrasive, accelerates the iron level. The oil analysis performed at the oil change period will show both the abnormal dirt and the resulting abnormal wear. Now the problem is evident and can be corrected. Of course we would have eventually been made aware of the problem, but not until after the wear had created a loss of power, drop in compression and expensive damage to the engine.

AVCO Lycoming has used SOAP for over 20 years as a tool to aid them in the development of new engines. A bulletin was issued to make the aircraft mechanics and aircraft owners aware of their feeling on the subject. Limited time prevents us from reading the entire bulletin, but the highlights point out that "Oil Analysis does not replace other maintenance techniques," that the most important aspect of oil analysis is safety.

Now that we have covered the basics on why SOAP is used, let's talk about how, especially in the field of aviation. The first step is to purchase a kit from one of the laboratories. The cost will be about $15.00 or $20.00, which will cover all the costs of analysis and a phone call if a serious problem is detected. The kit itself consists of a two-ounce bottle, some packing to absorb shock and leaking oil, a mailing box and, most important, the information form which must be filled out completely. This asks for pertinent information about the engine make and model, hours on the engine and oil, and any overhaul history. This is very important as a diagnosis of the laboratory data cannot be made without it. Of equal importance is the sampling procedure instruction which explains how to sample and warnings not to allow outside contamination of the oil. What is needed is a representative sample of the oil from the crankcase taken while hot so all wear metals and contaminants are in suspension.

The lab will perform a series of laboratory tests in two categories, including emission spectrometer measurement and physical and chemical tests. The wear metal portion of your report is the spectrometric measurement of the wear metals in the oil. For example, Aluminum may be 2, meaning there are two parts in a million parts of oil. An "N" notation means that the amount of Aluminum is normal for this particular sample. Chromium may be 8 ppm, the "A" indicating an Abnormal amount. Iron may be 62 ppm, "S" meaning Severe. Silicon (dirt) may be 17, also Abnormal.

These elements are measured by a direct reading emission spectrometer. It is a machine that operates on the principal that each of the 103 elements known to man has an atomic structure that "transmits" on a different frequency and, when burned, produces light of different colors, some of which we can't see. For these elements to emit "light energy" of their own frequency, they must be burned at approximately 4,000 degrees F. To accomplish this, a small sample of oil is inserted into the spectrometer. A very high voltage AC spark is applied generating the necessary heat. The sample and all elements then create photon energy. The energy created by this burning is focused by a lens onto a refracting grid inside the machine. This grid refracts the light much like a prism. When the focused "light energy" bounces off this grid, it is divided into the respective frequencies of each element and directed toward the other end of the spectrometer. Here very sensitive photo multiplier tubes are arranged at exactly the point where the frequency of each element appears. Just like on a radio dial, the same elements, like radio stations, are at the same spot "on the dial" every day. These photoelectric cells report the amount of energy to the computer which converts it into parts per million.

The completed report includes the written diagnosis which tells you, in short, simple terms:

1. If you have a problem;
2. If so, the level of severity;
3. The probable cause;
4. Recommended maintenance action.

During diagnosis is when the engine and oil information filled in on the sample form is considered. For instance, if there are 500 hours on the engine it tells the diagnostician the engine should be wearing in the normal section of the bathtub curve wear pattern. In the previous example there are only 11 hours on the oil. 62 parts per million of iron would be normal if the oil hours were 50, but with only 11 hours, 62 ppm is too much metal generated in that period of time. Therefore, the iron content is classified as "S" = Severe. The diagnostician's experience in this type of engine led him to report a possible broken ring. The Chrome is from the rings. The iron is from rings and cylinder walls, and the abrasion is being produced by the abnormal dirt, indicating a leak in the air induction system. Reports will be of varying appearance from various laboratories. We just have to make sure that the laboratories have experience in aircraft engines.

As I said earlier, with that background in Spectrometric Oil Analysis and having visited many labs, I was greatly concerned with what the labs are finding from the volcanic ash. I contacted three major commercial laboratories here in the United States. I went a little further and contacted the United States Army at Ft. Lewis, Washington, which had aircraft in the Mount St. Helens area for an extended period of time. Now we get to the current news for the day. I expected to find major problems being reported by the oil labs as a result of aircraft operating in this environment. I am extremely happy to report to you today that all of the laboratories, the three major civilian laboratories and the military lab at Ft. Lewis, report no major problems to date. Please note that I qualified it when I said "to date." All of us agree that somewhere down the road we expect trouble. We really expect trouble inside the engines. But as of today we don't have it. The FAA has been out with a lot of directives, and the operators have been extremely careful. They've done everything they can to prevent damage to their aircraft. Those that are on oil analysis programs are sampling now more than ever. The oil labs are watching them closely. We've done a lot of study and it's just wonderful to be able to say we haven't had any major problems at this time. The Army men that were up in the Mount St. Helens area for an extended period of time took great care to protect their machinery; they even wrapped parachutes around their helicopter rotor heads when they were on the ground overnight and around their tail rotor gear boxes and other parts to keep that dust out. It was so bad that all of them that were in the area wore out their combat boots from the abrasiveness of the ash. I was a bit surprised to learn that the Army was so concerned that they even replaced the boots for their people free. I never heard of that in my time. I thought that you had to buy them.

The FAA is coming out now with their latest General Aviation bulletins, and they are recommending that all aircraft operating in the area be placed on a spectrometric oil analysis program if they are not already on one. They are recommending sampling at about every 50 hours. 25 hours is just great, 100 hours is a little bit too long at this time, so 50-hour sampling is ideal. The ash itself, as you have already felt, is extremely abrasive. We're not going to get into a chemical analysis, although there are several chemicals in it. It is acidic, it has sulfuric acid in it, and it has a high iron content. Any lab working with the ash should be aware of what the metallic content of the ash is so that they can give a proper analysis of what is happening inside the engine. One last point, as an accident investigator, I think that it's extremely important that whenever we have an accident that involves an engine failure of any type, the investigator should ascertain if that aircraft has been or is on an oil analysis program. If so, you should then request the reports and analyze them to see what the internal history of the engine has been as far as wear is concerned. It can mean a lot to an investigation. With that I close. Thank you.

The General Aviation Fixed-Wing Accident And The Emergency Locator Transmitter,

A Follow Up Report

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At last year's seminar, the author presented a paper on the study being done for NASA on aircraft crash damage and the ELT. This paper is a summary of the results of that study, and the data base which exists as a result of that effort. The complete report is titled "Systems Analysis of the Installation, Mounting, and Activation of Emergency Locator Transmitters in General Aviation Aircraft" and will be available through the National Technical Information Service.

INTRODUCTION

The Emergency Locator Transmitter (ELT) is a small, relatively inexpensive radio transmitter with a self-contained power supply, designed to transmit a characteristic signal on 121.5 and 243.0 MHz in the event of an aircraft crash. These units have been in military use since the mid 1950s, and have been required on most general aviation aircraft since 1974. They are required to have a means of automatic activation in the event of a crash, and are built to meet a Technical Standard Order (TSO) of the Federal Aviation Administration (FAA). This TSO (C91) was issued after Congress mandated the installation of ELTs as part of the Occupational Safety and Health Act (OSHA) of 1970.

The ELT is supposed to provide notification of and homing to an aircraft accident site, whether there are survivors or not. The Search and Rescue (SAR) community has found the ELT to be their greatest help as well as their greatest headache. The problem is that these units have very poor reliability, both as to the problem of false alarms and the failure to transmit a useable signal after the crash.

The National Aeronautics and Space Administration (NASA), as part of its effort to use space for the benefit of mankind, has established a Search and Rescue Satellite Program (SARSAT), designed to overcome several of the major shortcomings of the existing ELT system. These include providing a relatively continuous listening watch over the widest possible area, position fixing of received signals, and potential improvements in the transmitter units. This program covers both ELTs and maritime Emergency Position Indicating Rescue Beacons (EPIRB).

The SARSAT program includes the development of new transmitter electronics, operating at 406 MHz and transmitting a digital signal to the satelitte, as well as 121.5 MHz homing signal for ground and air search. This study is part of the effort to improve the aircraft ELT unit, to increase to probability of transmitting a useable signal to the satellite and reduce the probability of false alarms.

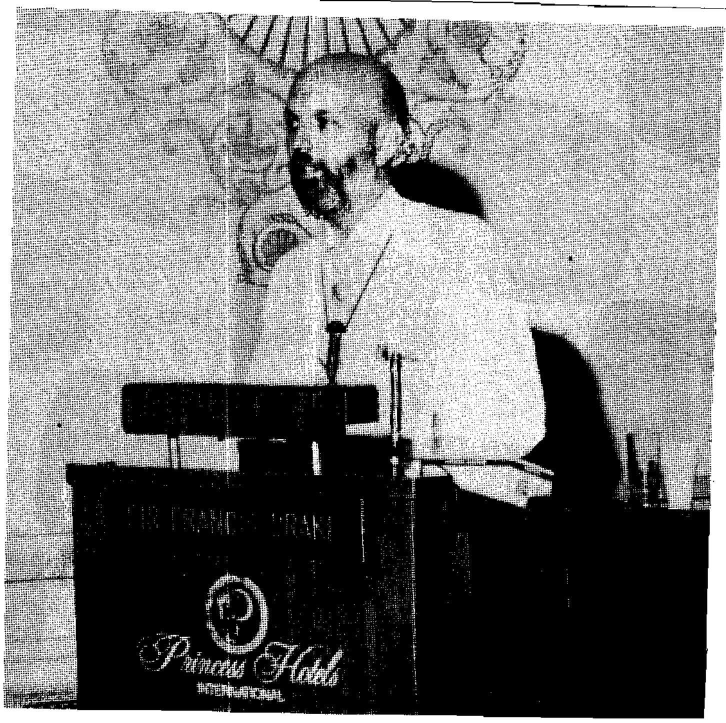
As part of this development effort, the Crash Research Institute (CRI) was tasked with studying the installation and mounting of ELT units as it related to the crash environment. The result has been the Crash Research Institute SARSAT Information System (CRISIS) data base.

The computer data bases now in existence for civil accident date (U.S., Canadian and ICAO, for example) do not contain any significant damage data. For the most part they are limited to a single entry (i.e. Destroyed, Substantial, Minor, None). In order to create a data base with the highest potential for having good data available, the CRI study was narrowed to the following type accidents:

a. Fixed-wing, general aviation aircraft under 12,500 pounds gross weight.
b. U.S. fatal accidents occurring during 1977.
c. Canadian fatal and serious accidents occurring during 1976, 1977 and 1978.

This group of accidents is the source of the CRISIS file. Within this file, the BASIC group is a random sample with respect to cause, ELT data, location in North America and quality of investigation. It is not random as to severity, but represents the most severe accidents only. The CRISIS data base contains about 90% of the U.S. accidents and almost 100% of the Canadian accidents that were reported and investigated for this time and accident injury group. The balance of the files were unavailable for study.

Some accident files are includes which were recorded by the government as fatal due to injuries to personnel outside the aircraft, apart of the formal definition of an aircraft accident. These cases are not included in the BASIC group, since only cases with an "injury index" of Serious or greater are part of BASIC.



The term "injury index", as applied to this data base means an assigned code for sorting based on the following definitions:

FATAL = All occupants of the aircraft died

FATAL WITH SURVIVORS = At least one occupant died and at least one occupant survived

SERIOUS = No occupant died, but at least one had serious injuries

Injuries and deaths to persons outside the aircraft were not considered in assigning these codes.

In addition, two other subcategories of cases were obtained:

1. SAR Group, U.S. accidents for 1976, 1977 and 1978 where the U.S. Air Force Rescue Coordination Center (RCC) reported the ELT aided in the search.
2. Canadian cases for 1976 through 1978 where ELT data was available, regardless of injury.

DATA COLLECTION AND DATA BASE

Encoding of Accident Data. Accident data was placed in the CRI SARSAT Information System (CRISIS) data base in machine readable form through the following process:

1. A data encoding form was developed.
2. A researcher analyzed the original government files including:
   a. Original data collection forms.
   b. The narrative report.
   c. The photographs.
3. The research quantified and transcribed this data onto the encoding forms.
4. The data on these forms was encoded in machine readable format and placed in the CRISIS data base.

The bulk of the data collection effort was the interpretation of the photographic and narrative record to describe the aircraft damage in much greater detail. The aircraft was divided into twelve zones as shown in Figure 1, plus main gear, nose or tail gear, and each engine and propeller. Each zone or component was described by the Location, Deformation and Attitude codes shown in Table 2.

While a large number of data elements were obtained, only the search data and damage data called for analytical judgment by the researcher. All the rest of the data that was obtained was taken directly from the narrative or accident report form.

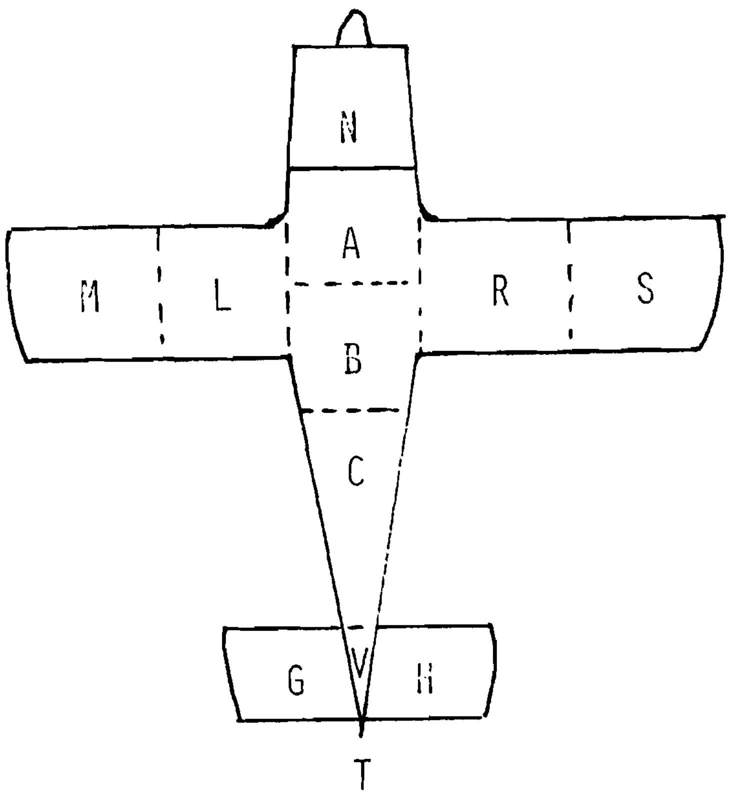
Confidence in the Data. Although the CRISIS data contains 1135 files and the BASIC set is 916 files, some questions may exist as to how representative these data elements really are. The quality of investigation by the original field investigators is unknown; therefore, some error is possible due to carelessness or poor investigation. The damage data was taken from photos wherever possible, and

Table 1

TOTAL DATA BASE CONTENTS BY INJURY, COUNTRY, AND YEAR

Injury Index	Country	C.Y. 76	C.Y. 77	C.Y. 78
Fatal	U.S.	23	469	27
Fatal	Canada	52	53	55
Fatal w/surv.	U.S.	4	108	9
Fatal w/surv.	Canada	18	12	8
Serious	U.S.	3	3	2
Serious	Canada	55	48	38
Minor/None	U.S.	8	9	8
Minor/None	Canada	51	59	13

BASIC Group in Boxes



N. Nose--comp or engine/fwd of cabin bulkhead
A. Cockpit--instrument panel to back of first seat
B. Cabin--back of first seat to rear cabin bulkhead
C. Aft fuselage--tail cone from bulkhead to L.E. of horizontal
T. Tail cone aft of horizontal
R. Right wing from fuselage to mid-wing
S. Right wing mid to tip
L. Left wing from fuselage to mid-wing
M. Left wing mid to tip
H. Right horizontal
G. Left horizontal
V. Vertical tail and tail cone below it

Figure 1

AIRCRAFT ZONES

from narrative descriptions when necessary. Canadian files generally have many photos as specific requirements have been established. No similar photographic requirement exists in the U.S., and over 180 cases, not counting those where wreckage was not recovered, have 3 or fewer photos of the wreckage.

In order to minimize the effect of missing data, calculations of percentages in the damage tables were made as percent of cases with data in the given field. This is based on the assumption that the absence of photos or data was random with respect to damage, and that the sample obtained was representative of all similar accidents. Damage data tables at the back of this paper are extracted from the basic study report and retain their original table numbers.

Table 2

CODES FOR DATA COLLECTION FORM

LOCATION CODES

0 Unknown
1 Continuity of structure back to section A
2 Attached to next inboard section, but not back to A
3 Almost separated, most structural continuity gone
4 Separated completely

DEFORMATION CODES

0 Unknown
1 Basically undamaged, minor dents and tears
2 Major dents, tears but still in near normal shape
3 Crushed/distorted/crumpled
4 Destroyed, pieces separated
5 Buried in wreckage/dirt/debris

ATTITUDE AT REST (PITCH AND ROLL)

1 ± 30 degrees of upright/normal attitude in both pitch and roll
2 30 degrees - 90 degrees from normal in pitch or roll
3 90 degrees from normal (inverted)

Computer Analysis. A computer data storage program was developed, along with specialized data analysis routines for this study. The data base is organized in files. Each file represents an accident and is identified by a four-digit file number, which is the primary access number for any file. If a particular file is needed, and the file number is not readily known, the brief print can be reviewed by aircraft type, registration number or government file number.

The data base is identified for study by four overlapping subsets:

ALL = All files

BASIC = The random group of severe accidents previously defined

SAR = Those identified by RCC as having ELT help in finding the aircraft

ELT = Those in which the ELT was recorded as aiding in the search in the accident file itself.

Each file is individually coded as to whether it is in the BASIC or SAR group, and an injury index is appended as described above. An NTSB or Canadian source code is also provided.

During the early phase of the study planning, a review of the general aviation fixed-wing fleet was prepared to facilitate analysis of groups of aircraft having similar characteristics that would relate to crash dynamics. Specific "type codes" were assigned to these groups and the number of aircraft in each category are shown in Table 3.

RESULTS OF STUDY

The General Aviation Fixed-Wing Accident. Since the BASIC file constitutes a random set of accident cases from the viewpoint of ELT data, location in the U.S. and Canada, and quality of investigation, it should give a valid representation of the major general aviation fixed-wing aircraft accident. They are considered major accidents in this report only due to the recorded level of occupant injury.

The composite picture that emerges from this BASIC summary has a number of interesting features:

1. Ground fire occurred in 22% of the cases, but did not usually involve the whole aircraft. The empennage was least often involved, being burned in only 9% of these BASIC accidents. Almost all the fires were associated with fatal accidents.
2. Inflight breakup occurred in 6% of the accidents, all of which involved fatalities.
3. Inflight fire occurred in 10 cases (1%), 9 of which were fatal.
4. Nearly one third of all the aircraft came to rest inverted. About one-half were upright within 30 degrees of normal.
5. Six percent of the aircraft were not recovered, most often because they were underwater.
6. The cockpit was severely damaged (Deformation codes 3-5) in 82% of the cases, the cabin in 76%, and the nose section in 91%. The nose was undamaged in only 2% of the cases.

Fatal Accident Comparison in the BASIC File. Table 7.14 (appended to this paper) shows the damage data for the BASIC subset "Fatal", meaning that all occupants of the aircraft received fatal injuries. The injury index "Fatal With Survivors" includes all accidents where at least one occupant was killed and at least one occupant survived the accident. This data is in Table 7.17 for BASIC. A comparison of the "Fatal" and "Fatal With Survivors" groups (Tables 7.14 and 7.17) clearly shows the more severe nature of the accidents with no survivors. For a summary of this data, see Figures 2 and 3. However, it also confirms the well known fact that it is possible to survive an accident that does severe damage to an aircraft. About 20% of the habitable areas were "destroyed, pieces separated" and yet someone lived through it. Fire also occurred about 17% of the time, compared to 27% in fatal cases, but the sections damaged are similar. Final attitude at rest is also similar.

In comparing the two national groups of fatal accidents, fire occurred in 30% of the U.S. fatals and 23% of the Canadian fatals, but empennage involvement is similar in both groups. Damage levels overall are more severe in the Canadian case; engines and propellers separate more often, and twice as many aircraft end up inverted. However, 11% of the U.S. accidents involve inflight breakup of the aircraft, and only 4% of the Canadian cases have this finding. There were a number of inflight fires in the U.S. data, none in the Canadian.

Comparing the "Fatal With Survivors" on a national basis again shows the Canadian accidents are more severe; fire occurs twice as often and more aircraft end up inverted. Table 7.38 is for the BASIC accidents with ground fire, which includes 22% of the BASIC set. The destruction of the aircraft is very severe, with only 2% of the cockpits and cabins, and 4% of the nose sections remaining in near normal shape. Only 23% of the aft fuselage sections were still near normal, and half of the vertical and horizontal tail surfaces were in near normal shape. (See Figure 4). All but 13 of these accidents involved fatalities, and 4% were preceded by inflight fire. The wings separated and were heavily damaged in about 85% of these accidents. The overall damage level is more severe than the set of fatal accidents, but the aircraft were upright a little more often.

Only one of the commuter-type aircraft (Codes G and H) was involved in fire on the ground, and this was a very localized fire. The percentage of ground fire for the remaining type code groups is shown in Table 4. Fire seems to be a

Table 3

NUMBER OF CASES BY TYPE CODES

TYPE CODE	CHARACTERISTIC	EXAMPLE	NUMBER OF CASES ALL	BASIC
A	Very light/home built GW ≤ 1200#	Pitts	37	33
B	Light utility/trainer Metal structure, 2-4 place	Piper Cub C-150	282	225
C	Cabin class, single eng. unpressurized	C-172	607	482
D	Cabin class, single eng. pressurized	TP-210	0	0
E	Cabin class, twin unpressurized	C-310	102	83
F	Cabin class, twin pressurized	C-421	21	19
G	Commuter 10+ pass. unpressurized	DHC-6	10	7
H	Commuter 10+ pass. pressurized	Metro	1	0
J	Unusual configurations, agricultural, wooden structure, biplane rear engine, etc.	Ag Cat C-337	70 (7 twin engine)	64

major problem in the pressurized twins. Table 5 shows ground fire involvement by aircraft type code and aircraft section.

Ground Contact and Final Rest Data. The data collection form provided a pictorial example for coding the aircraft attitude in pitch, roll and yaw at ground contact and final rest. This is difficult to determine, and experienced investigators will often disagree on the meaning of specific evidence. However, the Canadian form provides for this data and it was established for the U.S. data, whenever possible, by the researcher from narrative, witness or photographic evidence. Since it related to "whole body" position, it is more accurate for ground contact and less representative for final rest since the aircraft may be broken into many pieces.

Only 50% of the BASIC file had ground contact data, and 59% had final rest data. This data shows that about one-third of the accidents occur at near normal flight attitudes of wings within 30 degrees of level and nose level within 10 degrees. Nose-high attitudes are rare, but another third dive into the ground. Ground contact inverted is rare, but final rest inverted is quite common.

Data is also available to analyze impact kinematics. For example, 156 aircraft hit the ground with 30 degrees or less of roll and +10 and -10 degrees pitch. However, 243 air-

Table 4

FIRE DATA BY AIRCRAFT TYPE CODE

AIRCRAFT TYPE CODE		GROUND FIRE %	INFLIGHT FIRE %
A	Very light/home built	21	0
B	Light utility/trainer	16	0
C	Cabin class, single engine, unpressurized	21	0
E	Cabin class, twin, unpressurized	29	5
F	Cabin class, twin, pressurized	53	21
J	Unusual configurations	39	0

Table 5

GROUND FIRE INVOLVEMENT
BASIC SET BY AIRCRAFT TYPE CODE
DATA AS % OF CASES WITH FIRE

	Aircraft Type Code					
Aircraft Zone	A	B	C	E	F	J
Cockpit	100	97	84	68	64	72
Cabin	86	97	84	68	91	72
Nose	86	95	71	68	55	72
Aft Fuselage	86	78	60	52	55	52
Rt. Inbd. Wing	100	89	65	76	45	60
Rt. Otbd. Wing	86	54	38	60	27	52
Lt. Inbd. Wing	86	78	63	76	73	64
Lt. Otbd. Wing	86	57	38	76	45	52
Rt. Horizontal	71	59	29	28	45	40
Lt. Horizontal	86	57	31	28	36	40
Vertical	86	54	30	28	36	44

craft ended up in this position, including 72 from this group of 156. An additional 25 of the 156 ended up nearly inverted, and the rest were distributed in many other attitudes.

GENERAL CONCLUSIONS

The following general conclusions regarding the general aviation fixed-wing accident are applicable to the question of ELT system reliability:

1. Nearly one-third of all aircraft came to rest inverted.
2. Ground fire occurs in 22% of the cases, and in 56% of the cases where the ELT is destroyed.
3. The ELT is destroyed in about one-quarter of all fatal accidents.
4. When it is installed and activation status is reported, the ELT activated in about 62% of the fatal accidents, 69% of the fatal with survivors accidents, nearly 80% of the serious accidents and about 57% of the minor/none injury accidents.
5. In fatal accidents, the aircraft section least likely to be destroyed and separated into pieces is the vertical tail, but it is destroyed 16% of the time and crushed/distorted another 16% of the time. Almost the same condition is true of the horizontal tail surface.
6. In fatal accidents, the nose is undamaged in only 1% of the cases, the cockpits in only 2%. The prop is unbent in 2% of these cases. In serious accidents, the nose is undamaged in only 3% of the cases. In fatal with survivors cases, the nose was undamaged in 7% of the cases.
7. No ELT is installed in about 8% of the aircraft that are required by law to have them. Overall installation data shows ELT units in 82% of all aircraft, regardless of requirement.
8. Antenna cable disconnection and antenna breakage are important, although low percentage, causes of failure to transmit usable signals. However, a number of cases of final homing were done on units with no antenna.
9. In about 7% of the accidents where a search is required, the aircraft was underwater.
10. Initial alerting occurred in about half of the situations where the ELT aided in search. This indicates that the total system (transmitter, detection receiver and homing receiver) is less than optimum. The SARSAT program should dramatically change this situation.

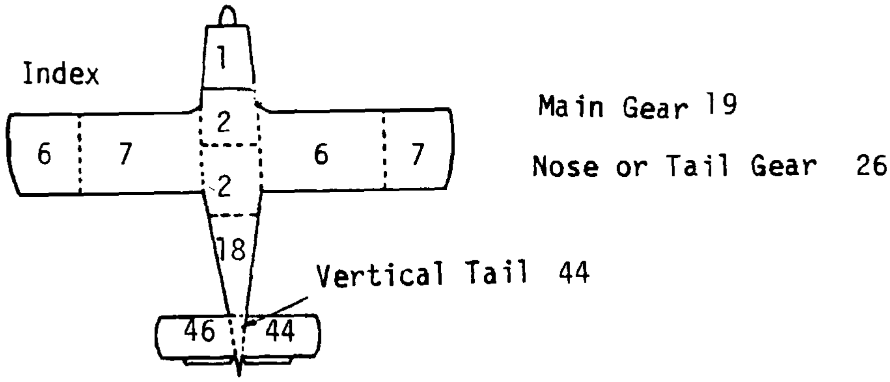
The CRISIS data base is now being used in ELT packaging and sensor design, and is available to answer other questions regarding the General Aviation Fixed Wing accident. The author will be glad to discuss your data needs or the contents of the basic report.

About the Author

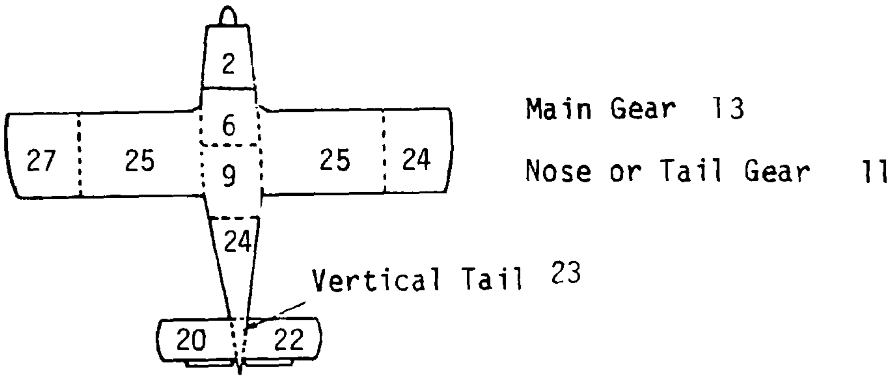
Dave Hall was Senior Product Safety Specialist for a general aviation engine manufacturer. He taught Aviation Safety and Accident Prevention at USC for four years, and now is affiliated with CRI in their NASA research. He also teaches at the Engineering Safety Center at Arizona State University and is involved in private consulting work in mishap prevention and mishap investigation. He is a PE (Safety) in California, and a member of SAFE, International Society of Air Safety Investigators, AIAA, System Safety Society, and Society of Flight Test Engineers. He holds an Airline Transport Pilot Rating and is an active general aviation pilot.

SECTION DAMAGE

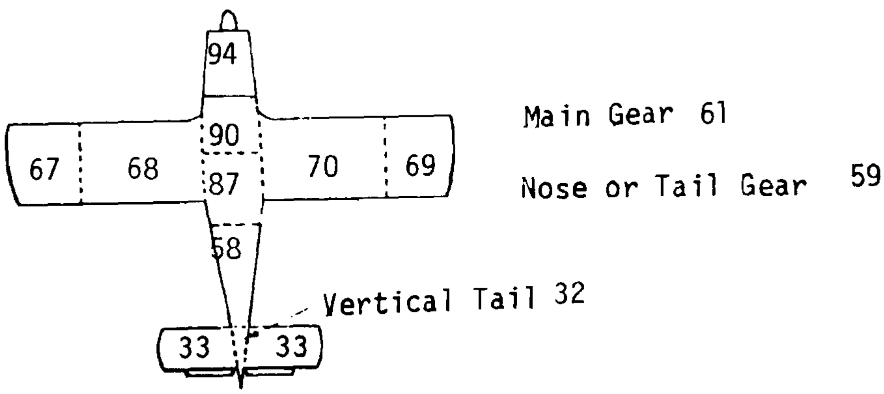
DATA SET:
BASIC, Fatal Index
Ref:
Table 7.14



% of aircraft where section indicated was basically undamaged (Code 1)



% of aircraft where section was dented or torn (Code 2)



% of aircraft where section was at least crushed (includes destroyed)(Codes 3 & 4)

Figure 2

DAMAGE DATA

	Involved in Fire (% of total with fires)	Location Data: % of total cases with data in "Location" code box 1	2	3	4	Deformation Data: % of total cases with data in "Deformation" code box 1	2	3	4	5	Final Attitude Data: % of total cases with data in "Attitude" code box 1	2	3
COCKPIT	82	-	-	-	-	2	6	48	42	2	52	20	27
CABIN	84	36	0	30	34	2	9	48	39	2	52	20	28
NOSE	75	23	0	38	39	1	2	52	42	3	51	21	28
AFT FUS.	61	39	4	21	35	18	24	34	24	0	51	22	27
TAIL CONE	26	35	17	16	33	38	7	25	30	0	59	20	21
RT INBD WING	71	30	0	17	53	6	25	41	29	0	53	22	26
RT OTBD WING	49	27	24	10	39	7	24	43	26	0	52	21	27
LT INBD WING	68	28	0	20	52	7	25	41	27	0	51	21	28
LT OTBD WING	51	27	28	9	36	6	27	42	25	0	51	20	28
RT HORIZONTAL	39	40	30	6	24	44	22	16	17	1	51	19	30
LT HORIZONTAL	41	40	30	6	24	46	20	16	17	0	50	19	30
VERTICAL	40	41	28	9	22	44	23	16	16	0	51	18	31
MAIN GEAR	46	34	9	16	41	19	13	37	24	8	-	-	-
NOSE/TAIL GEAR	43	33	7	21	39	26	11	32	27	4	-	-	-
ENG #1	64	18	1	30	52	6	21	44	23	5	46	22	32
ENG #2	-	9	7	13	70	5	18	50	26	2	60	7	33

DATA SET: BASIC Group
Fatal Injury Index

No. of Cases: 629
U.S. 75 %
In Flight Breakup
56 ; 9 %
Ground Fire Cases
168 ; 27 %
In Flight Fire Cases
8 ; 1 %

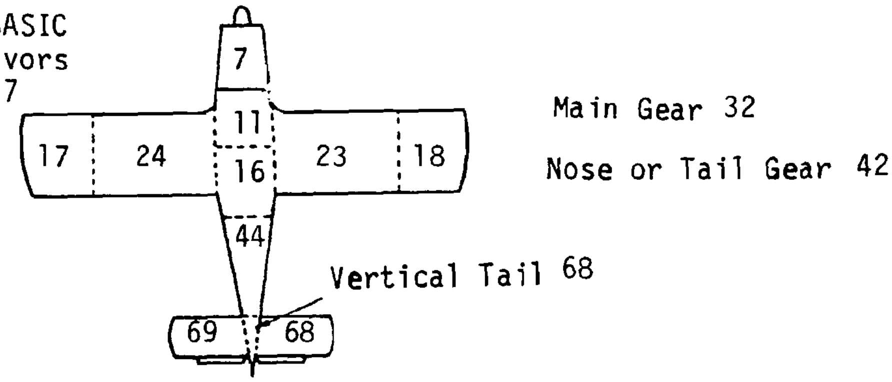
	Involved in Fire	Location 1	2	3	4	Deformation 1	2	3	4	5	Bent Yes	Bent No
PROP #1	-	15	28	6	52	3	21	50	16	9	98	2
PROP #2	-	7	36	2	56	2	13	53	29	4	98	2

TABLE 7.14 A

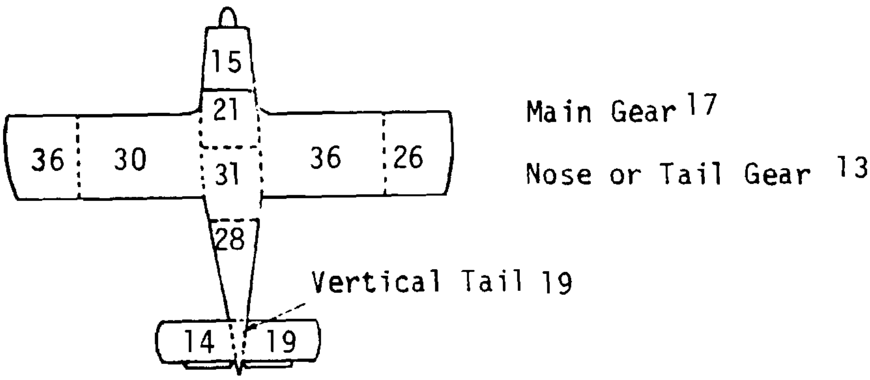
CRI REPORT 7846-14

SECTION DAMAGE

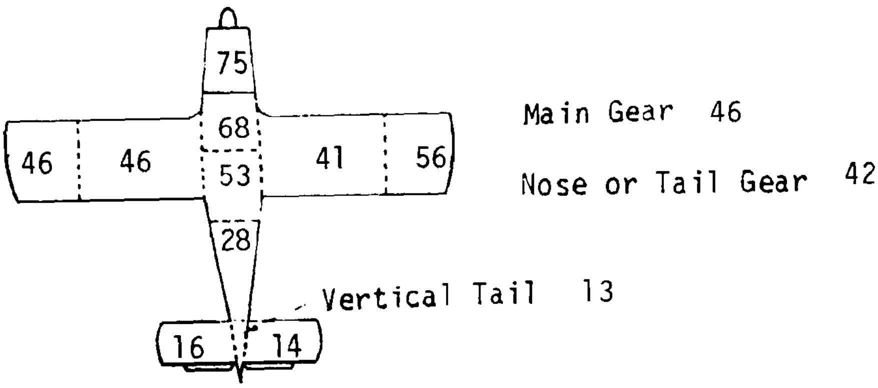
DATA SET: BASIC
Fatal with Survivors
Ref: Table 7.17



% of aircraft where section
indicated was basically
undamaged (Code 1)



% of aircraft where section
was dented or torn (Code 2)



% of aircraft where section
was at least crushed (includes
destroyed)(Codes 3 & 4)

Figure 3

	Involved in Fire (% of total with fires)	Location Data: % of total cases with data in "Location" code box 1	2	3	4	Deformation Data: % of total cases with data in "Deformation" code box 1	2	3	4	5	Final Attitude Data: % of total cases with data in "Attitude" code box 1	2	3
COCKPIT	80	-	-	-	-	11	21	45	23	0	47	20	33
CABIN	80	73	0	9	18	16	31	34	19	0	47	20	33
NOSE	64	42	0	30	28	7	15	49	26	3	47	21	32
AFT FUS.	64	70	2	10	17	44	28	17	11	0	43	22	35
TAIL CONE	16	71	14	2	12	76	13	4	7	0	56	12	33
RT INBD WING	68	50	0	17	34	23	36	39	12	0	48	25	27
RT OTBD WING	36	42	29	5	24	18	26	46	10	0	49	24	27
LT INBD WING	68	48	0	15	37	24	30	31	15	0	41	27	32
LT OTBD WING	44	43	33	2	21	17	36	35	11	0	41	28	30
RT HORIZONTAL	36	66	16	2	16	68	19	8	6	0	45	22	33
LT HORIZONTAL	32	66	19	1	14	69	14	10	6	0	44	23	33
VERTICAL	28	69	17	3	10	68	19	8	5	0	44	22	34
MAIN GEAR	36	48	6	7	38	32	17	32	14	4	-	-	-
NOSE/TAIL GEAR	28	49	7	17	26	42	13	29	13	3	-	-	-
ENG #1	64	36	1	27	35	20	33	28	13	6	47	21	32
ENG #2	-	25	17	8	50	27	36	36	0	0	40	0	60

DATA SET: BASIC Group, Fatal With Survivors

No. of Cases: 146

U.S. 74 %

In Flight Breakup 1 ; 1 %

Ground Fire Cases 25 ; 17 %

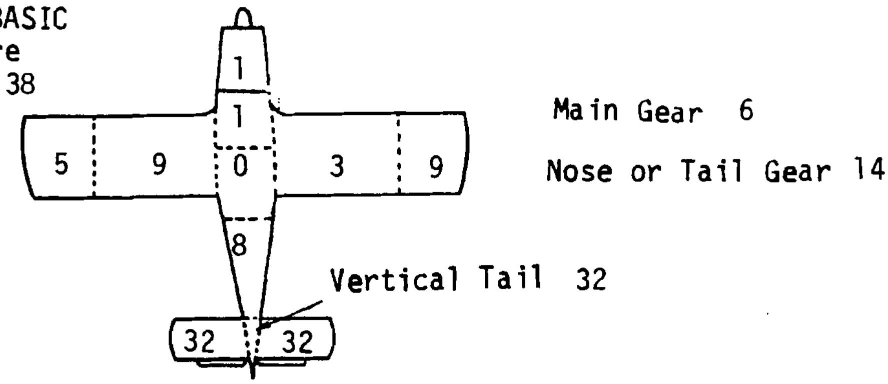
In Flight Fire Cases 1 ; 1 %

	Involved in Fire	Location 1	2	3	4	Deformation 1	2	3	4	5	Bent Yes	No
PROP #1	-	44	24	4	28	19	27	42	6	6	89	11
PROP #2	-	40	50	0	10	30	10	60	0	0	89	11

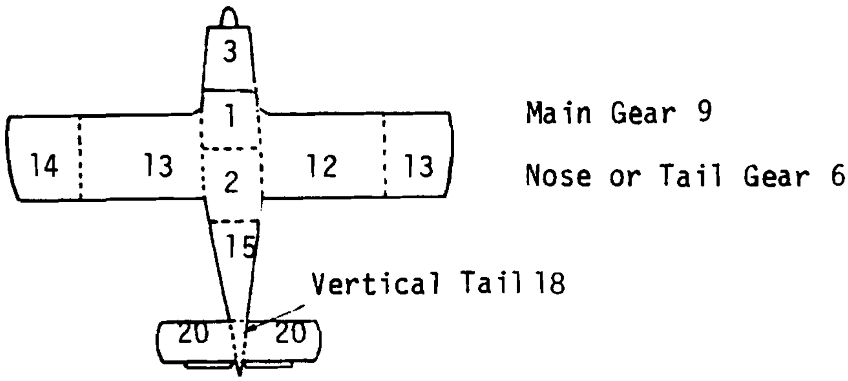
TABLE 7.17 A

SECTION DAMAGE

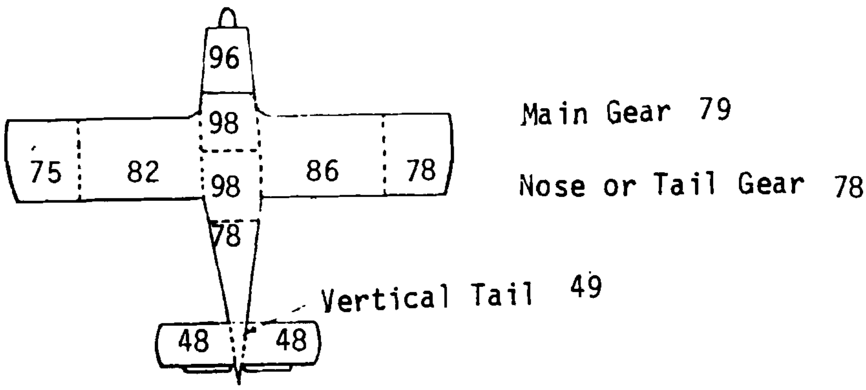
DATA SET: BASIC
With Ground Fire
Ref: Table 7.38



% of aircraft where section indicated was basically undamaged (Code 1)



% of aircraft where section was dented or torn (Code 2)



% of aircraft where section was at least crushed (includes destroyed)(Codes 3 & 4)

Figure 4

	Involved in Fire (% of total with fires)	Location Data: % of total cases with data in "Location" code box 1	2	3	4	Deformation Data: % of total cases with data in "Deformation" code box 1	2	3	4	5	Final Attitude Data: % of total cases with data in "Attitude" code box 1	2	3
COCKPIT	83	-	-	-	-	1	1	20	78	0	67	11	22
CABIN	84	18	0	15	67	0	2	20	78	0	67	11	22
NOSE	75	13	0	17	69	1	3	21	75	1	66	14	21
AFT FUS.	62	23	3	10	64	8	15	23	55	0	65	15	20
TAIL CONE	24	22	25	8	45	32	6	15	47	0	69	13	17
RT INBD WING	70	16	0	12	72	3	12	62	60	0	63	16	22
RT OTBD WING	46	16	22	8	54	9	13	31	47	0	62	15	23
LT INBD WING	68	15	0	12	73	4	13	24	58	0	61	14	25
LT OTBD WING	50	14	26	6	55	5	19	29	46	0	59	14	27
RT HORIZONTAL	38	22	34	5	39	32	20	15	33	0	58	13	30
LT HORIZONTAL	39	23	34	3	40	32	20	15	33	0	56	13	31
VERTICAL	38	24	31	6	38	32	18	15	34	1	57	10	33
MAIN GEAR	44	20	5	12	63	6	9	27	52	7	-	-	-
NOSE/TAIL GEAR	40	21	7	13	50	14	6	27	51	2	-	-	-
ENG #1	65	14	1	14	71	4	17	33	44	2	63	15	22
ENG #2	-	7	11	4	79	0	22	41	37	0	67	0	33

DATA SET: BASIC Group
Ground Fire Occurred

No. of Cases: 206

U.S. 70 %

In Flight Breakup
8 ; 4 %

Ground Fire Cases
206 ; 100 %

In Flight Fire Cases
8 ; 4 %

	Involved in Fire	Location 1	2	3	4	Deformation 1	2	3	4	5	Bent Yes	No
PROP #1	-	10	23	4	63	4	20	49	22	6	95	5
PROP #2	-	3	78	0	59	0	7	59	31	3	100	0

TABLE 7.38 A

Needed: Crash Impact Data

A. Howard Hasbrook, P.E., F.A.S.M.A. MO0742

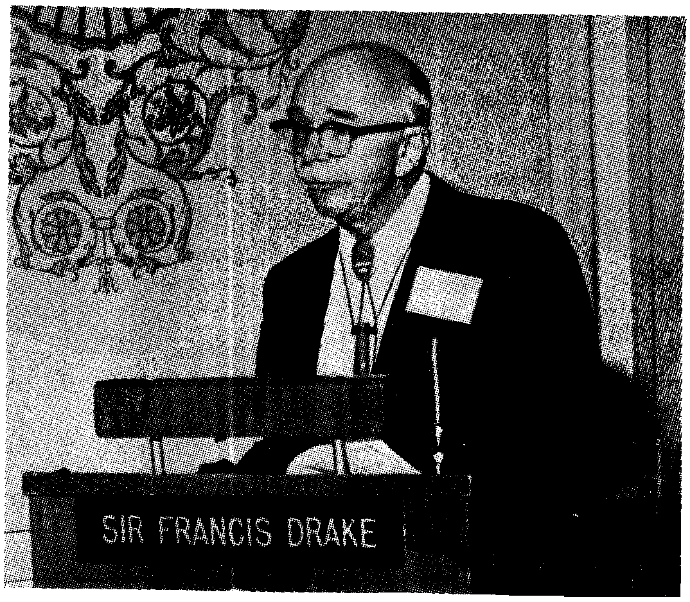
The principal objective of aircraft accident investigators is to look for evidence that will pinpoint the causes of accidents. This requires experience, objectivity, patience and the ability to perform deductive reasoning; talents that are so essential in finding, recording and reporting the data that are ultimately used by the accident analyst to determine the primary cause of accidents.

There is another area, however, in which we have "short changed" ourselves in our investigative efforts. That is the area relating to the very short time span-measured in seconds-covering the impact of the aircraft and its subsequent deceleration. This is the portion of the accident in which the aircraft sustains its major damage and its occupants undergo major crash force. It is here that these same investigative talents are so essential, and are so unused. For example, is it not strange that although research into the causes of injury in accidents has been going on for more than 30 years, so few real advances have been made in designing for crash safety? Could it be that such research has been hampered by lack of data; data that only the aircraft accident investigator can supply?

Aside from the need for pinpointing specific causes of injury in accidents, the Federal Aviation Administration has been trying for years to determine whether the present 9G crash load factor should be increased, and if so, how high. Lack of impact data from the hundreds of survivable accidents that have occurred each year has been a stumbling block in this regard.

And now, another problem caused in part by this lack of impact data has risen to plague the aviation industry during the last decade. I speak, of course, of the fact that the public is becoming increasingly enamored of the legal process of going beyond the cause of the accident to collect millions of dollars for alleged lack of properly designed (human engineered) cockpits and inadequate crashworthy structure, seats and restraint systems. Unfortunately, in this regard, jury awards to spouses, injured survivors and estates, exceeding one million dollars per accident, per person, have become the rule rather than the exception, particularly in the general aviation litigation field. This, of course, is not to say that some of these awards were not deserved. But there have been cases in which questions arose as to whether the courts and juries were given all of the facts that were needed to arrive at a just verdict, particularly in trials relating to crashworthiness or crash safety.

I am not pleading in defense of any one litigant-plaintiff or defendant. But we, as investigators and consultants, should be concerned that although pilot error is often the principal cause of most accidents, many end up in court with the allegation that "lack of crashworthiness" was the primary cause of injury or death. The manufacturer then finds it difficult, if not impossible, to defend himself against



sometimes biased and unfounded accusations of negligent design. His dilemma, of course, is too often the result of the lack of crash impact data in many FAA and NTSB accident reports rather than the alleged defective design. Therefore, I plead for the detection and reporting of all pertinent accident data so that all parties to litigation may have the opportunity of presenting all of the facts needed for a just and fair finding by jury or court. I would even go so far as to suggest that we have a responsibility to society to enlarge our sphere of interest, investigative efforts and talents to include the reporting of needed crash impact data.

Although some will say that impact data is included in most accident reports, few contain the kind of information needed for concise crash force analysis. For example, the notation that "the aircraft struck the ground in a steep nose down and right wing down attitude" provides little useful information for development of crash force angle data.

Another piece of useless information to the analyst is this type of statement: "The aircraft struck the ground at low speed." What is "low" speed? 50 mph, 75 mph, 150 mph? Since kinetic energy (and damage to the aircraft occupants) is a function of the square of velocity, more precise information concerning speed of impact would be most helpful in the analysis of the accident-and the evaluation of crash loads and crashworthiness.

In the above example, it would have been better for the investigator to describe the action of the aircraft prior to impact (from witnesses' statements) such as: "The aircraft was seen to recover partially from a nose high stall just before it struck the ground in a 20-30 degree nose down attitude."

Subsequent flight tests in a similar model aircraft by an analyst could provide a close approximation of what the speed was during stall recovery-and probably during impact.

Reports often contain statements like: "the aircraft came to rest 85 feet from point of initial impact"; nothing is reported on how much of that distance involved deep gouging (wherein the main deceleration, damage and injury took place), and how much related to skidding over the surface of the ground in a "low" deceleration condition. Without such information, it is difficult for the analyst to calculate G numbers that are meaningful, either in court or for research purposes.

What kind of crash impact data is so badly needed? It is detailed information that can be used by experienced crash injury and impact analysts to compute, in broad terms, the magnitude, direction and duration of crash loads imposed on the aircraft structure and on the occupants. The information can also be used to provide a basis for evaluation of the "crashworthiness" of structure, whether it be cockpit, cabin, seat or restraint system.

Certainly, I am not proposing that the accident investigator calculate or determine the crash forces imposed in an accident: that is a job for experienced analysts. But it must be emphasized that no analyst can determine the magnitude and direction of crash force in an accident-within the limits desired-if the accident investigator fails to report on this needed crash data.

In looking for this data, which is usually available at the scene of the crash, we might keep in mind that the force imposed in an accident is caused by changes in velocity of the structure, and of the occupants, over a given time or distance of deceleration or of acceleration. The directions in which forces are imposed are functions of both angular and linear changes of direction, and of the decelerations of the structure and occupants during the crash sequence.

The following is a list of the impact data needed from aircraft accidents; some of it is photographic in nature:

1. Impact angle: the angle (figure 1) between the flight path and the principal object struck (usually ground, pavement or water).
2. Flight path angle: the angle between the flight path and the horizontal (Figure 2).
3. Terrain angle: the slope of the terrain at the point of principal impact, measured to the horizontal (Figure 2).

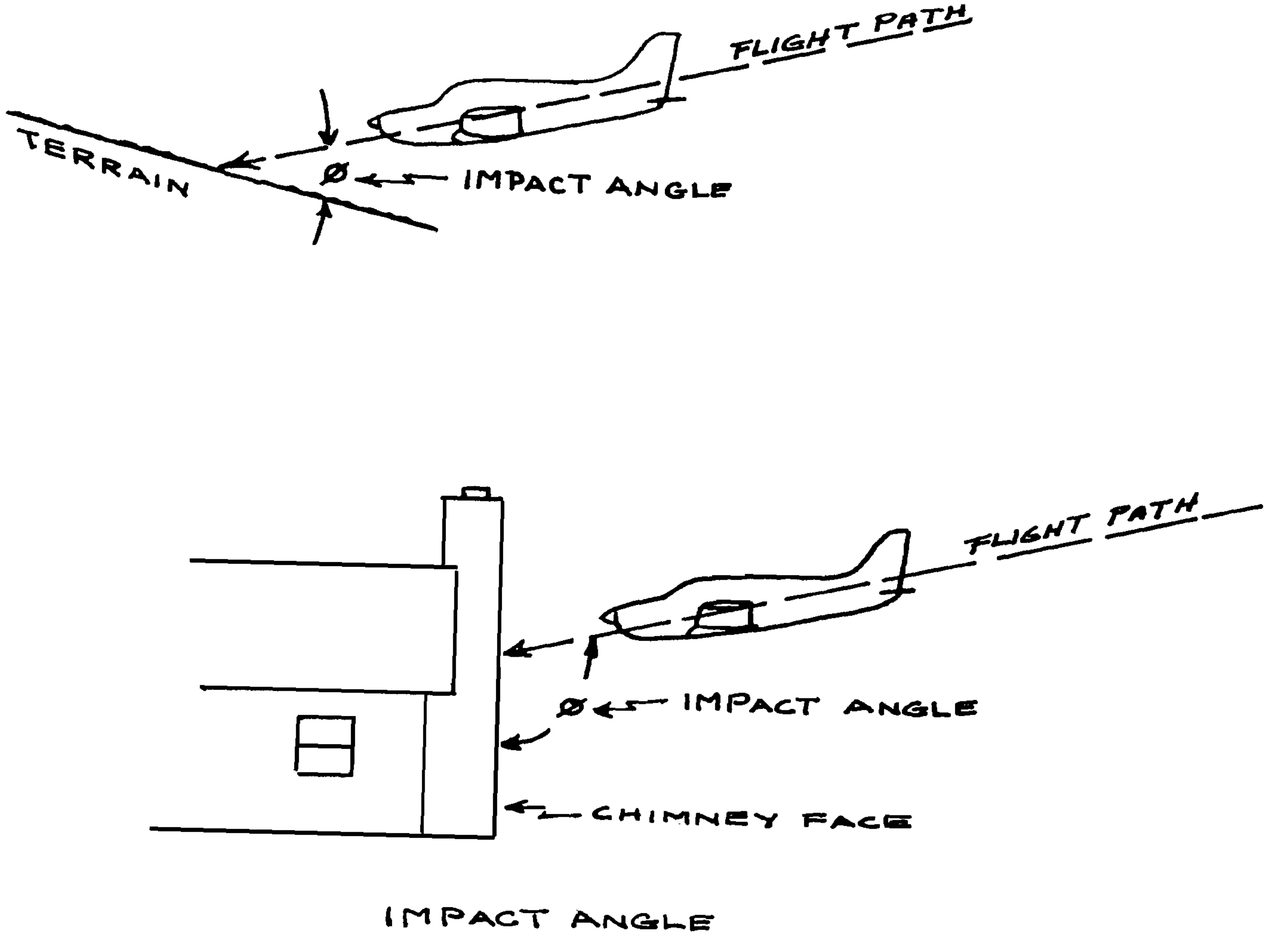
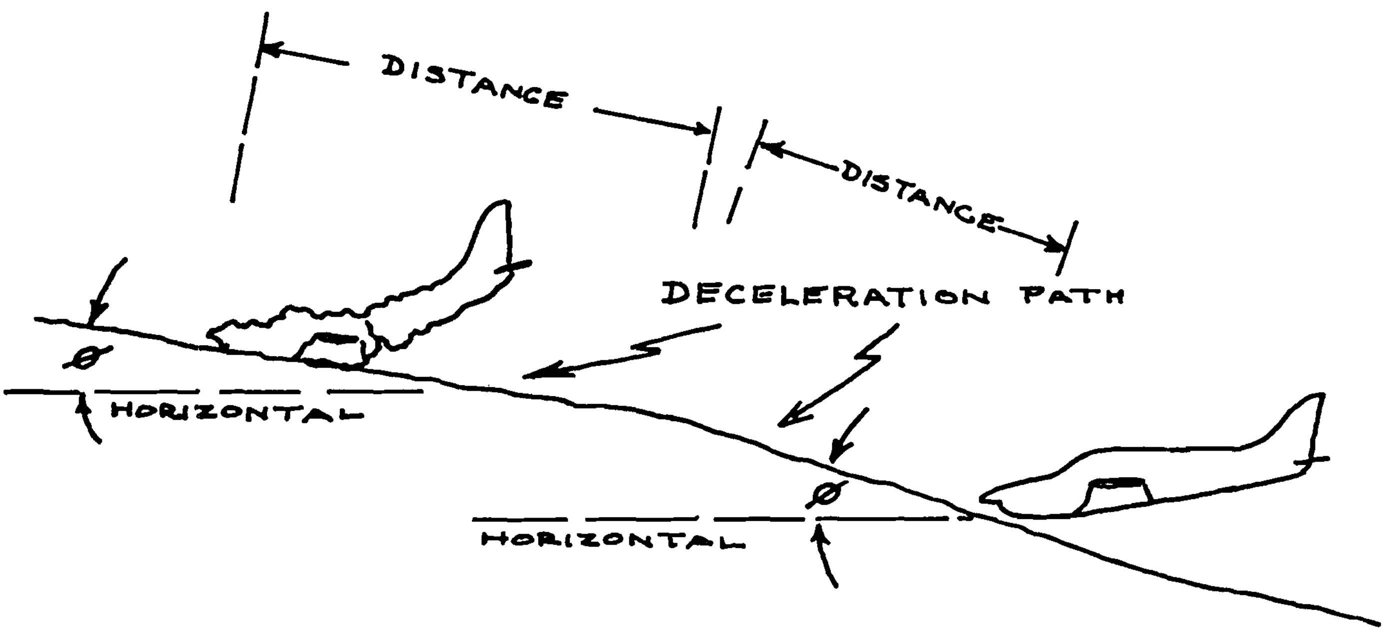


Figure 1

TERRAIN AND FLIGHT PATH ANGLES.

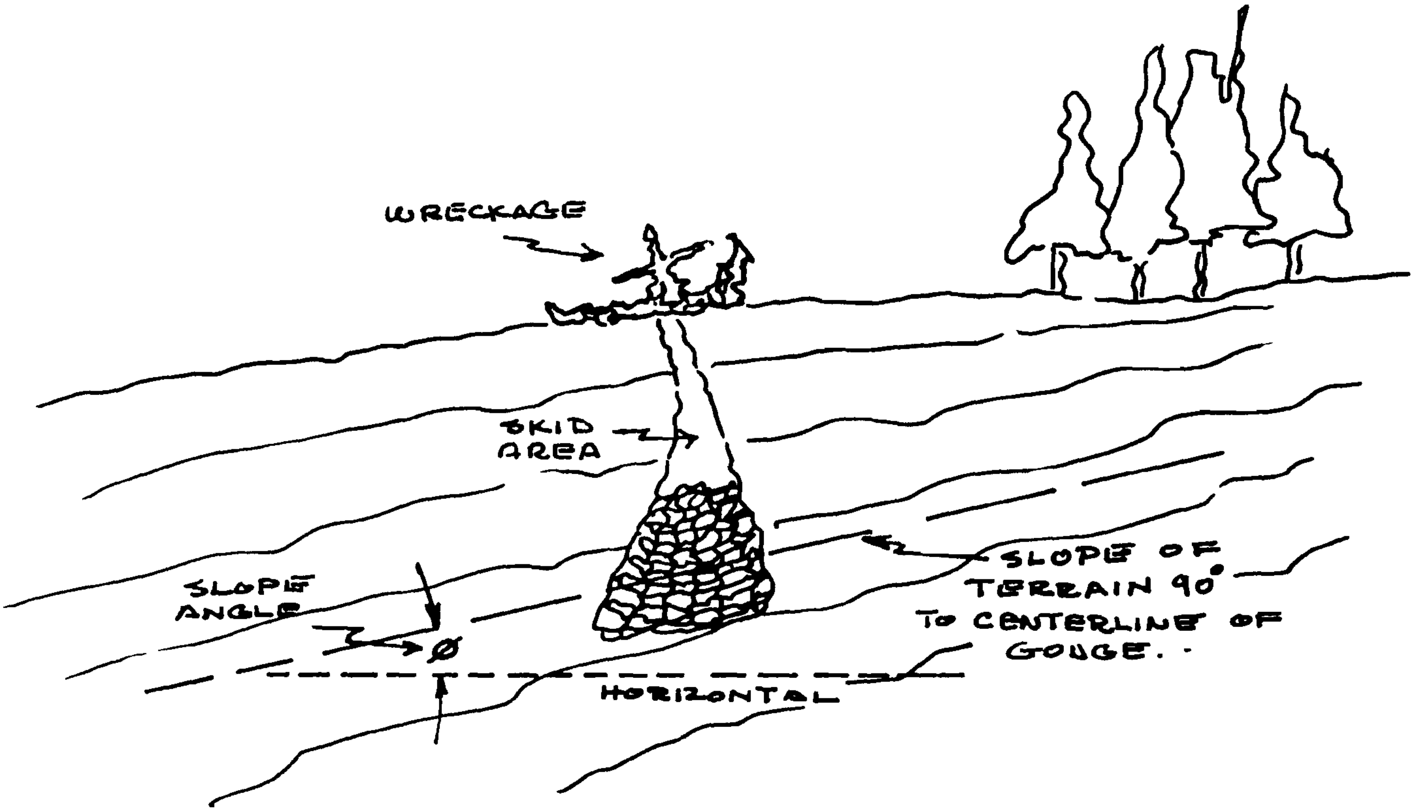
Figure 2

4. Terrain angle along deceleration path: the slope of the terrain in "pitch" and "roll", as measured to the horizontal, along the length of the deceleration path (Figures 3 and 4).
5. Pitch, roll and yaw angles of the aircraft at the moment of principal impact, measured to the horizontal (Figures 5 and 6).
6. Distance and angle between the principal impact point and any obstruction along the flight path, measured to the horizontal (Figure 7).
7. Length, depth and width of gouges made by the cockpit/cabin fuselage structure during its deceleration (Figure 8).



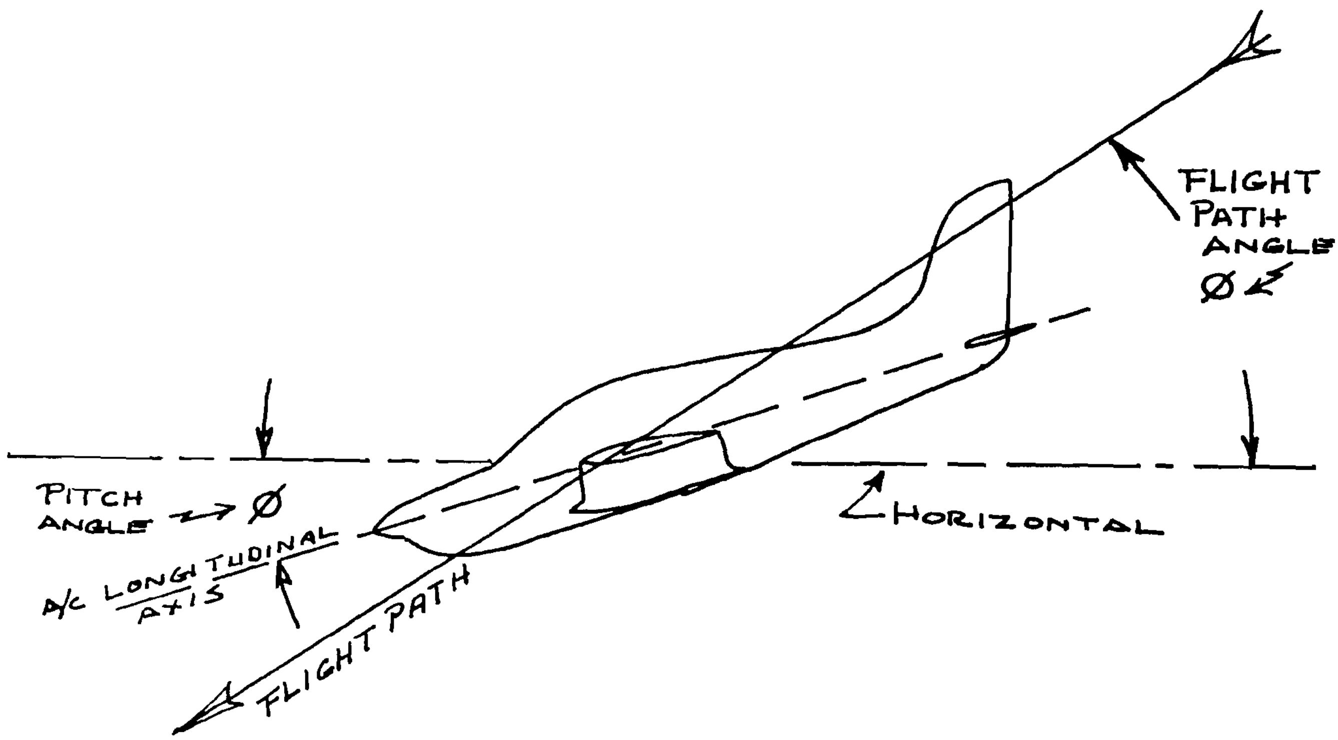
DECELERATION PATH SLOPE(S) IN "PITCH" AND DISTANCE(S) IN FEET, FOR EACH.

Figure 3



SLOPE ANGLE AT POINT OF PRINCIPAL IMPACT (MAIN GOUGE).

Figure 4



PITCH AND FLIGHT PATH ANGLES.

Figure 5

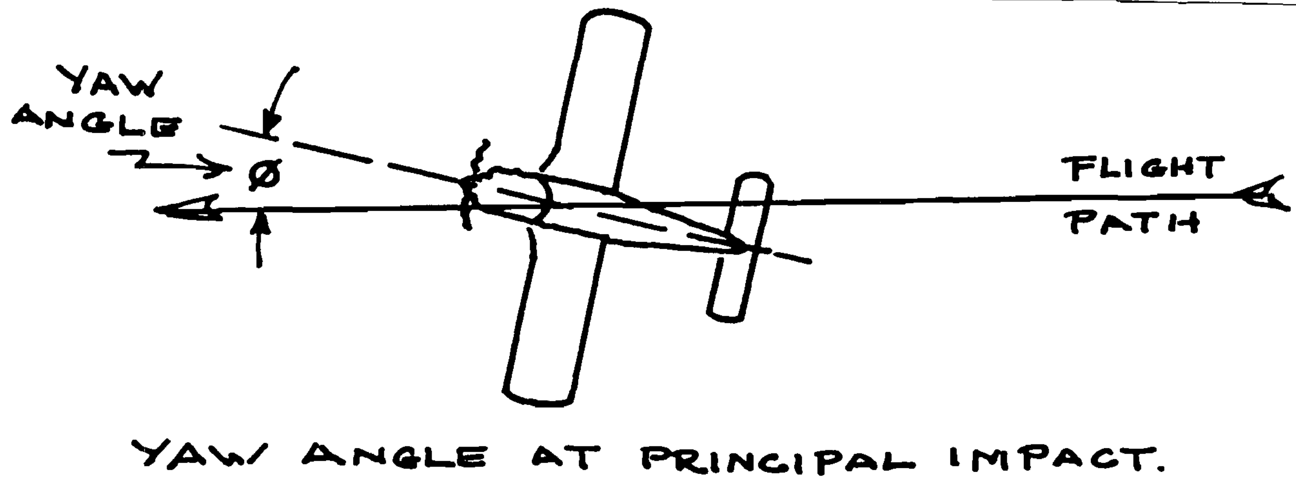


Figure 6

8. Distance of "skips" (Figure 9) between gouges (with notations concerning cartwheeling and flipping, if any, of the aircraft during such skips).
9. Length, depth, width and orientation of intervening ditches or other obstructions struck by the aircraft during its major deceleration.
10. Measurements of compression (foreshortening) of major portions of aircraft structure, particularly in and ahead of the cockpit/cabin area.
11. Measurements of deflection of firewall, bulkhead, instrument panel, control wheel/stick, belly, sidewall and roof structure, and seats.
12. Sequence of overlapping color photographs taken in both directions along the impact/deceleration path.
13. Views of obstructions or objects struck prior to principal impact.
14. Views of principal impact area taken from four sides.
15. Overlapping views of entire fuselage taken from approximately eight cardinal points of the compass.
16. Close-up exterior views of nose/cockpit/cabin structure from approximately eight cardinal points of the compass.

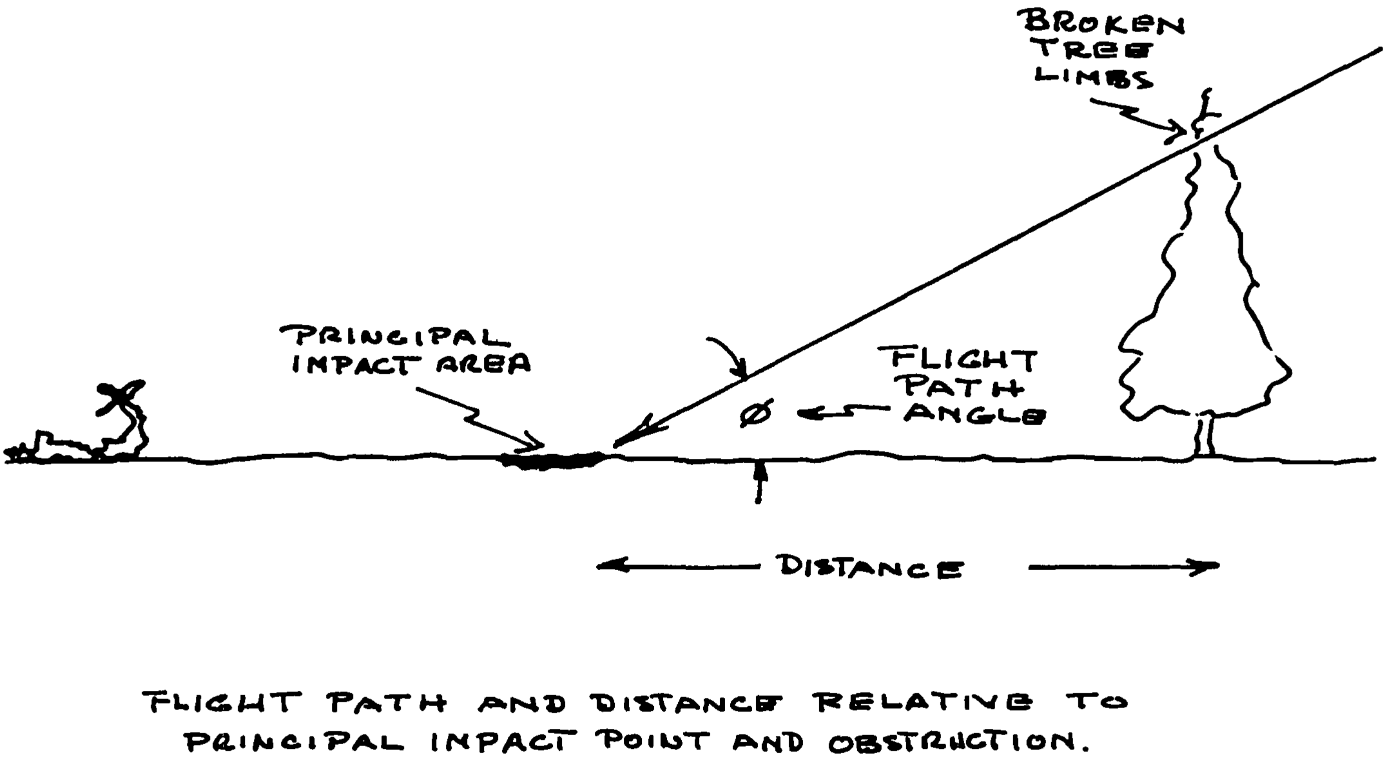


Figure 7

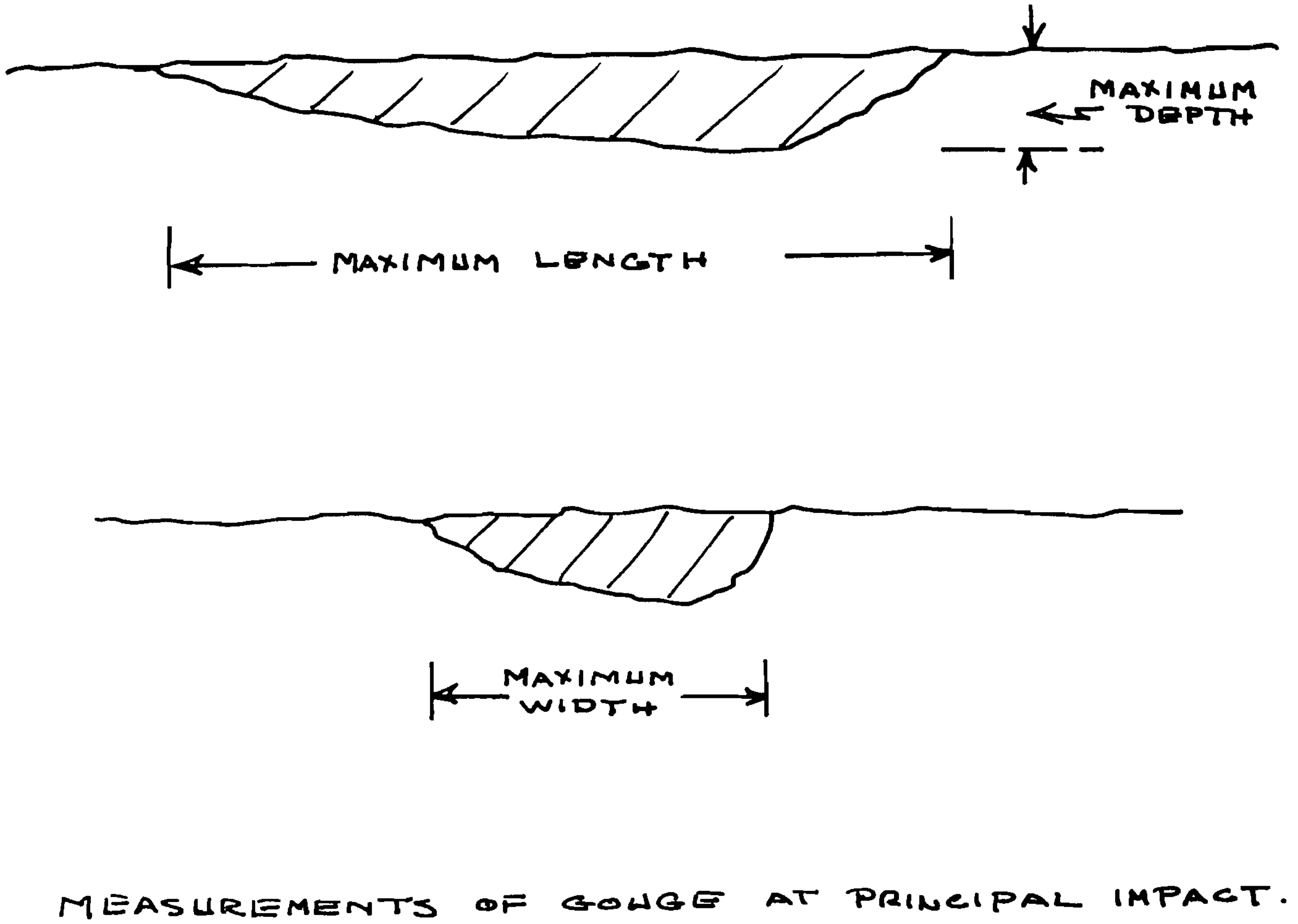


Figure 8

17. Close-up views of major areas of structural damage, including belly structure.
18. Comprehensive views (using flash illumination) of the interior of the aircraft, including views of the instrument panel, instruments, controls, rudder pedals, overhead, side and floor structure, seat rails, seats (and their attachments), and the restraint systems.
19. Views of any structures that show evidence of having been struck by any object such as a human occupant (as indicated by such things as head shaped depressions in the glare shield, tissue and hair imbedded in instrument panel cut-outs, etc.).

It should be borne in mind, however, that fatal injuries can be sustained during impact against heavy or rigid aircraft structure without leaving or depositing any blood, human tissue or hair on that structure.

In general, one should expect to take from 50 to 100 photos to adequately cover a general aviation accident; an airline crash may require 200 to 500 pictures. A ruler, yardstick or tape should be included in the photos to provide a means of measurement by the photo analyst.

In closing, it might be argued that it is not the responsibility of the aircraft accident investigator to provide information needed for litigation. I would suggest that while accident investigation aimed at preventing future accidents is of prime importance, the cause of justice for those involved in post-accident litigation is also of major social importance. Since a true picture of the accident sequence is difficult to develop and describe without the data outlined above, little can be done to offset the often misleading opinions of some "experts" who tend to advocate, rather than analyze-to the detriment of both aviation and justice.

I submit that without this much needed data, the FAA and the manufacturers cannot make logical and needed advances in design requirements for improved crashworthiness and crash safety.

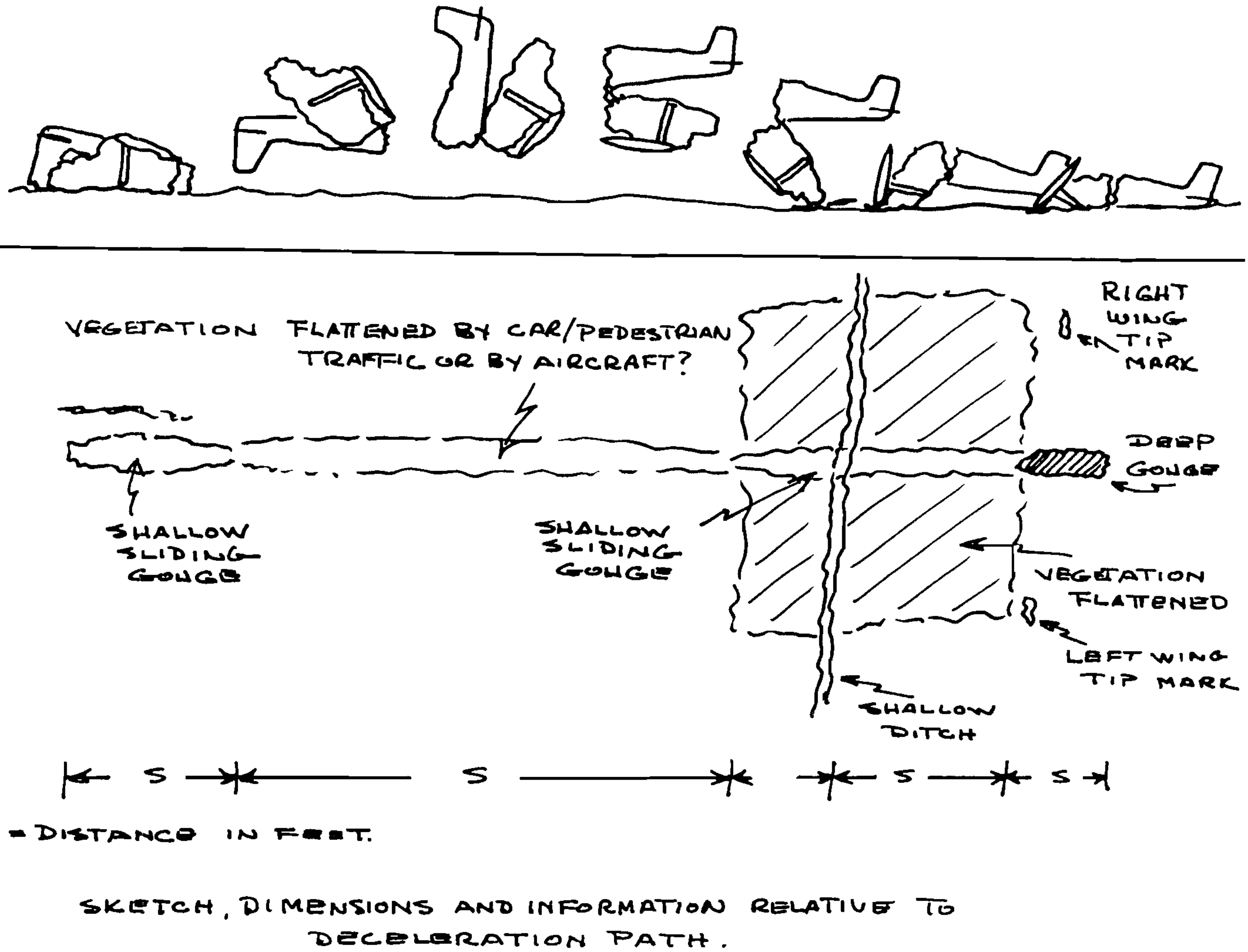


Figure 9

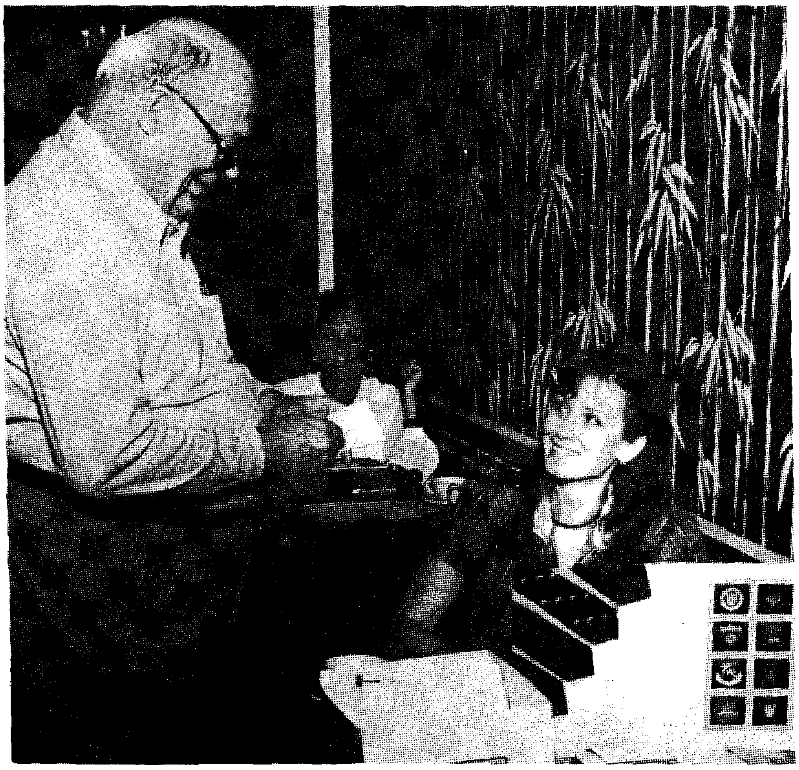
About the Author

A. Howard Hasbrook is an aviation safety consultant specializing in crash injury investigation and analysis; accident investigation and analysis; in-flight operational research; crash safety and human factors design of flight instruments, cockpits, cabin interiors, seats and restraint systems, and expert testimony relating thereto. He is a licensed professional safety engineer (California) and an FAA Accident Prevention Counselor.

His professional history includes positions as Chief of Flight Performance and Chief of Crash Safety at the FAA's Civil Aeromedical Institute, and Director of Aviation Crash Injury Research at Cornell University.

Howard has been a licensed pilot since 1934. He holds an FAA Commercial Certificate with single- and multi-engine land, instrument, jet and Flight Instructor ratings. He has more than 14,000 hours pilot experience. He has been a Member of ISASI since 1974.

Don Heisley accepts "Host-with-the Most" Award



Walt Horne

"Careful, George, it might go off"

Advanced Technology Analysis Of Aluminum Alloy Fractures In Aircraft Components

T.W. Heaslip, R.K. McLeod & D.S. Rupert*
**Speaker - Chief, Aviation Safety Engineering*
Aviation Safety Bureau
Transport Canada

INTRODUCTION

One of the most difficult and deceptive kinds of fractures to analyse in the aftermath of an aircraft accident are the subtle failure modes in aluminum alloy aircraft components. This presentation will seek to demonstrate the need for knowledgeable visual analysis at the scene, careful stereo-microscopic analysis of suspect components, and finally, if required, in-depth metallurgical and electron microscopic analysis in the laboratory. Some of the analytical techniques and pit-falls are pointed out using actual examples of critical failures. The use of up-to-date advanced technology in analysing premature failures is described. Three examples are given from accidents occurring this past year.

FIRST EXAMPLE – Wing Spar Attachment Fitting Failure

A Beech King Air suffered in-flight wing separation while cruising at about 1,700 feet altitude. An eyewitness below the flight path observed the right hand wing separate outboard of the engine nacelle. The aircraft went into an uncontrollable rolling dive, crashed and burned, killing both occupants (Figure 1).

Figure 1 - Crash scene.

The separated outboard wing section was found some 2,100 feet from the main wreckage (Figure 2). Visual inspection by the field investigators indicated three of the four outboard right wing attachment fittings had failed in ductile overload mode, but the forward lower outboard wing attachment fitting was suspect (Figure 3). It displayed a large discolored zone typical of a massive precrack of a progressive nature (Figure 4). This fitting, normally known as a "bathtub" fitting (Figure 5) because of its shape, is the most critically loaded of the four attachment fittings in normal flight. The remaining three attachment fittings are not (nor are they required to be) capable of carrying flight loads if the subject fitting suffers catastrophic failure. The wing and mating parts therefore were subsequently forwarded to the laboratory for detailed analysis.

Low magnification stereo-macroscopic examination (Figure 6) of the failed fitting did not provide any definitive information as to either the origin of the cracking or the mechanism of cracking for the discoloured precracked zone. Stereo examination did, however, suffice to determine that the clean and brightly reflective remainder of the fracture was ductile overload in mode. It was not clear whether the precrack had initiated at the bottom of the "bathtub" and grown through its bottom and into the spar attachment

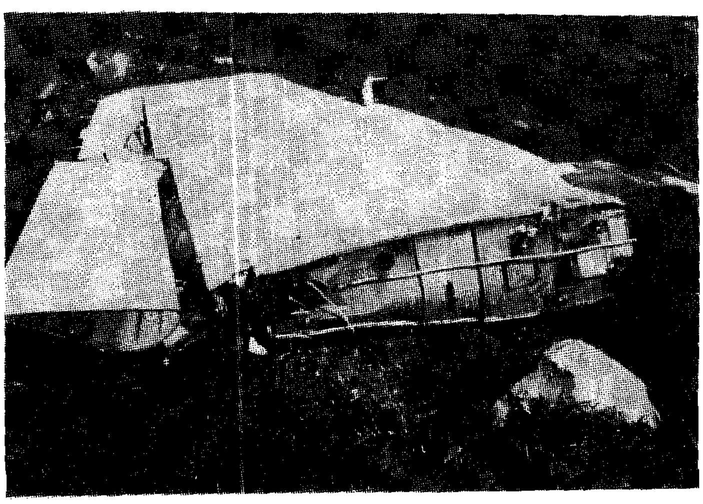
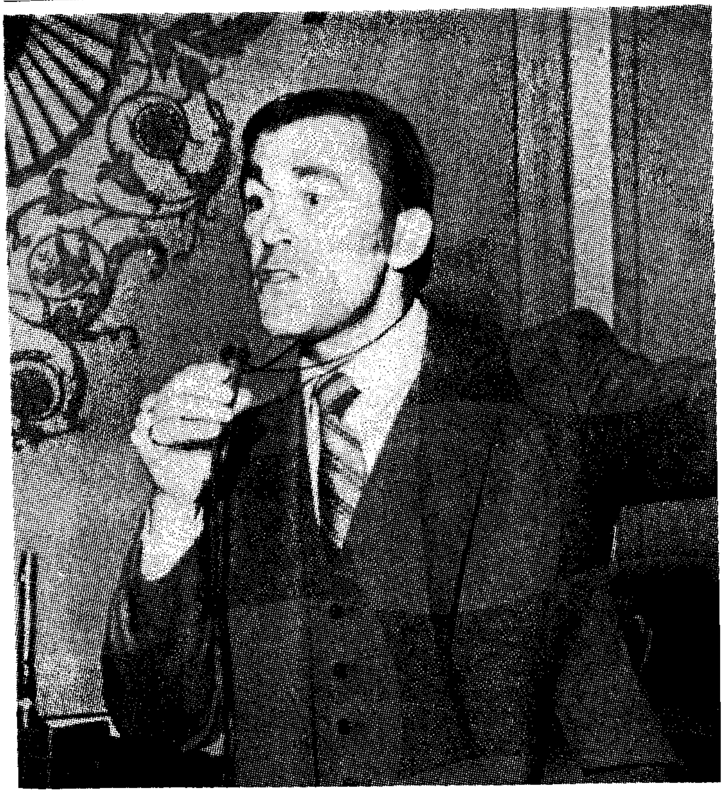


Figure 2 - Separated outboard wing section in a farmer's field.



flange, or whether cracking initiated in the flange at a rivet hole and had grown through the "bathtub" bottom.

By subjecting the fitting's fracture surface to high magnification scanning electron microscope (SEM) examination (Figure 7), it became possible to identify the origin and mode of crack initiation and propagation. SEM evaluation detected three different zones within the precracked area (Figure 8) as follows:

Zone (a) — isolated facets of transgranular fracture characteristic of fatigue crack growth mixed with areas of intergranular separation.
Zone (b) — essentially all intergranular cracking.
Zone (c) — almost all transgranular fatigue cracking.

SEM analysis of these observed propagation zones established that the cracking originated at the "bottom of the bathtub" along the bolt hole recess radius. The precise origin (Figure 9) was identified as being an intergranular area between two fatigue facets. A secondary crack (Figure 9) running essentially parallel to, but slightly displaced from, the primary crack, showed similar fracture face morphology to the intergranular cracking. Sharp transitions from intergranular to fatigue modes and from fatigue back to intergranular modes were apparent throughout zone (a) (Figure 10). The intergranular cracking was found to be multi-pathed.

All of the intergranular cracking was characterized by a liberal distribution of hemispherical "holes" on the grain boundary surfaces (Figure 11). Such holes were virtually absent from any transgranular fatigue facet (Figure 12). Subsequent metallurgical examination of sections through the forging showed a multitude of roughly spherical voids distributed throughout the forging. Etching to reveal the internal metallurgical structure (Figure 13) showed these voids were distributed along the grain boundaries.

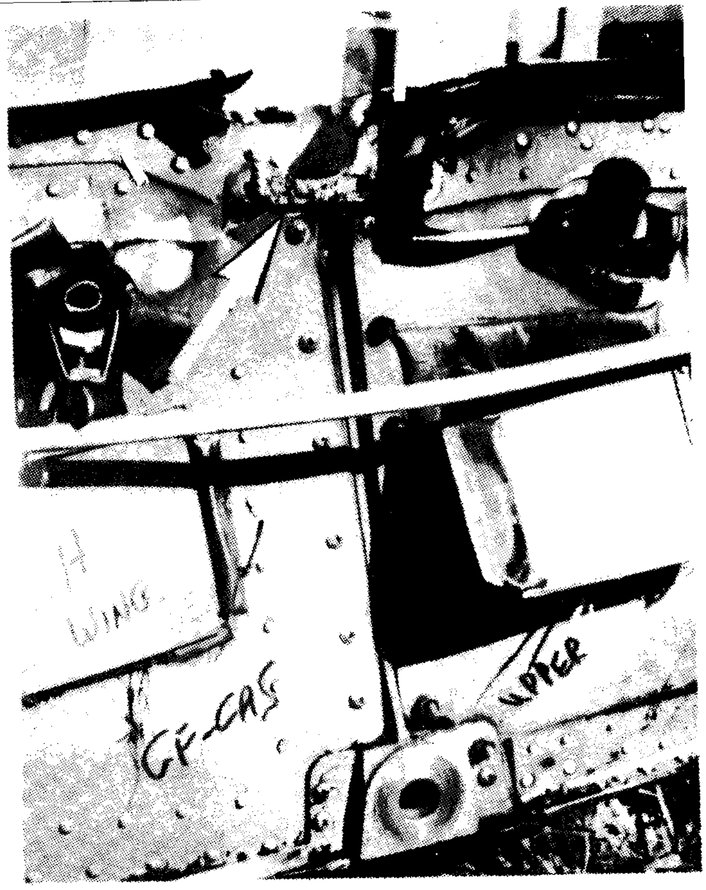


Figure 3 - Suspect wing attach fitting (arrowed).

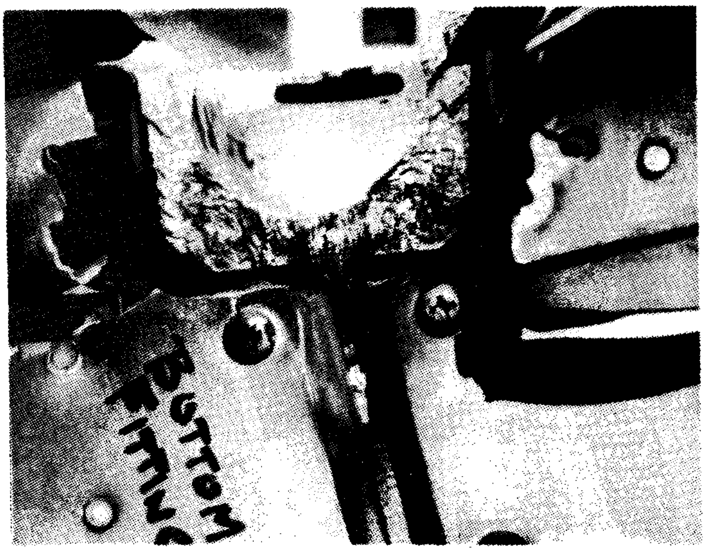


Figure 4 - Discoloured fracture face of fitting.

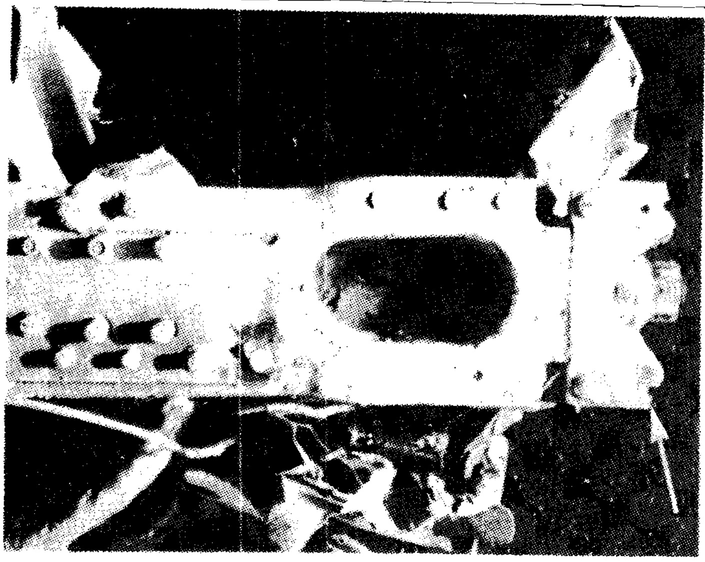


Figure 5 - Inboard half of fracture (arrow) and mating bathtub fitting.

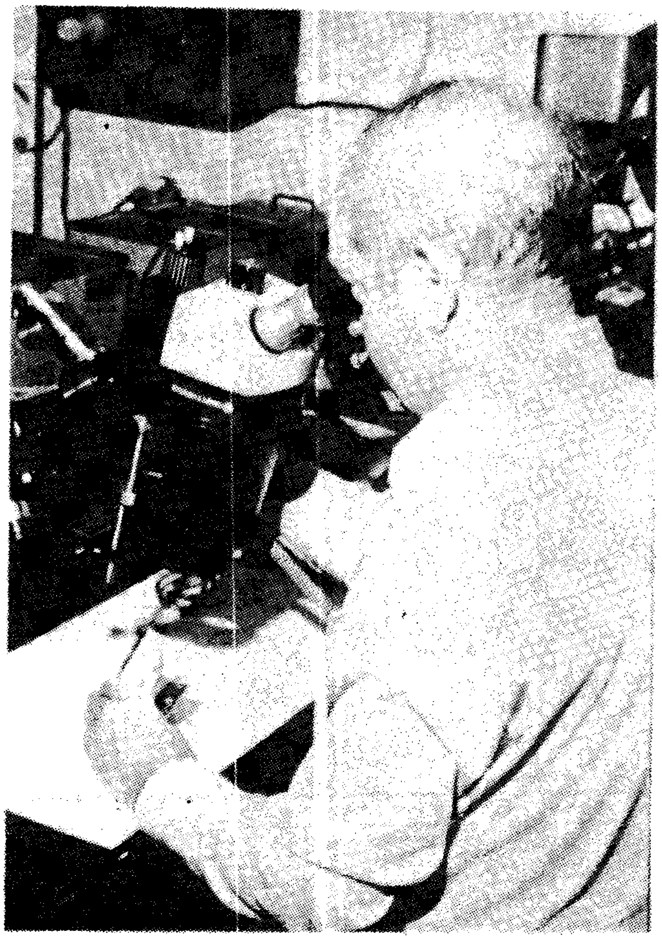


Figure 6 - Stereo-macroscopic examination of fitting failure.

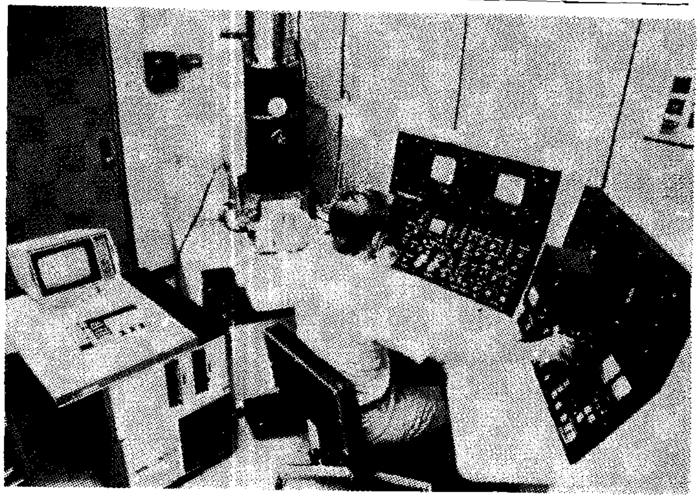


Figure 7 - High magnification scanning electron microscopic examination of fitting.

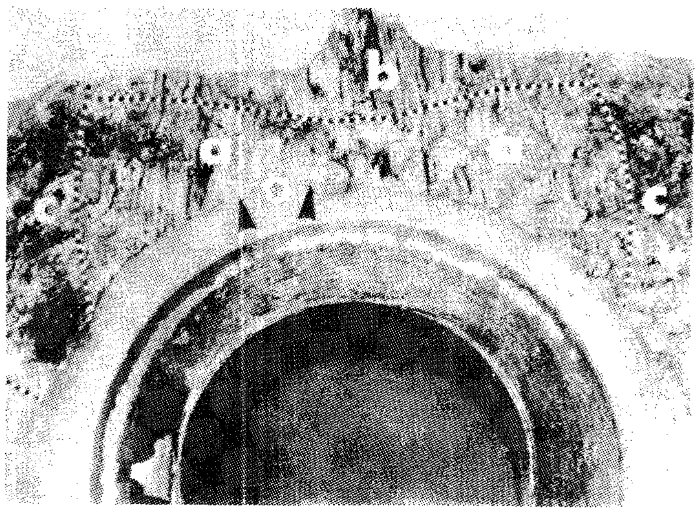


Figure 8 - Three pre-crack zones disclosed by SEM analysis.

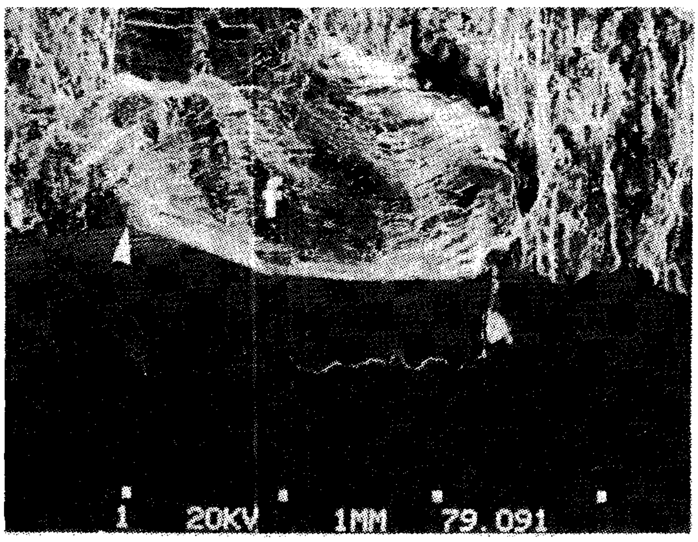


Figure 9 - SEM image of intergranular origin at left with fatigue zone initiating at arrow. Intergranular secondary crack clearly evident below the fatigue zone. (X25 approx).

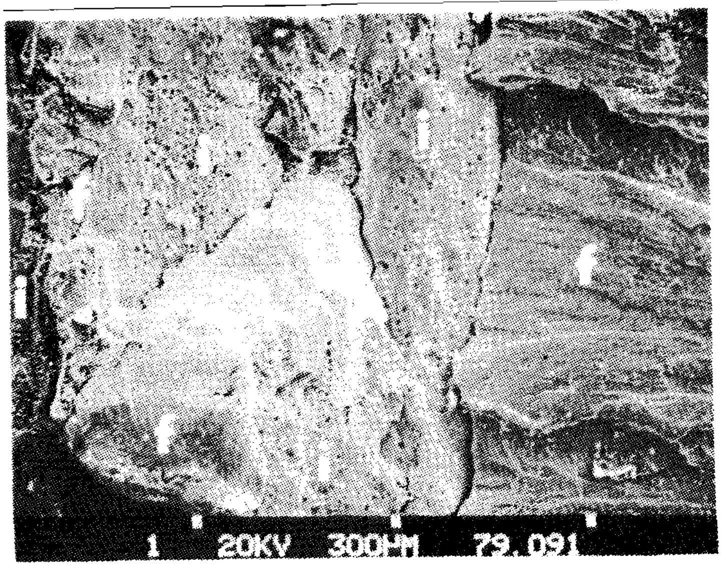


Figure 10 - Mixed intergranular and fatigue fracture in Zone "A". Holes evident on intergranular fracture areas. (X100 approx.)

The fatigue facets were then examined in detail with the SEM finding clearly defined striations (Figure 12) all transgranular in nature. The variable crack arrest line spacing was typical of operational loading induced fatigue crack growth. The intergranular facets however showed no striations in the SEM. Replicas were then taken of the intergranular zones to produce transmission electron microscope (TEM) samples. Even at TEM magnifications, an order of magnitude greater than possible with SEM (100,000X vs 10,000X), no evidence of crack arrest lines was observed in any area of intergranular fracture. Therefore, *intergranular* fracture was *dominant* in zones (a) and (b) with islands of fatigue fracture present in zone (a), whereas *transgranular* fatigue cracking was *dominant* in zone (c) with essentially no intergranular cracking in evidence.

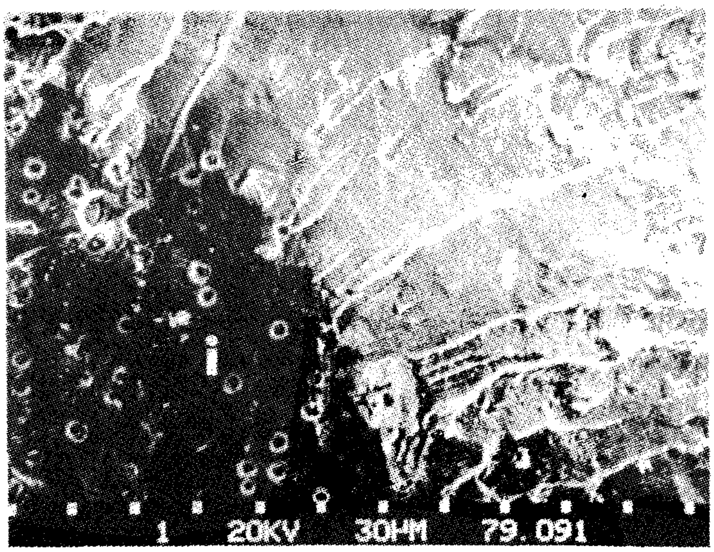


Figure 11 - Hemispherical holes distinctly on intergranular areas but not in fatigue areas. (X300 approx.)

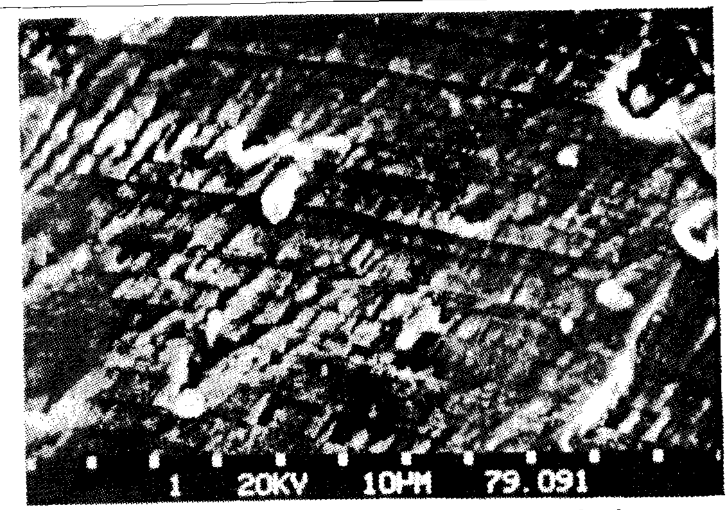


Figure 12 - SEM image of area in fatigue Zone "C". (X1000)

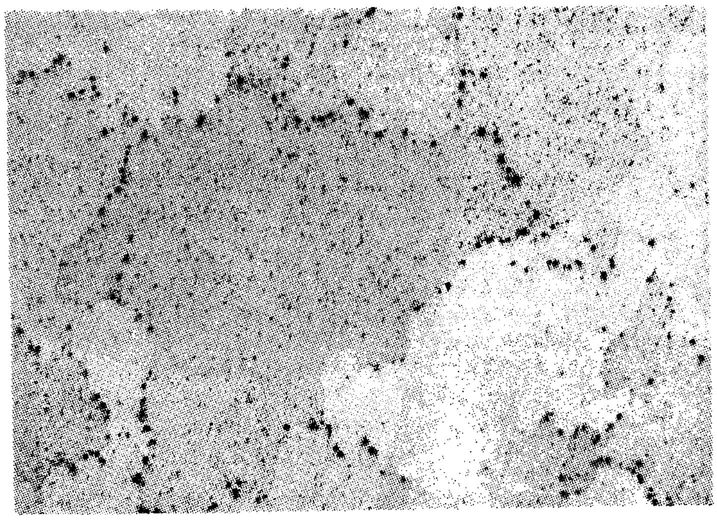


Figure 13 - Etched metallurgical microspecimen with spherical holes displayed on the grain boundaries. (X50)

Figure 14 - Macrosection of failed fitting. Intergranular trend of crack growth from origin (arrow) disclosed. (X3 approx.)

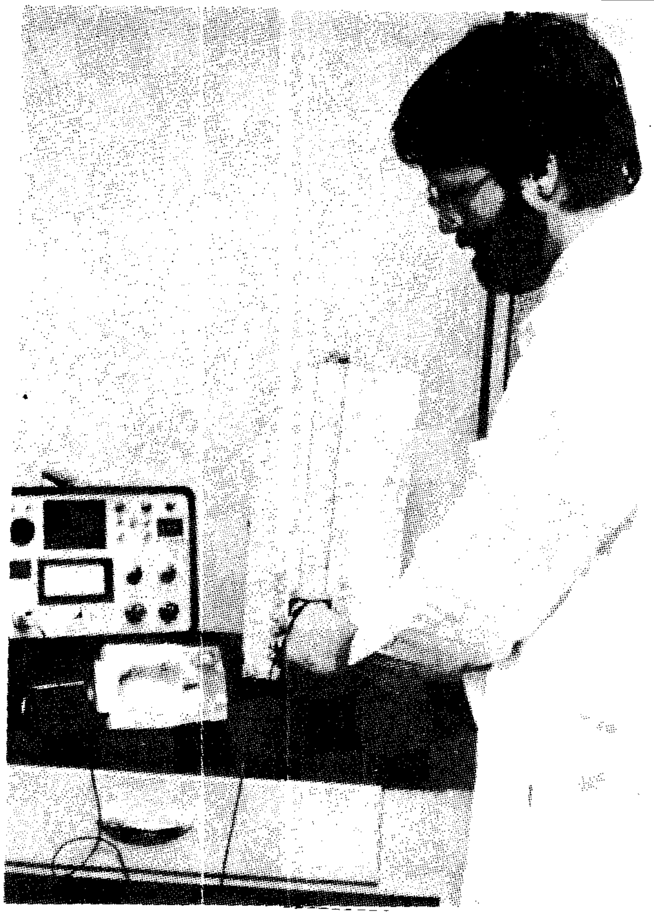


Figure 15 - Unbroken left wing fitting being eddy current cracked for cracks.

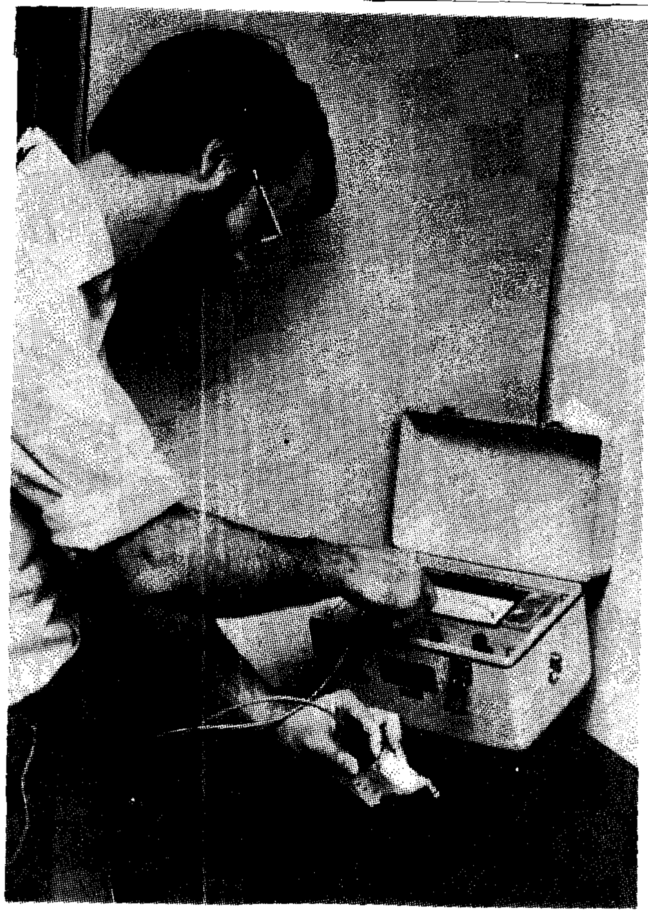


Figure 17 - Conductivity test being performed for heat treatment condition of fitting.

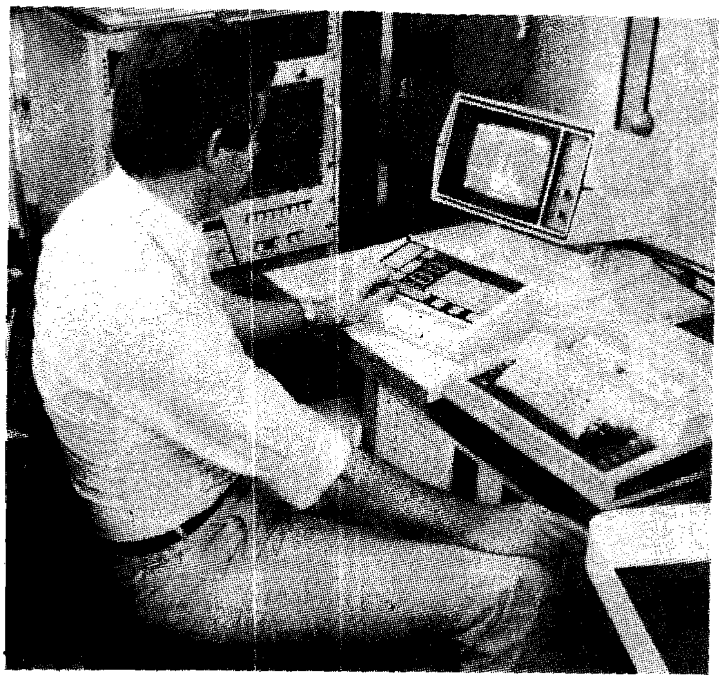


Figure 16 - Energy dispersive X-ray spectrometric analysis being performed on fitting for chemical composition.

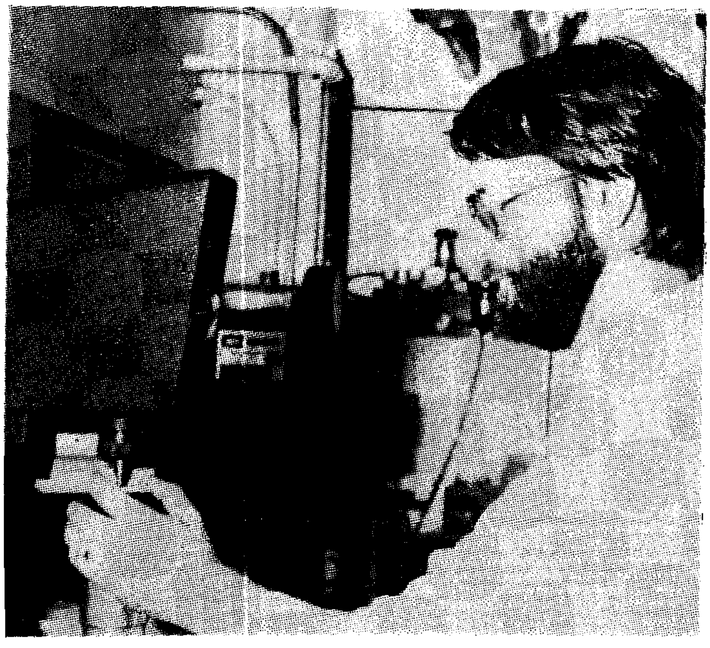


Figure 18 - Hardness tests to confirm correct strength level of fitting.

In this investigation, the investigators were lucky enough to have both halves of the failed fitting available for examination. The inboard part of the fitting still held under the wing attachment bolt was fortuitously flung clear of the intense post-crash fire which consumed most of the wreckage, and this portion provided most of the SEM and preliminary metallurgical evidence. The outboard part of the failed fitting, being partially enclosed in the separated wing panel, was also relatively undamaged. When removed from the wing remnant, it was used for further metallurgical and fractographic analysis. Multiple secondary intergranular cracking was observed on the outside surface of the "bathtub" remote from the origin (but adjacent to the fracture). This confirmed the multiple path nature of the intergranular crack growth previously observed during SEM evaluation. The fitting was sectioned spanwise (perpendicular to the fracture face and through the origin area) (Figure 14). This confirmed the intergranular crack path followed the grain flow within the fitting.

The unbroken left wing attachment fitting from the lower front spar was also recovered from the wreckage. It was dye penetrant and eddy current (Figure 15) inspected to determine if it was cracked in the same location as the failed fitting, and no cracking was found. It was then sectioned in the same plane as the failed fitting and a similar grain flow pattern was revealed. No tiny hemispherical holes were found on the microsection. Of significance however was the fact that the grain flow (at the same location as the point of origin of the fractured fitting) was flowing perpendicular to the free surface. This had occurred because during the formation of the bolt hole recess, the manufacturer had machined away the original forging surface, exposing the end grains at this critical location. Such exposure of the "end grain" at the free surface was also oriented such that the short transverse grain direction was aligned with the principal tensile stress developed in service.

General evaluation (Figure 16) of the failed forging via energy dispersive X-ray spectrometric analysis (a technique for analyzing all elements simultaneously) confirmed the forging was made from the specified 2014 aluminum alloy. Conductivity testing (Figure 17) confirmed the forging had been heat treated to the requried -T6 temper, and hardness tests (Figure 18) confirmed the correct strength level had been thereby developed. As far as was possible, given the fitting's failed condition, the fitting was found to be dimensionally correct.

From all of the above sophisticated laboratory analysis a serious deficiency in the *manufacturing process* was therefore identified as having contributed to the fitting failure. This deficiency consisted of a broad distribution of tiny spheroidal voids located on grain boundaries. As yet the mechanism of formation of these voids has not been positively determined, but it is believed that they are probably a result of the formation of hydrogen gas. It was also apparent that the existence of the voids adversely affected the life of the fitting. The pattern of crack growth revealed that failure originated as intergranular fracture at a location where the grain flow was perpendicular to the free surface and propagated along the hydrogen bubble weakened grain boundaries.

The described failure mode was unique in our experience. This investigation therefore demonstrates the value of in-depth analysis of a failure, which in the initial field stage appeared to be a simple progressive failure. Subsequent airworthiness action disclosed other similarly cracked fittings which were close to premature rupture. The available evidence suggested that only the fittings in a single production batch were defective in this manner.

There are, of course, many other contributing factors involved in the subject accident investigation which have not been discussed since they were not pertinent to this description of the use of current and advanced technology.

SECOND EXAMPLE – Propeller Blade Failure

A newly licensed pilot was on the first leg of a cross-country flight in a Piper PA-28R-200 aircraft when he radioed a Mayday, stating that he had "severe vibration problems". He attempted a forced landing in a field but the aircraft undershot the field and struck trees. It crashed (Figure 19) killing the pilot and front seat passenger and injuring three young children. Fortunately there was no post-impact fire.

Preliminary investigation at the accident scene revealed that approximately 4-3/4 inches of the tip of one propeller blade was missing (Figure 20). No other anomaly was found that could have created the vibration problem reported by the pilot. It was also found from an examination of records that the pilot only had half an hour on the aircraft type. Of interest was the fact that the aircraft was equipped with an automatic gear extension system that would raise or lower the gear without input from the pilot at predetermined airspeeds. It was believed by the investigators that the gear extended during the forced landing approach to the field without the pilot selecting it, causing the aircraft to undershoot.

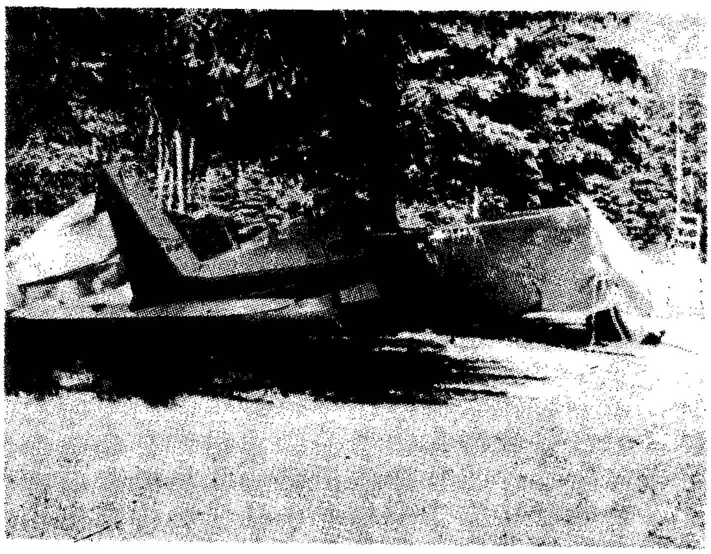


Figure 19 - Crash scene.

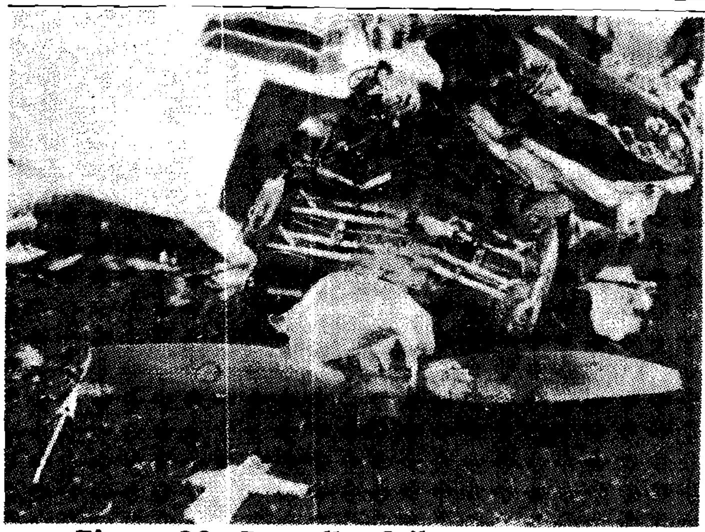


Figure 20 - Propeller failure (arrow) 4¼" from tip.

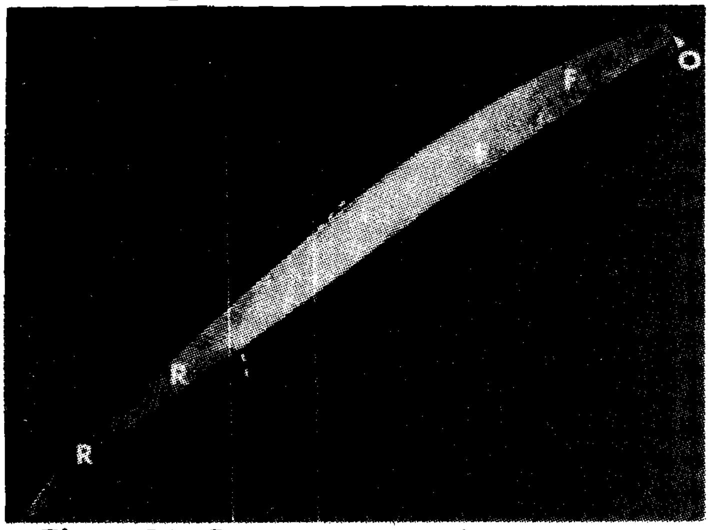


Figure 21 - Stereo-macroscopic examination with flat Zone "F" and ductile angled Zone "R" disclosed. Origin is at "O".

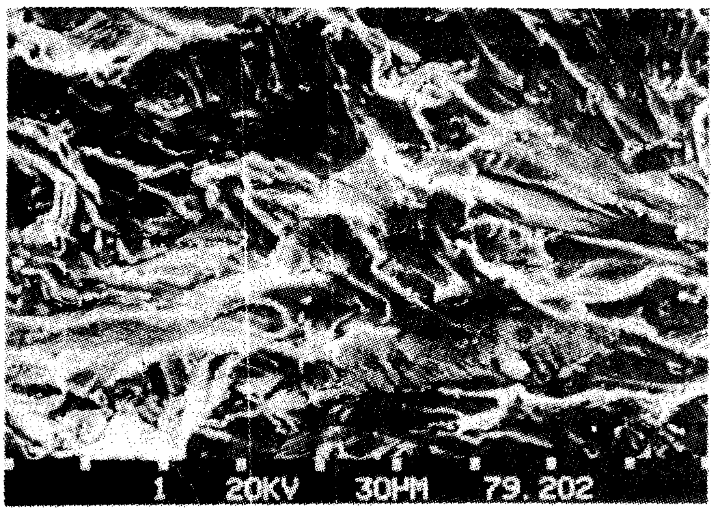


Figure 22 - SEM image displaying faceted cleavage-like surface at origin typical of initial stages of fatigue in aluminum props. (X500 approx.)

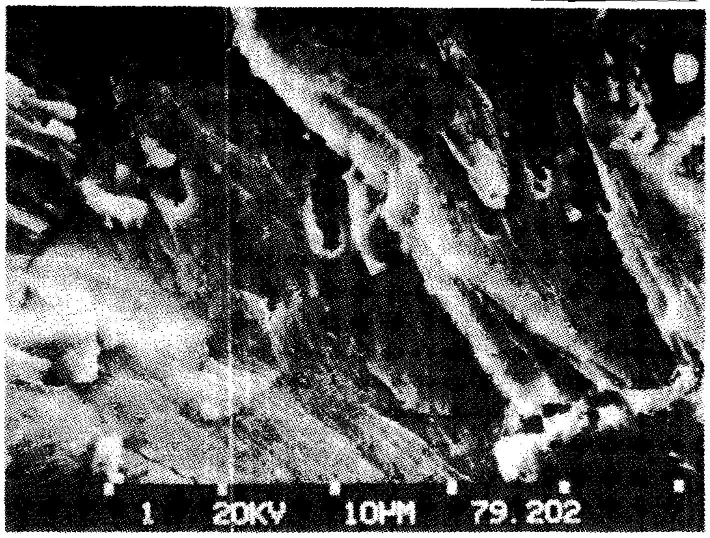


Figure 23 - SEM image of fine striations typical of fatigue. (X1750 approx.)

Laboratory stereo-macroscopic examination of the fracture face (Figure 21) of the failed blade revealed that it was relatively flat and perpendicular to the blade face over approximately 80% of the fracture area. Part of this area exhibited a highly reflective, faceted surface. The remaining 20% of the fracture face area was a dull grey with a much finer texture and was at an angle of approximately 45° to the blade face. This region was typical of an instantaneous overload rupture located on the trailing edge of a blade. A dark adherent substance was found on the fracture face surface near the leading edge (Figure 21). Investigators at the scene had been concerned that this indicated a crack may have existed when the blade was last overhauled or painted.

After cleaning the fracture face in an ultrasonic cleaner containing 1, 1, 1- trichloroethane solvent, very faint beach marks indicative of a fatigue mode of failure were apparent on the flat portion of the fracture face. The fracture face was next examined in the scanning electron microscope. The origin displayed a faceted cleavage-like mode of failure typi-

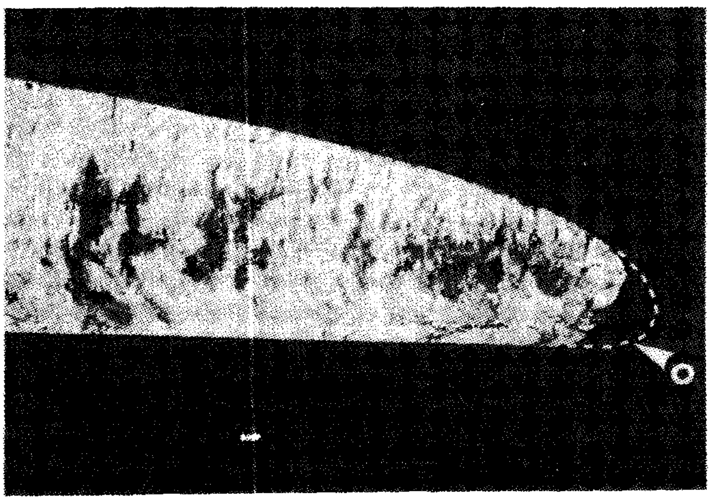


Figure 24 - Origin of fatigue apparently removed by repair of previous damage. Dotted line gives original shape of leading edge.

cal of aluminum propeller blades (Figure 22). A fatigue mode of failure was confirmed by the presence of isolated patches of striations (Figure 23). The relatively fine spacing of the striations indicated a very high-cycle, low-stress mode of crack propagation. Examination of the origin area on the leading edge of the blade, as was indicated by beach and ratchet markings, did not detect any definite initiation point. It was found that the point of fatigue initiation had been dressed out (Figure 24), suggesting that fatigue propagation had continued from a crack that had been incompletely removed by a repair operation.

There were several dressed areas on both blades where previous damage had been removed. Almost all of the repairs did not conform to the standards and specifications required by both the propeller manufacturer and government publications. The repairs did not remove enough material, left a sharp undesirable "V" shape and did not maintain the airfoil contour of the blade's leading edge.

Wave-length dispersive X-ray spectrometric analysis (a technique to analyze one element at a time) of the blade material found ity to be typical of an AA2025 aluminum alloy as specified by the manufacturer. Spectrometric analysis of the suspect black substance adhered to the fracture face revealed it to be a carbon based material that contained traces of sulphur, chlorine, calcium and potassium, suggesting the propeller had struck rubber or some other such material during the crash after fracture occurred. The substance was definitely not the black paint with which the face of the blade had been painted as had been suggested. Hardness testing gave results of 109 to 112 Brinell Hardness Number (BHN) which was well above the required minimum of 100 BHN for the T6 temper specified for the material. Typical hardness for a 2025-T6 alloy is 110 BHN. Metallurgical examination of the material revealed the microstructure to be typical of a forged 2Q25-T6 aluminum with no significant defects or deficiencies being apparent. Both blades were inspected using a high sensitivity fluorescent liquid penetrant but no other cracks were detected. The blade pitch angles at various radial stations were checked and found to be within the tolerances specified by the manufacturer. The blade width and thickness were above minimum specifications along the complete blade length. No anomalies that could have contributed to the failure were found in the propeller hub assembly.

This was a relatively simple failure to analyze, however sophisticated technology was able to discount many factors which may have contributed to the failure including the possibility of improper overhaul. The basic problem was determined to be inadequate maintenance.

THIRD EXAMPLE — Rolls Royce Dart Impeller Failure

A Fairchild F-27 was taking off at Quebec City airport at 18:55 hours on 29 March 1979 when the propeller assembly and the front section of the right hand engine separated from the aircraft just after lift-off. A substantial in-flight fire developed in the damaged engine remnants, wheel well, undercarriage and adjacent wing. The aircraft's crew attempted to perform a low circuit and return to the airport, but were unable to maintain flight and the aircraft crashed about one minute after lift-off. Seventeen of the twenty-four occupants, including all three crew members, were killed. The aircraft was destroyed by impact and post-crash fire (Figure 25).

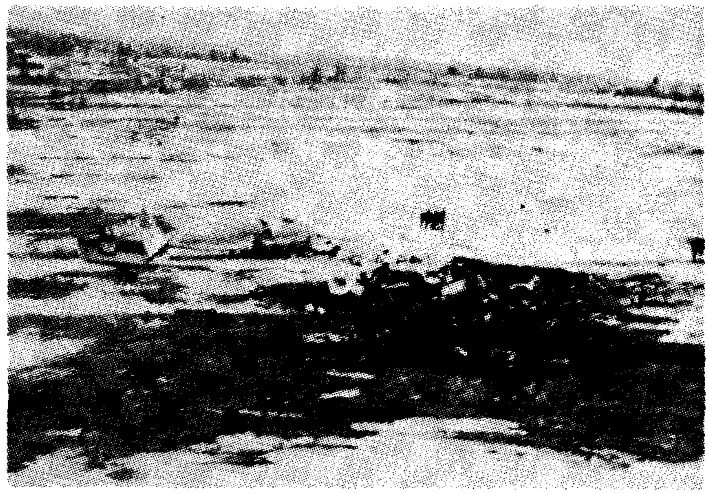


Figure 25 - Crash scene.

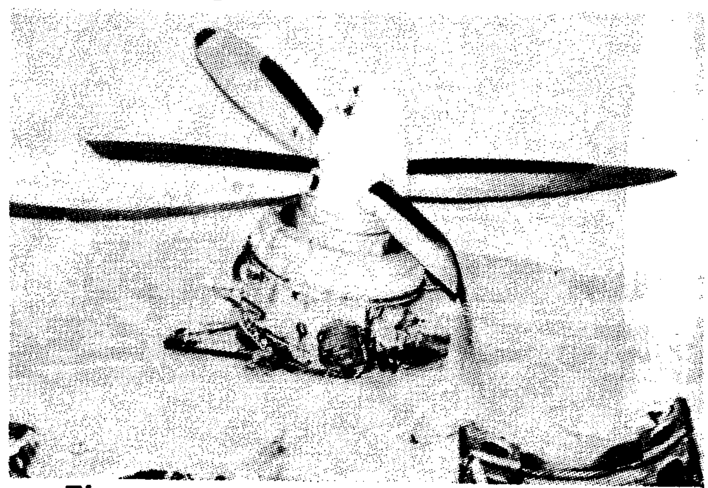


Figure 26 - Section of right engine which separated on take-off.

Preliminary on-site investigation suggested separation of the propeller assembly and the front section of the right hand engine (Figure 26) was possibly the result of bursting of the low pressure or first stage centrifugal compressor impeller. The pieces were sent to the laboratory for in-depth analysis. The impeller remains (Figure 27) displayed a major diametral burst fracture. The primary fracture face (Figure 28) was examined in the stereo-macroscope in detail, with no obvious differences disclosed in fracture topography. The river markings were highlighted (Figure 29) to identify the primary origins of the impeller rupture. Again no pre-cracks were immediately discovered at the origins. The fractures were subsequently cleaned with acetone to remove any volatiles and a lighter zone was suddenly visually apparent at the bore/rear abutment face corner (Figure 30).

Detailed stereo examination of the grey zone and light zone could discern no difference in topography (Figure 31). However, a smeared burr was discovered curled over the origin which when broken off disclosed a darker appearing zone. This was an angled precrack which was golden-brownish in shade (Figure 32) which closely matched that of the Alocrom treated (corrosion protection) surface of the

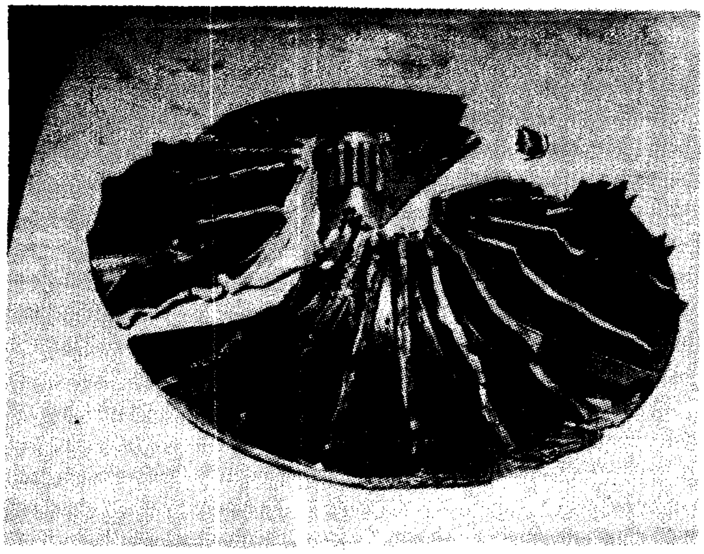


Figure 27 - Diametral burst of low pressure first stage centrifugal compressor impeller.

impeller. It was apparent that the original orientation of the precrack was 45° to the radial/axial plane of the major crack (Figure 32).

The balance of the rear abutment face and bore face and connecting chamfer were then subjected to careful non-destructive testing to determine if any other precracks were present in the impeller. A large secondary cracking indication was revealed by solvent removable fluorescent penetrant inspection. The crack was broken open (Figure 33) and appeared as two cracks angled at 45° and perpendicular to each other, both gold-brownish in colour. A small silvery zone was evident at the periphery of the brown crack B (Figure 33) which was oriented in the radial/axial plane.

The primary fracture origin (Figure 31) and the large secondary cracks (Figure 33) were then subjected to SEM examination. Typical mixed fatigue and ductile overload zones (Figure 34) were found in the light zone of the primary origin. This explains why the stereo-macroscopic examination discerned no topographical differences between

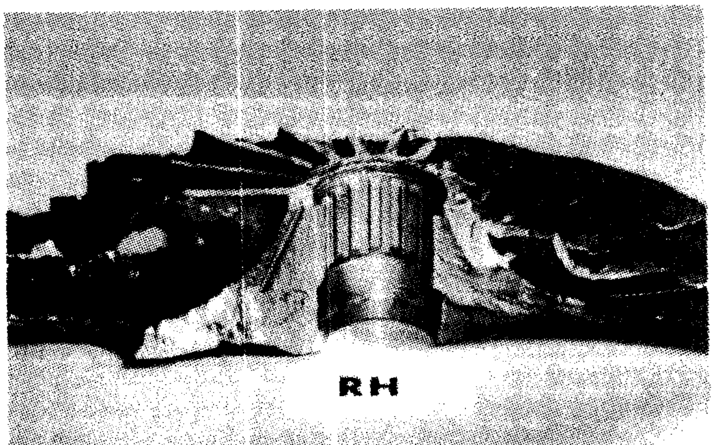


Figure 28 - Fracture face of failed impeller.

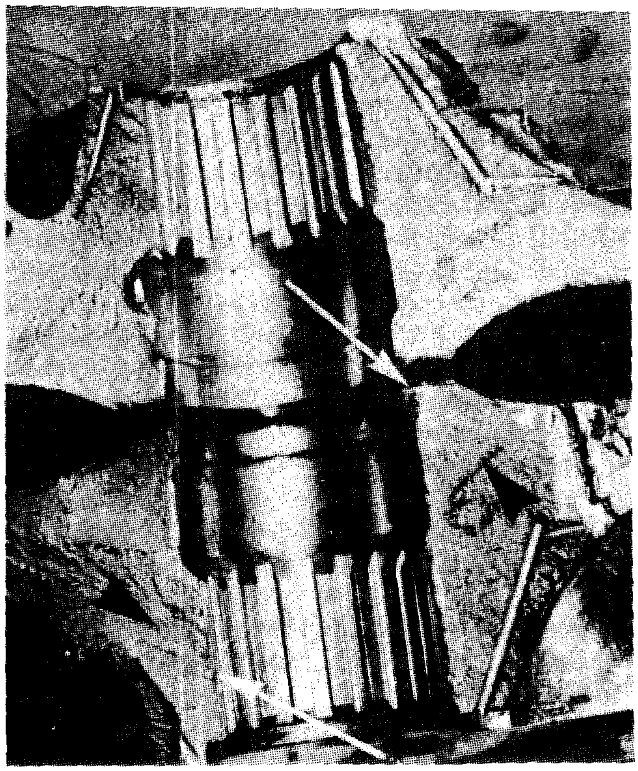


Figure 29 - River markings (black arrows) on fracture running back to origins (white arrows).

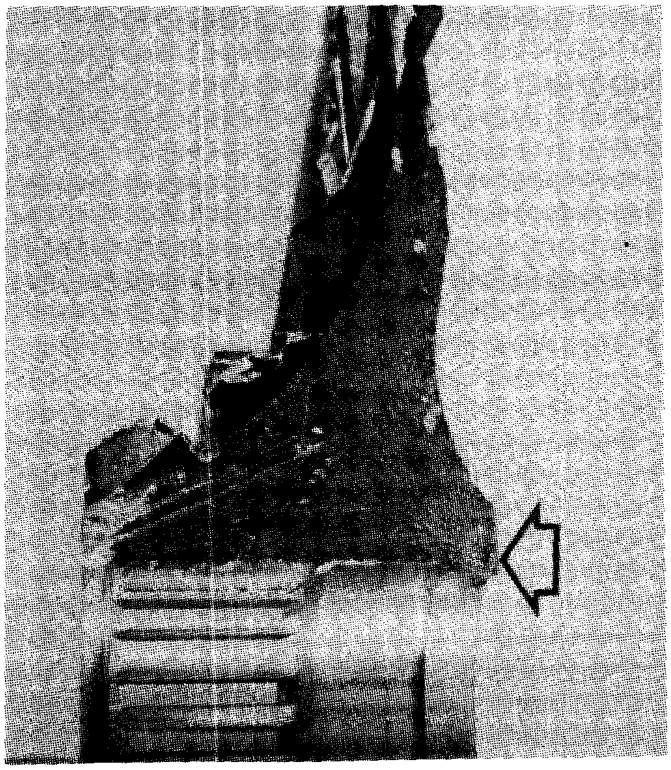


Figure 30 - Fracture after cleaning with acetone. Lighter zone at origin (arrow) appeared.

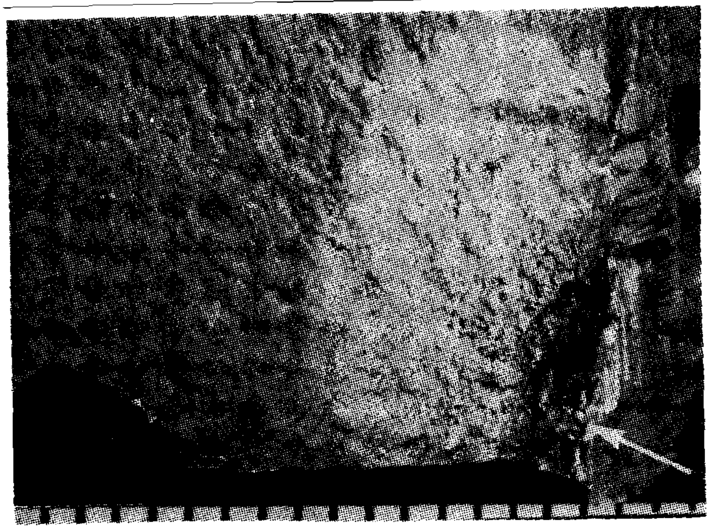


Figure 31 - Fracture topography appears same in grey zone and lighter zone. Dark zone (arrow) shown under smeared origin.

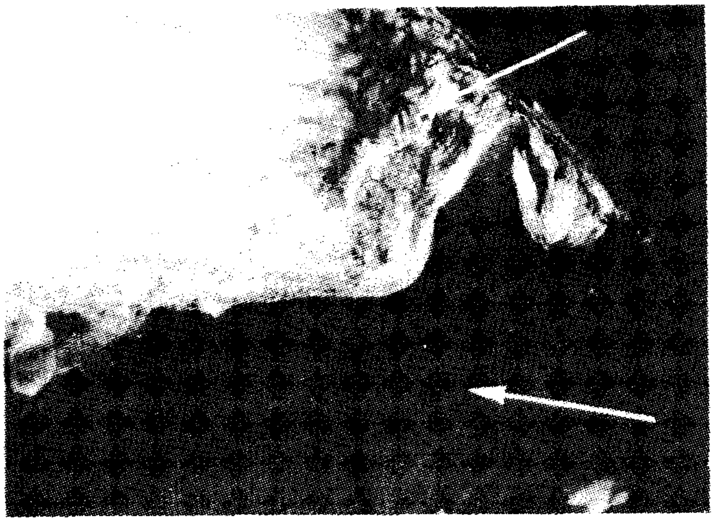


Figure 32 - Angled dark zone pre-crack displayed same golden-brownish colour as impeller bore (arrows).

Figure 33 - Two 45° gold-brownish secondary cracks, A and B. Highly reflective flat silver zone below arrows.

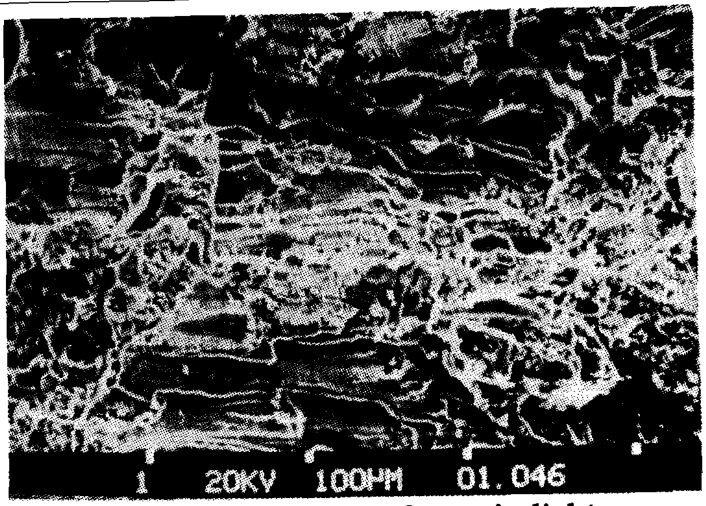


Figure 34 - SEM image of area in light zone (Figure 31). Zone is mixed fatigue and ductile overload. (X250 approx.)

the light precrack and grey overload zones. Clear and definitive microfractographic features of fatigue were disclosed in the light zone at high magnifications (Figure 35). Outside of the light silver zone and into the grey zone, no fatigue could be found and the entire area was characteristic of ductile overload rupture (Figure 36). SEM evaluation of the secondary crack (Figure 37) also revealed a similar pattern of topographic features to those seen on the primary fracture. Zone F (fatigue) is the silver zone at the periphery of the brown crack B. The brown coloured 45° angled precrack zones in the primary and secondary cracks were characteristic of fatigue crack growth, however the microscopic fine details were masked by predominantly chemical attack to the extent no fine striations were clearly discernable in the SEM. Subsequently TEM evaluation did reveal some possible fine striations in the brown precrack areas.

During SEM evaluation, energy dispersive X-ray spectrometric analyses of the various surfaces were simultaneously carried out. In addition spectrometric analysis of a clean bulk sample of the impeller material was performed.

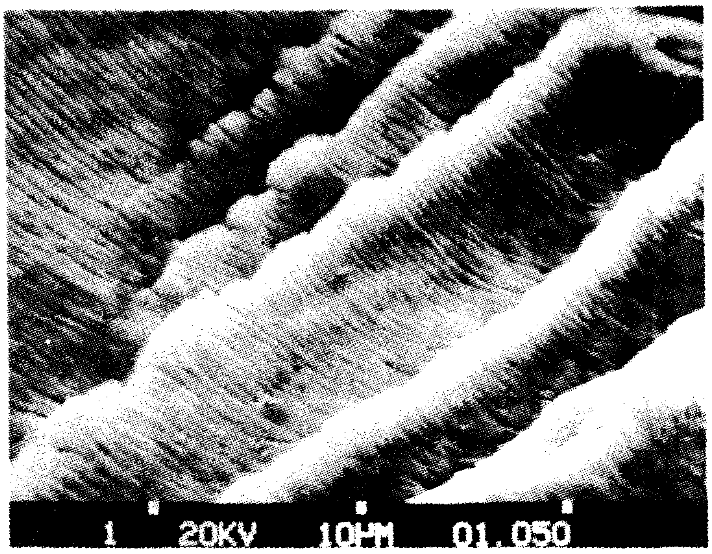


Figure 35 - SEM image typical of a fatigue area in light zone. Distinct striations are displayed. (X3000 approx.)

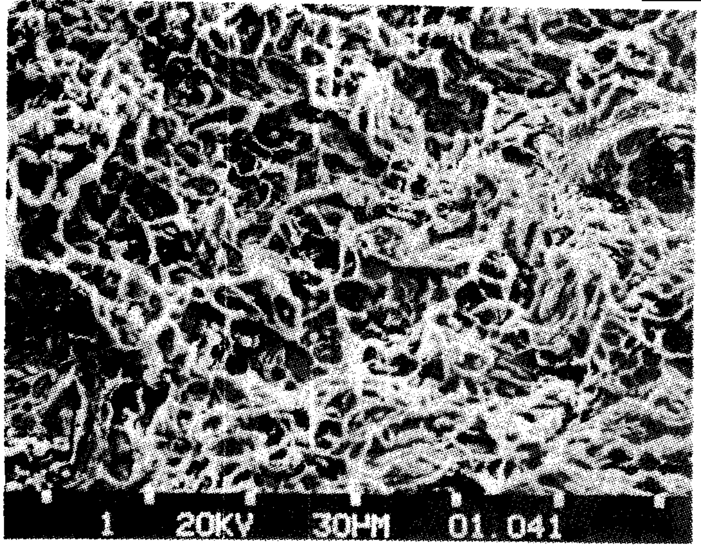


Figure 36 - SEM image of completely ductile overload in grey zone (Figure 31). (X500 approx.)

The impeller bulk material exhibited the characteristic spectrum for the specified Hiduminium RR 58 alloy (Figure 38A). It was also noted that there was no significant amount of chromium present in the basic RR 58 alloy. Analysis of the bore (Figure 38B) adjacent to the fracture surface showed a characteristic chromium peak superimposed on the RR 58 spectrum from the bulk material of the impeller. The impeller has a surface protective conversion coating applied via a proprietary "Alocrom" treatment, which explains the chromium peak. X-ray spectrometric analysis of the golden-brownish precracks (Figure 39) produced similar chromium peaks. It was concluded that the precracks were Alocromed and that variations in the height of the chromium peaks indicate greater or lesser quantities of chromium present, which in turn would represent a thinner or thicker Alocrom coating.

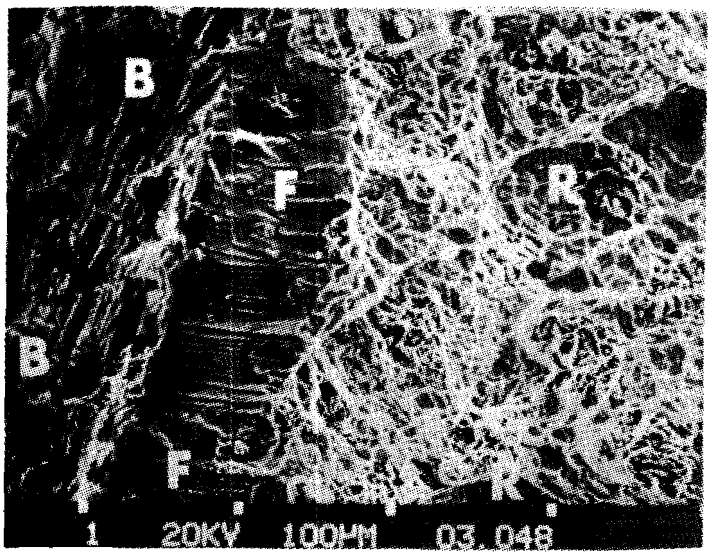


Figure 37 - SEM image clearly delineating three zones in the secondary crack. "B" is brown precrack angled at 45° to axial/ radial plane, "F" is small fatigue silvery zone, and "R" is ductile overload gray zone.

Again this kind of analysis allowed a definition of the mode of failure and a determination of the sequence. Although there is considerably more evidence and pertinent investigations in a number of other areas not described, the sequence could be summarized as:

(a) The impeller suffered in-service fretting damage to the rear abutment face;
(b) High-cycle, low-stress fatigue cracks originated from fretting and propagated at 45° due to impressed torsional loading;
(c) At overhaul when the impeller rear face was machined at least three fatigue cracks existed and were not completely removed;
(d) Subsequent penetrant testing did not detect the cracks;
(e) During the Alocrom application, the activating chemicals seeped into the fatigue cracks producing the characteristic brown colouration and effectively defining the magnitude of the crack's growth at the time of overhaul;
(f) Operation after overhaul caused the existing fatigue cracks to grow at an accelerating rate due to centrifugal loads only. (Installation of an anti-frettage shim had eliminated torsional cyclic loading);
(g) When the large crack had grown to critical flaw size during the last takeoff, catastrophic rupture occurred.

Subsequently world wide changes were made in overhaul procedures to preclude this kind of failure.

SUMMARY

An attempt has been made to demonstrate that there is considerable technology available to the investigator to aid in failure analysis. Failures are not always as they originally seem. The investigator must be aware of, and effectively employ, or obtain the services of:

(a) Optical, stereo-macroscopic, scanning electron microscopic and transmission electron microscopic examinations;
(b) Non-destructive testing techniques;
(c) Mechanical testing;
(d) Chemical testing such as energy dispersive and wave length dispersive X-ray spectrometric analysis.

In Canada we are constructing a new facility which has been designed for high technology analysis of aviation (and other modes) vehicle structures, systems, powerplants and components. It will be a resource centre available to Canadian investigators, hopefully by March of 1981. Members of ISASI are certainly welcome to visit this Facility located in Ottawa, Canada.

REFERENCES

Transport Canada, Aviation Safety Engineering Facility, Engineering Report Numbers LP 77/79, LP 91/79 and LP 202/79

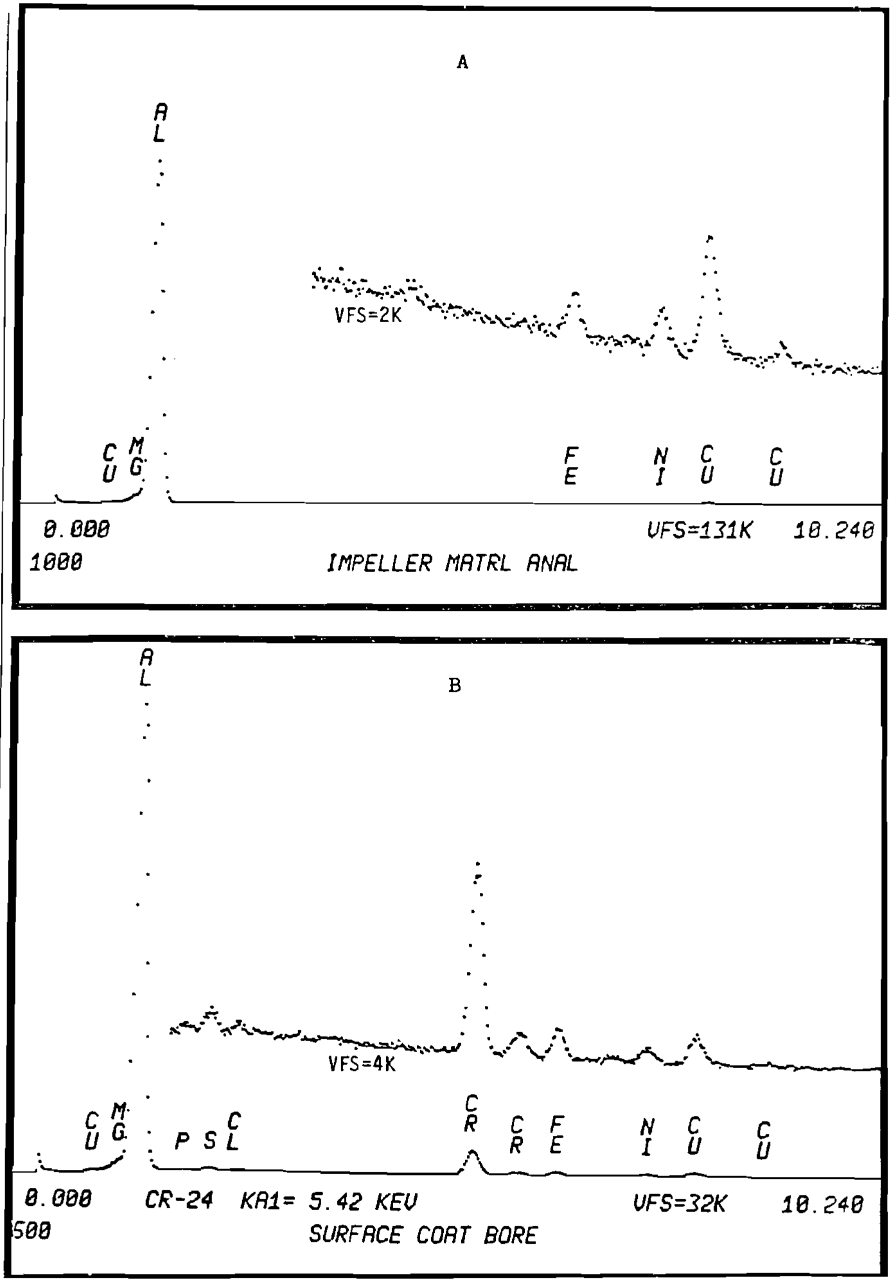


Figure 38 - Energy dispersive X-ray spectrometric analysis of (a) impeller base material, an aluminum alloy with no chromium; (b) bore surface with Alocrom protective treatment; displays chromium peak.

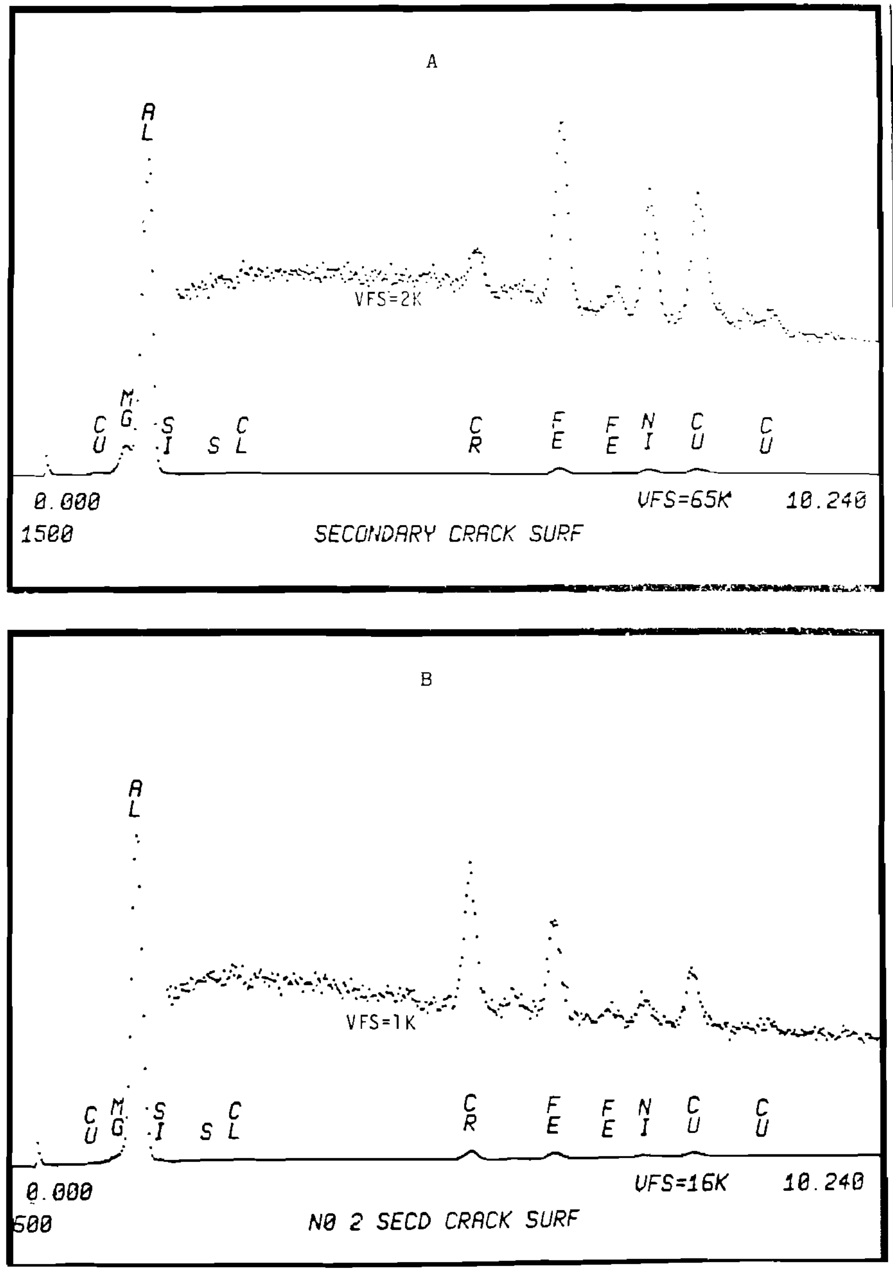


Figure 39 - Spectrometric analysis of (a) precrack surface showing chrome peak and (b) another secondary crack showing chrome peak. The different peak heights are due to varying thickness of Alocrom coatings.

Electron Beam Techniques In A Helicopter Transmission Failure Analysis

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INTRODUCTION

Electron microscopy and associated electron beam techniques are not new; they have been in scientific use for decades. However, their widespread availability for failure analysis is new during the last ten years. Failure analysis is a frequent hand-maiden of accident investigation.

The earliest form of versatile electron beam analytical instrument equipment, known as the transmission electron microscope (TEM), arrived on the commercial scene in the 1940's. It allowed the formation of a very high magnification image, due to several scattering mechanisms, by the transmission of the primary electrons in the beam through a specimen. It also allowed electron diffraction at low angles from a specimen surface. The microscopic imaging function was limited to thin foils for examination of the internal structure of a material or to the use of replicas for the study of surface topography. Replication complicates the analytical process and in some instances introduces uncertainty in the image interpretation.

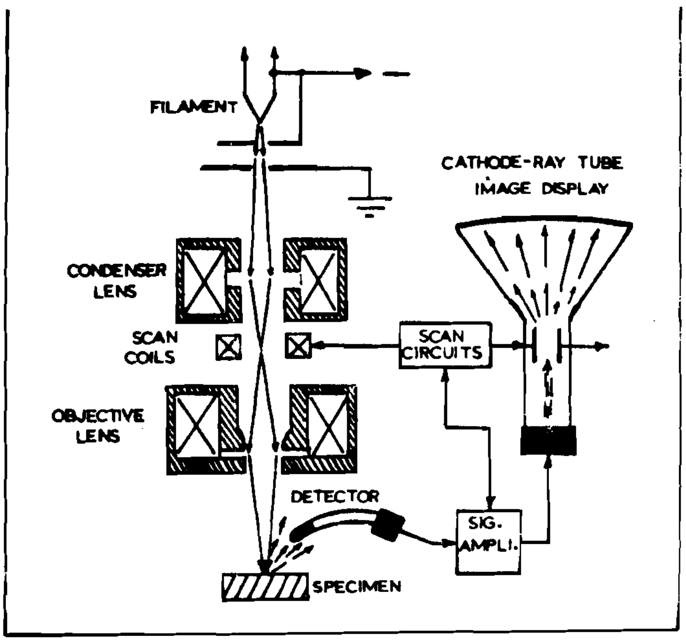


Figure 1 Schematic Diagram of SEM

The scanning electron microscope (SEM), which was first available commercially about 1965, looks only at the surface of an original specimen. The image is formed by measuring the intensity of either secondary electrons (ones knocked out of the surface atoms) or backscattered primary electrons as a function of position of a scanning primary beam. The intensity, properly amplified and conditioned electronically, modulates a video display on the face of a cathode ray tube, as shown schematically in Fig. 1. Secondary electrons produce a soft, and backscattered electrons a hard, image contrast. Therefore, contrast control is possible in most SEM's by varying the ratio of the two.

As soon as a secondary electron is knocked out of an atom in the sample, the atom, now in an excited state, returns to its electronic ground (base) state by one of several possible mechanisms. The most probable is the production of an x-ray quantum by the transition of an outer shell electron of the atom to the inner shell where the secondary electron had been ejected. These x-rays have a discrete energy and a discrete wavelength for each atom. They "fingerprint" the atoms from which they are emitted. By stopping the scan and holding the beam at one surface position, we can chemically analyze the material at that position if a suitable x-ray detecting attachment is added to the SEM. When the energy dispersive spectrometer (EDS) attachment is used, the x-rays are collected on a lithium-drifted silicon detector and an entire qualitative spectrum can be counted in a few minutes. This spectrum is usually displayed on the face of a cathode ray tube. Some SEM's have the ability to modulate the video presentation with a chosen x-ray line intensity during slow scan, thus "mapping" a given chemical element.

Finally, the depth of field presented by scanning electron microscopy at any given magnification is far greater than available with light optics.

THE ACCIDENT

Helicopter main rotor transmissions are complex, highly-stressed vibratory assemblies which reduce the engine speed to the much lower main rotor speed. They are carefully designed for efficiency and reliability using premium steels, bearing alloys and lubricants. Nevertheless, failure does occur occasionally in these transmissions.

Bob Jensen (l.) and Sheldon Roberts

Such a failure led to the crash of N5096V, an S-55B helicopter near Valdez, Alaska, on August 12, 1971. This aircraft was operated by Trans-Alaska Helicopter on contract to the State of Alaska. A ground observer saw the main rotor and a portion of the main gear box separate from the helicopter at an altitude of 200-400 ft AGL. The pilot and photographer passenger were killed.

THE INITIAL INVESTIGATION

Let us first understand the mechanical arrangement of the transmission shown in Fig. 2. The gear reduction ratio of 11.3148:1 was accomplished by a bevel gear stage followed by two planetary stages. The second planetary stage, where the failure occurred, contained eight 9310 steel pinion gears running between a sun gear and a ring gear which is a fixed part of the housing. The end loading of each pinion gear was absorbed by two thrust washers made from SAE J460 (formerly 791) alloy (a bearing bronze containing principally copper, zinc and lead). The entire assembly was held in a carrier of 4340 steel. A photograph of such a second stage transmission minus one pinion assembly and the cover plate is shown in Fig. 3.

The thrust washers, when adequately lubricated, floated between the pinion gear ends and the carrier surfaces while also overlapping a spacer-roller bearing assembly. The gear teeth and ends were case carburized to R_C hardness range of 60-64, the carrier was through-hardened to R_C 34 and the thrust washers were specified as half-hard (nominally R_B hardness 68). The shape design and the surface finish of the thrust washers is discussed later in this paper.

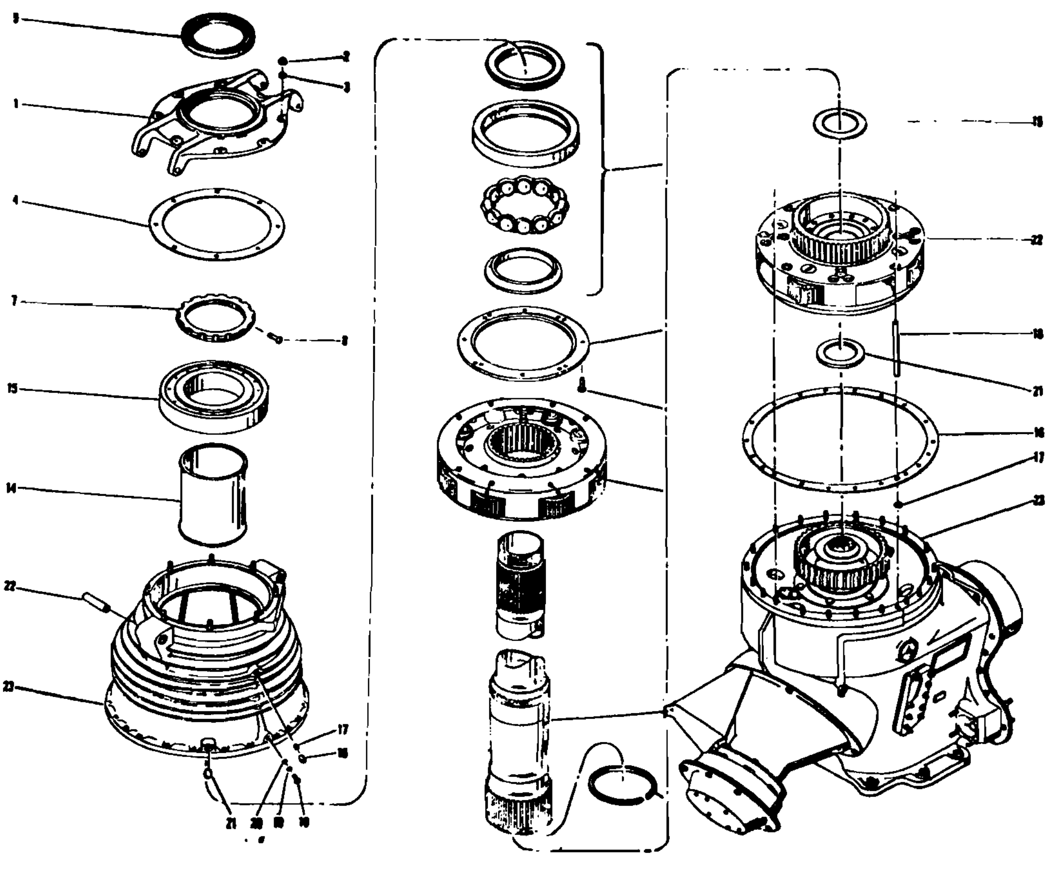


Figure 2 Exploded View of Main Gear Box

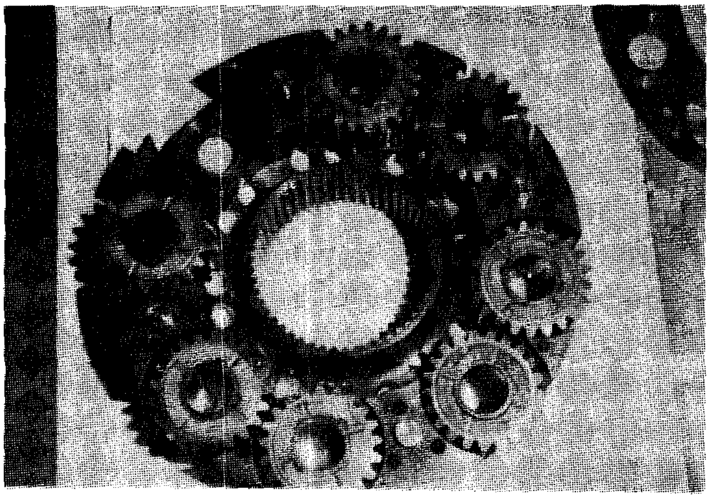


Figure 3 Second Stage Planetary from an Exemplary Transmission

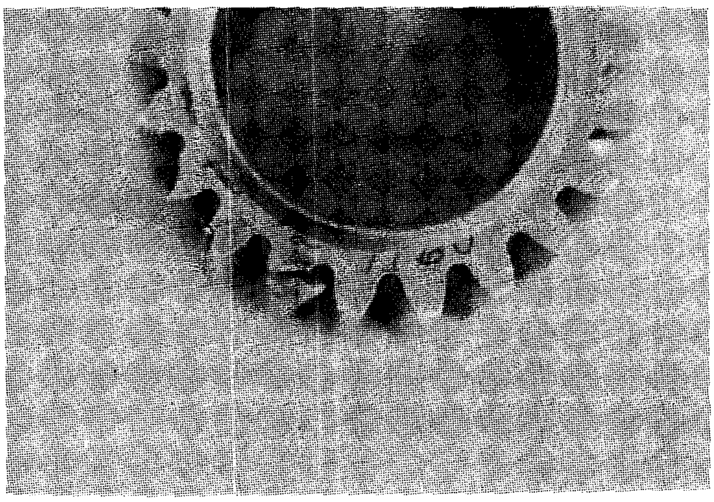


Figure 4 Pinion Gear Showing "Electric Pencil" Marking and Sheared Teeth

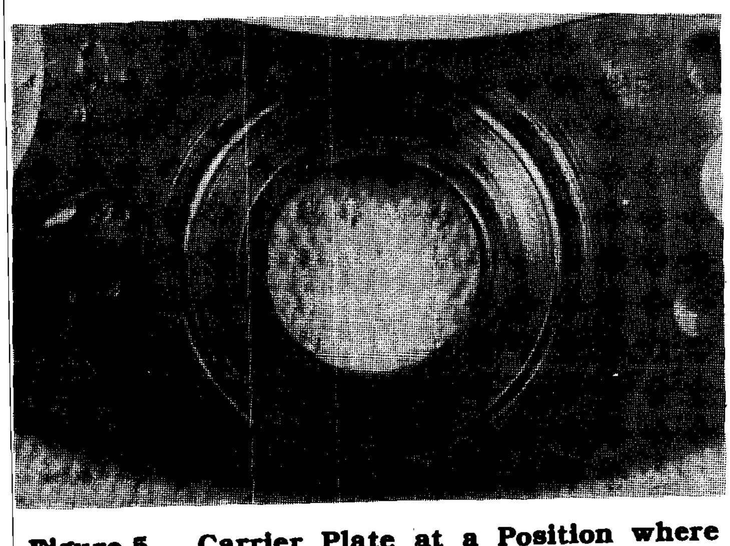


Figure 5 Carrier Plate at a Position where Thrust Washer was Cut Through

The earliest investigators, representing the aircraft manufacturer, the owner and the overhaul facility which had supplied the transmission, found, under the auspices of the NTSB, that a catastrophic failure of the planetary second stage of the main transmission had led to the crash. Two theories for the cause of this failure had been suggested when the present authors entered the investigation in 1973. They were:

1. "Electric pencil" markings had been made on the end of some second stage pinion gears. (Fig. 4) It was thought that such markings had led to localized wear and cutting through of thrust washers as the start of the second stage failure sequence.

2. It was determined that during storage of the helicopter, the transmission had been filled with an oil of the running type rather than the recommended preservative type. Many pits had been observed on the surface of pinion gears from the planetary second stage. These were thought to be corrosion pits and the source of fatigue failure in the gears.

It was found that several of the pinion gears had cut through a bronze thrust washer and then into the steel carrier. In the process of steel cutting steel which ensued, massive overheating, discoloration, shearing of gear teeth and multiple fatigue cracking occurred. (Figures 5, 6 and 7.) This led to complete disintegration of two gears and severe damage to several others.

The challenge of the investigation was twofold, to determine:

1. Whether gear fatigue failure preceded or followed thrust washer failure, and

2. What condition caused the first failure.

RECONSTRUCTION OF THE FAILURE SEQUENCE

Only a few of the thrust washers had cut through completely on the outer diameter where the gear and washer are in contact. In the final second planetary stage failure, thrust washers, some cut through and some not, were damaged and sometimes fragmented. The reconstruction of the remains of one thrust washer is shown in Fig. 8.

As the case hardened gears cut into the carrier plate, heat built up rapidly from the cutting and rubbing friction. Especially after the carburized case had been torn from the gear, gear core and carrier plate (both in the relatively soft condition of approximately R_c35) began a "stick-slip" welding and breaking process which led to the checking and cracking shown in Fig. 6. A large area of welded residue can be seen at the bottom of Fig. 5.

This process led to the formation of multiple fatigue cracks both in the carrier plate and in some gears. Metal became red hot and sparks flew in the final disintegration. These many cracks proceeding together were clearly the result, not the initial cause of failure. In order to identify the cause, the cutting through of thrust washers was examined.

The manufacturer had evolved the design of these washers over a period of years from a simple bronze toroid

Figure 6 Enlarged Area of Figure 5 showing Fatigue Cracks

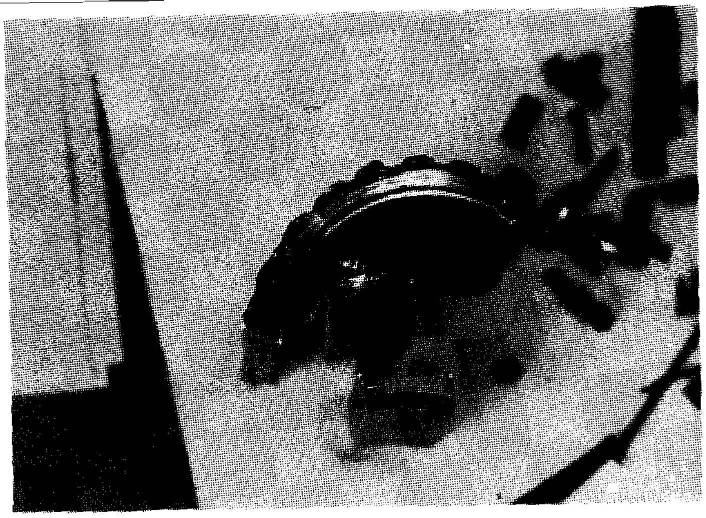


Figure 7 Fragments of Disintegrated Pinion Gear Showing Fatigue Cracks

(Fig. 9a) to a similar part with a nominally 0.0002-inch overlay of lead-tin alloy (Fig. 9b) and finally to a more complex part with oil channels and half-moon cutouts also overlaid. (Fig. 9c) The washers shown in Fig. 3 were made in either the original or the intermediate design and later modified to the final design by machining.

The usual function of a lead-tin overlay on a bronze bearing such as these is to reduce susceptibility to fatigue failure. Cyclic loading which leads to fatigue can arise from a slight helical content of the cut of the pinion gears, from deflection of the carrier or from a cyclic torque input from elsewhere in the helicopter. The function of the added grooves and cutouts would be to improve oil flow to the bearing surfaces. If cyclic loading is excessive and/or oil flow inadequate to the surfaces, fatigue failure of the thrust washer can occur.

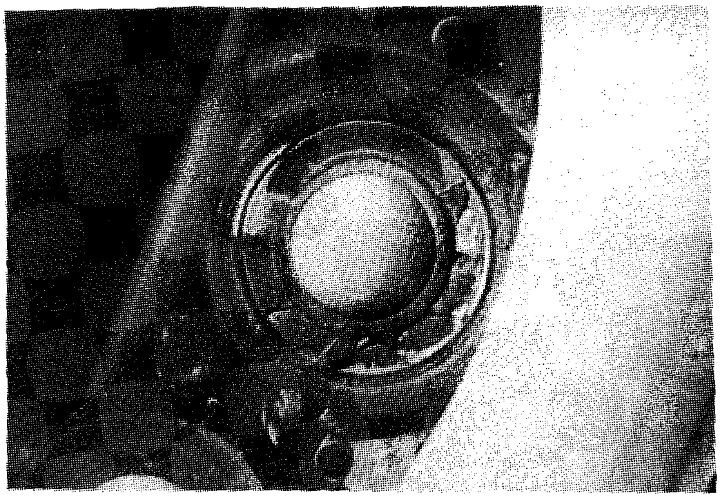


Figure 8 Reconstruction of Thrust Washer in Position on Carrier Plate

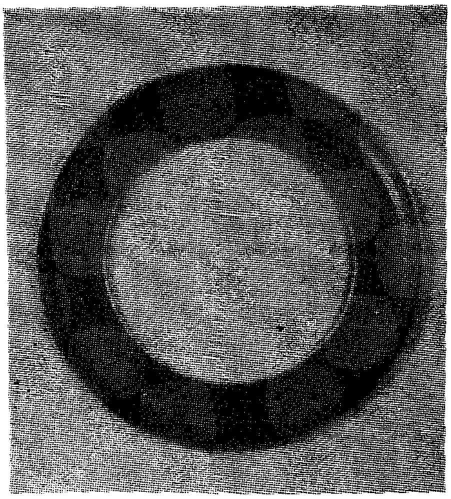


Figure 9a Early Type

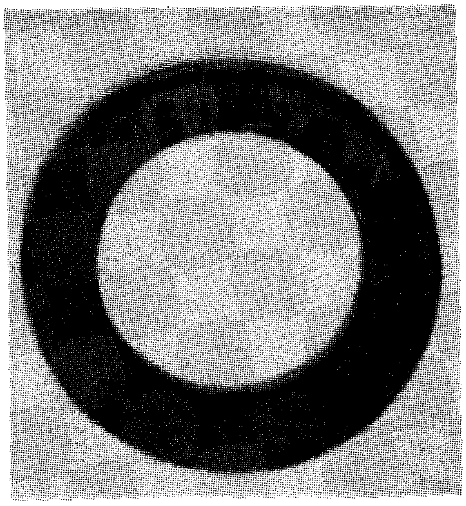


Figure 9b Intermediate Type

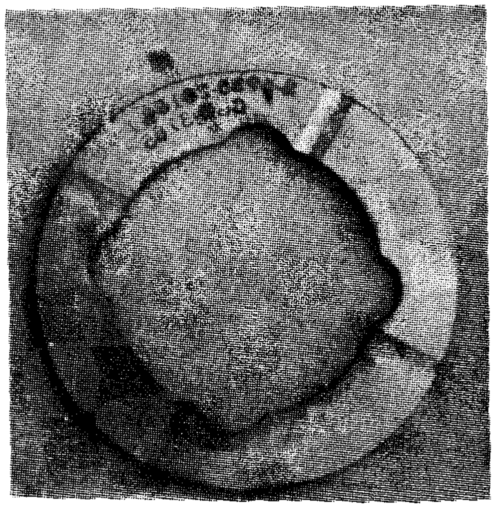


Figure 9c Final Type

Figure 9 Thrust Washers

Figure 10 Pits at Pinion Gear Tooth Root and also on Smeared Surfaces

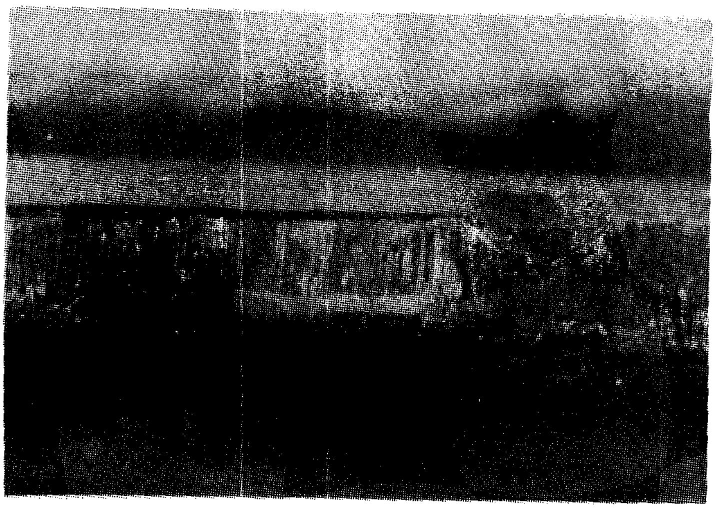


Figure 11 Pits and Discoloration on Smeared Surface from Final Breakup

Examination of the thrust washers and fragments thereof in this second stage showed that they were of the earliest design; that is, without lead-tin overlay and without grooves and cutouts. Furthermore, examination of a gear which had received the "electric pencil" face markings (Fig. 4) and its mating thrust washer showed that wear of the washer was not restricted to the marked area. The markings, which are apparently softer than the remainder of the gear face, were worn down. A combination of cyclic loading, a lack of lead-tin overlay and a washer geometry which allowed less oil flow combined to cause fatigue failure of the washers.

THE PIT STUDY

It still remained to explain the pits which were widely but non-uniformly distributed. No pits could be detected on any of the first planetary stage gears. They were seen profusely on second planetary stage pinion gears but hardly at all on sun and ring gears. Their density was often high at the root of pinion gear teeth (Fig. 10) leading to the original theory that they were a source of gear fatigue failure. The sources of these pits were determined by careful observation both optically and with electron beam techniques.

The optical observation yielded three clues:

1. The pits were densest in areas where the greatest heat discoloration had occurred.
2. Pits had often formed on surfaces which had been freshly formed by shear or fracture in the final breakup.
3. The pits showed a crater-like, rounded shoulder shape rather than the sharp, often undercut shoulder of corrosion pits.

Figures 10 and 11 illustrate these observations.

Figure 12a SEM Micrograph of "Hot Spark" Pit

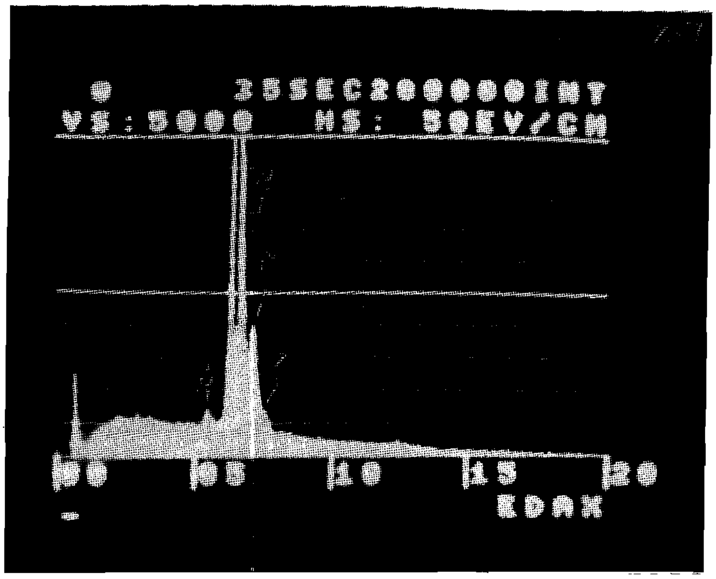


Figure 12b Energy Spectrum from within Pit of Figure 12a

The final resolution of the pit question was made possible by the SEM augmented with EDS. Fragments of those gears which had broken up most completely were studied. Many pits were examined and the presence of *melting* was the common ingredient to all of them. Pits were formed thermally in two ways.

Many pits resulted from hot sparks of steel landing on hot pinion gear surfaces. (The sun and ring gears were cooler.) Such a pit is shown in Fig. 12a. A larger fraction of the pits resulted from particles of bronze dust (widespread because of the cutting through of thrust washers), which burned a pit into a hot gear surface, leaving a foreign residue, Fig. 13a.

The energy spectra shown in Figs. 12b and 13b correspond to x-ray emission from the pit and nearby gear surface positions shown in Figs. 12a and 13a. The presence of melting and hot checking of the sparks' residue is apparent in Fig. 12a. The presence of copper, zinc and lead in large quantities in the pit spectrum of Fig. 13b is a clear contrast to the background. Many pits were studied and all corresponded to one type or the other.

SUMMARY AND CONCLUSION

With the help of the SEM-EDS combination, it was proven that the pits were a product of the catastrophic final breakup of the transmission second stage. The initial fatigue failure was that of the thrust washers, not the pinion gears. Unimproved washer design which limited lubricating oil access and lack of a lead-tin alloy overlay contributed to the initial failure.

About the Authors

C. Sheldon Roberts holds a B.Met.E. degree from Rensselaer Polytechnic Institute, and S.M. and Sc.D. degrees in Metallurgy from the Massachusetts Institute of Technology. He has been involved in materials research and development for more than thirty years, both in industry and as a Material and Processes consultant in failure analyses. Sheldon is a member of the American Society for Metals, IEEE, Metallurgical Society of AIME, Phi Lambda Upsilon, Sigma Xi, Tau Beta Pi, and ISASI. He is a Registered Professional Engineer in California (MT521), and an FAA licensed Commercial Pilot with Multi-engine and Instrument ratings.

James R. (Bob) Jensen holds a B.S.M.E. from Stanford. He had various engineering assignments up to and including Senior/Chief Flight Test Engineer at Hiller Aircraft, and was Chief Engineer, Aviation Safety and Accident Consultant for Progressive Aviation of San Jose, California. Bob has been an independent engineering consultant since 1977, specializing in aviation safety and accident consulting, and laboratory and flight testing for fixed- and rotary-wing aircraft, engines and accessories. He is a Registered Professional Engineer in California.

Figure 13a SEM Micrograph of "Burning Bronze" Pit

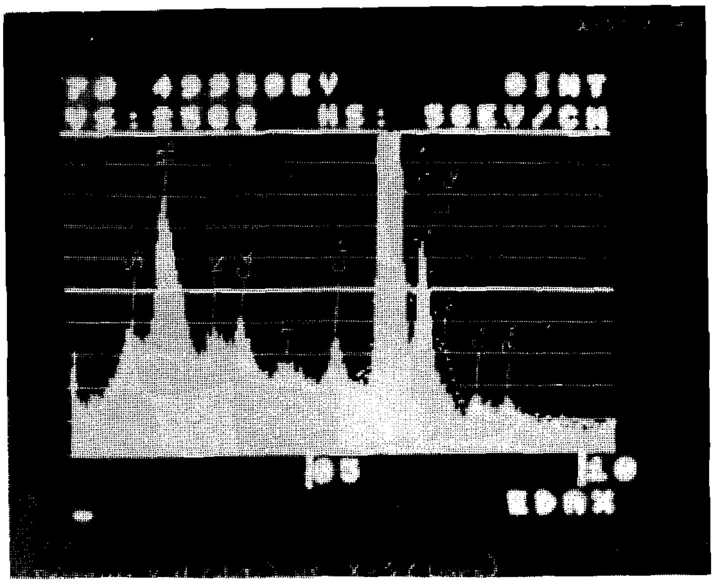


Figure 13b Energy Spectrum from within Pit and on Nearby Surface of Figure 13a.

Wreckage Mapping

Frederick H. Matteson AO1167

INTRODUCTION

Part III of the ICAO Manual of Aircraft Accident Investigation (Reference 1) states, "The precise location of the accident site must be determined and recorded. This can be achieved by plotting the bearings and distances from known positions on a large-scale map or by using aerial photography of the accident site in conjunction with a suitable map". It goes on to say, "After the initial study of the general scene of the accident has been made and photographs taken, the first step in the actual investigation is usually that of plotting the distribution of wreckage." Two methods are suggested depending on the degree of scatter. The first is measuring the bearing and distance from a common central point to each wreckage item. The second is to measure perpendicular offsets from a base line along the wreckage trail. In mathematical parlance these two methods are referred to as polar and cartesian coordinates respectively. There are other ways of making the survey and the manual mentions using the services of a land surveyor.

Over the years I have viewed many wreckage distribution maps and have found that their quality varies greatly. Shortcomings appear when use of the map is attempted and some are listed:

1. Failure to identify positively the items mapped. The use of item numbers as suggested in the manual solves this problem.
2. Failure to locate the wreckage with respect to permanent landmarks or references. This is especially important if portions of the wreckage are missing and later recovered.
3. Failure to label north as true or magnetic.
4. Failure to map all wreckage.
5. Failure to dimension locations completely. It takes two dimensions to define a location of any item. (Three if not at ground level!)
6. Use of general directions and estimates of distances; for example, "The right wing was found a quarter of a mile east of the main wreckage."

The purpose of this listing of shortcomings is not to find fault with investigators for not being more diligent, but rather to examine the task with the objective of allowing the investigator to do a better job with less time and effort expended. There are ample reasons why shortcomings arise, including the pressure of other tasks, inhospitable terrain and weather, hazards to the investigator, interference from the public and shortages of time, equipment and assistance. Investigators also may be tired, uncomfortable and lacking insights as to the relative importance of the various items they encounter at the site.

ANALYSIS AND POSSIBILITIES FOR IMPROVEMENTS

From a practical viewpoint the primary objective in the quest for an improved mapping method must be to simplify and speed the measuring task. A high degree of accuracy such as that required of land surveying is not necessary. The larger the number of items to be mapped and the greater their scatter, the harder the task. This is primarily a result of the time and effort required to measure distances. Investigators often pace off distances. The location of an object by two distance coordinates requires much more time spent in pacing than the angle and distance technique because the bearing to an object can be measured while standing in one spot. If the terrain is difficult, pacing the distances is difficult, if not impossible; the accuracy of the result may also suffer. An alternate to pacing or chaining is the use of distance measuring instruments such as the range finder, sextant with stadia rod, geodimeter and tellurometer. Any of these instruments may provide a superior alternative to pacing or chaining, but tend to have disadvantages of size, weight, cost and impracticability of one-man operation. Where such disadvantages are acceptable the use of modern surveying devices should be considered. For example, the Hewlett Packard HP 3805A Infrared Light Source Distance Meter offers a range of a mile with accuracy better than a tenth of a foot, weighs less than 17 pounds and sells for about $5000 US. More expensive models are available with range capability up to five miles. Using a single fixed target, one-man operation is possible. The 3805A measures slope distance and some models compute horizontal distance.

Another technique for locating points on a surface is by triangulation. The lengths of the sides and the angles in a triangle can be determined if three side lengths, two sides and an angle, or two angles and a side are known. Because of the ease of angle measurement the two angle and one side case is most interesting. If two objects are visible from the area of the wreckage site and the distance between them can be measured, then that length can be used as a common side for triangles, the opposite angles of which subtend from items of wreckage. Figure 1 shows a sketch of the scheme. The objects chosen will best be those which can be relocated at a future date. This suggests fence posts or gates, power poles, etc., and should be photographed for a permanent record.

straight trail for which measurement errors may be calculated for unit heading errors. The reference landmark objects and wreckage items remain symmetrically disposed. In this case the optimum distance between the reference objects is 95 percent of the length of the trail and the optimum distance between the trail and the objects is 17.5 percent of that trail length. If the distribution is not uniform along the trail (the equal spacing is in a sense uniform) the optimum distances will be different. By weighting the errors associated with the middle item by a factor of five, the optima for a trail with a heavy concentration of wreckage in the center have been created. For this case a distance between the reference objects of 55 percent of the trail length and located 22.5 percent to its side resulted in minimum errors. Error magnitudes do not vary greatly as one departs from the optima. As a generalization, when using two landmarks for mapping by taking bearings, those landmarks should lie roughly parallel to the trail of wreckage and about 15 to 35 percent of the trail length to one side, and should be from half to one trail length apart. Figure 5 presents these results graphically. Whether the method described offers an advantage over others must be judged by the investigator.

REFERENCE

1. International Civil Aviation Organization, "Manual of Aircraft Accident Investigation", Document 6920-AN/855/4, Fourth Edition, ICAO, Montreal, Canada, 1970.

About the Author

Dr. Matteson is a self-employed consulting engineer specializing in aerodynamics and flight safety. Previously he was employed by NACA as a research scientist and by Hiller Helicopters as a flight test engineer and aerodynamicist. He is a member of the San Francisco Chapter of ISASI.

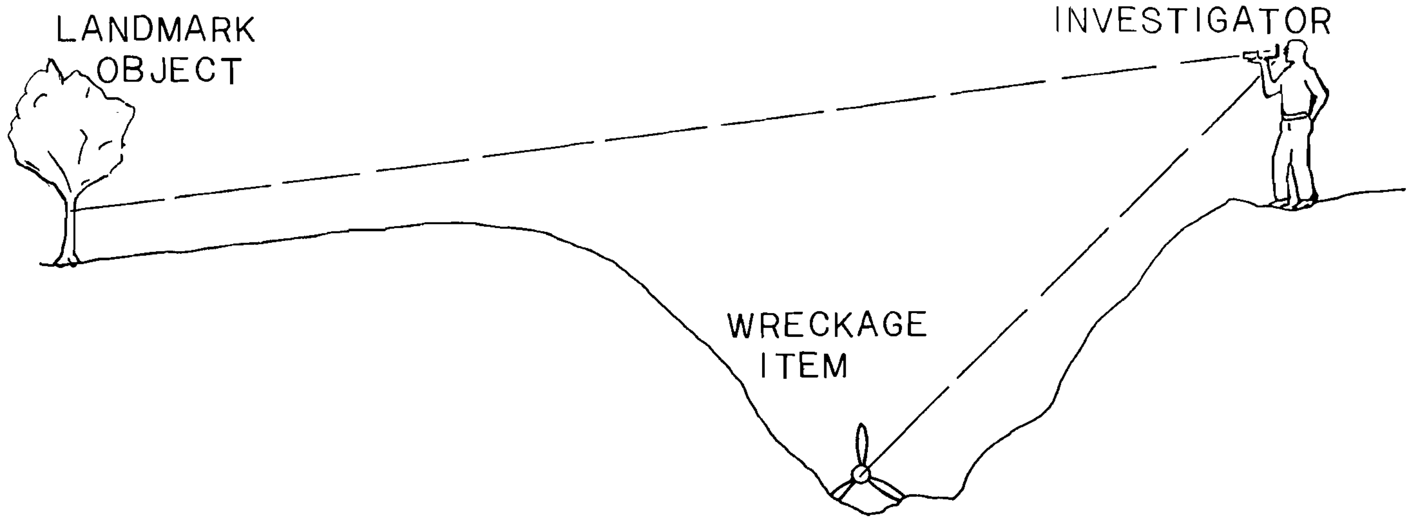


FIGURE 4 - WRECKAGE IN A RAVINE.

from the landmark objects. Considering the error of measurement in bearing to one object (the other bearing remaining constant), the minimum linear vector error results when the angle between that bearing and the other object is 90 degrees. If equal errors in both bearings are assumed, the error associated with the nearer object is smaller than that for the further one with the minimum total error being when the wreckage item lies equidistant from the objects. Now if we examine the errors of a series of items each equidistant from two objects the item representing the minimum error vector lies at a point about 35 percent of the distance between the objects resulting in an angle of about 110 degrees between the bearings. From this discussion it can be seen that the landmark objects preferably will be located as symmetrically as possible with respect to the wreckage trail and, if that trail is curved, on the concave side.

Although of interest, studies of one item do not reflect the reality of actual wreckage trails whose characteristics may vary greatly. So let us examine a simple case of three items representing the first, middle and last items in a

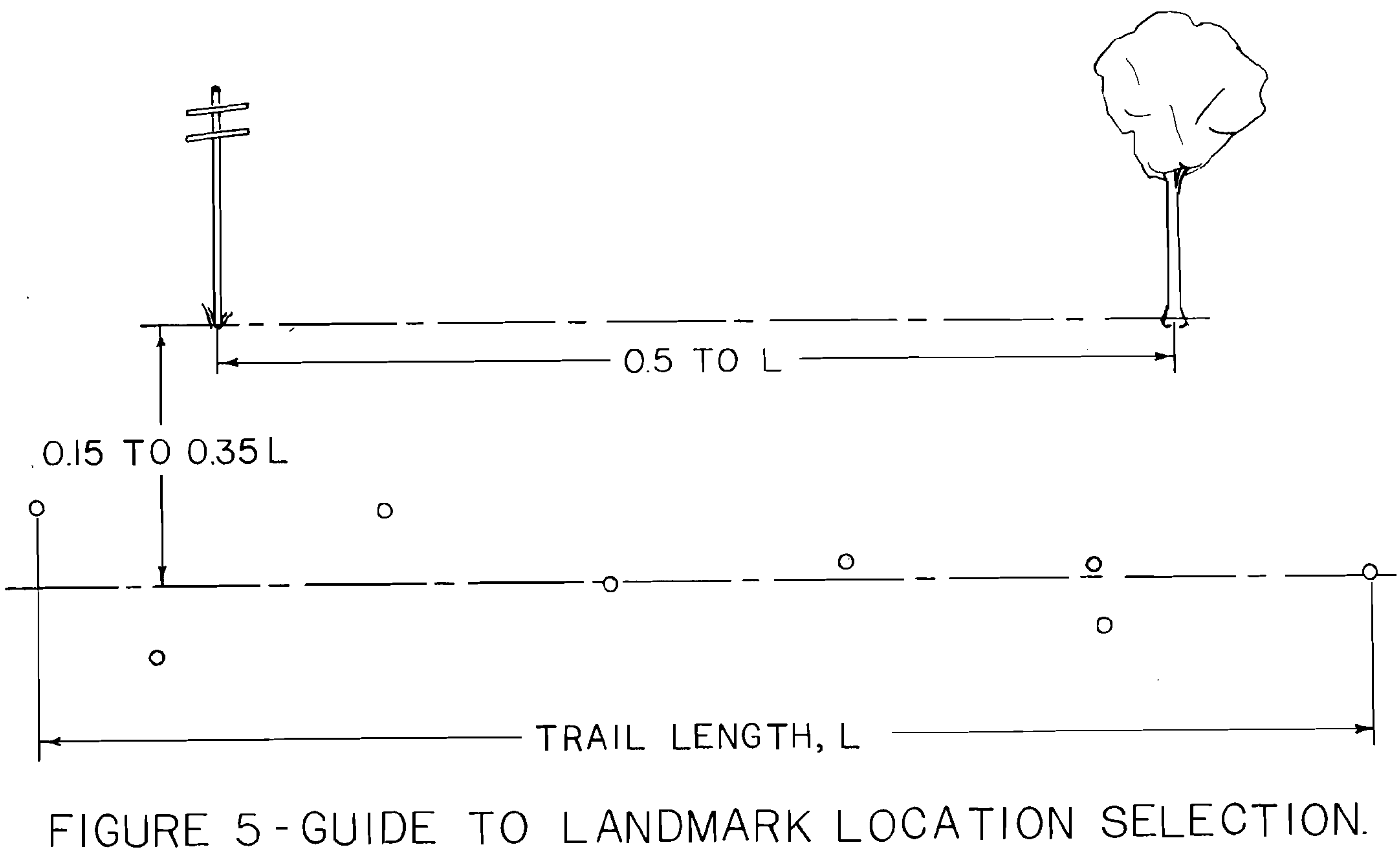


FIGURE 5 - GUIDE TO LANDMARK LOCATION SELECTION.

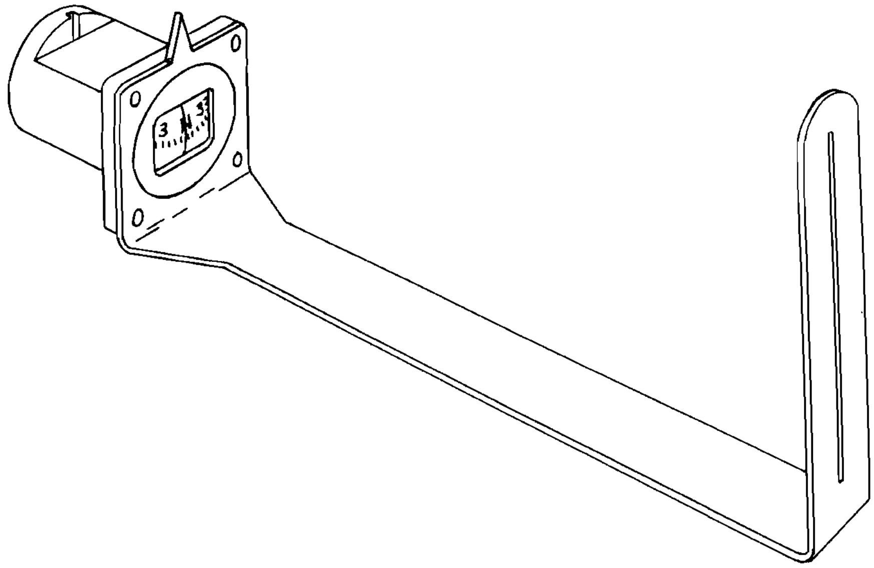


FIGURE 2. - SIMPLE HAND-HELD PELORUS

ERROR MINIMIZATION

The accuracy of the map of wreckage using the above method will be depending on the location of the landmark objects selected with respect to the wreckage trail. Analysis of the problem offers some guidance. Considering an angular error in bearing measurement to an object, it is apparent that the less the distance the less the lineal error that results. Also apparent, I believe, in triangulation is the fact that the closer the wreckage item is to being colinear with the landmark objects the greater the accuracy of the perpendicular or "x" dimensions but the poorer the accuracy of the "y" dimension such that when the bearings are 180 degrees apart its "y" location is not determined at all.

If the vector sum of the x and y errors arising from a unit bearing error is used as a measure, then these opposing influences should result in an optimum at some distance

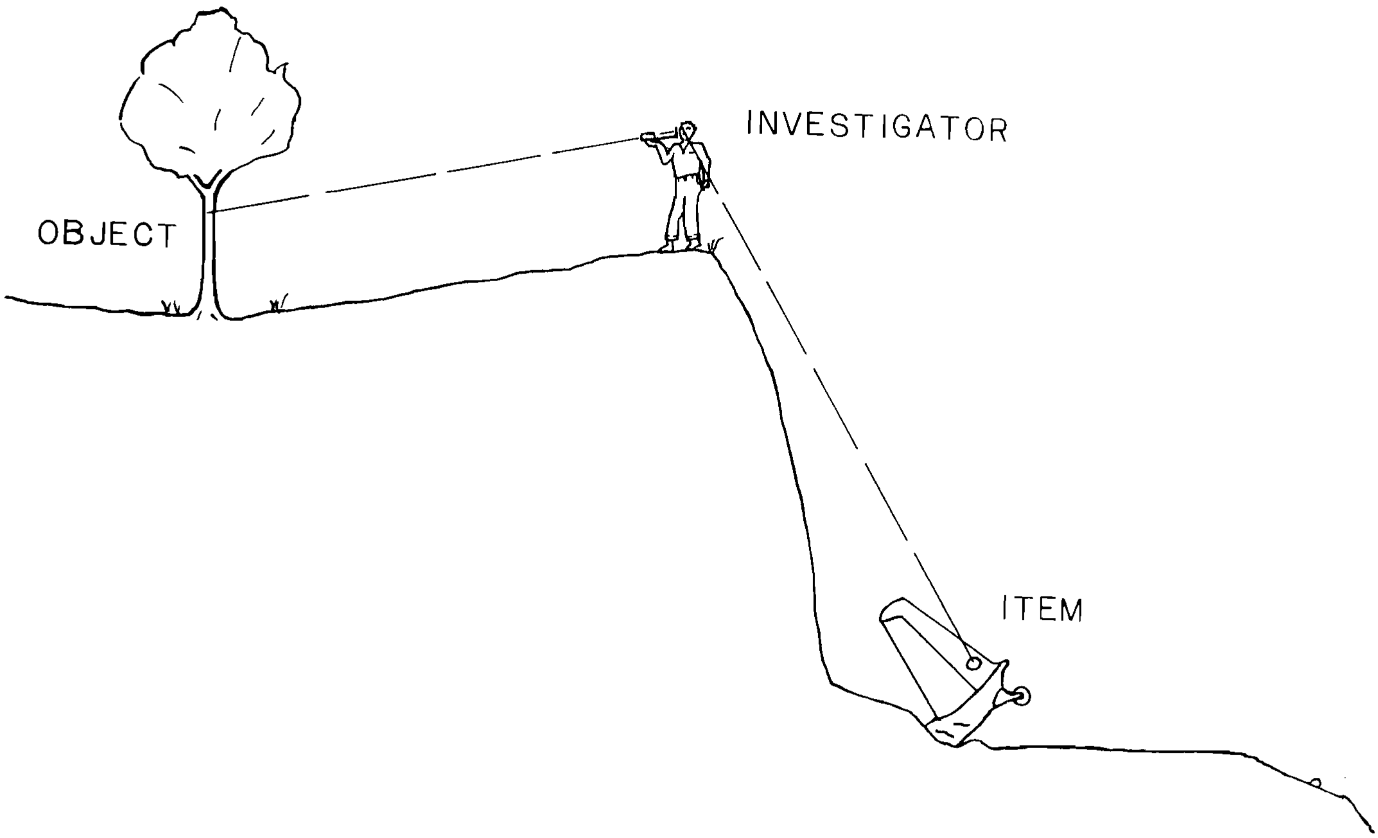


FIGURE 3 - WRECKAGE BEHIND AN OBSTACLE.

The angular orientation of the reference objects, τ, can be measured from magnetic north and the angles to each object from an item of wreckage, Θ_1, and Θ_2, likewise can be determined. If we label the angles with apices at the wreckage item, Object 1 and Object 2 respectively γ, α, and β then,

$$\gamma = \Theta_2 - \Theta_1$$
$$\beta = \tau - \Theta_2 + 360°$$
$$\alpha = 180° - (\beta + \gamma).$$

In practice the investigator can take two angle readings from north to the two reference objects at the location of each wreckage item and thereby locate all the items with respect to a set of reproducible landmarks. The measuring of the distance between the landmarks need not be done immediately.

The angle measurements can be made using surveying instruments; however these devices are usually made for tripod mounting and may not be practical. A pelorus such as used to get bearings aboard ship can be employed, or a simple version which is easy to carry and use can be constructed with a standby compass. If angles are measured in the horizontal plane to elevated objects then distances determined will be horizontal. Figure 2 shows such an instrument.

Even though angle measurements are often far easier obtained than distance measurements in the field, there are instances when problems arise. Wreckage falling in forests or deep swamps results in very difficult, if not impossible mapping, sometimes making locating and recovery an arduous task. There are some procedures which can simplify certain mapping problems. Should a piece of wreckage be located behind an obstacle or in a ravine hidden from the landmark objects, it may still be possible to obtain bearings. The sketches of Figures 3 and 4 show two procedures. In Figure 3 the item lies out of sight of the tree behind a hill. If the investigator stands on the hill between the item and the tree and sights to the tree and the item he can obtain the bearing by moving until the bearings to each of the two lie 180 degrees apart. In Figure 4 the item is hidden in a ravine. By standing on a far bank the investigator can view both the item and the landmark object; when all three are in line he can get the bearing.

The investigator may record his measurements on a clipboard or in a notebook. At times the wind, rain, cold and necessity for operating cameras and other equipment can impose difficulties in recording data and observations. Modern technology has provided tape recorders, some with remote controlled microphones, that allow fast recording of material in chronological sequence. For example, the Sony M-200 recorder permits two hours recording time per cassette, weights only nine ounces and easily fits into a shirt pocket. It runs on a rechargeable battery pack.

Although bearing data can be plotted directly, again modern technology in the form of the hand-held programmable computer allows rapid conversion to orthogonal coordinates which facilitates plotting on maps or graph paper. To start, one of the landmark objects is selected as the origin and directions, north-south as the "y" and east-west as "x". In the following equations the first object (1) is selected. The radial distance from a wreckage item to this object, B, is

$$B = \frac{\sin\beta \cdot l}{\sin\gamma}$$

$$x = B\cos(-\Theta_1 - 90°)$$
$$y = B\sin(-\Theta_1 - 90°)$$

Although compasses point to magnetic north, maps are laid out to true. If the variation, δ, is taken as positive when easterly, then the coordinates with respect to true are, x_δ and y_δ.

$$x_\delta = x\cos\delta + y\sin\delta$$
$$y_\delta = y\cos\delta - x\sin\delta.$$

The computations have been programmed for the Texas Instruments TI-59 computer. Those desiring this program on magnetic cards may contact the author.

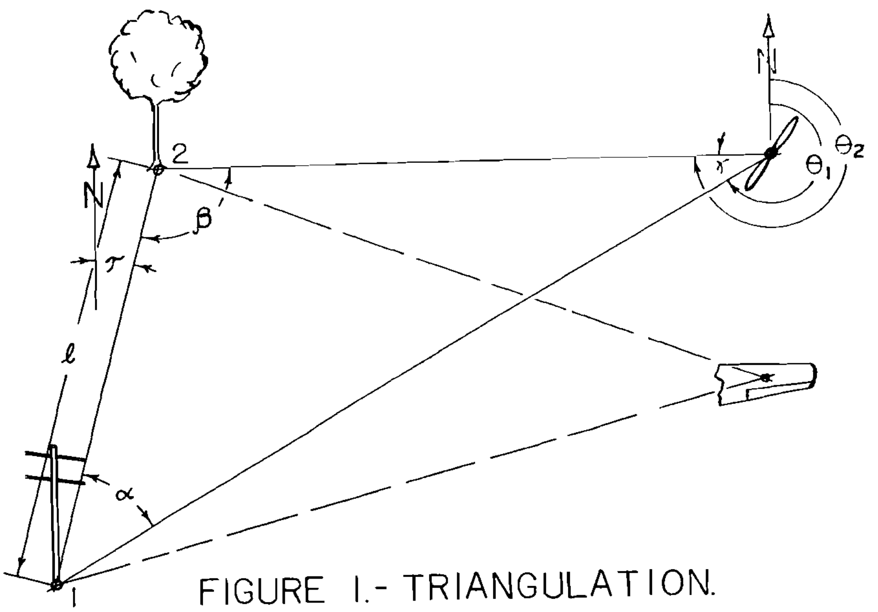


FIGURE 1.- TRIANGULATION.

Soaked, Scorched Or Altered Logs And Maintenance Documents

Methods of Preservation and Restoration

George E. Posner, C.L.I., M-421

Those of us who have investigated aircraft accidents eventually notice that airplanes come to grief in areas quite inconsiderate of the investigation that is sure to follow. They end up in rivers and lakes, swamps and even oceans. Recovered aircraft pulled from these areas usually carry water-soaked airframe and engine logs, maintenance documents, navigational notes, ATC clearances and charts. No written data aboard the aircraft is beyond scrutiny; all is of interest.

It is easy to imagine the discouragement of an investigator when these important papers are first seen. It is important to know, however, that if prompt action is taken, these documents can often be restored to legibility. But prompt action *is* essential and proper procedures must be followed.

Never attempt to obtain information from these documents when they are wet. Do not attempt to open log books or to spread out charts. Constant supervision over these documents must be maintained so that other persons into whose hands they may be temporarily entrusted are also warned that they must not be handled in any way except to be transported.

The most immediate effort to be made is to stop bio-deterioration. Mold and other spores find a happy home in soggy paper. Wet paper exerts internal forces while drying, which further damages the fibers. Resins and other paper coatings begin a cementing effect and field dust begins to adhere. These physical and chemical changes must be arrested.

All documents, books and papers must immediately be frozen to zero degrees Fahrenheit (minus 18 degrees Celsius) or lower. Refrigerator trucks and trailers can sometimes be commandeered, or in some cases, even small vehicles with refrigerator components such as ice cream trucks may be used. Dry-ice boxes are even a possibility. The logs and documents are then moved to some nearby town or city where long-term cold storage facilities are available. There are many such cold storage facilities, even in small towns, and they are usually not expensive to rent. When everything is safely stored at sub-zero temperatures, you have bought time and breathing space and can plan, with no sense of urgency, their proper restoration.

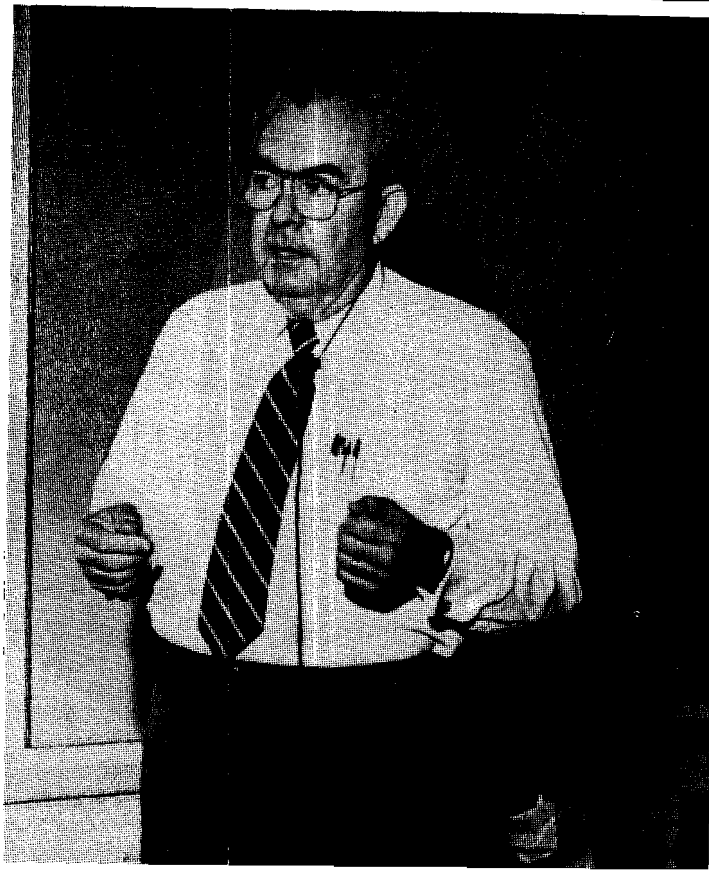
The documents must now undergo a process known as freeze-drying. Everyone knows that water will boil at room temperatures in a high vacuum. The ice will sublimate, rather than melt, and pass directly to vapor without going through the water phase. When the documents are dried in this way they can usually be subjected to an initial examination. Sometimes, though, they have been overdried and the paper is as brittle as potato chips. In this case a slow and partial remoisturization is indicated.

Some resin coated papers may be stuck together because of the cementing action of the paper coating. This stack of papers is called "blocked." The unblocking of coated papers sometimes calls for rewetting and redrying, a procedure which may be repeated several times.

Some log books may not have dried evenly and they resist uniform paper separation. Rewetting and redrying can sometimes be effective. Some workers have found that a microwave tunnel dryer, together with high vacuum, will separate or unblock otherwise hopeless cases.

Freeze drying and vacuum chambers are not found at every street corner, and it is best to remember that there is no hurry to get the material out of cold storage. Your sources may be food processing plants, high-technology manufacturing plants, universities and Air Force Bases. I have not inquired into the suitability of the high-altitude (physiological) test chambers for the type of freeze drying described here, but it would seem a suitable experiment for persons interested in the field restoration of soaked documents.

Once opened, many documents have revealed a hopeless case of ink rivering and deterioration of writing or printing. The first attack is usually with ultra-violet reflection photography, as opposed to ultra-violet fluorescence. Forensic photographers, accustomed to these procedures, can usually be employed at this last stage of restoration. A space-age high-technology procedure is becoming available: the digital image enhancement of vague and faint writings or entries. The same procedure used to "clean up" photographs of Venus and Mars can also be used to visually enhance entries too faint to read, even with the reinforcement of ultra-violet photography. The bibliography found



at the end of this paper gives one source for this unusual technical support. Perhaps you can find other sources closer to your facility.

Burned or charred documents represent opposite kinds of problems. Instead of too much water, there is not enough. Paper fibers have been oxidized and embrittled. As with soaked paper, it is essential that no effort be made to read these documents at the crash site. Every effort must be made to protect books which have been subjected to high heat. No attempt should be made to open them in the field and scorched materials must be protected from physical damage. They should be removed to safety slowly and carefully. Curb your curiosity. Don't even *think* of turning a page. Once they have reached safety a plan must be formulated to obtain whatever information may be available.

The first problem with charred documents is that they must be flattened so that they may be photographed. In some instances this may be a relatively simple procedure. The first attempt is to obtain an office letter tray or "in basket" made of wood. Place one document in the tray and cover the top with a damp cloth, creating a type of humidity chamber, and let it absorb moisture overnight.

Another procedure is to mix a solution of equal quantities of water, glycerine and alcohol, wetting the document slowly with an eye dropper. This is quite a slow process and no attempt should be made to hurry things along. If the fibers will accept any moisture at all, this procedure should do it.

If the paper resists all efforts to flatten and begins to break, try a solution of polyvinyl acetate applied with an atomizer. Before application, prepare an adequately large sheet of glass with a silicone release agent. Polyvinyl acetate is a powerful adhesive intended to bond the paper fibers, but trouble will ensue if the glass plate is not properly prepared.

If your back is to the wall, you can, of course, attempt to photograph the document a small section at a time and assemble several small segments of photographs. This is the way the Dead Sea Scrolls were photographed, and if they can do it so can you.

Photography of burned documents is usually effective with infra-red reflection. If no distinction is achieved, there is an interesting procedure, quite well known but fairly time consuming. The document is placed between two sheets of very sensitive photographic film, such as Kodak Tri-X, emulsion-to-emulsion, bound up in a print frame and allowed to remain in total darkness for a month. The fogging action of charred and oxidized paper will contrast against the printing, ink and writing. The film is then developed and the writing is often revealed. It is important, though, that you start with a flat document. Log books must have been remoisturized and carefully disassembled.

Scattered and sun-bleached documents can usually be photographed with a process known as infra-red luminescence. A qualified forensic photographer should have the facilities for this kind of photography at his laboratory. The U.S. Postal Service has several crime detection laboratories across the country in addition to the one in Washington, D.C., and has facilities for infra-red luminescence photography. It can be supposed that Post Offices in other countries would also maintain similar facilities available to government air safety investigators.

Documents are not always damaged by fire or water. Sometimes people will attempt to change the contents of a logbook or of a maintenance procedure entry, in order to avoid punitive action or to escape legal liability. The air safety investigator should always review these records with keen observation, good judgment and a healthy sense of skepticism. Once a document comes under suspicion of having been altered, there are routine methods of screening. Log books covering long periods of time will obviously have been prepared with several different pens, and the printing or handwriting will have some variance, even if made by the same person. It is hard to imagine any genuine series of observations, or actions, spanning several shift changes, that would be completed with the same pen.

Infra-red luminescence can usually distinguish between pens, each ink luminescing at a slightly different rate. One manufacturer's ballpoint pen will luminesce differently from another. A normal document, under this type of inspection, should show varying luminescence rates.

The watermark of paper usually displays the manufacturer's logo. There is often an inconspicuous spot in or around the logo indicating the year of manufacture. It would be difficult for anyone to explain why a sheet of paper manufactured in 1979 is found in a logbook manufactured and assembled in 1976. Or how a letter found in the files was supposedly written in 1977 on paper manufactured in 1978.

Typewriter type-styles also change, and IBM Selectric type elements are introduced. Antedating documents is a tricky business, even for the skilled forger. Polaroid photographs are dated. The first two symbols are of a letter and

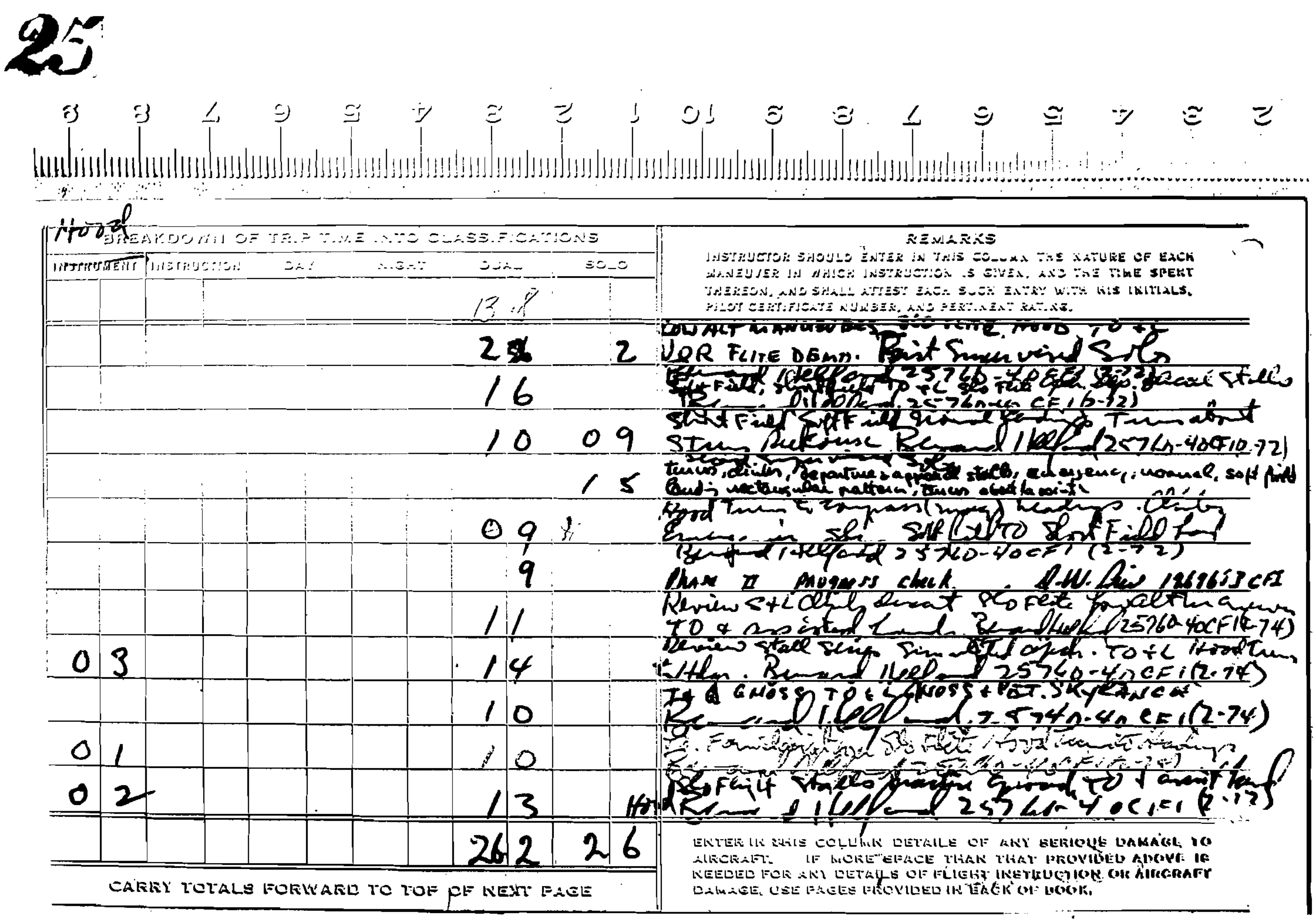


Figure 1

Flight log examined by dichroic filtration, two negatives prepared, sandwiched with .005 Kodapak diffusion sheet and printed slightly off register. Variations in entries are exaggerated with this procedure. The log is quite normal, showing routine variations in pens, handwriting and reflection densities. Without such variations the log entries are suspect.

number. The letter refers to the month of manufacture, "A" being January, "B" for February, and so forth. The second symbol is the year, with "8" being 1978.

Even cameras leave their microscopic signatures, with imperfections on the film aperture apparent to minute examination. Small burrs on the pressure plate will leave tiny scratches identifying the camera which took the picture. Xerox machines, after being in service for awhile, will develop characteristic scratches on the drum. These scratches will identify which Xerox machine was used to copy the document. The absence of scratches will sometimes establish evidence, even negatively.

Typewriter type styles will classify a typewriter as to make or manufacture, and imperfections in typing will often identify the particular typewriter used in preparing the document or letter.

Typewriter grid overlays will verify the number of paper insertions used in the preparation of the document. Sometimes it is normal for a paper to be removed and reinserted into the typewriter several times for the completion of a document. At other times it is suspicious that all typing was not completed at the same time. How embarrassing it would be for someone to relate that the document was typed over a period of several days—the paper being re-filed after each entry—only to have the investigator prove that the grid overlay showed the typing to have been done at one sitting.

The professional document examiner (see your friendly yellow pages under Document Examiners) is accustomed to verifying or ruling out questions involving document alterations, and usually qualified to testify on his findings at Board hearings or courts of law.

Every air safety investigator is a document examiner, and documents of all descriptions pass through his hands. Soaked and charred documents have specific procedures, but there is nothing so effective as care and good judgment in detecting and handling the altered document.

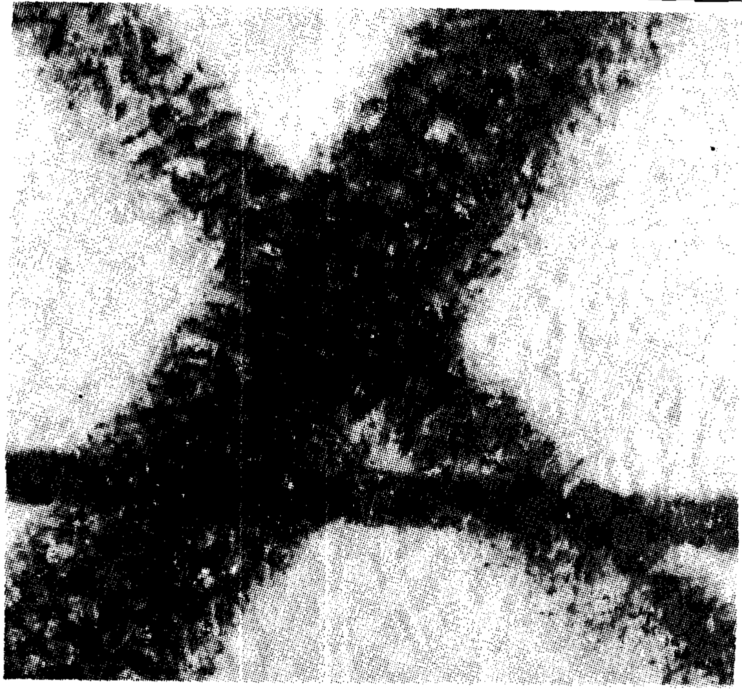


Figure 2

Sequence of entries are important. The entry from a prior observation should be beneath the entry from the later observation. Could it be any different?

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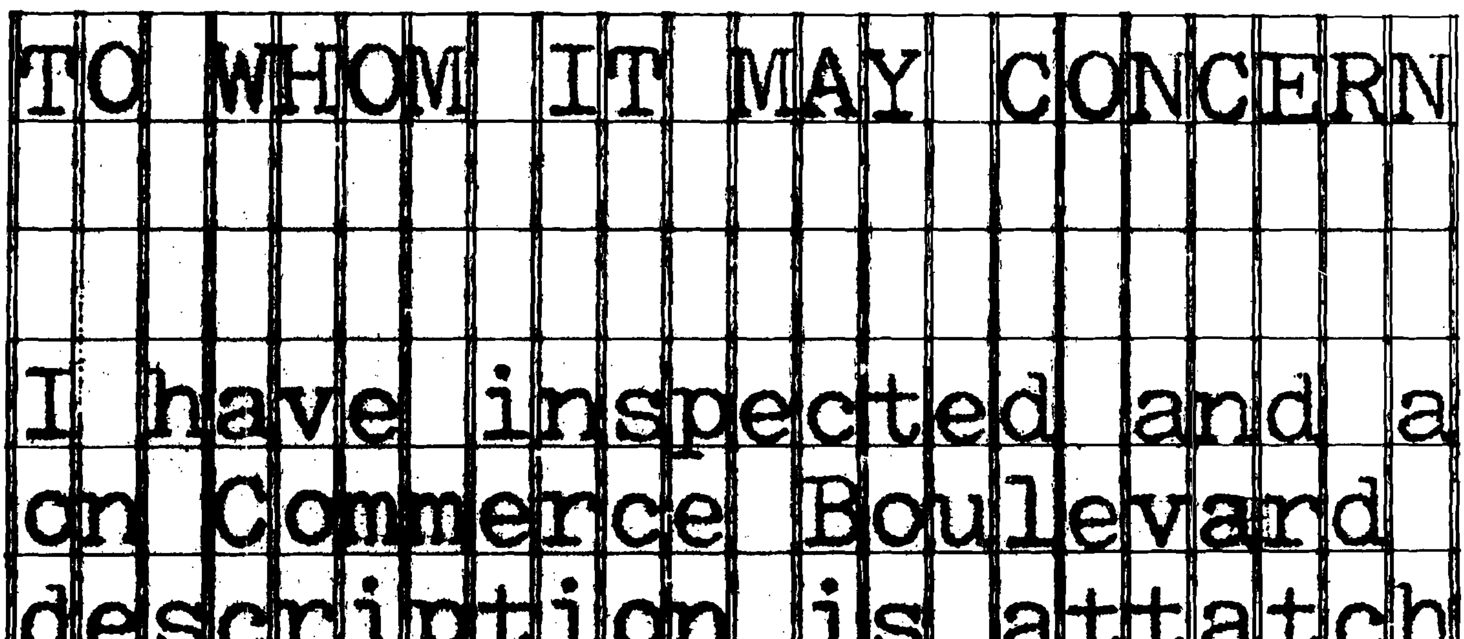

Figure 3

The typewriter grid overlay can detect how many times the typed sheet of paper had been removed and re-inserted into the typewriter. It can also detect if all typing was made with the same paper insertion. This sample shows one paper insertion. It is practically impossible to reinsert the paper so that it could be realigned this closely.

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About the Author

George Posner, founder and President of the San Francisco Chapter of ISASI, is a Legal Investigator with long experience in forensic and analytic photography, including photography of questioned documents. George was Vice-President and senior investigator for the R.F. Bowen Company from 1958 to 1970, at which time he formed his own investigative organization—George E. Posner Associates.

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Aircraft Accident Photography

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INTRODUCTION

These days, almost everyone owns a camera and knows how to use it. Or perhaps they own a camera that knows how to use itself; modern cameras leave very few decisions to the photographer. This paper assumes that you are one of those people and if you wanted to know more about photography, you'd go to a camera store and buy a book on it. There are several.

Aircraft accidents present some unique problems to the photographer. Over the years, many people have developed solutions, and maybe some of them can help you.

First, it might be wise to sit down and list all the reasons why you want to photograph the wreckage in the first place. These reasons will influence the type of pictures you take and the order in which you take them.

Verify and record damage. If this is your only reason, you have a fairly easy task. You might consider photographing an undamaged plane or component for comparison, as this will make the damage more meaningful.

Record conditions which may be altered. If the wreckage is to be moved, this may be your first priority.

Educate. This is probably the most common reason for photographing an accident, but the least appreciated. At some future date, you are going to use the photographs to explain the accident to someone who wasn't there and (perhaps) knows nothing about airplanes. Realizing that the camera doesn't have the capability and field of view of the human eye, you should consider taking enough overviews and scenic shots to orient the person to what you really want him to look at. Consider the standard Hollywood film technique of a distant shot followed by a medium shot followed by a close-up. The sole purpose of the first two shots is to get the audience oriented and prepare them for the close-up. It's a good technique, but you have to foresee the need for it while you are out there snapping pictures.

EQUIPMENT

As you well know, aircraft don't always crash in convenient places. You may be able to drive your station wagon full of equipment right up to the wreckage, but you ought to be prepared to get by with only what you can reasonably carry.

Cameras. If you are only going to bring one camera, a 35mm Single Lens Reflex is unquestionably the most versatile. If you bring a smaller format camera, you lose lens capability and get a negative that won't enlarge as well as a 35mm. If you bring a larger format camera, you get a larger negative, which is good, but you add weight, bulk, complexity and cost. Suit yourself. This paper is pitched to the 35mm crowd.

Lens. If you are only going to bring one lens, let it be a Macro lens. (Some camera manufacturers call this a Micro lens.) Most 35mm cameras are sold with a "standard" 50mm lens. It will focus from infinity down to about 18 inches (from the film plane; not the lens). You can buy a Macro lens for your camera, either as original equipment or as an additional lens. It will also focus at infinity, but it will get you within about 9 inches of your subject and produce a full-size 1:1 image on the negative. The alternative to a Macro lens is a set of extension tubes or close up lenses which can be used with the 50mm lens. Frankly, they are a nuisance and they don't have the flexibility of a Macro lens.

Film. Your choice of film depends almost entirely on what you intend to do with the pictures. Are they going to be printed black and white in multiple copies of a report? If so, you might as well stick to black and white film in the first place. On the other hand, are the pictures to be printed in one or two copies to aid and document the investigation? If so, use color. Are your pictures to be enlarged for display purposes? If so, select a "slow" film, say ASA 64. Fast films become noticeably grainy as they are enlarged much beyond snapshot size.

In general, try to settle on one readily available type of film and use it for all your investigation work. Get to know its characteristics thoroughly through practice. If you are shooting black and white, always carry a few rolls of color. There are some situations (medical evidence, mid-air collision paint smears, etc.) where color is indispensable regardless of cost.

Flash. Use a strobe in preference to flashbulbs, which are a real nuisance. Since most of your flash work will be to fill in some additional light during daylight, you can get by with a small, inexpensive strobe unit. There are, of course, some excellent automatic strobe units available which give you a lot more flexibility.

Auxiliary Equipment. You can go broke buying camera equipment and get back strain from carrying it. For aircraft accident photography there are four inexpensive and easy-to-carry gadgets that you really need. With these, a strobe and a 35mm Macro lens camera, you can do almost anything. (Fig. 1.)

Tripod (small). Maybe you think you can hold the camera steady enough to get good close-up shots, but look at the risks. You may only get one opportunity and by the time you find out that the camera moved, it's too late. The tripod is also essential for some of the techniques to be discussed later.

Camera Clamp. This lets you clamp the camera to something (almost anything) while you set the scene in front of it. You also use the clamp to help small objects stand up and be photographed.

Cable Release. If you think you can trip the shutter without wiggling the camera on a close-up, good luck. Most modern cameras have no way to lock the lens open without using a locking cable release and the "B" setting.

Extension Cord for the Strobe. There are situations where you must get the strobe out of the line of the lens or you'll get flashback, particularly when photographing an instrument panel. (Fig. 2.) With nothing to bounce the strobe off of, you absolutely need an extension cord.

Batteries. Even if you just changed them, bring spare batteries for your camera and strobe.

PROTECTING YOUR EQUIPMENT

As an investigator, you're going to carry some fairly expensive equipment out into the boondocks in all kinds of grungy weather—cold, heat, dust, rain; you name it. How are you going to protect it?

Rule #1 is that both the camera and the film will work best if they are kept dry, dust-free and as close to "room

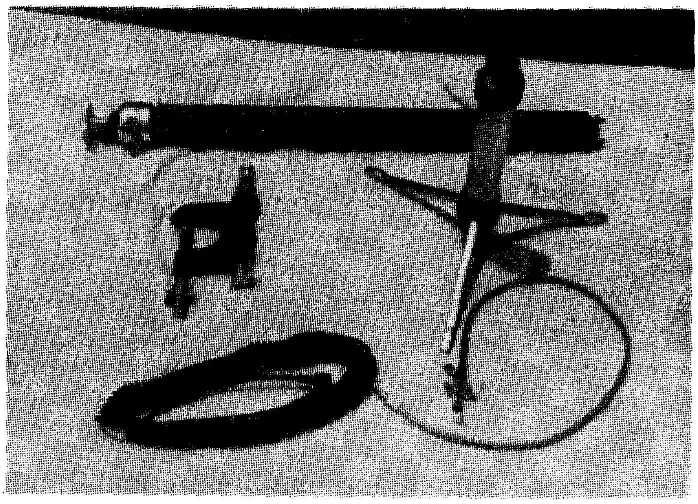

Fig. 1. You'll need these. Tripod, Camera Clamp, Extension Cord, and Cable Release.

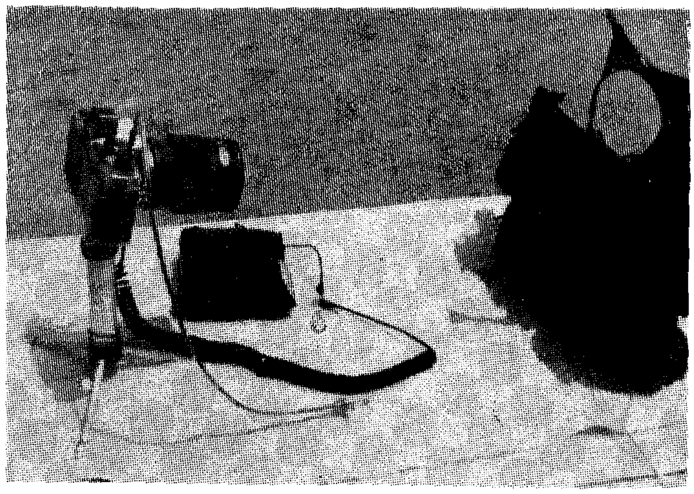

Fig. 2. If you need flash to help light an instrument panel, use an extension cord to get the flash away from the line of the lens.

Fig. 3. Wet weather? Try the old plastic-bag-and-rubber-band trick.

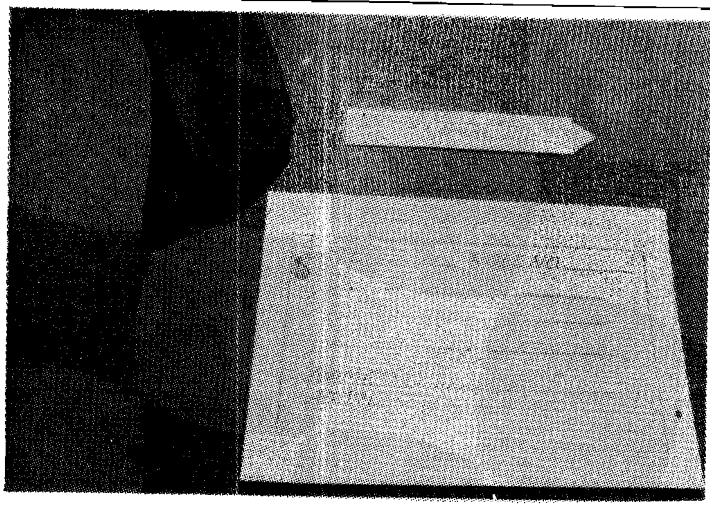

Fig. 4. There are a lot of easy ways to identify film rolls, pictures, and parts.

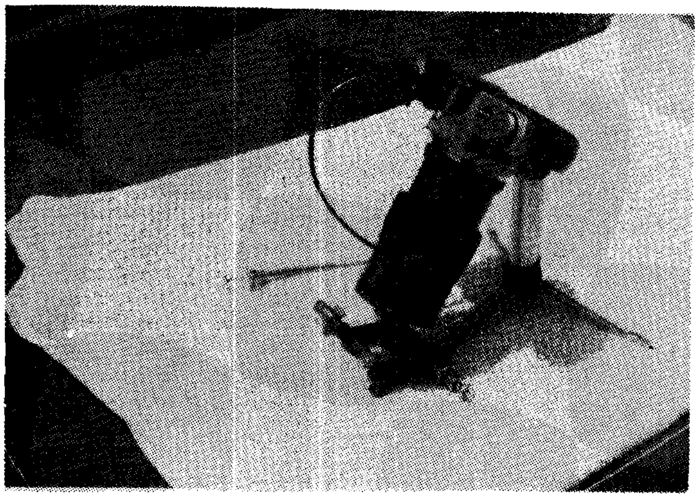

Fig. 5. Setup for photographing a lightbulb filament. Bulb is held in place by the Camera Clamp.

temperature" as possible. One very satisfactory solution is a styrofoam ice chest about big enough to hold two 6-packs. This will hold a camera, strobe, batteries, and a lot of film, and protect them from either severe heat or cold. If it's raining, carry a supply of plastic bags and rubber bands. Put the camera in the bag and a rubberband around the lens. (Fig. 3.) Tear away the bag in front of the lens, which, incidentally, should already be protected by a Skylight filter. If the filter gets scratched, you can always replace it for a few bucks, but if the lens gets scratched...? With this plastic bag scheme, your camera is safe and you can still work the controls and focus through the viewfinder.

It might also be wise to invest in a small protective bag to carry exposed film through airport security devices. Regardless of what they tell you, *repeated* exposure to these x-ray machines will show up on the film. Incidentally, many airlines now routinely x-ray checked baggage, too, so packing the film in your suitcase won't necessarily save it.

PHOTO IDENTIFICATION

One nagging problem facing all photographers of aircraft accidents is how to keep track of what the pictures are meant to show. One chunk of bent airplane tends to look a lot like any other chunk, and a close-up photograph can be absolutely unidentifiable. Here are some suggestions.

Identify each roll of film. Snap the first picture of the roll at a photo card that gives the date, roll number, subject and your name and address. (Fig. 4.) Not only does this identify the roll, but it may save your life someday when the film gets lost in processing. They can look at it and tell who it belongs to.

Identify each (or most) pictures in the roll with a number. You can do this by either purchasing a special back for your camera that allows you to dial in a number that prints in the corner of the picture or by merely putting a number in the scene as you take the picture.

Keep a log. A ¾ size stenographers notebook is ideal for this because it will fit in your hip pocket and leave your hands free for picture taking. (If you can't find a ¾ size steno book, take a full-sized one and cut about two inches off it with a saw or a big paper cutter.) The steno book is also useful because you can stand it up in the scene with a number on one of the blank pages. Finally, if you invest in one notebook per accident, it can become a permanent record of your investigation notes (front to back) and photo log (back to front).

PRIORITIES

Rather than using the random snapshot method of capturing an accident on film, you ought to have a reasonable plan on what needs to be shot first. This depends somewhat on the accident, but the following list will work for most of them:

1. Get pictures of the perishable evidence first. This is anything that is likely to be removed or changed. It includes medical evidence, personal effects (if significant), documents found at the scene, instrument readings, switch positions, radio frequency settings, flight control and trim tab positions, and power control settings.

2. Get aerial photographs, if possible. The appearance of the wreckage from the air will change markedly as people and vehicles start trompling it.

3. Get overviews of the overall wreckage scene, if feasible. Sometimes it isn't.

4. Get overviews of the wreckage using shots from cardinal compass points or a series of overlapping (by about ½) shots along the wreckage trail.

5. Photograph the major components. This provides a photographic record that all the major pieces were present and accounted for.

6. Now get the rest of your equipment and work on close-ups and photos of significant evidence. You've got the accident well documented by now and this phase can continue leisurely throughout the field investigation.

7. Witnesses. If significant, take pictures from where witnesses were standing. Show what view they had of the accident.

8. Documents. If you can't obtain the original or a copy of significant documents (airfield maps, weather charts, notices posted on walls, etc.) use your camera. With your tripod, strobe, cable release and extension cord, you can, in fact, set up a mini-production line for photographing documents.

9. Finally, go out and shoot a roll on an identical, but undamaged aircraft. Invaluable for showing someone where a wrecked part came from and what it's supposed to look like.

TECHNIQUES

Here are some "tricks of the trade" you might find useful at your next accident.

Close Ups. Focus and depth of field become extremely critical when you're working really close—on a light bulb filament, for example. (Fig. 5.) Use the tripod and cable release. Run the lens all the way out and then focus by moving either the object or the whole camera back and forth. Much easier than turning the lens. Watch your depth of field. If you need more depth of field, you have essentially two choices. Back up a little, or shoot at a speed slow enough to allow you to use the smallest possible aperture (largest f-stop number) on your lens. You may find yourself shooting at (say) 1/30th of a second to get f22 on your lens and make the exposure meter happy. No problem, as long as you have the camera on a tripod and are tripping the shutter with a cable release.

Fill-in Flash. Don't be afraid to use your strobe to add some light to the dark spots in your scene. Shoot at the speed you are synched for (probably 1/60th) and adjust the f-setting with the camera pointed at the bright area. Then hold the strobe well away from the camera (using the extension cord) and use it just to add some light to the dark areas. Easy. Try taking pictures of your automobile instrument panel when it is in shadow. Try some without flash and take some with the strobe held at various positions around the camera.

Night Photography. If you suspect that the sun is going to rise tomorrow, your best plan is to wait for it. Unfortunately, you are sometimes forced to take your pictures at night and you didn't bring enough equipment to create that much light. A single flash from your strobe isn't going to get you much.

Actually, there is a neat trick called "painting with light" which is ridiculously easy and yields consistently good results. Basically, you are going to open the camera lens and then walk in front of it with your strobe (no extension cord) and illuminate the wreckage from various points by manually flashing the strobe at it. The camera will record only what the strobe illuminates. You won't show in the picture at all. To make this work, you need a tripod to hold the camera absolutely still and a locking cable release to hold the lens open. If there is some ambient or background light, you may also need a friend to hold something dark in front of the lens while you are moving to a new position with your strobe. Here are the procedures:

1. Camera on tripod, focused, shutter at "B," lens at appropriate setting for a single flash with the strobe at the distance away from the subject you are planning on using, say 15 feet.

2. Have your assistant (you don't need one if it is really dark out there) hold something black in front of (but not touching) the lens.

3. Open the lens and lock it open with the cable release.

4. Take your strobe and work in front of the camera from one side of the scene to the other. Try to maintain

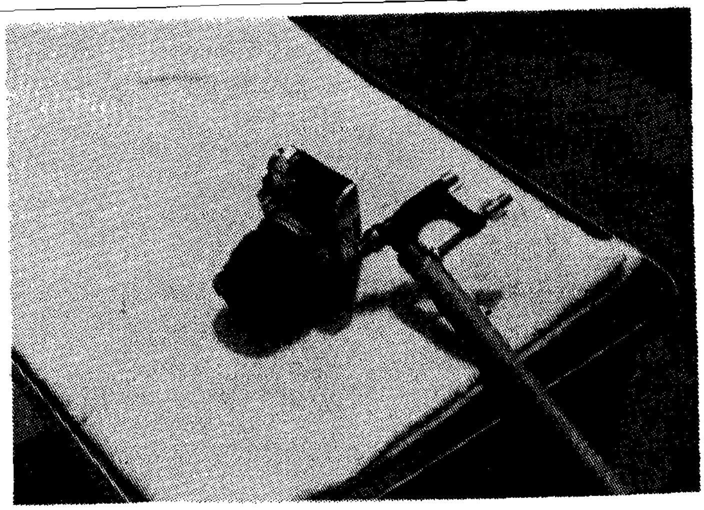

Fig. 6. Camera clamped to a pole and ...

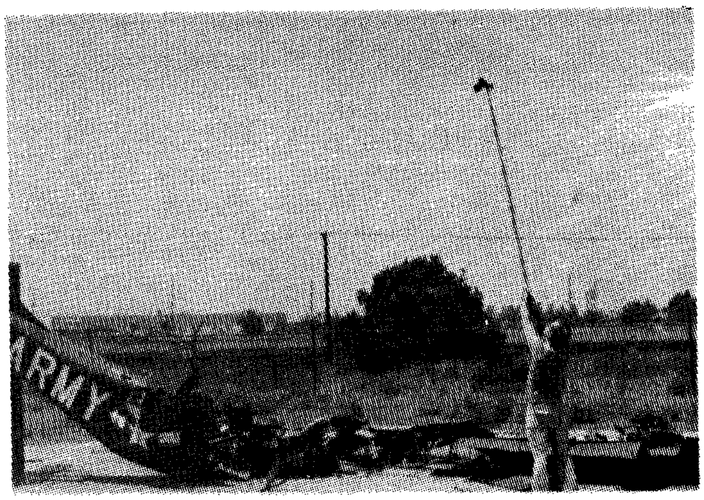

Fig. 7. ... used to get an overhead shot of the wreckage.

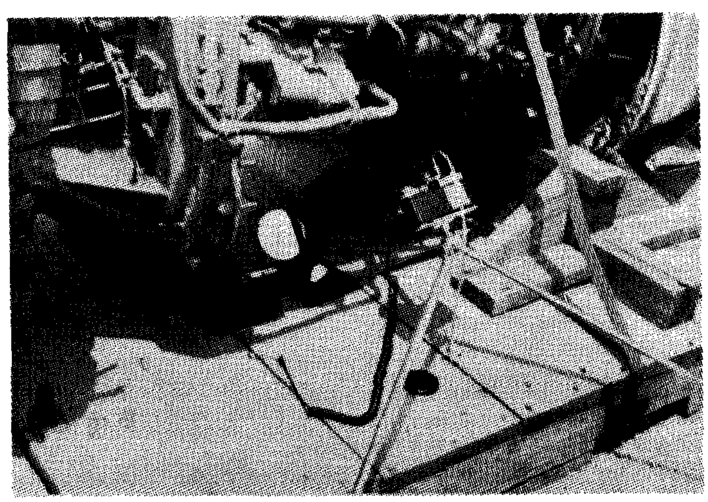

Fig. 8. Mirror setup. Camera focused through the mirror; strobe illuminating the bottom of the engine.

roughly the same strobe-to-subject distance (15 feet). Aim the strobe at the wreckage, never at the camera.

5. When you are ready to flash it, instruct your assistant to uncover the lens and cover it back up as soon as you flash the strobe. Repeat this as often as necessary to illuminate the whole wreck. You may need anywhere from two to a dozen flashes. Remember, the camera will only record what is being illuminated when the lens is open, nothing else.

6. Close the lens by unlocking the cable release.

Texture. Scratches, dents and wrinkles which are perfectly obvious to the human eye don't always show up too well in a flat photograph. If you have this problem, try moving the object around or propping it up so that the sun goes across it at a low angle and makes shadows out of the dents and wrinkles. If that won't work, maybe you'll get a better shot if you wait until the sun drops to a low angle later in the day. If that's no good, try putting the object in shade by blocking the sun. Then use your strobe (extension cord) at a low angle to create the shadows. For raised scratches or embossed numbers, try rubbing chalk across them and blowing away the excess. Enough will usually adhere on one side to make them stand out in a photograph. For depressed scratches, borrow some engine oil and smear this across the surface and wipe it off. The oil that stays in the scratches will make them easier to photograph. (You might not want to do this if the oil in the scratches is going to impede further examination of them.)

Height. Would it help if you could get about 12 feet above the wreckage and shoot down on it? Maybe, but who carries a ladder to aircraft accidents? You don't need one. All you need is your camera clamp and any piece of lumber, pipe or broomstick that is six to eight feet long or longer. Clamp the camera to the pole and let the automatic timer trip the shutter while you hold the camera over the wreck (Fig. 6 & 7.) It is helpful to have an assistant off to one side who can tell you when the lens is pointed generally where you want it.

Mirror Shots. Can't get the camera into or under the wreckage? Try a mirror. A lady's folding compact mirror about 5" x 5" seems to work pretty well. With a tripod, you can set this up so well that no one will be able to tell it was done with a mirror. Focus on whatever you see in the mirror. If you need fill-in flash, try to get the flash directly on the subject and use the flash-to-subject distance. If not, mount the flash on the camera and use flash-to-mirror-to-subject distance. (Fig. 8.)

PROCESSING

If you are serious about aircraft accident photography, you ought to do business with a professional processing laboratory and discuss procedures with them before you go out to the accident. Take their advice on films and bring back any additional information they want to help them give you their best product.

Now keep in mind that film is not particularly expensive and neither is developing it; but prints can go out of sight, especially big prints. You took a bunch of pictures out there, but you probably aren't going to use all of them. Of those you use, you may want them cropped or printed in different sizes or quantities depending on your needs. Considering this, it's dumb to start out by ordering an enlargement of each and every picture you took. Ask for proof sheets.

When the processor makes a proof sheet, he lays strips of developed 35mm negatives on a sheet of 8x10 print paper and prints it. If you were shooting 20 exposure rolls, all 20 will fit neatly on one 8x10 sheet. The first one, of course, was the one you took of your identification card, so that also identifies the proof sheet. The pictures also show the little numbers along the border of the film which helps match them with their negative. The pictures are small (35mm to be exact) but they are big enough to identify, correlate with your photo log, caption and decide which you really want printed. Furthermore, the proof sheet is an ideal way to file the pictures by roll number. You can pull it out and look at all 20 at once. The cost of the proof sheet is about the cost of one un-enlarged print and one sheet of 8x10 paper.

SUMMARY

If this paper has a central theme, it's this: Get organized. Stick with simple, versatile equipment. Come prepared to protect your equipment. Keep track of what you are doing. Do it in some logical order. Don't be in a hurry. Use the tools you've brought with you to hold things steady while you set up the perfect picture. If you don't know what a good processor can do to help you, get hooked up with one and find out.

Good luck on your next accident.

About the Author

Dick Wood has been involved in aviation safety and aircraft accident investigation since 1963. At the time of his retirement from the United States Air Force, he was Chief of Safety Policy and Programs for the USAF Directorate of Aerospace Safety. He is a pilot with over 6000 hours of diversified flying experience.

Dick is a Professional Safety Engineer (California) and a Certified Safety Professional. He is a member of the American Society of Safety Engineers (Chapter President), System Safety Society and International Society of Air Safety Investigators. He currently lectures in Accident Investigation and Safety Program Management for the University of Southern California and consults in both safety and accident investigation.

NTSB Improved Aviation Accident Data System

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INTRODUCTION

The National Transportation Safety Board (NTSB) is a small, independent U.S. Government agency (i.e., not under the Department of Transportation), whose role it is to determine the cause or probable cause of transportation accidents, and to make recommendations which are designed to reduce the likelihood of future accidents to appropriate agencies. NTSB maintains an Aviation Accident and Incident Information System which provides data on all occurrences involving U.S. registered civil aircraft (worldwide) and occurrences involving aircraft of foreign registry in U.S. territory. Advancements in air safety are measured and specific problem areas identified through the statistics, and accident prevention information developed using this system.

In October 1978, a task force was established at NTSB for a period of 3-4 months to explore the use of electronic data processing (EDP), and to recommend further agency alternatives with respect to its use, particularly with regard to the Aviation Accident and Incident Information System. The initial step in the review process was the identification of all existing NTSB EDP applications and resources in an effort to provide a rational basis for future planning. A list of goals for the future NTSB database management function was constructed.

With the advent of FY-1980, budgetary allocations permitted the "data project" to begin. Another task force was formed in January 1980 and was divided into two groups: a Substance/Elements Subgroup and the Systems Subgroup.

The objective of the Substance/Elements Subgroup was to translate the responsibilities of the Safety Board, as defined in the statutes, into the basic types of output and data required. This group is now in the process of examining the usefulness of old data elements as well as defining a new set of input data elements for the aviation system, with special attention to human factors and crashworthiness items. Our schedule calls for testing of data collection methods to assure that data satisfies the Board's needs with regard to special studies, safety objectives and oversight programs.

The objective of the Systems Subgroup was to gather data on and procure the necessary hardware, software and communications networks that will support the new NTSB data system.

The data project is a major NTSB undertaking and has the full support of top management. Many people are involved in this effort. The author of this paper is a member of the task force, but certainly cannot claim credit for the work that has been done or that will be done. This has been a team effort from the beginning and will remain so until it is completed.

PRESENT NTSB DATA SYSTEM

Existing NTSB data systems are scattered among several computers. The Aviation Accident Data System is the oldest and the largest; it was conceived and developed in the early 1960's and was put on the DOT Federal Highway computer in 1964. Each accident record contains up to 285 data elements; approximately 4,800 records are entered per year. This is solely a batch system, which means that there is no direct communication between the Air Safety Investigator (ASI) and the computer. The ASI fills out a coding form when he/she returns from the scene using alphanumeric codes instead of plain English-language entries. This form is reviewed and then sent to Washington where it is keypunched, checked, rekeypunched, and so on. Elapsed time from the accident to the completed computer brief can be as much as 12 months because of the labor requirements, data procurement delays and Board functions. There are a lot of manual transfers of information inherent in this system.

The aviation system is not flexible enough to do significant statistical analysis. It is not user friendly; it is not interactive; it is not responsive to our present-day needs. The data are not current. It includes little or no human factors information or crashworthiness information since most of the data elements have been "frozen" since 1964. The system is tailored to the hardware and software that existed in the early 1960's. The most universal criticisms heard from those both inside and outside NTSB is the system's general obsolescence. It has never had a major full-scale agency review since its inception.

The Safety Recommendation System is the second major NTSB data system. It is modern, efficient and interactive. NTSB has terminal access to a remotely located timesharing computer upon which the Safety Recommendation data base resides. The potential for use of this system has not yet been fully realized. Its one major drawback is its cost. We pay for each inquiry made, so more use mean higher costs.

Other NTSB batch systems are the Railway Accident System (also on the Federal Highway computer), the Public Inquiries (Docket) cross-indexing system (on a small in-house machine), and assorted management systems (accounting, workload, manpower, inventory supply).

The fragmentation of our overall data system is apparent. Using several computers does not allow for economies of scale.

CRITERIA FOR NEW SYSTEM

We would like our new system to correct known past deficiencies. This will be no small task. We need a responsive data system, one from which the information will be available within a reasonable time after the accident. To do this, we plan to place an interactive terminal in each of the ten NTSB field offices so that the accident file can be opened immediately after the investigator returns from the scene. He/she can ten add to the file as more information becomes available. Data entry will be in plain English; few if any numerical codes will be used at data entry time. Checking data entries will thus be easier; the coding and keypunch steps, and many of their assorted checks, will be entirely eliminated. The system will provide "menus," operator prompts and some input-error detecting capabilities. In other words, it will be "user friendly." The field terminal concept also has the advantage of allowing each field investigator instantaneous access to accident and recommendation data so that he/she can conduct a more knowledgeable investigation.

We need a system which encodes relevant data. There is much information that should be in the current data base but is not. The current list of data elements is being reviewed and expanded. We are especially interested in collecting human factors and crashworthiness data.

We need a data system which is capable of performing statistical analyses on the data elements so that large bodies of data can be reduced to meaningful problem overviews in a relatively short period of time.

We plan to improve the report format to reflect the more sophisticatead data processing capabilities available with the new system.

We need a fixed cost system. NTSB currently spends a substantial amount of money on our assorted computer systems, and this amount increases with increasing use. We plan to hold this amount at a fixed value by running all our applications on a single in-house machine. We anticipate that the fixed cost system will be no more expensive than our present spending, and will provide us with extra computational capacity for new applications.

The system must be accessible to all NTSB employees who have a need for computer services. The system must be subjected to visible management controls (accounting, security, etc.).

Finally, the new NTSB system should be compatible with ICAO's ADREP system. ICAO has set up a working group scheduled to meet next May which will discuss possible improvements to the ADREP system. Members of the group include representatives from Australia, Canada, Finland, Federal Republic of Germany, United Kingdom and the USA. We feel that our contribution to the ICAO effort will be more significant after our experiences in redesigning our own aviation accident data system.

HARDWARE/SOFTWARE

The Systems Subgroup issued its document specifying hardware/software requirements via an advertisement in the Commerce Business Daily on August 8, 1980. The document required a computer, peripherals, network, and software to permit increased NTSB computer capacity at a fixed cost using state of the art equipment. State of the art means a small, very powerful computer that can provide an interactive and/or batch mode environment that is powerful enough to process all present NTSB data plus have extra capacity for expansion. The contract for the hardware, software and communications network was awarded to ADP Network Services on September 8, 1980.

Prior to delivery and acceptance of the hardware, we will have begun conversion of the existing data systems to the in-house operation. Great efforts will be made to insure that the transition occurs smoothly. We plan to run old and new systems in parallel until the new systems are debugged, validated and completely operational. Then we will phase out the old system.

The new aviation accident data system will be a concurrent part of this initial effort. We plan, however, to perform data collection field tests and work on further forms definition before implementing and testing the new Aviation Accident Data System software. We expect that several iterations will be necessary before a completely satisfactory package is developed.

SUBSTANCE/ELEMENTS

The Substance Group is concerning itself with a general review of all the fields in the present aviation accident data system: operations, weather, air traffic control, etc. The recognized need for the greatest improvement and expansion, however, is in the areas of human performance and crashworthiness/survivability for field accident investigations. (NTSB headquarters generally investigates major air carrier accidents). Crashworthiness and survivability deal with crash dynamics and the engineering side of things: aircraft structures, seats, restraints, kinematics, environment, injuries, postcrash fire, emergency equipment, evacuation and rescue, and ditching.

Human performance is divided into four broad categories: operational, medical, workspace and behavioral factors. Operational factors include training, qualifications, experience, adherence to procedures and prior accident history of pilots, controllers and other persons involved in the conduct of the flight. Medical factors include physical, pathological and physiological considerations, as well as results of postmortem examinations and toxicology. We expect to expand and improve upon our data collection efforts in these two areas, and our forms will reflect extensive changes in the data elements.

We are also exploring the possibility of obtaining additional information in the workspace and behavioral categories, although these areas present more difficulties in gathering objective data. Workspace factors include design, location and functioning of controls and displays, and the operational environment (including cockpit environment, runway environment and the air traffic control environment).

The Substance/Elements project is being developed in three phases. The definition phase began in February 1980 in which criteria for the information gathering process were established, data elements were identified, and other data systems (NASA, FAA, U.S. military, Canada, Australia, etc.) were reviewed. We discussed our needs and shared ideas with the NTSB Board members and staff, with FAA, and U.S. military services, foreign government representatives, ICAO and other aviation-minded groups.

The development phase began in May, in which desirable kinds of input data were specified in greater detail (data requirements), the desired end products were explored and reviewed with the NTSB analysis staff (what uses will be made of the data?), and preliminary data formats were developed and reviewed by the analysis staff, the Chief of the Field Accident Investigation Division and the FAA. The test phase began in September 1980, and will continue for some time.

CONCLUSION

NTSB is designing and installing a new data processing system; a concurrent effort is the design of a new Aviation Accident Data System. Although it is too early at this writing (September 1980) to present specifics of the system, the aviation community should be informed of our intention to revise and improve the present system, especially in the areas of human factors and crashworthiness information.

ACKNOWLEDGEMENTS

Many thanks to Jim Danaher, Emerson Eitner, Chuck Fluet, Bernie Loeb, Matt McCormick, and Jim Shepard for their thoughtful contributions, comments and suggestions. The task force was begun by NTSB Managing Director Jim Shepard under Marty Clarke, prior to his retirement, and Emerson Eitner. The Hardware/Software Subgroup is headed by the author and includes Emerson Eitner, Chuck Fluet, Dave Kelley, Jim Shelby and Paul Voorhees. Former NTSB employees on the group include Bill Campbell and Dennis Boyd. The Substance/Elements Subgroup is headed by Jim Danaher and includes Ron Battocchi, Steve Corrie, Al Dickinson, Bob Evans, Bill Halnon, Don Kuhns, Bernie Loeb, Tom McCarthy, Matt McCormick, Ron Schleede, Bob Spermo, Vern Taylor and Rick Van Woerkom.

About the Author

Carol Roberts assumed duties as Chief of the NTSB's Laboratory Services Division on October 1, 1979. She joined the Laboratory Services Division in July, 1972, as an Electronics Engineer. She has worked in the Flight Data and Cockpit Voice Recorder Laboratories. She received an award for special achievement in May of 1976 for her work in setting up the digital recorder laboratory for NTSB. In April 1980, she was nominated to be the U.S. representative to the ICAO Flight Recorder Study Group.

Prior to joining NTSB, Carol was employed by the Harry Diamond Laboratories and the U.S. Naval Research Laboratory, both in Washington, D.C.

She received the B.E.E. (Summa Cum Laude), M.E.E. and Ph.D. degrees in Electrical Engineering from the School of Engineering, Catholic University, Washington, D.C.

Carol holds an Instrument Rating and a Commercial Pilot's License, and has had a brief fling at hang gliding. She is a member of a number of aviation and engineering associations, including ISASI, the Institute of Electrical and Electronics Engineers (IEEE), the IEEE Computer Society, Tau Beta Pi, and Sigma Xi. She has been active in SASI/ISASI, having been president of the Washington, D.C. chapter from 1977-1979, secretary/treasurer from 1975-1977, a member of the International Council from 1976-1978, and a staff member of FORUM from 1975-1978. She was co-coordinator of the 1976 ISASI seminar, and has presented papers at the seminars in 1974, 1975, and 1977.

Failure Of The C-5A AFT Pressure Closure

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In the closing weeks of the war in Southeast Asia, the United States Air Force dispatched a C-5A aircraft, serial number 68-218, to the Republic of Vietnam for purposes of evacuating a large number of Vietnamese orphans. After offloading its inbound cargo at Tan Son Nhut Air Base, Vietnam, the aircraft onloaded 247 orphans and several military, Department of Defense, and medical personnel to attend to the orphans' needs during the flight. There was a total of 330 persons on board. In addition to the normal cargo hold area of the C-5A, there is a large troop compartment above the cargo hold. Approximately 140 personnel were seated in this troop compartment. The cargo hold and troop compartment were filled to capacity and at 1603 hours local, the aircraft departed Tan Son Nhut, destination Clark Air Base in the Philippines.

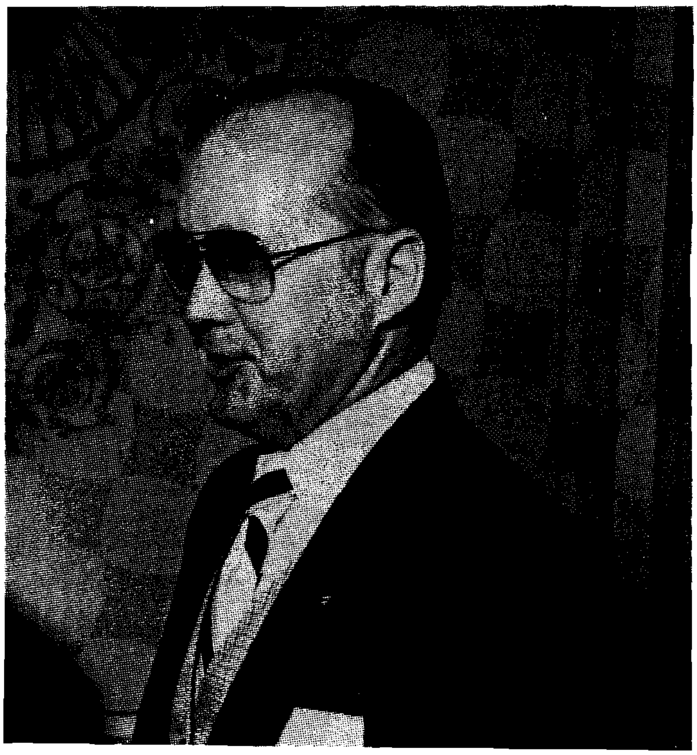
MISHAP EVENTS

The aircraft took off at a gross weight of 464,000 pounds and started on a southeasterly course. At an altitude of 23,372 feet, a loud explosion was heard and the crew compartment filled with vapor condensation. At the same time, both pilots felt a sharp kick in the rudder and a slight vibration of the control yoke. It was obvious that the aircraft had suffered a rapid decompression. Oxygen masks were deployed, crew and medical personnel immediately began to attend to the youngsters, and the aircraft started a shallow slicing left turn descending and returning to Tan Son Nhut Air Base. At the time of the rapid decompression, the aircraft was approximately 15 miles at sea, southeast of Vung Tau. A check of the aft part of the aircraft disclosed that the aft cargo loading ramp and the rear pressure closure door had been blown completely out of the aircraft. Due to the fact that the pilots were required to give their undivided attention to control of the aircraft, all aircrew and medical team members were required to perform without direction. This was done in a highly commendable and professional manner. Loose articles were stowed and passengers were prepared for a crash landing. All crewmembers were advised to prepare everyone for a crash landing. They were returning to Saigon.

As they descended and rolled the aircraft out on a heading for Tan Son Nhut, it was apparent that the rudder and elevators were completely inoperative. Fortunately, the aircraft was trimmed for approximately 255 knots at the time of the rapid decompression. The pilots were able to turn the aircraft with the use of spoilers and ailerons and control the nose attitude by adjusting throttles. They made a long sweeping turn, heading for runway 25L at Tan Son Nhut. Landing gear were lowered at approximately 10,000 feet using both normal and emergency extend systems. On final approach, approximately 45 degrees off the runway heading and at 4,000 feet, in a shallow bank turn, the nose dropped sharply and the aircraft rate of descent increased to 4,000 feet a minute. The pilot realized immediately he was not going to make the runway; he rolled the wings level using aileron and advanced all four engines to full throttle in order to check the rate of descent. As the nose raised and the rate of descent slowed, the pilot concluded a crash was inevitable and pulled back all four engines to idle.

The aircraft, as shown in Figure 1, made its first contact in a muddy rice paddy, slid along for approximately 1,000 feet, dragging off all 28 of its wheels, became airborne at an angle of 12 degrees, stayed airborne for approximately 2,100 feet until it had crossed the Saigon River, and again struck down in a marshy rice paddy on the opposite side of the river. The aircraft slid quite smoothly in a straight line 1,500 feet through the marshy terrain, shedding large and small sections of its cargo compartment. Near the end of the slide, it broke into four distinct sections: the large tail section, the troop compartment which represented the upper third of the fuselage, the crew flight deck section, and the wing. Fortunately, the wing was separated in one piece and took most of the fuel with it. The other three large remaining sections, while badly shredded, did not experience the kind of fuel fire generally associated with an aircraft crash.

The surviving crew and medical team members with the assistance of rescue helicopters from Tan Son Nhut spent the next 90 minutes in a most heroic rescue effort. Many male and female crash survivors with injuries as serious as broken arms, legs, and ribs waded through the chest deep water to rescue large numbers of orphans with total disregard for their own injuries. They placed them on helicopters which shuttled between Tan Son Nhut and the wreckage. As a result of these monumental efforts, 175 people survived this crash.



THE INVESTIGATION

Within minutes of the crash a message was flashed to Headquarters Air Force and actions were initiated to assemble an accident investigation team. The team, which consisted primarily of Air Force military and civilian personnel and contractor personnel, was dispatched to Saigon via Clark Air Base in the Philippines. The investigative team paused long enough at Clark Air Base to interview the survivors who had been flown to the hospital there.

Number 218 had a couple of on-board recorders which would greatly enhance the investigation. The first was a Crash Data Position Indicating Recorder (CDPIR) which was ejected during the rapid decompression off of Vung Tau. The second recorder was the MADAR (Malfunction Analysis, Detection and Recorder) which normally monitors 168 parameters during the flight of the C-5. The MADAR was functioning all the way to impact at Tan Son Nhut. In the course of the rescue efforts at Tan Son Nhut, one of the crewmembers had the presence of mind to retrieve the tape cassette from the MADAR recorder. Unfortunately, the tape he picked up was a spare and the primary tape and the recorder itself disappeared in the unbelievable pilferage which occurred during the rescue operation. Subsequently, the original tape was bought back from the local population when a reward was offered by the investigating team. This turned out to be a most profitable $270 investment.

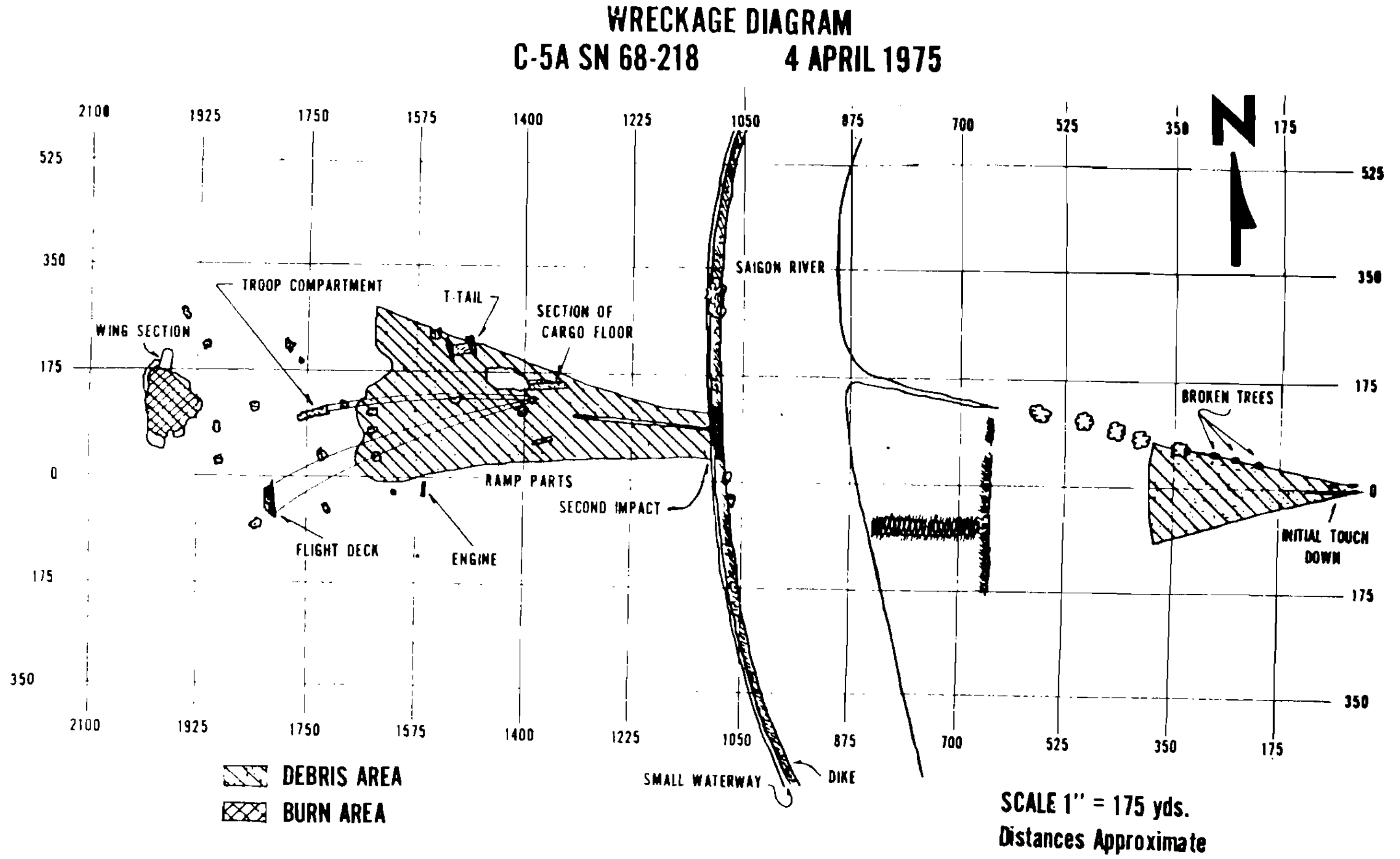


Figure 1

The investigative team was split into two functional groups: an administrative function which attended to business at Clark Air Base, and a technical team which went on to the crash site at Saigon. Upon arrival in Saigon, the team was briefed on the political situation existing in South Vietnam. The withdrawal of Vietnam and US forces was proceeding at a rapid rate, and this accident posed some complications to the planning strategy. The technical team was not allowed to carry any weapons into the area, and seven RVN soldiers were provided for security of the primary area of the wreckage. It was necessary each night to abandon the wreck site in order to protect the personnel involved. All movement to the site was conducted by helicopters since there were no other means of getting to the site because of the heavy marshy terrain. Within 2 days, all avionics and communications equipment was pilfered from the aircraft. Attempts to stop removal of any portions of the wreckage by scavengers were met with serious resistance. Each investigative member had to become his own diplomatic representative on the scene. It proved to be far more prudent to trade a sandwich for a cargo ramp lock when dealing with these people, some of whose sacred burial grounds had just been destroyed by the aircraft during the crash.

In view of the political situation which existed at the time, sabotage and enemy ground fire were investigated immediately and in very short order were put to rest as a possible cause. While it was very obvious, from the interviews held at the hospital at Clark Air Base, that a rapid decompression had occurred at the rear pressure door, much pick and shovel work remained to be done to establish the reason for the rapid decompression. The investigative team retrieved large and small portions of the aircraft which were considered significant in the investigation. These portions were returned to Tan Son Nhut by helicopter where they were loaded on a C-141 and transported to Clark Air Base in the Philippines. The key portions of the area around the rear pressure door were reassembled in a hangar at Clark. Again, while there was heavy circumstantial evidence as to the area of the failure, proof regarding the exact cause was something else again. During the final 1,800-ft slide, the aircraft had shredded so badly in the mud that finding key pieces was extremely difficult. The recovery problem was attacked in three general areas. First, the Navy was given a salvage task to search the shallow ocean floor 15 miles southeast of Vung Tau in the area that the CDPIR was recovered. The CDPIR had an on-board locator beacon and was picked up shortly after the rapid decompression. Secondly, a series of handbills were printed in Vietnamese and dispersed to the local population. These handbills contained pictures of some of the critical components that were required and offered rewards for their return. Finally, a very heavy probe and dig operation, using picks, shovels, and a vast number of Vietnamese personnel, was started.

The aircraft crashed at 4:30 in the afternoon Saigon time on the 4th of April. On the 19th of April, with security failing in the area of the crash site, further wreckage search at the crash site was abandoned. also on the 19th of April, the buy-back program succeeded in obtaining the key MADAR tape. A meticulous backtrack of recorded course and airspeed to locate the point of rapid decompression, coupled with a trajectory analysis of the door and ramp, provided a more precise location for the Navy salvage crews to search. On the 27th of April, the Navy team found a 19 by 12-foot section of the aft ramp and a 7 by 11-foot section of the rear pressure door. This hardware was subsequently flown to Kelly Air Force Base in San Antonio, Texas, for detailed laboratory analysis. A special U.S. Army team was dropped at the crash site with cutting torches and saws. They succeeded in cutting the rear pressure door overhead beam out of the wreckage. This heavy beam was airlifted in two pieces by helicopter back to Tan Son Nhut and subsequently taken on to Clark. Figure 2 is a photo of this beam. The view is looking aft.

At Clark the technical team assembled a large amount of evidence indicating that the initial failure had occurred at the forward edge of the right side of the rear cargo loading ramp. However, several of the key portions of wreckage in this area were missing and the proof was still to come. The board moved to Travis Air Force Base, California, and to San Antonio, Texas, for laboratory work. Meanwhile, extensive analyses were being undertaken in the areas of computer simulations, fault analyses, laboratory examination, and personnel interviews. It was evident from an analysis of the MADAR tape that hydraulic systems number 1 and 2 were lost at the time of the rapid decompression. At the same time, the control cables to the tail were mechanically severed. Figure 3 shows the damage to the pulleys as the cables were pulled through. This produced the rudder kick and control column vibration. The alternate electrical trim was also cut at this time. Number 3 hydraulics were normal; however, the severed cables which lead to number 3 would have prevented it from working. The rudder yaw augmentation electrical wires were also cut. Since number 1 and 2 hydraulics were gone, this made the left aileron inoperative. However, right aileron and spoilers were fully

Figure 2

operative. The initial contact ground scars were very revealing and useful. There was a MADAR data dropout just about the time of touchdown. One wheel of the aircraft contacted a small earthen dike and then recontacted another dike 165 feet away. Using the recorded speed and distance, a vertical sink rate was calculated to be less than 1 foot per second. The decision to abort the attempt to land on the runway and roll the wings level and add full power was key in saving many lives.

The technical team took particular care not to presume too much from the initial interviews of the survivors at the hospital. The usual investigative reviews of personnel medical histories, environmental conditions, weather, human factors, maintenance, and design were examined and found not to have a bearing on the accident. In the final analysis, the MADAR tape substantiated most of these preliminary conclusions. The preponderance of evidence pointed an accusing finger in the area of the ramp system. A meticulous fault analysis was conducted on the cargo ramp actuation and locking system to determine whether or not it might have malfunctioned or received an inadvertent electrical or hydraulic command to unlock. In the end it was found that erroneous commands to the system to unlock were not responsible since the system is incapable of lifting and unlocking the ramp under the 6½ psi differential pressure conditions which existed at that time. The ramp locks themselves became the next target of the analysis. The complete lock system on the right side was not considered the point of initiation since locks number 4 through 7 failed while in a fully locked condition. These locks actually bore evidence of an overload. The number 1 thru 3 locks on the right-hand side were considered most probably the point of initiation for the failure. Right side ramp locks numbers 2 and 3 showed no evidence of a high overload. No portion of ramp lock number 2 on the right side was found. These locks will be further addressed in the discussions of the aft ramp structural failure itself.

Examination of the aft ramp (Figure 4) structural failure indicated a failure mode of critical bending and shear at the right butt line 84 beam at approximately ramp station 33. This beam lower cap failed primarily in tension at ramp station 33. This same beam upper cap failed in a combined tensile and bending mode at ramp station 19 and examination of the ramp itself showed this upper cap to be deformed upward from ramp station 19 to ramp station 33, indicating rotation of the beam about ramp station 19 and the hinge at ramp station 0. The right butt line 84 corrugated web between ramp station 54 and 75 showed evidence of shear deformation and cracking diagonally. The lower member of the fuselage half of right but line 84 hinge fitting failed in compression, apparently due to a high vertical load at the hinge line. Since there was no evidence of fatigue in the butt line 84 beam, the failure pattern described above can only result if the beam hinge becomes overloaded. A most likely cause of this overload is a sudden transfer of latch loads at the right forward end of the ramp. Structural analysis of the ramp was made. Assuming latches 1, 2 and 3 suddenly lost load-carrying capability, the load carried by the transverse bulkheads at ramp stations 33, 54 and 75 would have been picked up by the butt line 84 beam and then distributed to the hinge at the forward end and to the traverse bulkheads at ramp stations 95 and aft. Analysis of the right butt line 84 beam web indicated that this condition will result in failure of the web at ramp station 33 and consequently failure of the beam caps, followed by progressive failure of the remaining locks on the right side and the remaining hinges. The rest of the failure pattern of the ramp indicated that the right side number 1, 2 and 3 locks failed in some manner, either by unlocking or by structural failure of a lock component. Figure 5 is a sketch of the lock system.

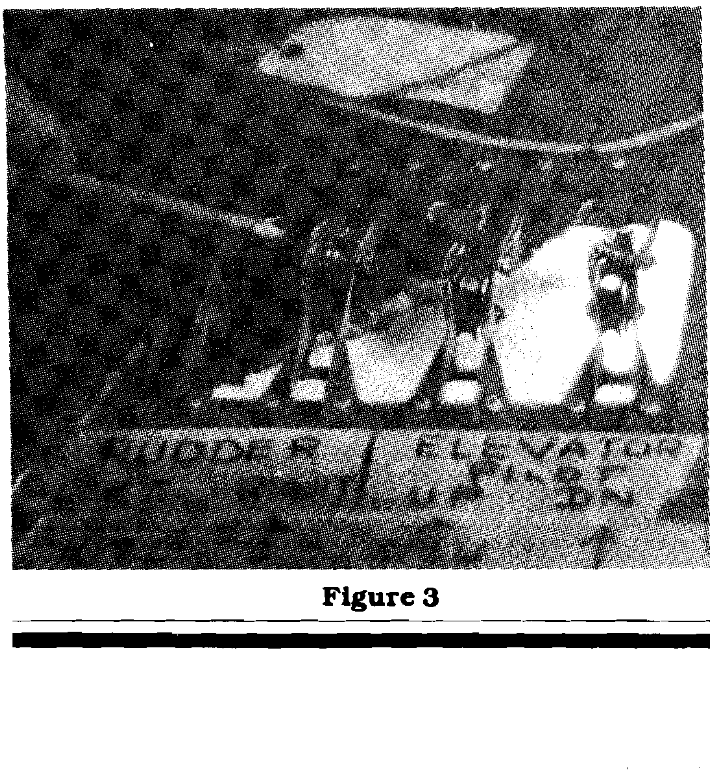


Figure 3

Examination of the right yokes number 2 and 3 showed no evidence of a high overload. Structural analysis of the bellcranks in an unlocked position showed that a failure will occur at a load less than that required to yield the yoke components. None of the components from right lock number 1 were recovered; therefore, no assessment could be made of the condition of the lock. However, as discussed above, lock number 1 must have become unlocked to result in failure of the ramp.

FAILURE SEQUENCE

The failure sequence outlined herein is estimated to have occurred in an elapsed time of less than 1 second. An analysis of all available evidence indicated that the most probable initiation point of failure involves locks number 1, 2 and 3 of the right side of the ramp. Figures 6 and 7 show a layout sketch of the ramp, pressure door and torque deck.

1. The right side ramp locks number 1, 2 and 3, due to a combination of rigging problems together with a sudden detachment of the tie rod between locks number 3 and 4, suddenly dropped their load (Figure 8).

2. The load previously carried by the above locks was dynamically transferred through the ramp structure to the fuselage hinges and the remaining locks 4 thru 7 of the right side (Figure 9).

3. The dynamically applied load overloaded the butt line 84 hinge, the ramp butt line 84 beam webs and caps, and right lock number 4. This overload resulted in a simultaneous failure of right butt line 84 beam and the locks sequentially from 4 thru 7. This resulted in the ramp structure tearing from right to left at ramp station 33.

4. As the lock number 7 failed on the right side, the ramp lowered together with the attached pressure door and started to rotate about the left lock system.

AFT RAMP STRUCTURAL ARRANGEMENT

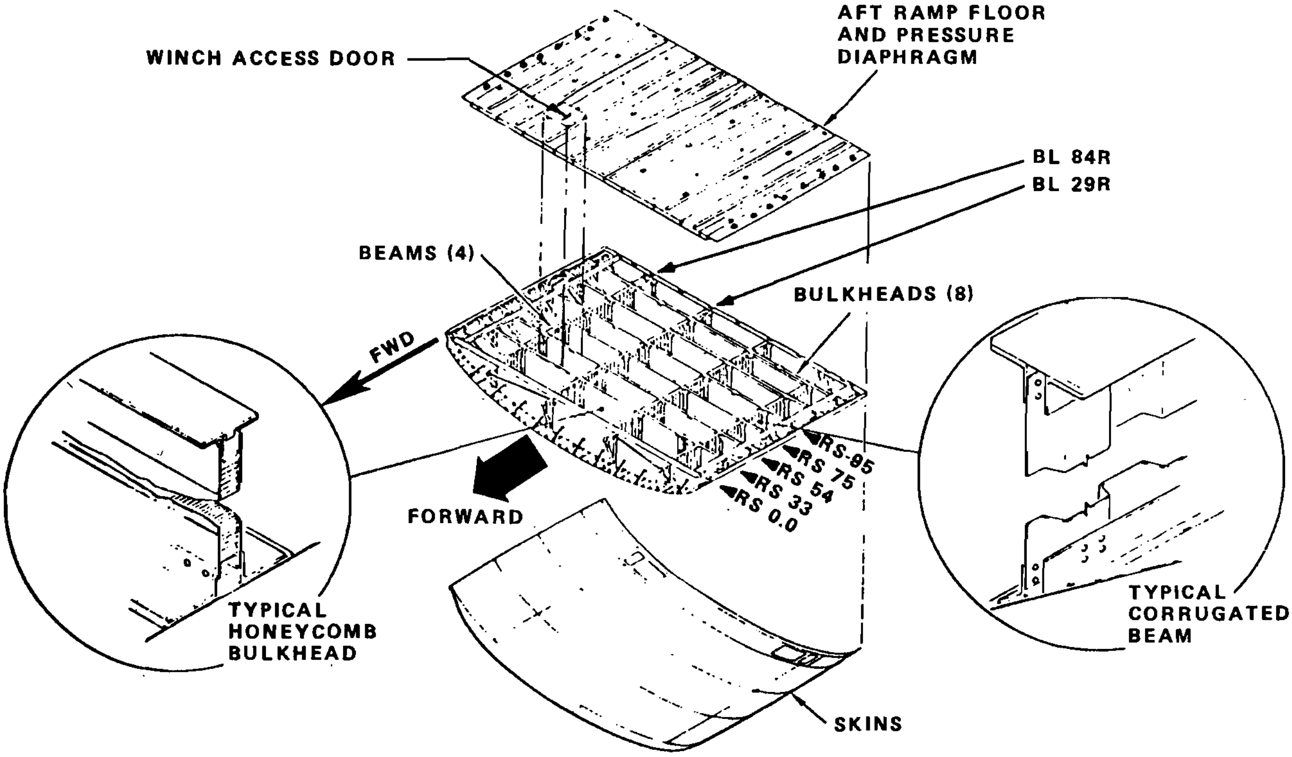


Figure 4

AFT RAMP LATCH SYSTEM

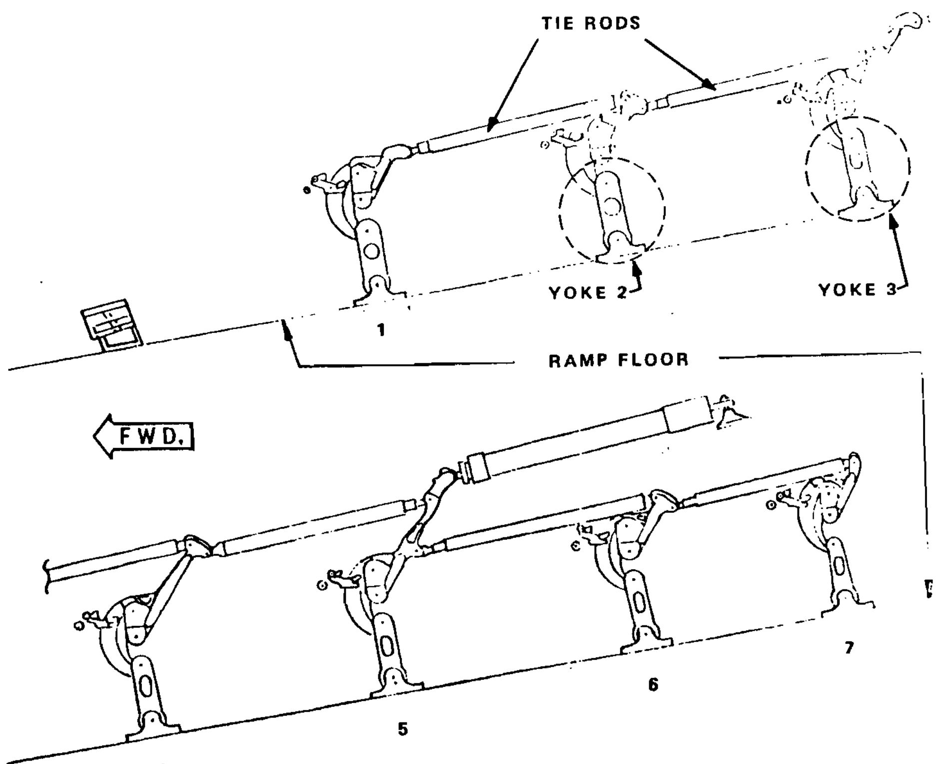


Figure 5

AFT BODY TORQUE BOX

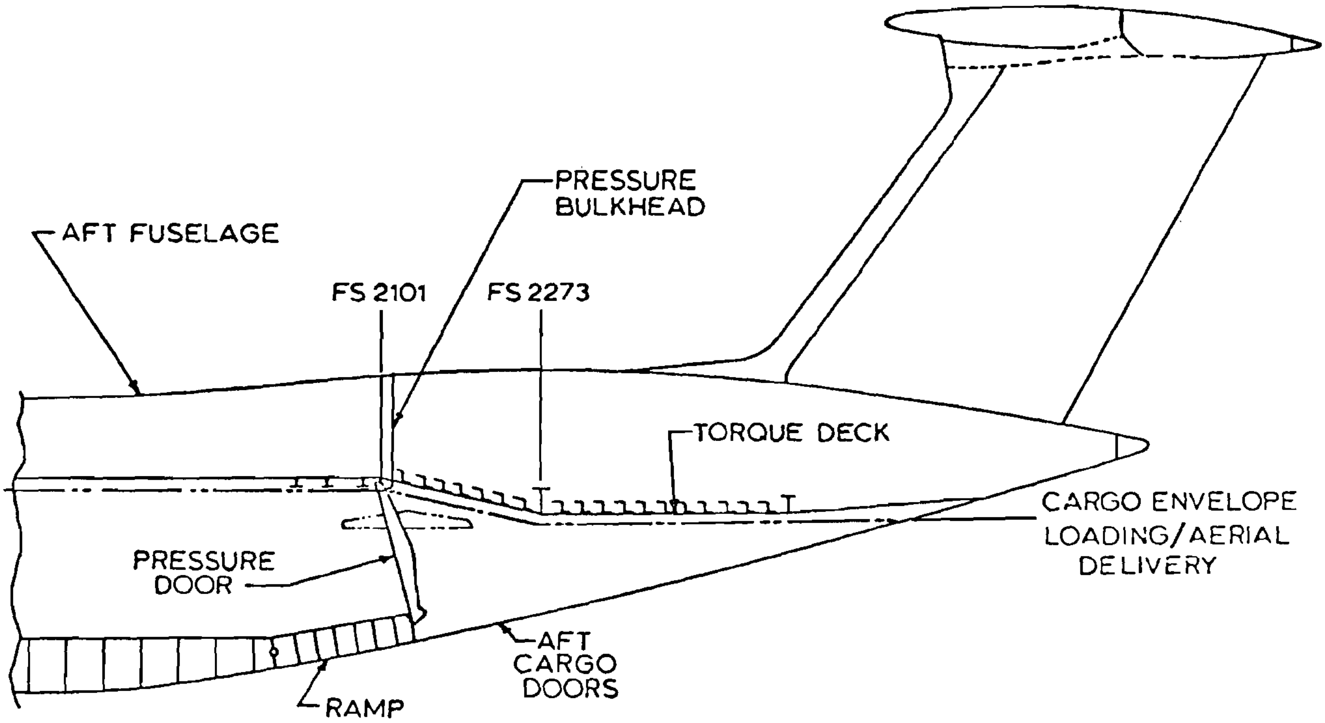


Figure 6

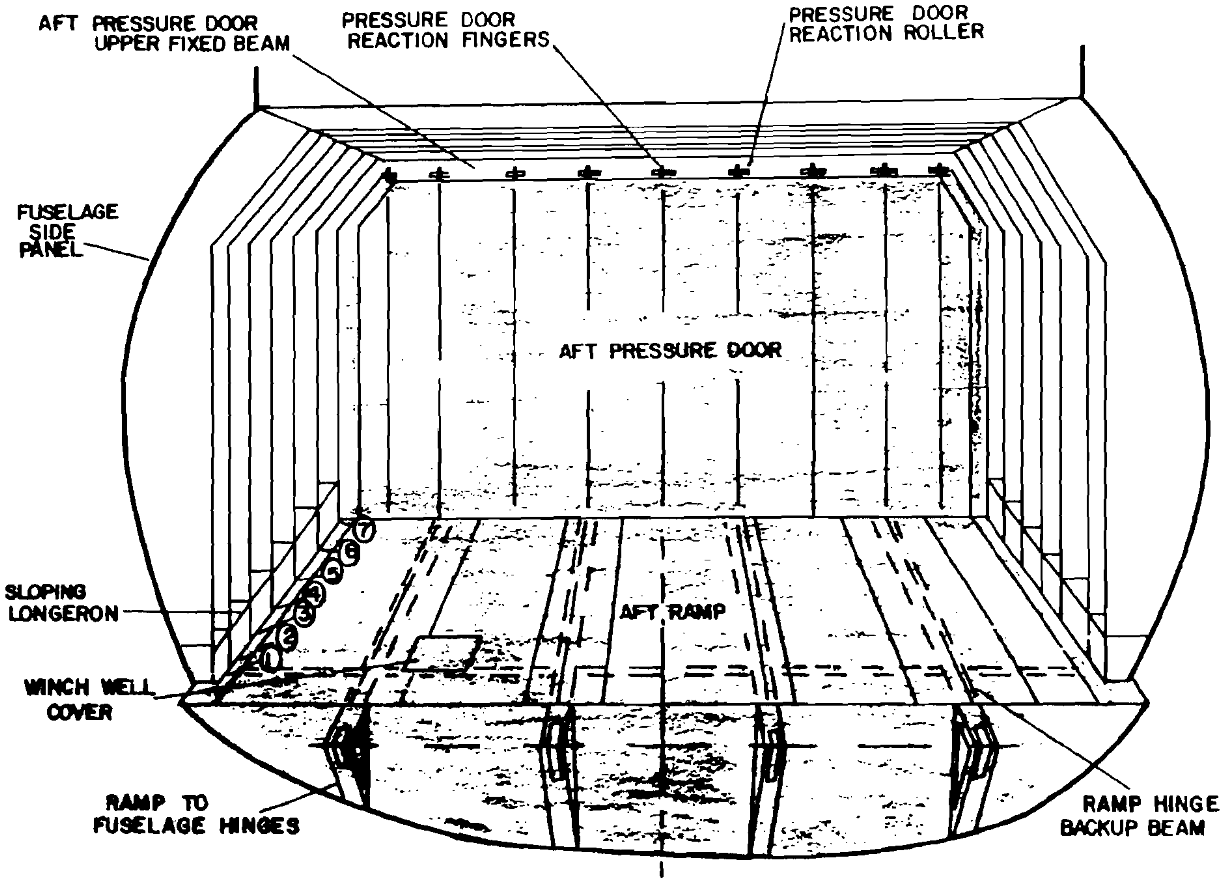


Figure 7

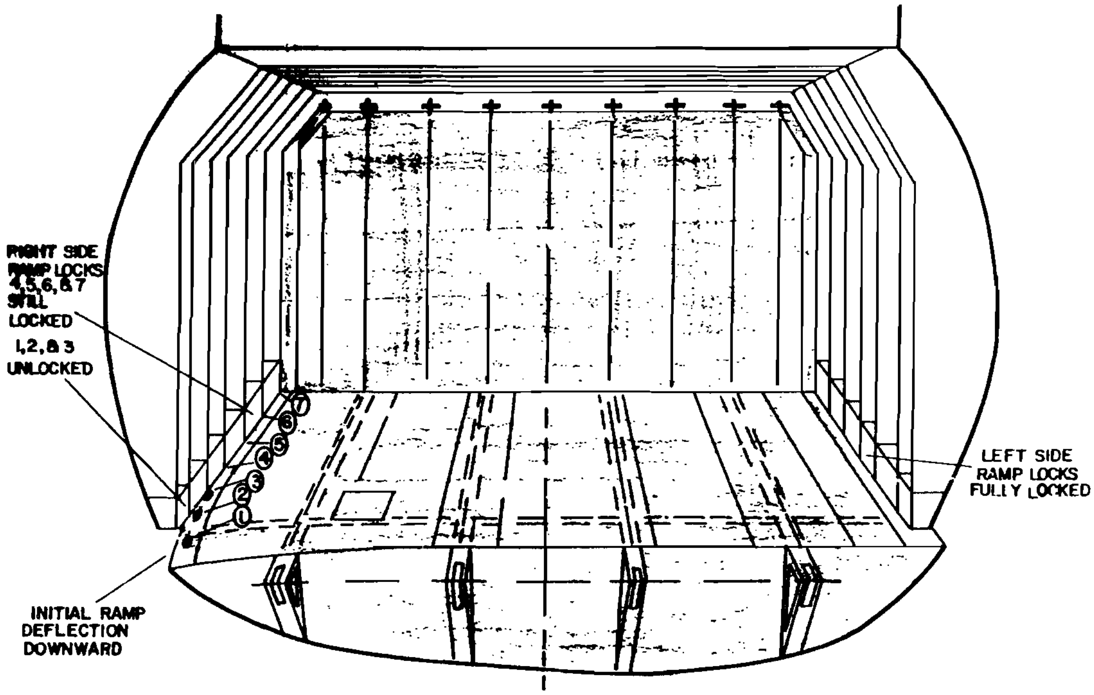


Figure 8

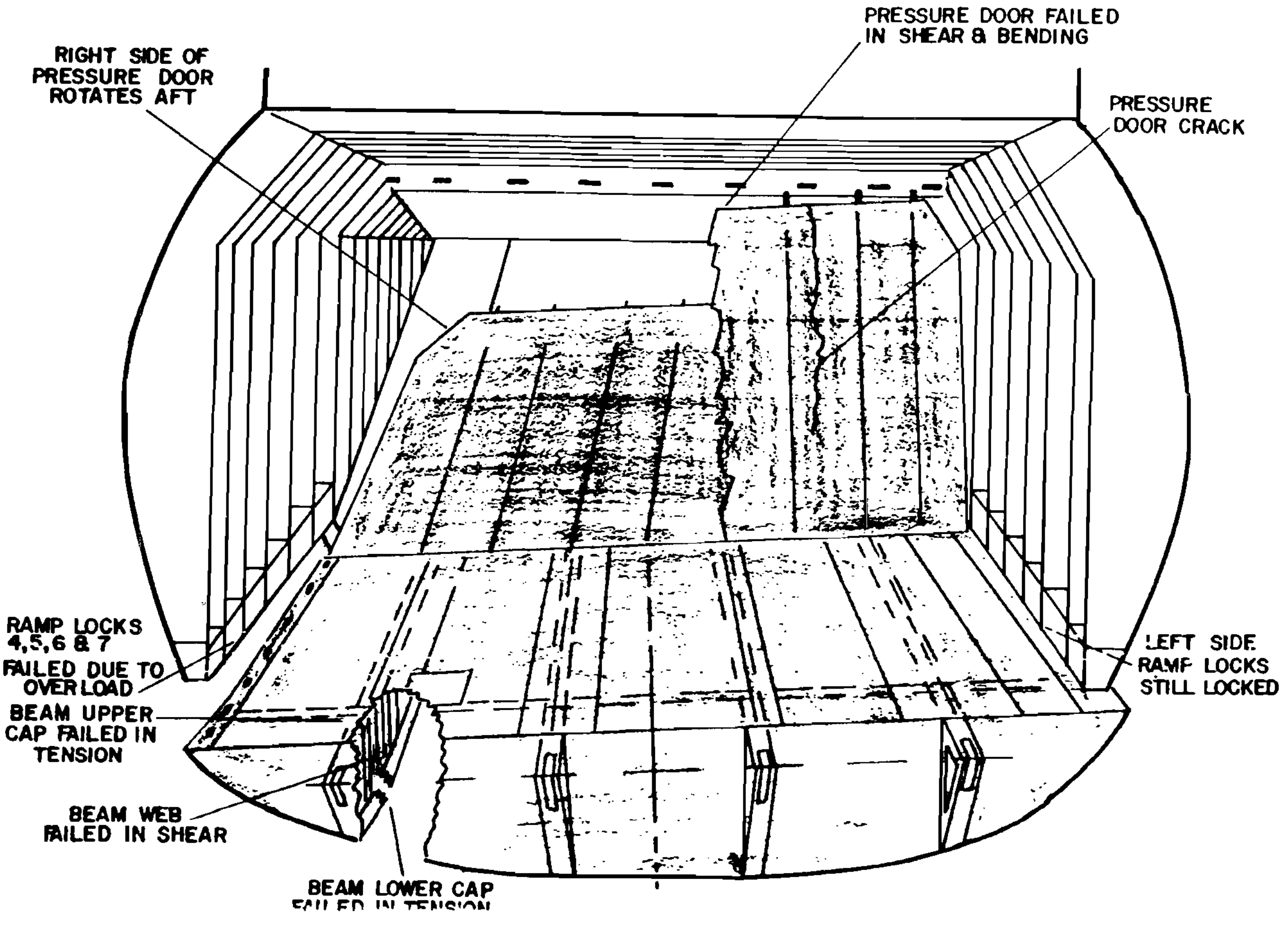


Figure 9

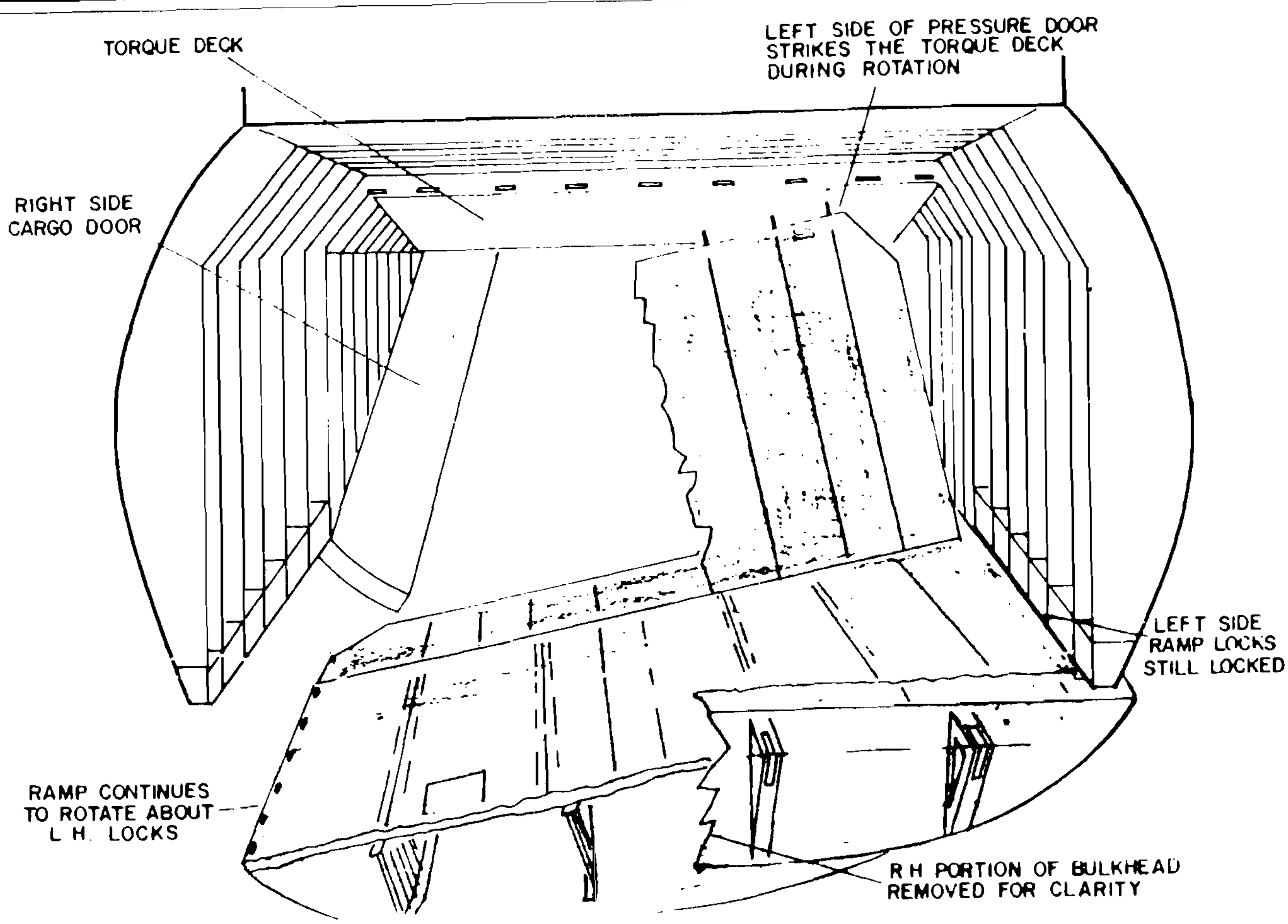


Figure 10

5. During the initial lowering of the ramp and pressure door, the fingers of the pressure door slipped to the right and down off the station 2101 pressure bulkhead rollers, allowing the 6½ psi cabin air to impact the sloping torque deck, deflecting it upward symmetrically about the aircraft centerline. This escaping cabin air blew the side doors open and failed the center door. The center door first departed the aircraft; subsequently the right side cargo door departed the aircraft.

6. When the six right side pressure door fingers cleared the rollers and passed through the light seal structure, the pressure door failed in bending and shear at left butt line 28, starting at the top due to the restraint of the remaining three fingers on the left side.

7. The left three pressure door fingers slipped off the rollers (Figure 10), causing the sloping torque deck to be impacted by the rotation of the remaining left side portion of the pressure door, rupturing hydraulic systems number 1 and 2, as well as severing all control cables and the lower portion of the wire runs immediately above the torque deck. The forces of the escaping cabin air contributed to the upward motion of the torque deck structure and failure of the control cables. The right side of the pressure door had dropped sufficiently to clear number 3 hydraulic system lines.

8. The ramp which had torn completely across from right to left at station 33 together with the pressure door continued to rotate to the left until it twisted out of the left lock system and departed the aircraft.

9. A major part of the sloping torque deck located in the center of the fuselage immediately aft of the overhead pressure door beam was torn from the aircraft (Figure 11).

10. The CDPIR was deflected upward and ejected due to air pressure from the aft fuselage resulting from either the cabin air entering this area or ram air picked up because of the damaged torque deck.

MISRIGGING

In order to study the effects of misrigging in the aft ramp locking system, a complete full-scale layout was made of the number 1 thru 7 locks (Figure 12), including the floor brackets, yokes, hooks, programming links, bellcranks, tie rods and actuator assemblies. This full-scale engineering mockup could be manually operated and the tie rods could be adjusted such that misrigging cases could be simulated. A kinematics analysis of a wide range of potential misrigging errors was conducted. It was concluded that while misrigging might readily contribute to this type of failure, misrigging alone will not result in failure of the tie rods or bellcranks or cause the entire lock train to unlock. There are, however, conditions of rigging which can cause unlocking of part of the locks if the tie rods become detached or experience a complete failure of the bellcrank. A review of the records and inspection of all fleet aircraft revealed there had been numerous cases of bent tie rods which required replacement. There were also cracked bellcranks which were discovered on subsequent inspections. It was found that it is

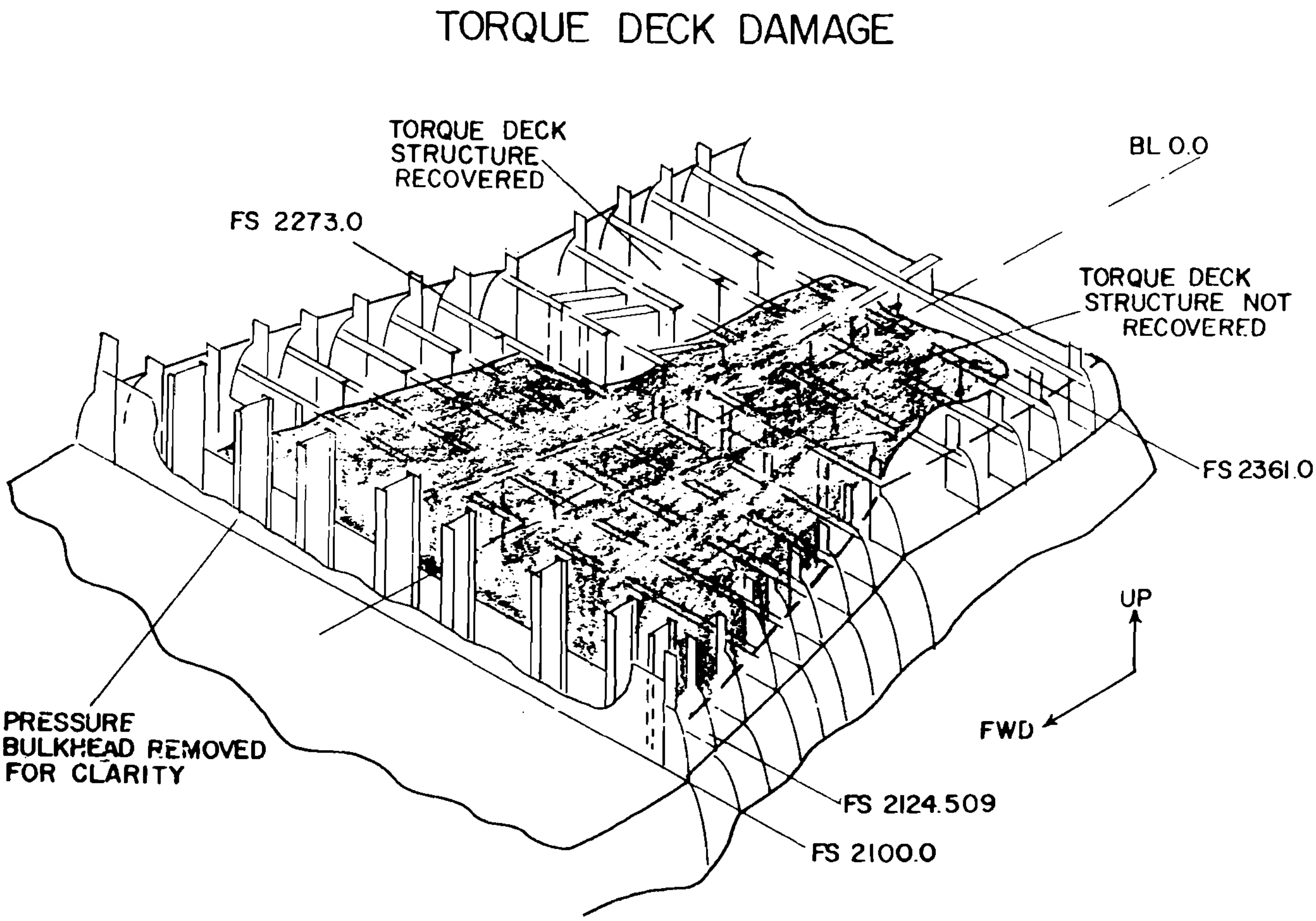


Figure 11

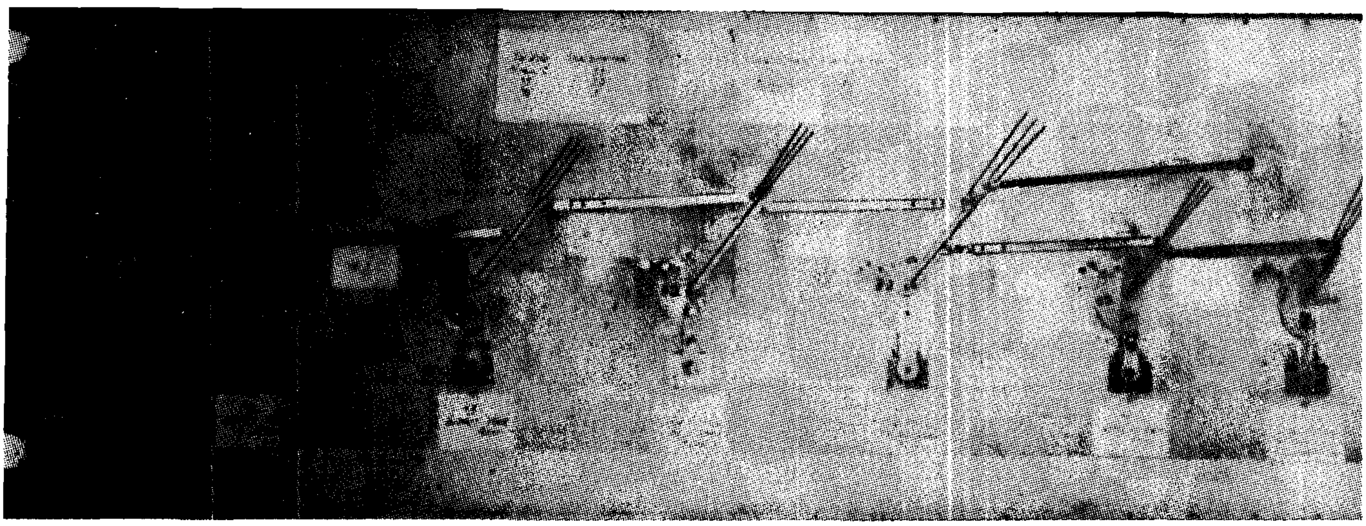


Figure 12

not unusual for a lock system to stall during locking due to impact of the hook tip on the yoke upper eccentric shaft. In fleet operations, cracked bellcranks have been found following operations when this condition was experienced. Occasionally, this resulted in a buckled tie rod. Tests were conducted to determine the degradation of tensile strength of a buckled tie rod. Some test failures occurred at approximately 600 pounds in two tie rods which were buckled. This failure load is well within the loads which can be expected from a misrigged condition.

Detailed laboratory and design analyses were conducted on components around the pressure door and the following areas were found not to have contributed in any manner to this failure: the center and side doors, the upper and lower pressure door hinges, the upper pressure door fixed overhead structure, sloping longerons, ramp structure, ramp to fuselage hinges, ramp actuator and lock actuator, left side ramp locks, and right side ramp locks 4 thru 7. The most probable initiation point of this failure appears to be the right side locks number 1, 2 and 3 and the tie rod interlocking locks number 3 and 4. Any reasonable out-of-rig condition of locks number 1, 2 and 3 would not precipitate the failure assuming the tie rod was structurally intact and the tie rod bolts properly installed.

All C-5As in the Air Force inventory have received a complete disassembly and inspection of the aft and forward cargo ramp locking systems. Design modifications have been made to the locking systems to facilitate rigging and to assure that all individual locks are securely engaged during flight operations.

About the Author

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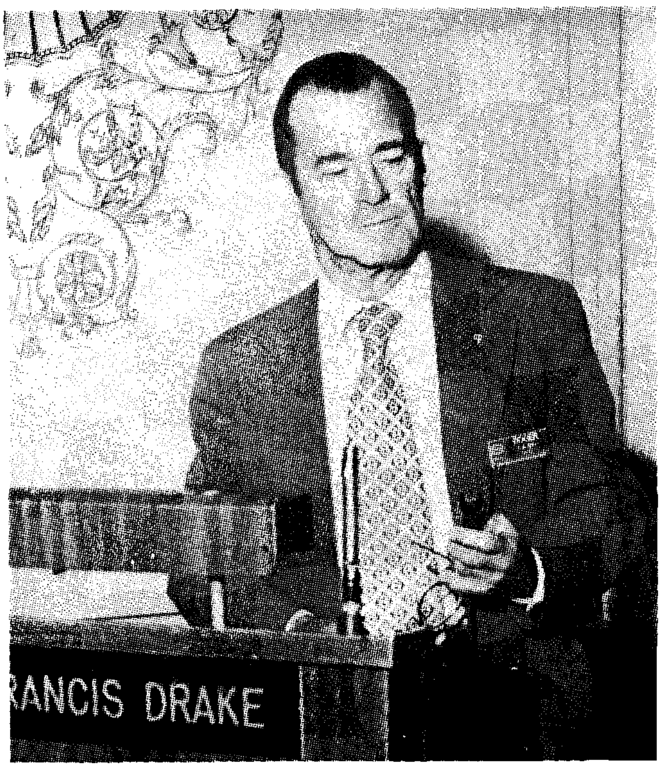
2. *Review of USAF aircraft mishap reports with emphasis on technical analysis of evidence*
3. *Providing technical assistance to mishap investigating boards*



Roger Smith, Canadian SASI President

Banquet Speaker, Alan Stephen, CAAA

Accident Investigation The "Game" We Play

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> *Mishaps are like knives that either serve us or cut us as we grasp them by the blade or the handle.*
>
> James Russell Lowell[1]

On September 25, 1979, one year ago, it was the author's privilege to address the International Society of Air Safety Investigators annual seminar on the subject "Investigation Can Prevent Aircraft Accidents."[2] The thesis being that the 1978 PSA midair collision in San Diego should not be considered an accident. It was a loss associated with an assumption of risk taken when an historically established cause continuum had not been resolved and could be expected to repeat.

Everyone hoped that the second worst air tragedy in United States history would lead to positive preventive action to terminate the midair problem. Unfortunately, a critical review of the facts concerning this hazard indicate that the problem has worsened rather than improved. These facts lead one to conclude that air safety is a game we play rather than a creed we follow.

Headlines Prophesy Disaster

Is another midair on its way? According to the press the probability of such an event is imminent. Headlines introducing stories about airline safety have become common in all kinds of publications. Of particular significance were the following:

"Is Air Travel Becoming Too Dangerous?"
Changing Times[3]

"Air Safety—Why the Growing Worry?"
U.S. News and World Report[4]

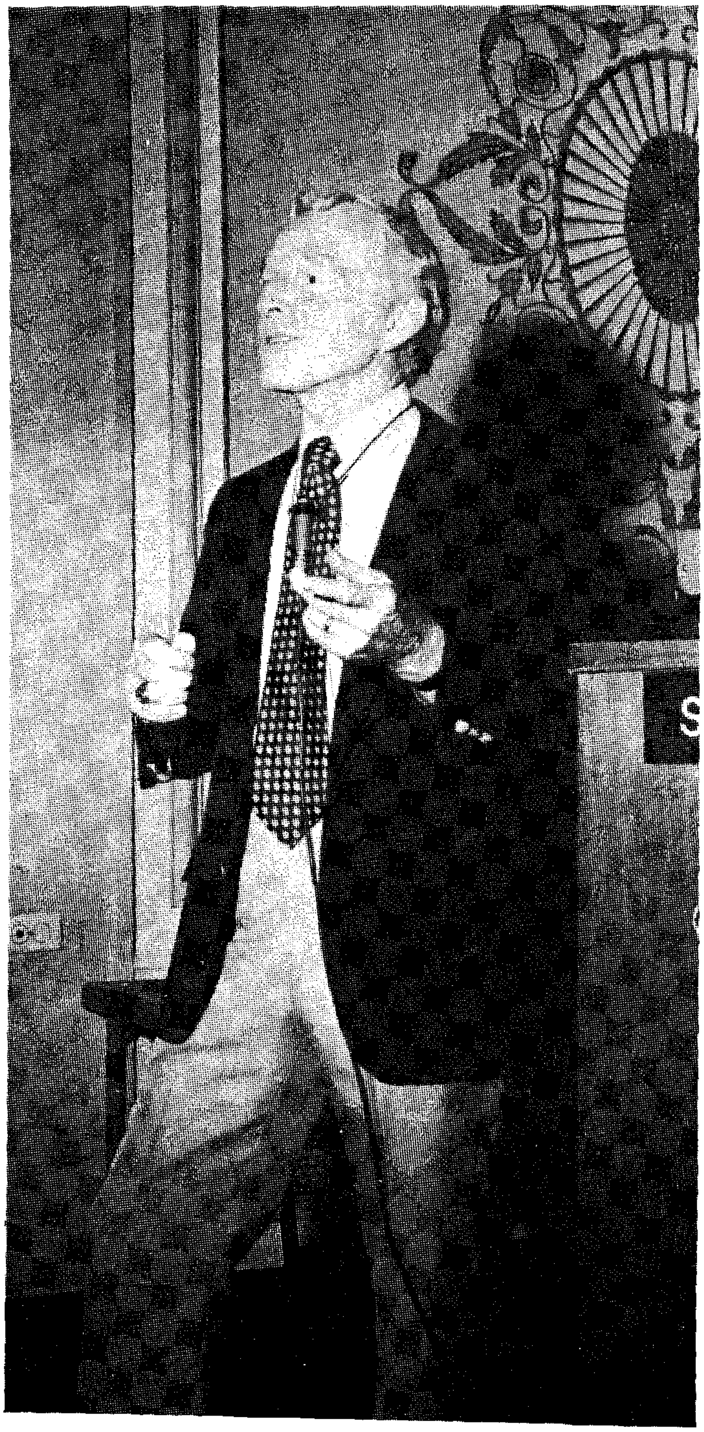
"How Safe Are Our Skies?"
Ladies Home Journal[5]

"Crowded Skies—and a Big Push for Air Safety"
U.S. News and World Report[6]

"Airline Safety. A Special Report"
Playboy[7]

Safety professionals have long hoped for more frequent and attentive press coverage of the problems in aviation that concern accident prevention. Unfortunately, there is little such coverage in the aviation press; the notable exception being *Aviation Week and Space Technology*. However, to find so much coverage in the non-aviation press is noteworthy. It suggests an unusual public concern, bordering on fear.

Ralph Nader's criticism of air safety is nothing new, it is expected. But when the coverage includes special staff reports in civil newspapers and magazines, like *Playboy*, the logical conclusion is that there must be something tangible that would spark such interest.



Most of the articles were exposal in nature and included many problems that affect air safety. But the main influence in all articles centered around the tragedy of the PSA midair collision and the Chicago DC-10 accident.

The DC-10 was the worst accident in United States history; however, the prospect of it repeating - the loss of an entire engine and pod - is very unlikely. Design and material problems usually result in effective preventive fixes.

Going from Bad to Worse

Midair collision problems are not so easily fixed. The press is clearly telling us that this game is going badly; that that public is about to lose more than its luggage. This controversy has been fueled by dire warnings of danger by both the pilot and traffic controller associations. Press releases and statements relative to Congressional hearings on air safety have been added. The result is a crescendo of opinion that the midair collision problem has become a real "can of worms."

The following factors have been publicized as having seriously affected air safety:

1. ***Increased traffic.*** General aviation aircraft have increased by 4 percent every year, while airports have been decreasing. Los Angeles had fifty-three general aviation airports in 1949. Today they have decreased to eighteen[6] Langhorne Bond, administrator of the Federal Aviation Administration (FAA), warns that the congestion may necessitate congressional rationing of airspace in ten years.[6] The FAA estimates that in the next ten years the number of general aviation aircraft in service will increase from 187,000 to 291,000. The air carriers will increase from 2,555 to 3,183.[20]

2. ***Near midair collisions.*** The number of reported near misses were almost double in 1978 (504 reports) what they were in 1973 (275 reports).[6] The United States Air Force (USAF) has collected more than 900 near miss reports since January 1977. In that period they had two collisions with civil aircraft, and two USAF aircraft collided maneuvering to avoid a civil aircraft. Approximately 76 percent of the USAF near miss reports involved civil aircraft. Most of the civil aircraft were unaware of USAF activities and were not participating in the air traffic control system.[8] It appears that the military are having the same trouble with general aviation aircraft that the air carriers are.

There have been reports of near misses between PSA aircraft and private aircraft in the San Diego control area - virtually duplicates of the PSA midair collision in 1978. Other airlines have reported similar occurrences in other traffic control areas.

3. ***Air traffic control system failures.*** The FAA relies upon its radar data processing (RDP) technology to control air traffic. Like most technology, it presents special problems when it malfunctions. John Galipault, president of the Aviation Safety Institute, has been quoted as saying:

> "We see more reports each week of radar data processing (R.D.P.) failures...and many are catastrophic...the FAA...readily admits that the 9020 computer systems are reaching their performance limits...IBM warned the FAA back in the late sixties

that the 9020 would not do the job of controlling the 1980 traffic volume.[7]

The FAA has reported 2,595 unscheduled interruptions of RDP service in the first five months of 1980. Of these 289 were outages, which are failures that last longer than one minute.[9] One outage in New York lasted two days.[6] Representative Whittaker (Kansas) charges that there have been four times the computer outages that FAA has reported.[9] Whichever number is correct, the system outages occur at a rate of more than one per day.

Howard E. Johannssen, president of the Professional Airways Systems Specialists, also blames FAA for concealing the dangers associated with the outages. "Over the past few years, we have become increasingly anxious, angry and frustrated concerning computer and other system outages," is what Johannssen told a Congressional subcommittee on government activities and transportation.[10]

Committee chairman, Rep. John L. Burton (California), has stated:

> "The broadband system is about as reliable a backup system to narrow band as two tin cans are to a telephone.
>
> "I say there is a problem and possible disaster, because the primary computers are malfunctioning all over the country.
>
> "Indeed, there are a few minutes during the breakdown when the planes are flying blind and the controllers are scrambling to re-identify flight patterns, speed, and altitude...yet the FAA still refuses to admit a problem."[10]

4. ***ATC radio failures.*** Computer failures are not the only hazard reported. There have also been reports of ATC radio communications with aircraft failing. Regardless of the computer input, without the ability to communicate with the aircraft, ATC loses control of traffic. Aircraft then must proceed in the blind without knowledge of where other traffic is located. In instrument weather this poses a serious danger and makes a midair collision a distinct possibility.[7]

All of these problems have put extra loads on the traffic controllers. Following a near miss of three USAF Phantoms near George Air Force Base, Ernie Scarborough, an Edwards controller, said, "We're reaching acrescendo of problems. There comes a time when its no longer possible to be superhumans."[6]

The general feeling of airline pilots was expressed by Captain John J. O'Donnell, president of the Air Line Pilots Association, when he stated, "The specter of a midair collision haunts every professional pilot."[3]

In Defense of the System.

As expected, the critics of the traffic control system and its dangers aim most of their attacks at the FAA. Being responsible not only for air traffic control but for all civil air safety, the FAA cannot deny its involvement.

Administrator Bond rejects criticism of FAA when he states, "Prior to 1972, we had 10 midair collisions involving air carriers in a period of four years. In the remaining eight years, we have had one."[6]

Regarding comments that the FAA has been too slow and only reacts to disasters, Bond points out that Congress controls the appropriations and without the money FAA can do little. He insists that the computer breakdowns are declining and says that plans for new systems will correct the problem. The FAA also defends its slowness by claiming that technology for a reliable collision avoidance system (CAS) has only recently become available. By the mid 1980's FAA expects to have in operation a ground-based CAS, which they contend will be more reliable than the proposed airborne system recommended by ALPA. And, by the late 1980's FAA is planning to replace the present computerized air traffic control system.[5]

Whatever the reason for the delay, there is no doubt that it has not been because of a lack of financing. Since 1970, there has been a federal tax on airline tickets for the purpose of air safety. In 1980 that fund will reach 3.5 billion dollars. The FAA says that they cannot spend this trust fund money without Congressional permission.[5]

The FAA defense coincides with statements contained in an interview of John Galipault, included by Gonzales in the *Playboy* article. The day after he testified before Congress on RDP problems, Galipault was asked what Congress was going to do. He replied, "Nothing. I should learn not to go on these things. They're going to wait for a big mid-air before they do anything." Gonzales asked if the San Diego accident wasn't a big mid-air, being the biggest crash in U.S. history at the time. Galipault answered, "Not big enough....Maybe when two 747's collide..."[7]

John J. Kennelly, a trial lawyer who specializes in representing plaintiffs in aircraft accident litigation has supported the FAA. He says the FAA cannot obtain the funds it needs to hire qualified personnel. Kennelly advises:

> "Despite unduly alarmist criticism by some authors about airlines, aircraft manufacturers and even air traffic controllers, amazing gains in safety have been made in the last decades.
>
> "The first half of 1980 is now over, and there has not been a single passenger fatality in any major airline operations...."[11]

One can hardly criticize without becoming the recipient of counter arguments. The two most quoted critics have been the air traffic controllers and the pilots' associations. Counter arguments against the controllers postulate that their interest in midair collisions is because they can use it to advantage in wage negotiations. Pilots, on the other hand, are involved in dispute about whether jet airliners will be manned by two or three crewmembers. The pilots contend that three pilots provide better visual detection than two. The counter argument is that the pilots are interested in providing more jobs.

The Score in the Game: Midairs 39, Investigation 0

The arguments in defense of the system have substance until another midair becomes a reality. The PSA midair should have been enough of a priority, by example, to deter all opposition to effective prevention. Ironically, if it had not been for the press, the public and maybe even some safety professionals would be allowed to forget about PSA 182 -until the next air carrier midair repeat.

Regardless of any possible ulterior motives, the pleas of the pilots and traffic controllers must be heeded. If you do not believe that there is a midair problem, and that it is serious, you have not studied the history of midair collisions and recognized the magnitude and perpetuity of the problem.

Table 1 is an incomplete list of the major transport and air carrier midair collisions. It is incomplete in that it accounts for only the major accidents for which an accounting is readily available. The purpose of the table was not to document every air carrier or transport midair collision, but to emphasize the reality of the problem. The list includes those accidents which have happened world-wide, in that there should be no distinction about where an aircraft accident occurs. The list was restricted to airline type aircraft although many of the collisions were with military fighter or general aviation type aircraft. At least one aircraft is an airline type.

In summary, Table 1 covers the period from 1935 to 1979, 44.4 years, 16,194 days. The 39 collisions over that period averaged 1 collision every 415 days. The 2,340 fatalities averaged 60 per collision, and 98. 3 per collision during the last ten years (1969 to 1979).

It is interesting to note that the first large midair, listed in 1935, involved two Soviet aircraft. One the "Maxim Gorky," at the time the world's largest aircraft, which was struck by a 'oviet escort fighter plane. Ironically, the last major midair, ..sted in 1979, also involved two Soviet aircraft.

Not included in Table 1 was the worst aviation accident in history, the Tenerife collision between a Dutch KLM Boeing 747 taking off and a taxiing Pan American Airlines 747. It could be debated that this was a midair collision in that the KLM aircraft was airborne at the time of collision. However, in that both aircraft were not airborne the accident may not technically qualify as a midair collision. It was, therefore, not included in Table 1, although the circumstances involved were considered applicable to the midair problem.

TABLE 1

MIDAIR COLLISIONS OF TRANSPORT AIRCRAFT[12,13,14,15,16]

DATE	INCIDENT	LOCATION	FATALITIES
1935 May	Giant airplane "Maxim Gorky" & Soviet fighter	Moscow Airport	49
1938 Aug	Two Japanese aircraft	Tokyo, Japan	58
1948 Jul	Swedish DC-6 & RAF York transport	London, England	39
1949 Nov	Bolivian P-38 & EAL DC-4	Washington National Airport	55
1950 Dec	French Army transports	Tourane, Indo-China	30
1951 Apr	USN aircraft & Cuban airliner	Key West, Florida	43
1952 Mar	Two Soviet aircraft	Tula Airport, Moscow	70
1953 Jan	RAF transports	Valetta, Malta	25
1953 Mar	USAF RB-36 & B-29	Newfoundland	33
1953 Nov	Argentine AF transports	Mugueta, Argentina	20
1954 Apr	Trans-Canada DC-4 & RCAF trainer	Moose Jaw (Saskatchewan)	37
1955 Aug	USAF C-119's	Edelweider, West Germany	66
1956 Jun	UAL DC-6 & TWA L-1049	Grand Canyon, Arizona	128
1958 Feb	USAF transport & USN bomber	Los Angeles, California	47
1958 Mar	Capital VC-Viscount & Maryland ANG T-33	Brunswick, Maryland	12
1958 Mar	USMC transport & F-100	Okinawa	25
1958 Apr	UAL DC-7 & USAF fighter	Las Vegas, Nevada	49
1958 Oct	BEA VC-Viscount & Italian AF Sabrejet	Nettuno, Italy	31
1959 Dec	VC-Viscount & Fokker trainer	Rio de Janeiro, Brazil	49
1960 Feb	USN transport & REAL DC-3	Rio de Janeiro, Brazil	61
1960 Dec	UAL DC-8 & TWA L-1049	Staten Island, New York	136
1962 Nov	VASP (Brazil) C-130 & Saab-Scandia	Faraibuna, Brazil	27
1963 Feb	Lebanese VC-Viscount & Turkish AF C-47	Ankara, Turkey	104
1965 Oct	AVIANCA DC-3 & Piper private airplane	Bucaramanga, Colombia	19
1965 Dec	EAL L-1049 & TWA B-707	Danbury, Connecticut	4
1966 Jan	Garuda (Indonesian) DC-3 & DC-3	Southern Sumatra	17
1967 Mar	TWA DC-9 & Twin Beechcraft	Urbana (Dayton), Ohio	26
1967 Jun	USMC helicopters	Camp Lejeune, North Carolina	22
1967 Jul	Piedmont B-727 & Cessna 310	Hendersonville, North Carolina	82
1969 Sep	Allegheny DC-9 & Piper Cherokee	Shelbyville, Indiana	83
1969 Sep	Vietnamese DC-4 & USAF Phantom	Danang, South Vietnam	76
1971 Jun	Hughes Airwest DC-9 & USMC Phantom	San Gabriel Mtns, California	50
1971 Jul	All Nippon B-727 & Japanese AF F-86	Morioka, Japan	162
1972 Jun	Air Wisc. Twin Otter & N. Central CV580	Appleton, Wisconsin	13
1972 Jul	Two AVIANCA DC-3's	Los Palomas Mountains, Colombia	38
1973 Apr	Iberia DC-9 & Spanish CV990	Nantes, France	68
1976 Sep	British Trident & Yugoslav DC-9	Zagreb, Yugoslavia	176
1978 Sep	PSA B-727 & Cessna 172	San Diego, California	144
1979 Aug	Two Soviet TU-134's	Ukraine, USSR	173

39 total collision accidents, **2,340** total fatalities.

Although the emphasis of this paper is on airline midair collisions, it should be noted that general aviation midair collisions comprise the majority of such accidents. Data supplied by NTSB for a Flight Safety Foundation midair collision workshop held at the University of Southern California, on June 26, 1975, exhibited the ratio of type aircraft involved.

The statistical compilation covered the period 1956 through 1974.[17] Of the 450 midairs, 242 were fatal accidents involving 1,184 fatalities. The distribution of aircraft in the total was:

3 air carrier/air carrier	-	0.67% of total
18 air carrier/gen. avn.	-	4.00% of total
5 air carrier/military	-	1.11% of total
37 gen. avn./military	-	8.22% of total
387 gen. avn./gen. avn.	-	86.00% of total
450 midair collisions	-	100.00%

Some of the problems involved in general aviation midair collisions are the same as in air carrier collisions. Some are not. The subject of midair collisions in general aviation deserves to be treated as a separate and important study. Time does not permit it in this paper.

The history of the midair collision cause factor indicates that the previous accidents and investigations have not prevented recurrence. The score is midairs 39, investigation 0. It is no contest. Investigation is getting "skunked" by the midair problem. As long as the cause repeats, it means that the investigations, and all studies connected with them, have failed to justify their existence because their only objective is accident prevention. The game we are playing is not going well at all. No wins over 44 years is discouraging.

The defenses put up about the midair problem pale to a matter of "lip service" when the reality of the problem is realized. The rhetoric used by those defending this dismal record would indicate that maybe the speakers don't know that they have a problem. If they have to sustain another major midair collision to prove they have a problem, then they are most certainly part of the problem.

It is time to examine not only the midair problem but the system that has the responsibility to effect the solution to the problem. The newspaper, magazine and other writings that have attempted to expose the problems of air safety have credited the FAA with the prime responsibility for any failure in accident prevention. This is true, but the aircraft accident investigation responsibility must also be examined to determine if it has made its full contribution to safety.

The PSA Aircraft Accident Report

To understand the contribution of aircraft accident investigation to the prevention of the midair collision problem requires a critical examination of the NTSB Aircraft Accident Report 79-5: Pacific Southwest Airlines, Inc., Boeing 727-214, N533PS, and Gibbs Flite Center, Inc., Cessna 172, N7711G, San Diego, California, September 25, 1979.[18]

This paper will not attempt an evaluation of the factual and technical investigation. It will be assumed that the accident was thoroughly investigated and that the data is as accurate as could be accomplished under the circumstances. The example used in this paper for examination will be the conclusions of the report:

Probable cause. As listed in the accident report:

> "...probable cause...was failure of the flightcrew of Flight 182 to comply with the provisions of a maintain-visual-separation clearance..."
>
> "Contributing...were the air traffic control procedures in effect which authorized the controllers to use visual separation procedures to separate two aircraft on potentially conflicting tracts..."

The probable cause places the full emphasis on the flightcrew. More succinctly, this would be labeled as "pilot factor." The cause assessment was based on the fact that the flightcrew of PSA 182 were given a maintain-visual-separation clearance during their approach to San Diego Lindbergh Field and, according to the cockpit voice recorder interpretation by the Board, failed to maintain visual contact with the Cessna 172. The Board also said that the PSA crew did not report losing sight of the Cessna. As pointed out by ALPA, this is a matter of contention. The ALPA interprets the cockpit voice recorder tape as indicating that the PSA crew had made visual contact with a third aircraft, not the Cessna 172. They also feel that the crew was confident that they had passed the conflict traffic until they suddenly came upon the Cessna 172.

It should be pointed out that the PSA crew did not request a maintain-visual-separation clearance; it was given to them by the air traffic controller as an addendum to their approach clearance.

The contributing cause listed by the Board tends to refute the probable cause. It places the emphasis for using a visual separation clearance, when conflicting traffic was apparent, on the traffic control procedures. The seriousness of the conflict was apparent to the controller, who had the two aircraft located on radar, but not to the PSA flightcrew. If the visual clearance should not have been given by ATC, which it was, then why was flightcrew failure the primary cause factor? The flightcrew did not request the clearance and were not made aware of the seriousness of the situation when they were given it. The contributing cause seems to contradict the probable cause.

Recommendations. There were four recommendations included in the accident report, all addressed to the FAA:

> "Implement a Terminal Radar Service Area (TRSA) at Lindbergh Airport, San Diego, California. (Class I-Urgent Action) (A-78-77)"
>
> "Review procedures at all airports which are used regularly by air carrier and general aviation aircraft to determine which other areas require a terminal control area or a terminal control radar service area and establish the appropriate one. (Class II-Priority Action) (A-78-78)"
>
> "Use visual separation in terminal control areas and terminal radar service areas only when a pilot requests it, except for sequencing on the final approach with radar monitoring. (Class I-Urgent Action) (A-78-82)"
>
> Re-evaluation its policy with regard to the use

of visual separation in other terminal areas. (Class II, Priority Action) (-78-83)"

Although the probable cause of the accident was determined to be flightcrew failure, none of the recommendations addressed that cause. None indicated any action that would prevent another flightcrew from making the same failure. The recommendations and the probable cause are not consistent.

The recommendations provided even more evidence that ATC should not have given PSA 182 a visual separation clearance. The probable cause and the recommendations do not correlate, making the flightcrew cause invalid.

The principle effect brought about by the probable cause was to establish a basis for others to blame the flightcrew of 182 for the accident. If no recommendations were to be derived from that cause then it was not directed at prevention of recurrence. In fact, the flightcrew cause factor was counterproductive. It would be "buried" with the crew and forgotten. It took the emphasis off preventing recurrence because it provided a nonproductive answer to the accident. It became a one-time event, requiring no further action.

The contributing cause was much more productive than the probable cause. Or, it would have been had it not been overshadowed by listing the flightcrew failure as the probable cause. There was dissention among the Board members on the assignment of probable and contributing cause. Member Francis H. McAdams wrote a minority statement in which he emphasized that the contributing factor should have been given equal weight with the probable cause.

ALPA has petitioned the NTSB to reconsider its findings. President O'Donnell's statement said:

> "The previous finding of probable cause of this accident—flightcrew error—is an oversimplified and an incomplete analysis. This accident...was caused by deficiencies in existing ATC 'See and Avoid' visual separation procedures."[19]

The Investigation Creed

Analysis of the cause history of the midair collision problem indicates quite clearly that accident investigation has produced a negative contribution to the prevention of further recurrence. The conclusions of the PSA accident report further prove this. How then can accident investigation accomplish its objective of accident prevention? The answer is, simply, to comply with the investigation creed. The creed is the basic philosophy that governs the conduct of the investigation. That creed is as follows:

1. ***You shall follow the investigation formula:* I→ C→ R→ Pfa.** Investigation determines causes; causes determine recommendations; recommendations determine prevention of future accidents. There must be consistency; one part builds on the previous one. And, correspondingly, the subsequent parts relate back and correspond with the previous parts.

2. ***You shall research the history of the cause.*** Understand that all cause factors are repeat cause factors. They have all happened before. Every accident involves causes that have repeated and follow a continuum. The reason why the continuum continued is more important than the symptomatic cause. Reasons for repeats determine the root causes of accidents and are productive of accident prevention.

3. ***You shall not be biased, fear pressure or delve into politics.*** Prejudice and pressure will not produce root causes and prevention. Every investigator and investigation board is susceptible to inadvertent failing of this ideal. The only way to succeed is to keep in mind the fact that prevention is the only concern of the investigation.

4. ***You shall not indict, stigmatize or blame.*** Fault and blame are not within the purview of the investigation. The assignment or inference of blame is the concern of others, not the investigation. Assessment of blame will defeat the objective of accident prevention.

5. ***You shall not excuse, rationalize, mitigate, justify or extenuate circumstances.*** The investigation has an objective to prevent accidents, not to lessen the consequences. In fact, the greater the effect of the tragedy the more likely the corrective action will be taken.

6. ***You shall correlate the causes and recommendations.*** Conclusions and findings must be consistent. The relationship included in the investigation formula is paramount. It defeats the purpose of the process if the causes and recommendations are not mutually compatible. Causes that do not have preventive recommendations, and recommendations that are not based upon cause factors, are ineffective.

7. ***You shall search for the truth, the whole truth, and nothing but the truth.*** The investigation is a search for truth. Nothing else will supply the facts upon which preventive action must be based. When facts are not easily proved or are suspect, the investigation should deal with the subject candidly, expressly what is proved and what is not. An undetermined cause can, when properly handled, effect as much prevention value as proved causes.

The above principles are the most basic part of the investigation process. Without them the process would have little substance and would be ineffective. For some strange reason of human nature, these principles are the first things that get lost in the process. Investigators are most often careful to achieve excellence in the more technical aspects. They can conduct an exemplary investigation up to the determination of cause factors and recommendations; then they deviate from the creed and destroy most of the preventive value.

The author has had long experience in the education of aircraft accident investigators. In that time he has found that the student tends to take for granted the philosophy of investigation. It may sound so simple and logical that he feels no expectation of failing to apply it when the time comes. Yet, even though he may conduct an excellent investigation of the evidence, very often he will fail in the report writing process by either ignoring or forgetting the philosophy of what the investigation is all about. One can understand the student, in his impatience to use the techniques learned, overlooking the basics. But the same failure is also evident in many of the professional accident reports that the author has reviewed. It is a common failing, one that is evident in the PSA accident report. However skillful the NTSB was in the PSA investigation, they failed in the philosophy of accident investigation.

Midair Collision Prevention

The length of this paper does not permit a thorough study into the root causes of midair collisions. The research indicated that the problem is a complex one and will not be easily resolved. Not only are the technical problems complex but the extent of pressure being exerted by interested organizations is substantial.

There are some fundamental preventive actions that will have to be accomplished before the midair problem will be affected. Most of these have been publicized and have been recommended by midair collision studies previously conducted.[17,20,21]

Traffic separation. The faster the airliners fly, the greater the possibility of midairs. Especially between aircraft with great differential in speed. Terminal control areas and terminal control radar service areas are an improvement in traffic separation between large and small aircraft. However, the PSA midair proves that the system is not as reliable as required. The Aircraft Owners and Pilots Association (AOPA) is large and has exerted much pressure to keep the general aviation pilot from being ostracized from the large terminal areas. Until a more reliable and acceptable method is devised, the general aviation pilot may find the effect of continued midairs will take away the privilege that he so dearly fights for.

Collision Avoidance Systems (CAS). A system that will warn a pilot of conflicting traffic has been in the offing for a long time. The problem is that the cost of this or some other kind of Pilot Warning Indicator (PWI) has been high. The reliability is another concern. The FAA is planning to have a ground-based system in operation in the mid 1980's. They claim it will be more reliable than airborne systems and will not produce an unacceptable number of false signals. Such a system would relieve the general aviation pilot of the expense imposed by a required installation of an all-aircraft equipped airborne system. The unreliability proved by the failures and tests of the maintain-visual-separation procedure indicates the need for some other method.

Reliable Radar Data Processing. The system failures the FAA has been having in RDP shows a need to revise this system to make it work. Without its reliability, there is doubt that the modern level of air traffic can be maintained. The FAA does not expect to make revisions to the system for almost ten years. That is too long to wait., Something must be done in the interim.

Pilot education. The failure of the "see and avoid" method is evidenced by the fact that in every midair, large aircraft and small, the pilots failed to see each other in time to avoid colliding. Studies have been done that indicate pilots can improve visual acuity by special education. Recommendations were made over ten years ago to establish these programs.[20] They have not been made available to sufficiently accomplish their purpose, or they were not effective. Any experienced pilot knows that the longer he flies the better his visual acuity. He learns how to look and what to look for. There is also a need to continually educate pilots on the consequences of midair collisions and the requirement for vigilance.

"***See and Avoid.***" The method of relying on pilots to see and avoid conflicting aircraft has, as already explained, not been reliable. And the more the system employs aids like RDP and CAS, the more unreliable the "see and avoid" concept becomes. At the Second ISASI annual seminar, October 1972, Dr. James L. Harris presented a paper on the subject that applies to this concept:

> "I have a personal conviction that, though it is very easy to use the label pilot error on any accident in which one aircraft does not see another aircraft, ...it is a very damaging thing to do. In the first place it is...an accusation...even if men were performing up to the best of their abilities, the probability was not high that they would have seen each other, then by putting the label pilot error on the accident we simply sweep under the carpet the basic problem that does exist."[22]

A New Investigation Formula

The established investigation formula seems to be ignored often in the investigation process. The trouble is in the determination of the cause factors, or, most often in determining a probable or primary cause. This is the problem area. No one wants to be associated with the cause. Cause produces the defensiveness that gets in the way of prevention and destroys cooperation. It infers blame and stigmatizes. In many ways, cause is contradictory to the philosophy of investigation. The philosophy takes out the factor of blame and the cause puts it right back in. So, no matter how much we pull the teeth of fault and blame, the assignment of cause puts the bite right back in.

A better way would be to become very progressive in the process. Put all the emphasis on prevention. Change the formula to bypass the cause factor assignment. This will bring out cries of anguish from those who do not understand how little the cause means to prevention, and how much it detracts from prevention. It is, in essence, a luxury that spoils the process. And it is actually unnecessary. The cause factor does nothing but indicate the problem that the recommendations correct. It should be evident that there is a problem; the accident attests to that. The investigation and analysis will delineate the evidence and what failed. The recommendations can easily be prepared from that data.

The NTSB 1978 Annual Report to Congress began with the Board's statement about the importance of the recommendations:

> "The safety recommendation is the Board's end product. Nothing takes a higher priority; nothing is more carefully evaluated. In effect, the recommendation is vital to the Board's basic role of accident prevention...."[21]

The new formula would be one of the following:

$$I \rightarrow SOE \rightarrow R \rightarrow Pfa$$

The cause factors have been left out. In their place a "sequence of events" has been added. These events, listed chronologically, would not have the same inference that causes do. The "sequence of events" would be a logical conclusion to the investigation and analysis.

I→ F→ R→ Pfa

This formula is used by several military services to achieve prevention. The causes have not been replaced by the "findings" but have been integrated into them. NTSB uses findings as an introduction to the probable cause. The main difference between the military and NTSB use of findings is that the military does not follow their findings with causes. Those findings that are causal are so designated by adding the word in parenthesis after the appropriate finding. Finding number 12 of the PSA 182 accident report can be used as an example:

> Finding 12. The conflict alert procedures in effect at the time of the accident did not require that the controller warn the pilots of the aircraft involved in the conflict situation (Cause)

The only change in this quote from the report was the addition of the word "cause" in parenthesis. This method is also referred to as determination of multiple causes—causes listed without priority or discrimination.

I→ R→ Pfa

The above would be the most controversial formula. It would be objected to by traditionalists who, out of habit, feel they need to know the cause of an accident. As explained, the causes would be evident by the investigation and analysis. They would be left out of the formal report because of their controversial nature and negative emphasis. The recommendations would be listed, providing a positive and much less controversial conclusion to the process.

I→ Pfa, or
I = Pfa

These two formulas show the end result: the achievement of prevention of future accidents, They are not being recommended for adoption. They merely show that the shorter the formula, the closer the investigation comes to prevention of future accidents.

Winning

Winning is the only acceptable finale to the investigation process or "game." Winning is the only thing that will provide accident prevention. Losing is death and destruction. The investigation must not be part of the reason for losing the game. It must be a contributor, not a detractor. If the investigator plays by the correct philosophy it will win. It is imperative that we "Heed the Investigation Creed."

"Winning is not everything. It is the only thing."
Vince Lombardi[23]

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A New Digital Flight Recorder

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INTRODUCTION

This paper is intended to provide information on a new generation digital flight recorder designed for use in new generation aircraft, which can also be used in every current aircraft installation as a direct replacement without requiring any aircraft modification.

A description of the recorder, its function, and methods employed in data retrieval and data analysis are discussed.

SHORT HISTORY OF FLIGHT RECORDERS[1]

In April 1941, Civil Air Regulations, Amendment 100 became effective. It required a device to record altitude and radio transmitter operation. The compliance date was revised a number of times and finally in June 1944 the requirement was rescinded because of maintenance difficulties and inability to support the equipment.

In September 1947, a similar requirement was adopted which required recording of altitude and vertical acceleration. However, since no recorders were readily available which were adequate for the purposes intended or which offered acceptable reliability, the CAB again rescinded this order on July 1, 1948. No recorders were ever installed as a result of this regulatory action.

During the period from July 1948 to 1957, the regulatory agencies and industry representatives worked on a program to better define flight recorder requirements and develop acceptable hardware. The functions required to be recorded as a result of this new definition were altitude, airspeed, heading, vertical acceleration and time. Subsequently the regulations were revised to include the recording of the time of radio transmissions. In addition, some other optional data has been recorded by various operators. Agencies of some other countries have expanded the list of parameters required to be recorded.

Finally, with the introduction of new large wide-body jet aircraft, many other parameters have been added to the required list, and to the optional list as well. Because of the great amount of data required to comply with these new regulations, a totally new recording system was developed by the industry. This digital data recording system was adopted for inclusion in all wide-body and new generation aircraft recording system with many benefits available as a result of developments generated by space exploration programs.

The recorders designed during the 1950's are still in service and are likely to be with us for some time. However, there are strong incentives now which are making a replacement program for these older generation recorders desirable to the operators. The high cost of maintenance and operation of the old style scribe type recorders is the most eloquent argument for their replacement. However, up until now there has been no viable alternative available. With the introduction of the new Sundstrand Universal Flight Data Recorder this is being changed.

It is my pleasure to offer you an introduction to this new recording system today.

DESCRIPTION OF THE UFDR

The Universal Flight Data Recorder is a crash-protected airborne data recording system capable of performing the functions of the ARINC 542 series Flight Recorders and ARINC 573/717 Digital Flight Data Recorders. With the proper selection of optional equipment, it may be used interchangeably in an airplane operated by an airline without any aircraft modification. Data is recorded in digital form onto a magnetic tape with sufficient capacity to store a full 25 hours of flight data. The information is recorded in an ARINC 573 format.

Figure 1 illustrates the internal arrangement of the most complex version of the UFDR, which is packaged as a standard ARINC 404 1/2 ATR long unit intended to be mounted to a standard aircraft rack. It may be either hard mounted to the airframe or installed on a shock mounted tray.

The environmental enclosure is an upgraded version of previously utilized thermal enclosures. It consists of two halves, each consisting of a hardened steel outer shell, Min-K fire insulation, and fibre-glass liner. Intumescent plugs are incorporated at the belt entry and wire exit holes. The thermal enclosure is mounted to the chassis and the front panel with four vibration isolators. The environmental enclosure contains the tape transport assembly and supports the externally mounted drive motor.

The tape transport is a co-planer, peripheral belt driven device containing 450 feet of 1/4 inch magnetic tape, a reel drive belt, capstan/flywheel, and belt idlers. A primary drive belt couples the flywheel to the externally mounted drive

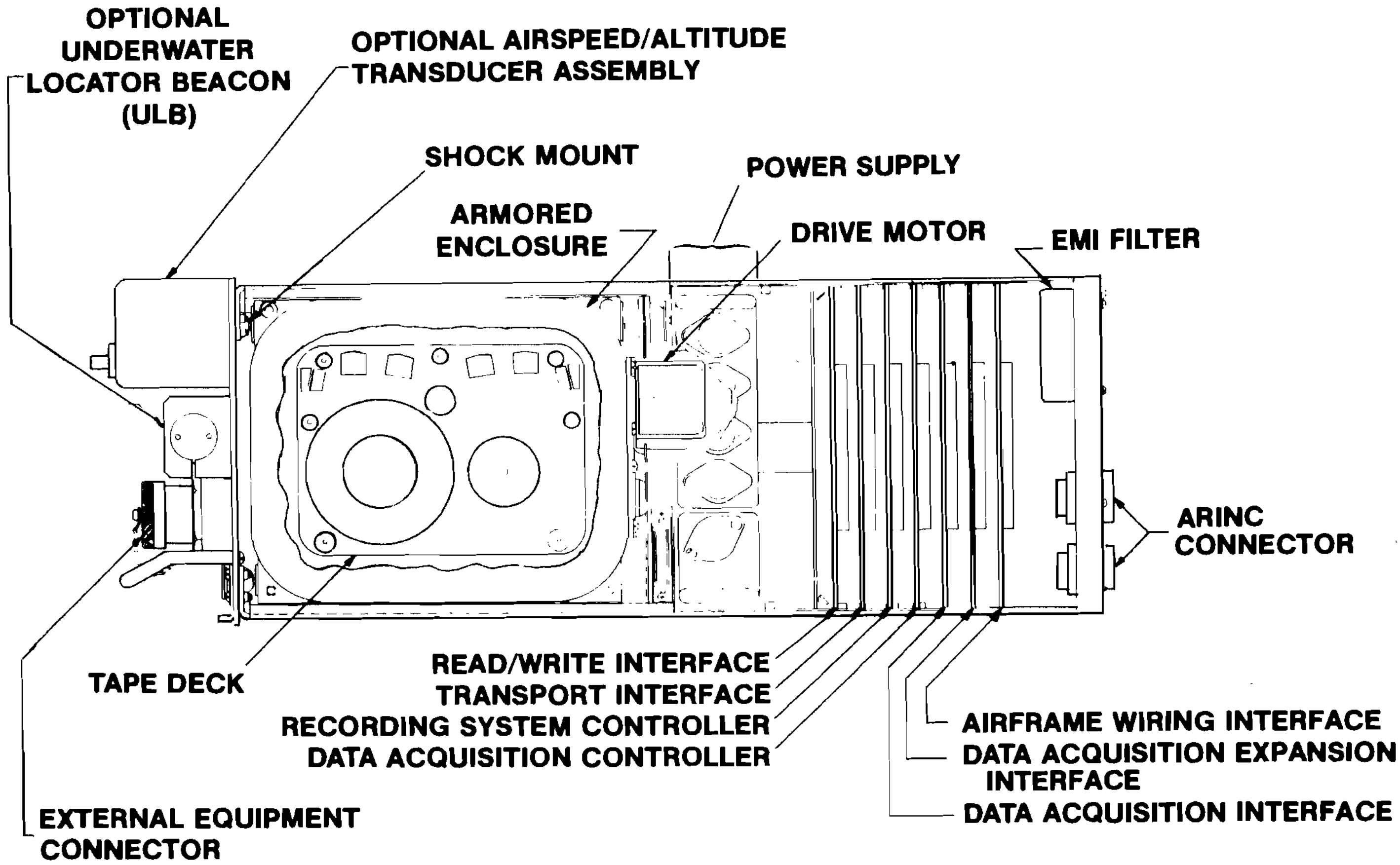

Figure 1. UFDR Internal Arrangement

motor through the enclosure wall. Also included within the tape transport are:

- Tape guides
- EOT/BOT sensors
- Magnetic heads

Four heads are used, two interleaved 4-channel read/-write heads and two interleaved 4-channel erase heads.

The external drive motor is a 7.5° stepper motor which operates in a semi-slew mode while driving the tape at a speed of six inches per second.

If 24 hours of data were to be recorded continuously on 450 feet of tape in an 8-track format, the resulting speed of 0.48 inches per second is well below the "slip-stick" oscillation speed for conventional transport designs. Secondly, from previous experience with the performance of ultra low speed recorders under vibration, 0.48 inches per second is considered to be much too low for adequate performance.

To overcome these problems, the operating tape speed for the UFDR was chosen as 6 ips for both write and read functions. This provides operation well above the "slip-stick" phenomenon with excellent vibration immunity, and the ability to utilize a single motor speed for both the 25 hour recording and fast playback functions.

In the write mode the recorder is, in effect, a single channel incremental recorder. It records blocks of data

separated by short inter-record-gaps (IRG's), with the tape coming to rest between each data record. Each (one) second's worth of input date (768 bits) is stored in RAM under microprocessor control. When this buffer is full, a preamble and postamble are added and the complete buffer contents (784 bits) are then recorded on tape as a short record at approximately 11.2 KBS at a tape speed of 6 ips. Data being received while the write cycle is in process is fed to a second buffer which simply alternates with the first on successive subframes (1 second data increments).

Since each 1-second record only results in a tape record of a little over 0.4", it is readily apparent that in order to yield a useful data to IRG ratio, the IRG's must necessarily be very short. In fact, the IRG's must be far too short to be able to stop the transport from 6 ips and then re-accelerate to 6 ips before the next record. A unique solution to this problem forms the basis of the tape motion utilized in the UFDR (Refer to Figure 3).

The forward motion of the tape required to write a 784 bit record at 6 ips consists of the following sequence:

1. Accelerate to 6 ips,
2. Allow the speed of the transport to stabilize,
3. Write 784 bits,
4. Decelerate to zero.

The total resulting forward motion is approximately 1.5 inches of tape travel to write a record, which is in fact, only 0.42 inches in length!

The tape is then "backed up" during the dead time between write cycles to a point exactly 0.48 inches from the starting point. This action yields a net average forward speed of 0.48 ips, the speed required to record 25 hours of data on 450 feet of tape.

The second increment starts from this point and overlays the first such that the second record starts exactly 0.48 inches after the start of the first, thereby leaving an IRG of only 0.06 inches.

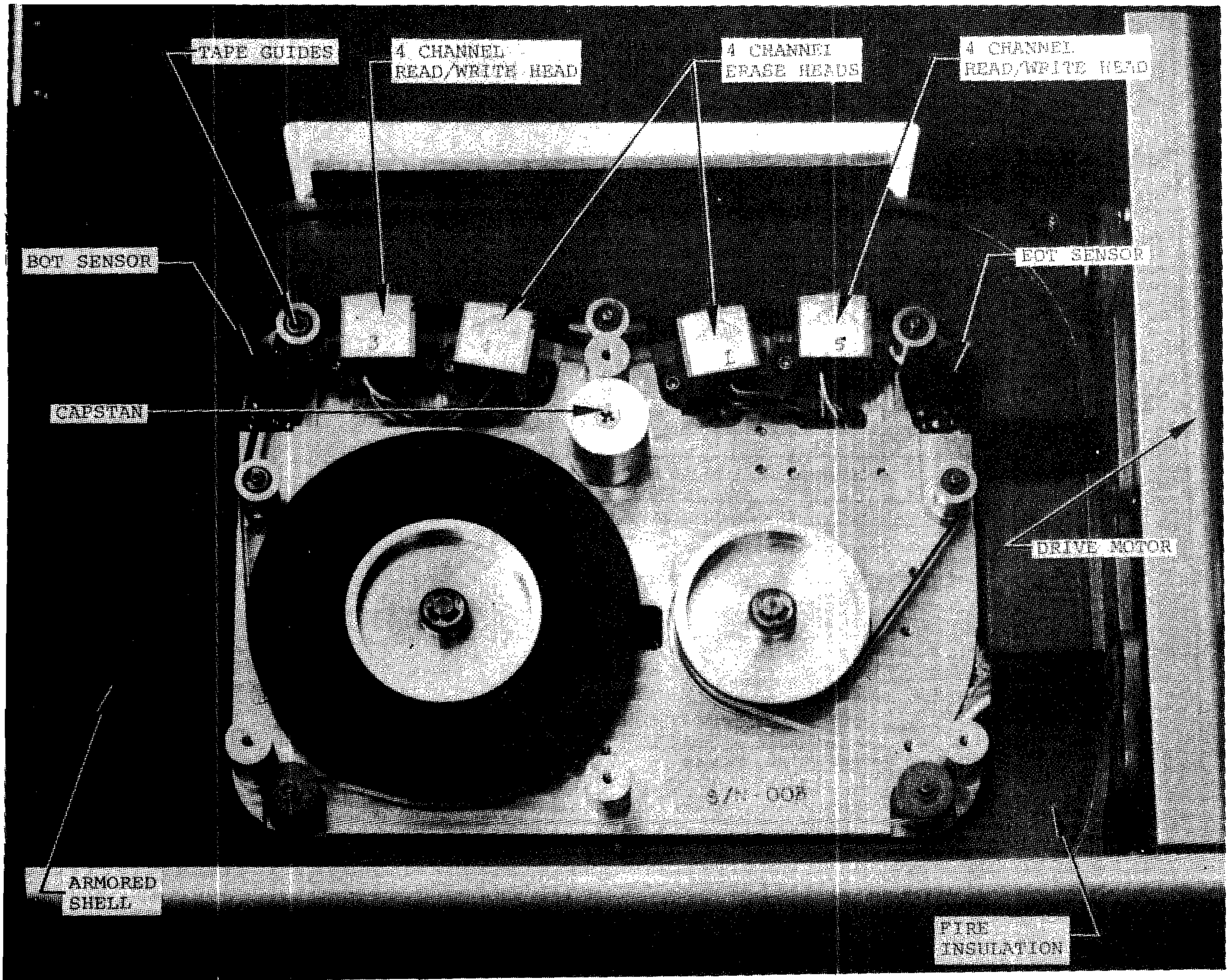

Figure 2. UFDR Tape Transport

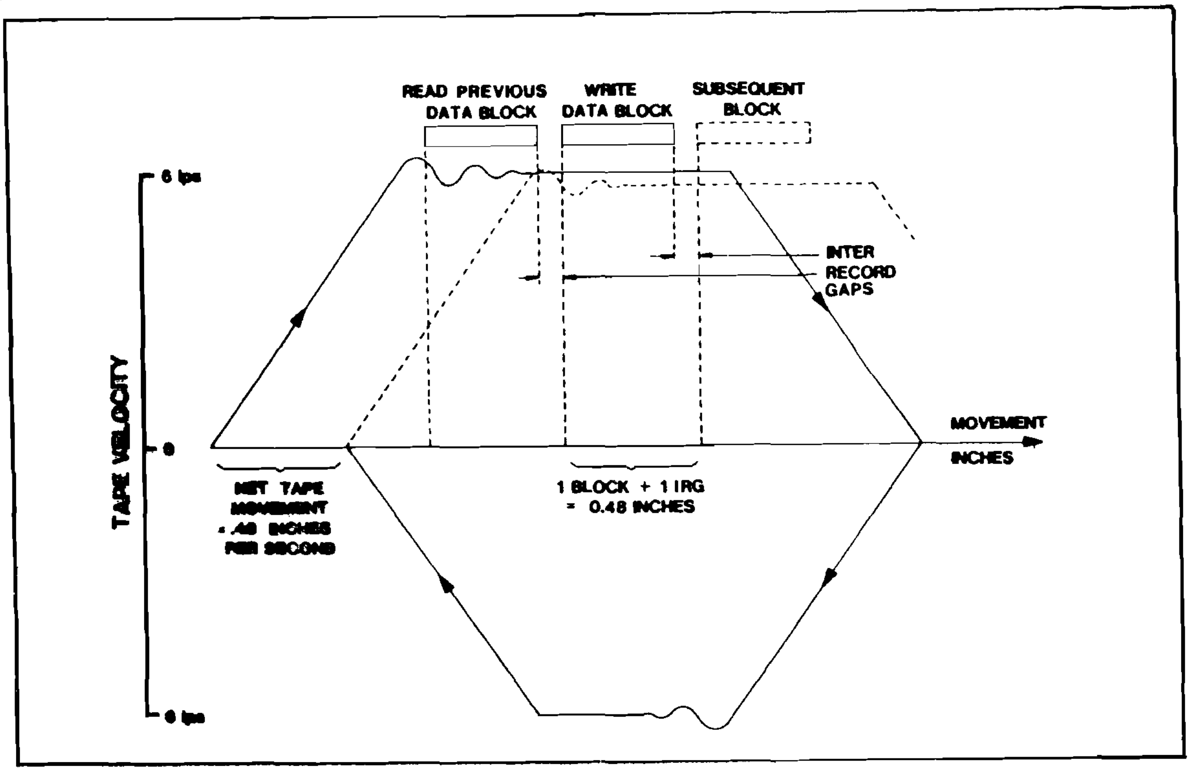

Figure 3. Tape Velocity Versus Displacement Graph

UFDR CHECKSTROKE (TM) CONCEPT

It is apparent that with this tape motion that the write head must be switched off during each backstroke in order not to erase the data just written by it. Similarly it must not be turned on again in the ensuing forward stroke until a point just past the previous record. Very conveniently, the head can be utilized as a read head when not actually writing. Thus, each written record may be read for checking purposes by the same head that just wrote it.

In the UFDR, the processor stores a unique number associated with each written record during the write process, which is derived by counting the number of bi-phase transitions that occur in the record. (A variable number, since input data is continually changing.) During each forward stroke, a read amplifier associated with the selected write head passes the bi-phase signal derived from reading the previous record to the processor for a transition count and subsequent comparison with the stored checkword.

This overall cycle of events taking place once per second; i.e., alternatively writing then backing up and reading, then finally comparing the written number of transitions with the number of transitions read, has become known as the UFDR CHECKSTROKE (TM) principle. It is actually by far the most meaningful input to the overall BITE circuitry, and effects a level of BITE for the UFDR that is far in advance of anything existing on previous flight recorders.

UFDR Fast Playback - Two methods of fast data playback are provided for in the UFDR:

1. The UFDR may be removed from the aircraft and attached to the Interface Unit of the Ground Playback Station, where the data may be extracted one track at a time as a serial data stream at a data rate of approximately 11.2 KBPS. Total playback time for the 25 hour record is approximately two hours.
2. The UFDR may be connected to a portable Copy Recorder on board the aircraft, and the contents of the 8 tracks simply re-recorded at high speed onto the Copy Recorder. All 8 tracks are copied in parallel in one pass from BOT to EOT of the UFDR in 15 minutes. A further 15 minutes is required to move the UFDR tape from its current position to BOT and from EOT back to its original position. Therefore, the UFDR will continue operation from the same point on the tape that it would have prior to the copying cycle. The copying process does not cause any erasure of the recorded data, and is completed in 30 minutes.

Both methods of playback involve the initial writing of a position marker tone. For a ground transcription with the UFDR removed from the aircraft, detection of the tone indicates when all 25 hours have been transcribed. In the on-aircraft copying process, tone detection indicates the point to which the UFDR tape must be returned for further service.

All playback of recorded data takes place at a tape speed of 6 ips. However, although this is the same speed at which recording takes place, the tape is run continuously at 6 ips instead of incrementally. Since the average recording speed is 0.48 ips, this represents a playback/record ratio of 12.5:1.

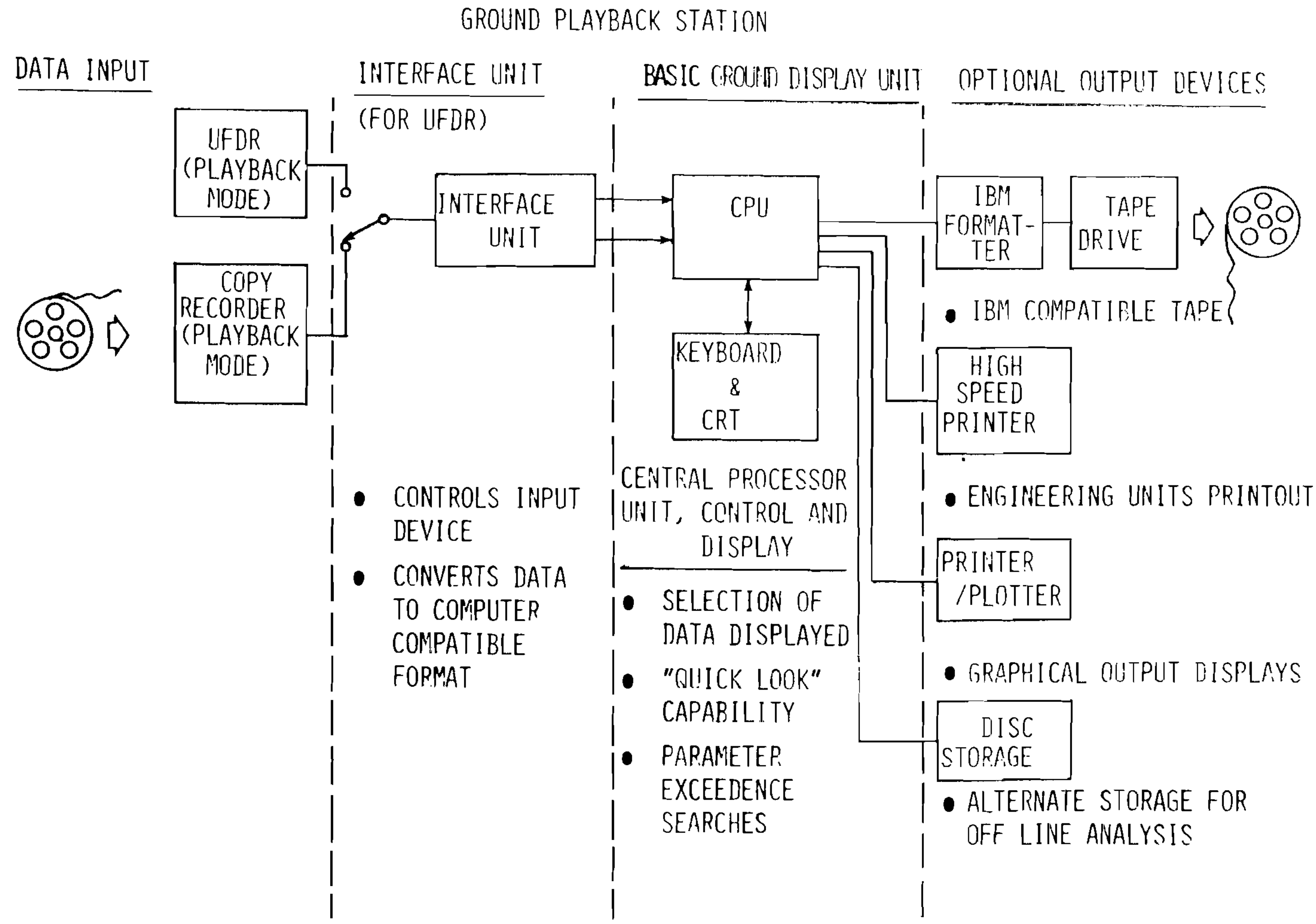

Figure 4 - Ground Playback Station Block Diagram

DATA RETRIEVAL AND PROCESSING

Since the data is recorded as digital data in an ARINC 573 format, the accuracy and repeatability is far better than that possible with the old scribe-type recorders. In addition, the method of data reduction and data analysis removes most of the subjective problems associated with interpreting the older scribe-type data. One other advantage of dealing with digital data is the ability to extract and analyze the data much more quickly than has been possible with the scribe-type units.

Data may be extracted from the UFDR as previously outlined using the UFDR as a playback device or using the copy recorder. In cases where data must be retrieved from inoperative recorders (such as in an accident), the tape can be removed and installed in a copy recorder for playback or can be analyzed on specialized equipment such as Sundstrand Data Control's Incident Analysis Station at the Redmond, Washington plant.

Concurrently, Sundstrand Data Control is introducing new, state-of-the-art equipment for use with their recorder products. Among this equipment is a new Ground Display Unit which may be used for "quick look" data analysis.

Existing transcription facilities may also be used with the addition of an Interface Unit and a minor modification to the existing transcription unit. Various options are available which will allow the data to be presented in analog graphical form or in digital format in engineering units.

SUMMARY

It has been my pleasure to bring you this short introduction to the new Sundstrand Universal Flight Data Recorder. This unit has been specified for delivery on many new airplanes starting in January 1981, and because of the increased reliability and economic benefits to the airlines, will also be appearing in many airplanes now in service as a replacement for older, more expensive to operate units.

Although the UFDR will provide many benefits to the airlines which are easily recognized, it will also provide a more reliable, more accurate and more versatile tool to the Air Safety Investigator.

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Fallacies In Aviation Safety Concepts

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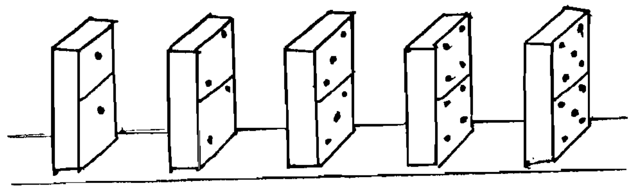
President Emeritus, Flight Safety Foundation

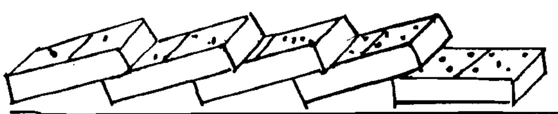
Aviation accident investigators and safety practitioners may be subjected to a variety of questionable beliefs, suppositions or postulates that have developed over the years in aviation. Even safety veterans have become intellectually wedded to dogmas that often are well founded but not invariably true.

Among a sample of such beliefs calling for further exploration are: that accidents or undesired events are the result of a sequence of proximate, preventable circumstances; i.e., the domino theory; that the interior of all-metal, well-bonded aircraft are immune to the effects of atmospheric electrics including lightning strikes; that reliability is synonymous with safety; that redundancy is a reliable safeguard against single-point failure.

THE DOMINO THEORY

The domino theory was the brainchild of a very great pioneer in modern accident prevention philosophy, H. W. Heinrich. He proposed this concept in 1931 in his well-known book, the classic *Industrial Accident Prevention*. His theory was based on a study of thousands of industrial accidents while he was Superintendent of Loss Prevention for the Travelers' Insurance Company. His book shows a sketch of five dominoes to illustrate his point. They represent Social Environment, Fault of Person, Unsafe Act, The Accident and The Injury. He asserted that "The injury is invariably caused by an accident and the accident, in turn, is always the result of the factor that immediately precedes it." He went on to say that "The occurrence of a preventable injury is the natural culmination of a series of events or circumstances which invariably occur in a fixed and logical order. One is dependent on another and one follows because of another, thus constituting a sequence that may be compared with a row of dominoes placed on end and in such alignment in relation to one another that the fall of the first domino precipitates the fall of the entire row." I.e., the concept of sequential events.





UNQUALIFIED ACCEPTANCE OF THE SEQUENTIAL THEORY

Recently an article in the ISASI ***forum*** states that "Accidents are the combined result of multiple factors which, together, produce a particular accident of a particular severity."(1) The NTSB has thousands of case histories in support of this viewpoint. A good example of the sequential theory is NTSB Report 3-1768. It reports on an instructional flight on April 26, 1979. The ceiling was low, with rain. The instructor pilot on a VFR flight plan continued into adverse weather although he had been briefed by the weather bureau in person prior to the flight. The visibility at the accident site was 1/4 mile or less, and mountains were obscured. The instructor was 55 years old, Air Transport rated with 5000 hours. His blood alcohol level was 0.158.

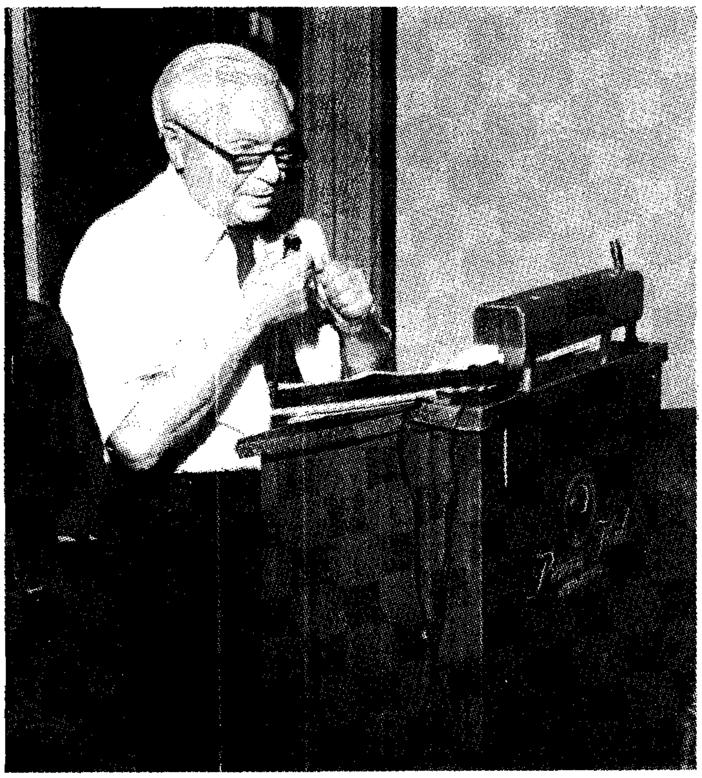
Among the dominoes in this series of causes were alcoholic impairment, disregard of weather briefing and flying VFR in IFR weather. Members of ISASI should be able to recall many similar sequentially caused accidents.

However, very significant exceptions to the sequential or domino theory cast doubt on its total acceptance. For example, the most frequent cause of disabling injuries in air transport operations is the encounter with unexpected clear air turbulence.

An unusual example of conflict with the sequential belief, potentially very serious, is the fracture of the windshield of an air transport by striking a rock at 35,000 feet. The rock had been thrown into low orbit by a suddenly erupting volcano-no warning, no sequence, no domino. This happened three times in 1979 as reported in *Flight International*.

But the most catastrophic examples of the inapplicability of the domino theory are the losses caused by bird strikes. An Electra taking off from Boston on April 10, 1960, struck a flock of starlings; 62 occupants were killed. A Lear Jet taking off from Peachtree Airport in Georgia on February 27, 1973, struck a flock of cowbirds; the eight occupants of the aircraft were killed. Many will recall the total loss of a DC-10 on takeoff from Kennedy Airport in 1974; the birds it struck caused a dollar loss of $35 million, fortunately with no fatalities. Much has been learned about reducing the bird problem around airports, but what can be done about encounters with birds at altitude? One such bird strike at 15,000 feet over Maryland resulted in the death of 17 occupants of a Viscount.

As a rule the domino theory of loss prevails but it should not be accepted as gospel truth.



LIGHTNING (Atmospheric Electricity)

Another widely accepted belief is that the interior of all-metal aircraft is protected from damage by the Faraday Cage principle of electronics. This means that the surface of aircraft covered with electrically conductive metals such as aluminum (it does not apply to titanium, a poor conductor) shields the interior from electrostatic charges produced by atmospheric electricity; but not always.

It is well known that lightning or atmospheric static can cause pitting of metal skin, pitting of engine and other bearings, destruction of radomes and interference with radio communication. Lightning strikes or static discharges have caused several fatal aircraft accidents. About half of all USAF weather related accidents are caused by lightning.(2)

The fatal accidents and serious incidents are usually, but not always, caused by discontinuities or gaps in the metal shielding such as may be caused by inspection plates or unprotected fuel vents. These gaps permit the fuel inside the all metal wings to be ignited by electrostatic charges, usually a lightning strike. Examples of such fatal accidents are a Constellation over Milan, Italy, many years ago; a USAF C-130 over South Carolina in 1978 and a Boeing 707 over Maryland in 1963. There is also strong evidence that a Boeing 747 of the Iranian Air Force was lost to a lightning strike over Spain in 1976.

Apollo 12, the second manned flight to the moon, suffered loss of instrumentation and control for several seconds when launched through a highly charged cloud at Cape Kennedy. There is at least one reported case of an electrostatic discharge causing the loss of an inertial navigation system.(3)

In 1977, a Boeing 727 descending into Seattle at night under IFR conditions was struck by lightning that knocked out all three (three for redundancy) power busses. The pilot lost all communication, all lights except emergency cabin lights and all cockpit instrumentation dependent on the power busses. His sole guidance to maintain safe flight under turbulent instrument conditions was supplied by a standby horizon indicator operated by an independent battery.(4) Fortunately, one of the three busses regained power after several minutes, enabling the pilot to communicate and navigate to a safe landing. Incidentally, the lightning strike caused considerable damage to some of the tail structure, and also destroyed a weather radio tower not far below the airplane.

After the Apollo 12 incident I wrote to many airlines requesting their experiences with lightning strikes affecting the interior of aircraft. One response of unusual interest came from Middle-East Airlines. On descent into Beirut, Lebanon, under stormy conditions, a necklace of artificial pearls, worn by a cabin attendant sitting with her back to a bulkhead, exploded as a very heavy strike occurred. The white nylon string turned brown.

Of course there are many related lightning incidents that have occurred outside the metal skin shielding, but perhaps induced by it. *Flight International* of August 11, 1979, reports the disappearance of the Heads-Up Display symbology on a Swedish Viggen intercepter following a lightning strike. Flameouts of turbine powerplants have been reported.(5) In one case involving a twin-engine corporate jet, both engines flamed out at 33,000 feet due to a very close lightning strike. The pilot was able to reignite the engines at 13,000 feet.

The lightning hazard threatens to become very much more serious. For example, the fuel situation will lead to the use of wider cut, more flammable fuel in place of the kerosene now generally used by the airlines. The accelerated use of computers with microcircuitry for control and instrumentation could adversely affect operations because the circuitry is sensitive to transient currents induced by atmospheric electricity. This could be catastrophically portentous for the coming fly-by-wire active control systems of aircraft.

The use of composites in the structure of aircraft threatens to increase the lightning hazard because the Faraday Cage protection is reduced. Even when the composite material is used in less vulnerable areas of the wing, the resulting discontinuity of metal shielding may increase the potential for electronic disturbance in the interior of the structure. The latest theory indicates that in all-metal shells, the currents induced by atmospheric electricity surge back and forth along the skin to create powerful electric fields within the shell. Discontinuation in the shell, such as caused by windows, augments the possibility of higher voltages due to the resistance created by the gap in the metal shield. Composites may introduce further problems with discontinuity of shielding [$V = IR$].

Much research is underway to reduce the hazards of lightning and atmospheric electricity. However, the point I wish to make is that the widespread belief in metal shielding for assured protection against this hazard should be regarded with considerable skepticism. Consult the experts.(5)

RELIABILITY, SAFETY, REDUNDANCY

Reliability and redundancy to achieve safety raise problems of semantics. Reliability of hardware usually means that the article or system will operate without failure for a specific time. Redundancy means, in the context of this discussion, the existence of identically similar extra articles or systems in position to assume a function if one or more fail. This is to assure the reliability of a system. In the discussion on lightning, I referred to the failure of three electrical bus systems due to a lightning strike. I suggest the term "clone" redundancy to accentuate such similarity.

It is not uncommon to speak of reliability and/or redundancy as being synonymous with safety. They are regarded as opposite sides of the same coin. This is often true, but again, this viewpoint should be regarded with great skepticism. Frequently they are not coincident, especially where the human factor becomes linked to reliability. This is probably the result of designing in isolation from human factors specialists. This isolation, in turn, may be caused by failure of the human factors specialists to express themselves in terms easily comprehended by the designers. Just recently the NTSB published a memorandum describing the reason for an unusually large number of wheels-up landings on two very popular general aviation aircraft designed over 30 years ago.(6) It placed the reason on confusion of the flap control with the undercarriage control. The retractable undercarriage of these airplanes has a reliable mechanism with several decades of operational history. It satisfies the definition of reliability, yet the mechanical reliability is not coping with the uncertainty of human reliability. This is not an isolated case. A famous, widely-used four-engine air transport with a very reliable retractable undercarriage suffered belly-landings for the same reason.

Three astronauts lost their lives at Cape Kennedy in 1967 due to an oxygen fire in a ground test of a space capsule. The hatch on this capsule, through which escape might have been possible, was very reliable in operation, but it took a long 90 seconds to open. After the fire a redesign permitted opening in 11 seconds. Accident investigators probably are more familiar with such design lapses than any other body.

In the previous discussion on lightning the recommendation was made that specialists in lightning and static effects should be consulted in the various stages of design. Similarly, human factors specialists should be consulted despite the apathy on this subject which one often finds among engineers. The nuclear industry discovered this the hard way and is now strenuously seeking human factors specialists. The precept is that mechanical reliability, *per se*, does not guarantee operational reliability; a union with human factors is urged. This should include maintenance of the product as well as its operation.

Reliability and safety are both important, but not always coincident.

RELIABILITY AND REDUNDANCY

Reliability of a system usually requires redundancy to provide alternative functional channels in case of failure. The discussion on lightning referred to the failure of the electrical bus systems of a B-727. They were triply redundant and all three failed. Control was maintained by a back-up or standby horizon indicator operated independently of the busses and with a different source of power, a battery. In the context of this discussion it is important to distinguish between identical redundancy and back-up or fail-safe systems.

A prototype of a fighter airplane suffered a fatal crash when identical metal tubes in each of two redundant hydraulic control systems failed simultaneously. Identical landing lights have been known to fail simultaneously. Such occurrences are fortunately very rare, but they should not be permitted in a high risk environment.

The principle of redundancy was first expressed some 500 years ago by the great artistic and mechanical genius, Leonardo Da Vinci, who described several aeronautical concepts such as the helicopter and the parachute, among others. In regard to bracing of wings he recommended that: "In constructing wings one should make one cord to bear the strain and a looser one in the same position so that if it breaks under strain, the other is in a position to serve the same function." An obvious example of this precept is the lift wire system on biplanes. The lift wires to each spar are duplicated so that if one fails the other assumes the load. This has happened.

It is conceivable that the double lift wires could fail simultaneously because of their identical design and their being subjected to similar vibratory or environmental stresses. This leads to a significant observation: identical system redundancy (I prefer to use the term "clone redundancy") without a back-up system contains the elements of single-point failure. It may also induce the additional hazard of pilot complacency by deceptive trust in the event of a failure. It took several years of advocacy before the standby horizon was installed as a back-up to redundant instrumentation because simultaneous failures of the redundant instruments was thought to be remote enough to disregard; i.e., complacency.

A survey among highly experienced retired airline pilots gave complacency a rating of 52 percent as the most important human frailty likely to cause accidents.(7) John P. Rankin of Boeing asserts that, "In fact, when redundancy is provided by identical components, location or channels, susceptability to common cause failures may be increased."(8) Collocated wire bundles is an example.

Methods are known to overcome the hazard of single-point failure that is possible with clone type redundancy. In the case of simultaneous failure of landing lights (or for that matter, automobile headlights) or metal tubes in redundant systems, the mean-time-between-failures distribution curve suggests that the redundant elements or systems be installed at different time intervals in operations. Fail-safe design, standby systems and the use of dissimilar materials are several other alternatives.

An analogy concerns the redundancy of flight crews. The copilot is presumed to assume control in the event the Captain is disabled. However, if both eat poisonous food at the same time, they may simultaneously become disabled. Good practice requires them to eat different food at different times.

The cliche' that redundancy is synonymous with safety is being challenged.(8) Engineers are beginning to disengage themselves from reliance on "clone" type redundancy for system reliability.

Other safety fallacies remain to be explored. Punishment to attain discipline or quality control; confidence in "tried-and-true" (and consequently untested) hardware in high risk, novel situations; reliance on probability studies and statistics; and several areas in the human factors or behavioral field are among them.

This discussion of the domino theory, of Faraday Cage protection against lightning, of the differences among safety, reliability and redundancy, leads to a postulate which is basic to safety and accident investigation: "Take Nothing For Granted."

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About the Author

Jerry Lederer was the first Director of the Safety Bureau of the U.S. Civil Aeronautics Board (now the National Transportation Safety Board), during which time he was also responsible for all Civil Air Regulations. He was Director of Safety for NASA until his retirement in 1972. He is President-Emeritus of the Flight Safety Foundation, and is currently Adjunct Professor at the University of Southern California's Institute of Safety and Systems Management. He is a member of the Advisory Council of the Institute of Nuclear Power Operations. Jerry was President of ISASI from 1970 to 1972.

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Eyewitness Failure

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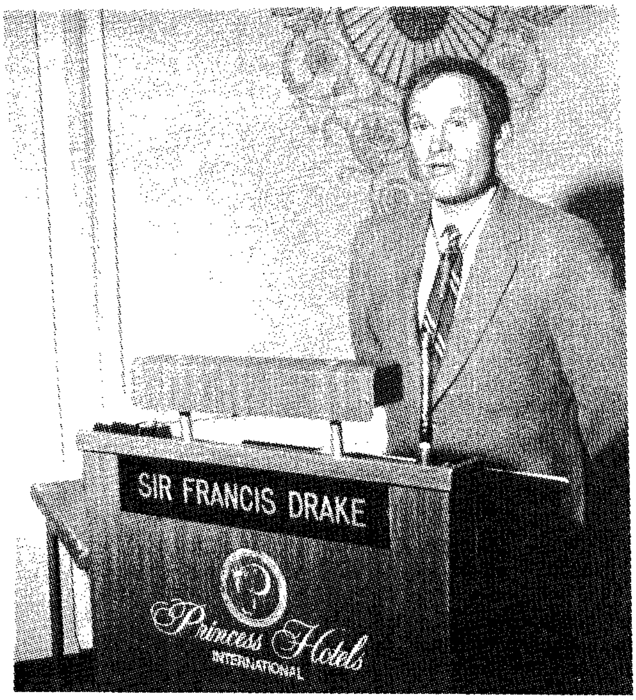

PART I. SOME PROBLEMS INHERENT IN EYEWITNESS INTERVIEWING

Captain Hal L. Sprogis

Much has been written over the past decades showing the unreliability of the eyewitness, yet there is a thread of unreasonable believability that still prevails. This is human nature working at her best, which causes us to want to believe each other.

We evolve a thought from something we see. We examine it and re-examine it, running it through our minds many times. We believe in this thought as we believe in ourselves. It becomes reasonable that we would want to communicate this thought faithfully and truthfully to other non-adversary humans. It becomes natural to want to believe eyewitness' statements.

I wish to put eyewitness reliability in a condition of being "stored in the bottom drawer," to let it remain there until it can prove its worth and earn a higher level of reputation. This paper is a statement and review of some of what is wrong, and is intended to serve as a companion to the following PART II paper by Dr. Richard Brown on some of what is right. These are some of the problems; Dr. Brown will touch on some of the solutions.

The term eyewitness failure probably best fits the situation that exists today for anyone who hopes to find the truth from observers of an event. Considerable material has been published, especially after the middle of this century, that has focused attention on this problem. However, even today some professionals still cling to aging and outmoded concepts. The "old concept" eyewitness is dead, and he should be buried! The perceived reliability of eyewitness statements has declined from a position of confidence to one of suspicion.

In the three centuries following 1431, when Joan of Arc was burned at the stake for witchcraft, it has been estimated that between 300,000 and 2,000,000 persons were executed as witches.[1] Many innocent persons lost their lives and scarcely any of those who were accused escaped punishment. Eyewitness testimony played a damaging role in sealing the fate of many of those unfortunates.

In *Witchcraft Delusions in Colonial Connecticut*, Taylor relates an example of an eyewitness report that was written into the evidence. The witness observed "The untieing of a cartrope of its own accord",[2] while near the property of the suspected witch.

Borchard cites more than two dozen cases wherein eyewitnesses failed. In these cases a total of 140 such failures of eyewitnesses resulted in positively accusing the innocent. In one case alone 17 eyewitnesses who were absolutely sure turned out to be wrong.[3]

The point of all this is that, even well into this century, the validity and general trustworthiness of eyewitness accounts of events was still highly acceptable. Some of this trustworthiness still lingers within our technology today and is of concern to the aviation accident investigator. Serious deficiencies are now being brought to light in a continuing drama of evolving research. Several specific problem areas have been localized. Some of these areas affect eyewitness preception individually or collectively and tend to cast doubt on the validity of any statement made by a witness.

Perceptual phenomena probably should be mentioned as a basic first offender. Coren and Girgus state their belief that "ultimately, when we know exactly how the visual system works, visual illusions should no longer exist."[4]

Research by Loftus and Yarmey show the substantial effect of memory errors in recall and in the recognition processes.[5,6] Furthermore these workers have put forward the ideas that perception of an event can be distorted by *individual needs, prior expectations, social pressures, knowledge* and *stress*. Regarding stress, psychologist Professor Robert Buckhout accomplished research with Air Force flight-crew members which confirmed that even highly trained people become poorer observers under that influence.[7] There are growing indications that the highly trained, professionally oriented eyewitness may be less reliable than even someone without such qualifications.

Recently an accident occurred involving the crash of a jet fighter. The jet fighter had a wing man in the two-ship formation who was giving assistance during the emergency. Finally the time came when the pilot in distress had to eject. Later the wing man testified that he saw his friend's canopy separate, that his friend then ejected, and that his parachute fully deployed. In fact his friend ejected through the canopy and died when he made ground contact after his parachute failed to open! Thus an example of a trained professional, under stress, who with the additional effect of prior expectations, had his recall of the real world severely altered.

In the summer 1980 edition of ***forum***, an article by the United Kingdom's College of Aeronautics, entitled "The Value of Eyewitness Reports," reminded readers that witnesses do not remember events, only their own perception of events, and perception can be faulty due to the witness selection or misinterpretation of what is seen or heard.[8] A pre-arranged incident at the College's Aircraft Accident Investigation Course was witnessed by a group of experienced pilots and aircraft engineers and their testimony can be considered as eyewitnesses failures.

Loftus also has shown that certain post-event information has the capacity to actually alter memory itself, instead of just coexisting with it and producing some confusion at recall.[9]

Finally, there is the problem of interviewer questioning technique. This area has now become a prime target as a source for the introduction of factually incorrect information into eyewitness testimony. Several aspects are involved. Even the use of such words as "smashed", "collided", "bumped", "contacted", "hit", "touched", etc. can markedly change the perceived severity of an accident with relation to the actual severity.[10]

Eyewitness failure is a reality that the accident investigator must come to grips with today to steer an effective course for truth. The route is treacherous, but not unnavigable. New technology in this and other human factors areas is evolving. The brighter side does exist.

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PART II.
SOME PSYCHOLOGICAL FOUNDATIONS FOR EYEWITNESS INTERVIEWING

Richard K. Brown, Ph.D.

Capt. Sprogis' thesis that eyewitness interviewing should be "stored in the bottom drawer" is based on substantial information garnered from numerous cases of invalid or unreliable information provided by eyewitnesses. This data may still be of value. Therefore, I suggest it will always be used by someone, particularly legal interests or media. Investigators, therefore, who better understand the reasons why people may distort perceived "facts" can improve their interview techniques and thus significantly raise the level of reliability and validity.

This paper briefly will address human personality development, the difficulties we all have in listening and assimilating new information, and some techniques and tips for conducting the actual interview.

Our personalities and behavior develop from a state of almost total "freedom" at birth through a series of restrictions and constraints by parents and society until, as adults, we conform to laws, rules and standards acceptable to those around us. Infants are uninhibited in their expression of needs, experimentation and investigation of their surroundings. When such behavior becomes unacceptable they are disciplined-usually punished-and their personalities are molded and behavior constrained accordingly. This process results in a structured, compartmentalized personality which only accepts new items of information which are consistent with the concepts learned, and commonly rejects those that are not.

When a new concept or idea is fostered upon us, we try it out for fit and decide whether to accept or reject. As pressure is applied to accept new ideas, we become uncomfortable.

In Capt. Sprogis' example of expectations, the pilot who "saw" his friend's 'chute open, when in fact it did not, demonstrates a response to internal pressure by which the pilot is saying, "My friend is alive, he could not die". This is an example of cognitive dissonance theorized by L. Festinger in 1957 and is technically the condition in which one has belief and knowledge which disagree with each other or with behavioral tendencies; when such condition arises, a person is motivated to reduce the dissonance through changes in behavior or cognition.

There are also physiological reasons for the distortion of our perception. We've all seen examples of how the eye will produce misleading information. "Shape constancy" is one; as a door opens, its rectangular shape appears to change to a trapezoidal shape. We continue to perceive it as a door although its shape is different to the eye. The top of a milk bottle is perceived as round, although when viewed from the side it appears elliptical. Thus there are both psychological and physiological reasons for people perceiving the same accident or situation differently.

In order to obtain information from an interviewee we must listen to what that person has to say. Sounds simple. But listening is perhaps the key to the entire interview. It also is difficult because as a person is talking to us we are busy formulating responses. As we listen to another's speech, our mind is busily engaged in formulating our answer.

We must let the witness discuss and relate the incident at great length without our interference in the process. Our minds are usually bristling with ideas and questions about the report but we must not interrupt or introject our thoughts-we weren't there, we didn't see it, and whatever we might state at this point will surely color the witness' report. Listen, don't talk.

Now, we must recognize another phenomenon. Each word, symbol, color-every item we might think about is a stimulus to our thought process. Moreover, such stimuli may have quite different meanings for each of us. Some may have very little variance, others surprisingly great. When we as interviewers introject our thoughts, we are casting new and perhaps inaccurate meaning into the interview situation.

An interview is little different from counseling. We are trying to gain information from someone. To illustrate the importance of the subject above, I'll refer to Carl Rogers and associates' (1951) "non-directive" or "client-centered" therapy. The objective of his method is to reduce the interviewer's interference to an absolute minimum. He simply nods his head to acknowledge the respondent's statements and may say "Uh-huh" but rarely, if ever, offers an interpretation or evaluation of what the client has said. The therapist (interviewer) is a patient but alert listener. The only time he or she speaks is to clarify the statement made: "You said you saw the plane dive..." Don't judge or elaborate. The purpose of the interview is to have the client report personal feelings or observations, not the interviewer. This innovative technique was markedly different from the psychoanalysis commonly employed and had a significant impact on the entire field of psychology.

Another example of the importance of being non-directive is the ink-blot test developed by Rorschach in 1921. The cards used were actually made by dropping a large blot of ink on a paper and folding that paper, allowing the ink to form a bilaterially symmetrical stain. Since no one designed the pattern and it has no "meaning" built in, it is considered completely ambiguous. Rorschach reasoned that no preconceived notion was transmitted. The respondent then had complete freedom to express whatever thought the ink blot conjured up from only his or her own perception. This is one of a number of "Projective Tests" developed by psychologists to obtain unbiased, factual information while minimizing distortion from "directive" outside stimuli.

Now, the techniques and tips on interviewing. Professor Chaytor Mason of the Institute of Safety and Systems Management at USC has taught the following concepts for many years. He advises the interviewer first to be prepared, as all good investigators are. The investigation kit should include a recorder, a model airplane and charts and graphs of the given situation; e.g., a layout of the cockpit or the cabin. He follows with a *when, where* and *how* approach:

WHEN:

As soon as possible after the incident. Considerable recall is lost in the first few minutes after an incident. Witnesses may also be lost. They often wander away and are not available at a later date. You should not ask for any personal information other than the first name of the interviewee at this time, nor should you give personal information about yourself. Because of this, it is advisable not to travel to the scene of the interview with the interviewee. It would be counterproductive to reveal something about yourself which would introduce a bias, and also difficult to avoid. Personal data such as address, full name and place of employment can be obtained at the end of the interview.

WHERE:

The interview should be conducted in a place approximating the scene of the event as closely as possible. A flight simulator is excellent for interviewing cockpit crew, and a cabin simulator is advisable for cabin crew or passengers. If these are not available, a quiet place where no interruptions will occur should be selected.

HOW:

First, reduce the anxiety of the interviewee. Use the first name and do not appear to be superior or inferior. Dress like the interviewee. Chaytor recommends that you have "nickel" bags of peanuts to give the interviewee. This munching of peanuts together helps create a relaxed atmosphere. Use a tape recorder. People are not so afraid of tape recorders now as they once were. Don't make it too obvious, but at the same time don't try to deceive. It is wise to tell the interviewee that the tape is only for your review of what is said and that when you have finished with it, you personally will send it to him or her. This helps relieve any anxiety over being recorded.

State the purpose of the interview at the very beginning; e.g., "To gather facts, to prevent future injuries and accidents, to help prevent..." etc. In starting out the conversation, simply ask the interviewee to "tell me everything you remember about this incident." Then don't interrupt. The interviewee may hesitate for long periods, but don't be in a hurry, just listen. If it is *necessary* to speak up, simply repeat what was said last. "You told me that the airplane was such and such..." and let the interviewee continue.

When the whole story is told, ask the interviewee to repeat the story stating that "None of us can remember everything; please tell me again and perhaps some additional things will come back to you." Usually the interviewee will tell the same story with some pertinent factors added. When the second interview is completed, then play back the second tape. The interviewee may wish to add or explain something on the tape. This should also be done on the recorder.

Now is the time to address items you feel might have been omitted or to clarify questionable statements. The questions you ask should start with the least directive ones. An example of a non-directive question is, "You told me the aircraft was in a spin. Will you show me with this model?" As you become more directive in your questions, such as "Was the left wing off or on the airplane?", the reliability of the answers decreases substantially. Again, the reason is that you might be suggesting certain responses or response concept to the interviewee.

With these tips, keeping in mind the psychological foundations discussed as well as practicing the art of listening, I believe we can improve reliability to the point where witness interviewing can be more credible and admissible, and contribute greatly to the prevention of harm.

Chuck Mercer, ISASI VP-elect

Assessment Of Engine Operation At Impact

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Accident Investigators will be familiar with techniques used to determine whether a piston engine or a turbine engine was rotating at the time of impact. This paper describes laboratory test methods of determining a further condition from which, in turn, a short term history of the engine operation prior to impact may be deduced.

The technique makes use of the fact that changes in metal hardness and grain structure following distortion or working are dependent upon the temperature of the metal at the time that the deformation takes place. Cold working can be detected in the form of hardness changes and the presence of microscopic slip lines. If similar deformation or working takes place at an elevated temperature there will be little evidence of hardening or slip lines in the microstructure.

If a flame tube, exhaust pipe or similar component is cold at the moment of impact and is crumpled or bent so as to produce a fairly severe cold work effect, work-hardening will be pronounced at the location of the bend. This effect has been found in Nimonic alloys and stainless steels used in the hot sections of engines. To determine whether work-hardening has occurred, the hardness needs to be measured accurately-a convenient method is to cut a small section from the acute bend, mount and polish the specimen, then make a series of micro-hardness measurements along one undeformed leg, around the bend and along the adjacent leg (See Fig. 1). Micro-hardness measurements are used because the size of the indentation is very small using this method, about 0.02mm in diameter, a necessity when dealing with thin sections.

It has been found that these materials will work-harden at a decreasing rate as the temperature increases. At temperatures of about 400°C the bending becomes "hot-working", as opposed to "cold-working" and is accompanied by little or no hardness increase.

A second method which may be used to determine whether the component under examination was hot when crushed is to examine the microstructure for evidence of slip lines. It has been found that polished and etched grain structure will show a multitude of slip lines if it had been cold worked but almost no slip lines if hot worked.

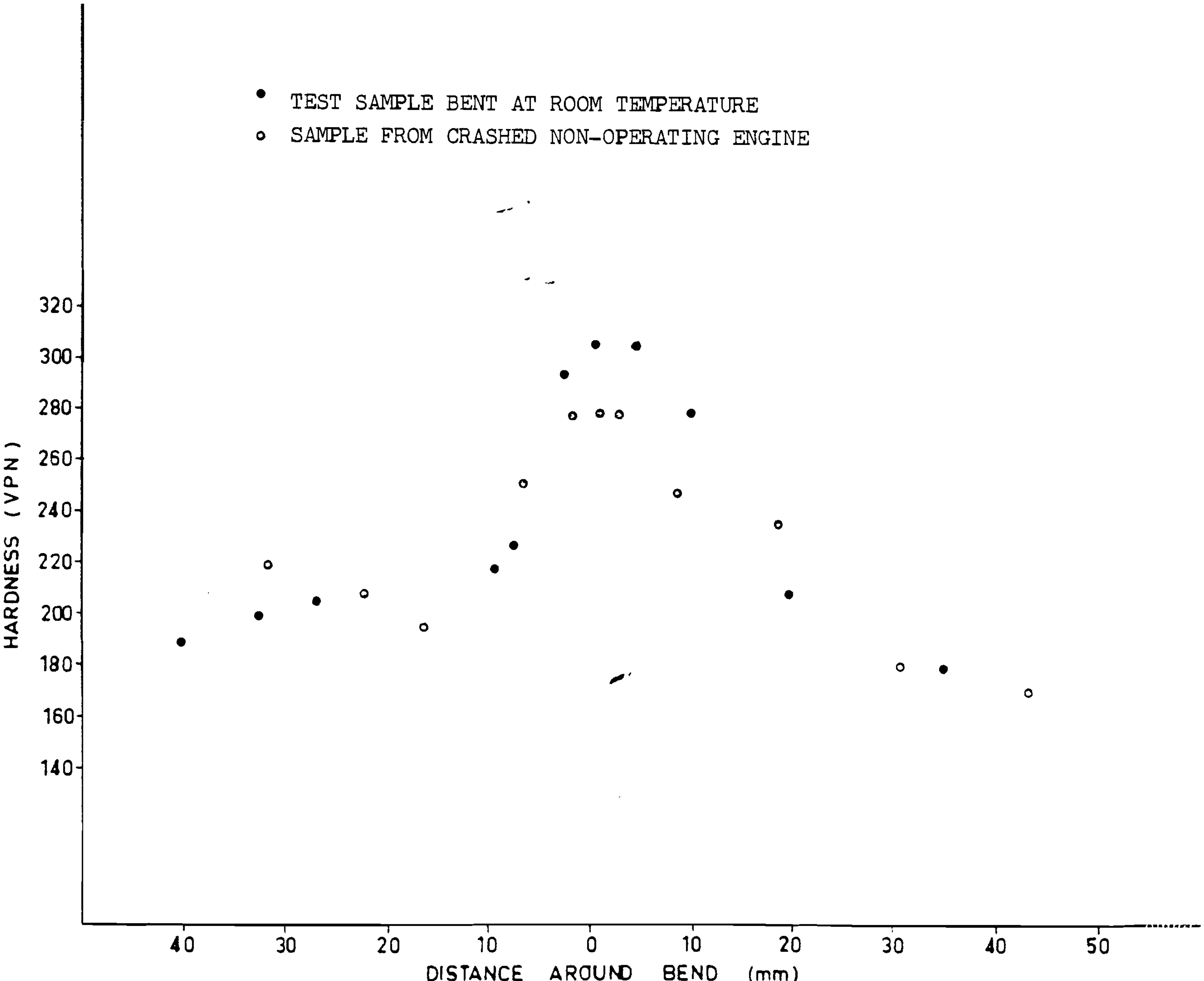
The procedure, when applied to aircraft components, should include a comparison with laboratory prepared test specimens, some of which which have been bent cold and some of which have been bent at an elevated temperature.

Figure 1 - Section of buckled exhaust pipe which has been mounted and polished in readiness for hardness measurements.

The graph at Figure 2 shows how the hardness has been found to vary around the bend of a test specimen bent at room temperature and a similar test specimen taken from a crashed non-operating engine. Note the peak in hardness at the acute bend. Figure 3 shows the hardness changes around a hot-bent speciment and a similar specimen taken from a crashed engine known to have been operating at impact. Note the relative absence of hardness increase in the hot worked specimens.

Figures 4 and 5 show the slip lines that occur in a cold-bent test specimen and an example from a non-operating engine. Figures 6 and 7 show the absence of slip lines in a test specimen which was above 400°C when bent and that of an operating engine at impact.

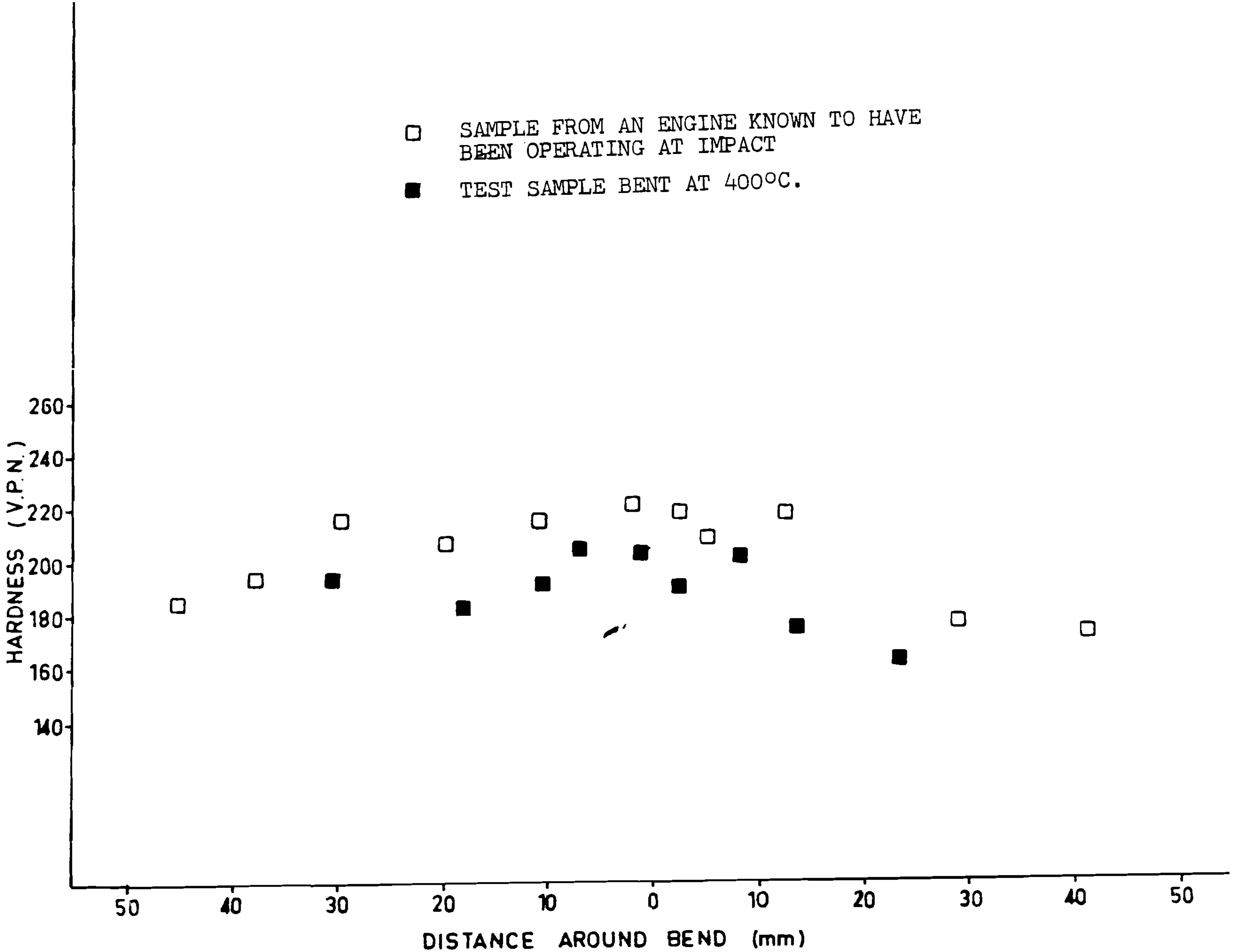
This technique was first used in the investigation of an accident to a four-engine turbo-prop aircraft. The aircraft crashed into the sea at high speed and at a high rate of descent. Propeller examination established that three of the four propellers were in the constant-speed blade-angle



TEST SAMPLE BENT AT ROOM TEMPERATURE
SAMPLE FROM CRASHED NON-OPERATING ENGINE
HARDNESS (VPN)
320
300
280
260
240
220
200
180
160
140
40
30
20
10
0
10
20
30
40
50
DISTANCE AROUND BEND (mm)

Figure 2

Figure 3


SAMPLE FROM AN ENGINE KNOWN TO HAVE BEEN OPERATING AT IMPACT
TEST SAMPLE BENT AT 400°C.
HARDNESS (V.P.N.)
260
240
220
200
180
160
140
50
40
30
20
10
0
10
20
30
40
50
DISTANCE AROUND BEND (mm)

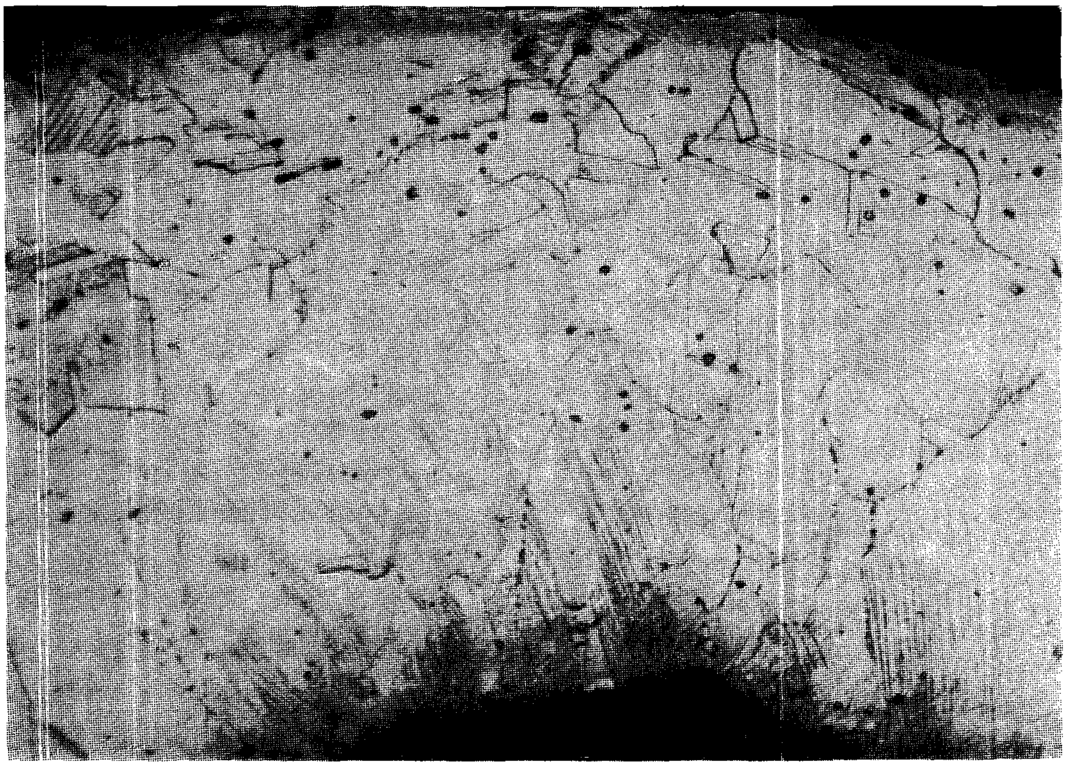


Figure 4 - A polished and etched specimen prepared from a non-operating engine. Note the numerous slip lines.

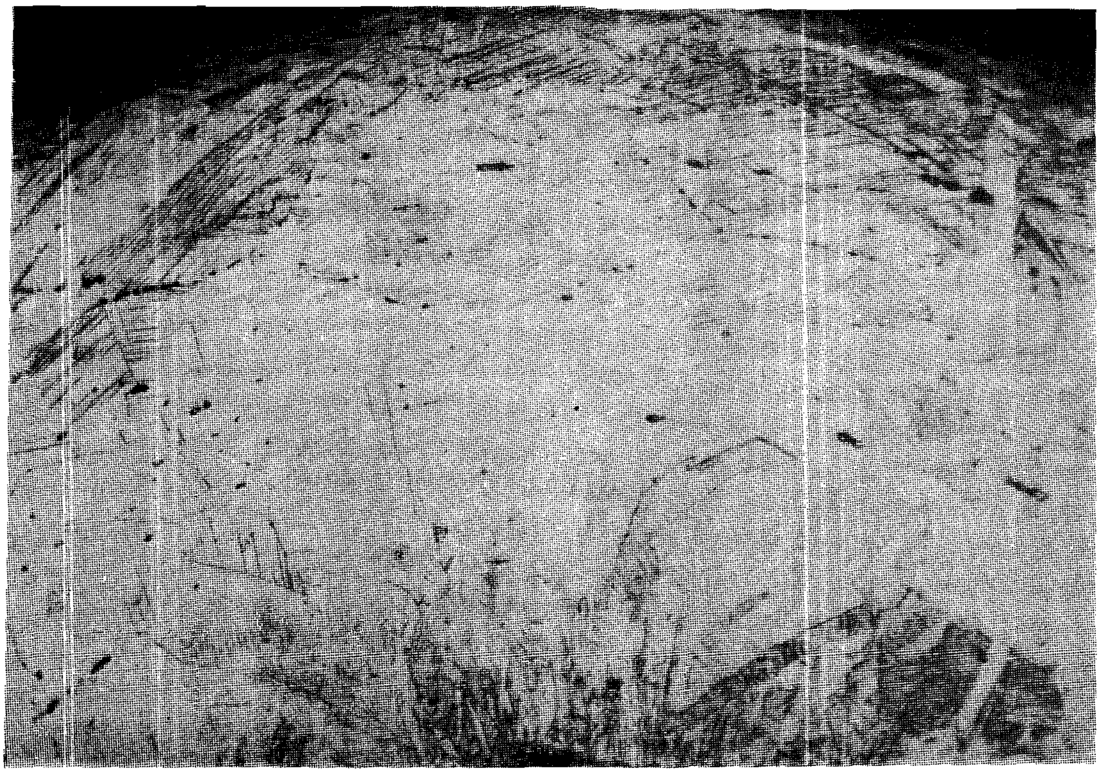


Figure 5 - Specimen bent at room temperature. The microstructure is similar to Fig. 4.

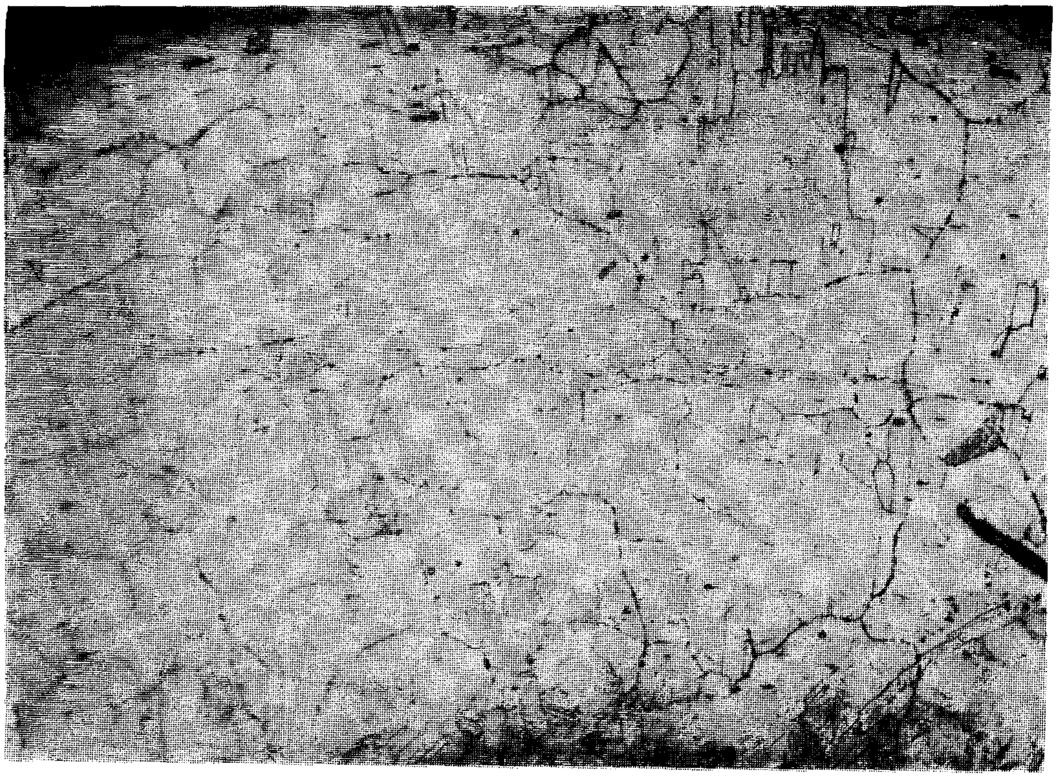


Figure 6 - A polished and etched specimen prepared from an engine known to have been operating at impact. Note the absence of slip lines. (Magn. X130)

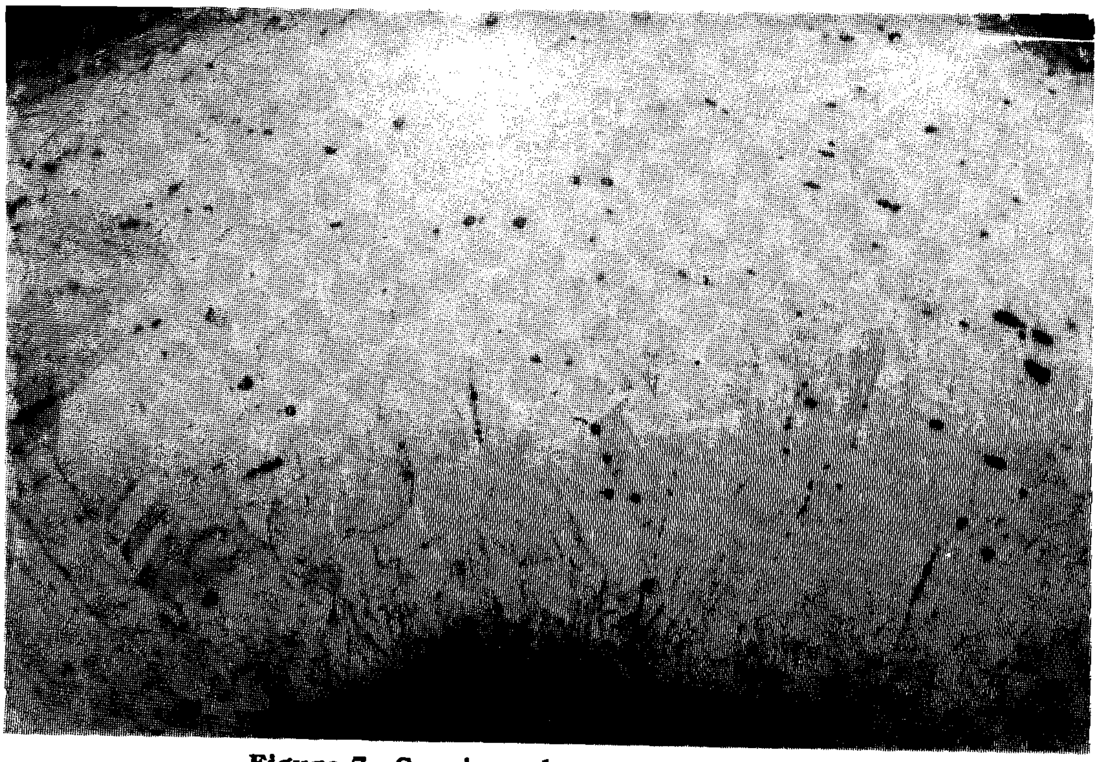
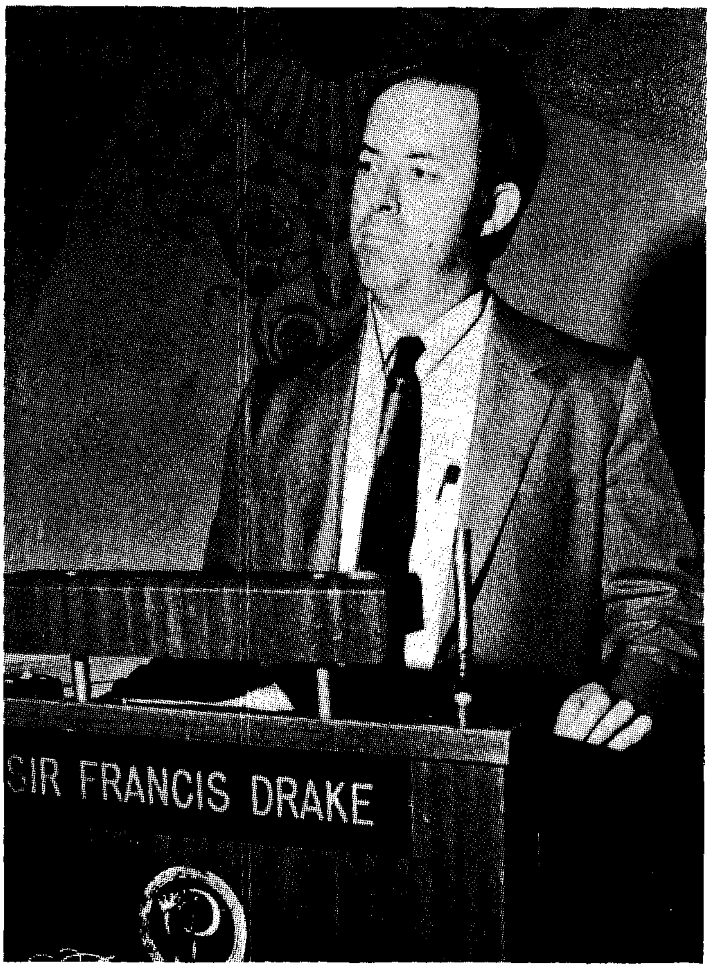


Figure 7 - Specimen bent at about 400 °C. The microstructure is similar to Fig. 6. (Magn. X130)



Capt. Geoff Molloy, QANTAS, presenting Mr. Whalley's paper

range, whilst the remaining one was mid-way between this range and feather. It seemed possible that the propeller was either going toward feather or coming out of feather at impact. If it had been moving toward feather at impact it is probable that the engine was operating with combustion taking place shortly before the commencement of the feathering action, i.e. the flame tubes would still have been hot at the moment of impact even though the feathering process had started. The other possibility was that the engine had been feathered for some time and was being unfeathered in preparation for an engine start at the moment of impact, in which case the flame tubes would have been cold. Using the technique described it was found that the crushed flame tubes were hot. Similar results were obtained from crushed flame tubes from the other engines. It was concluded that combustion was taking place in the engine shortly before impact and the propeller was in the process of feathering at impact. Other evidence showed that a loss of oil to the torque meter oil pump had initiated an autofeather action.

Examination of crushed exhaust pipes from two small twin-engine turbo-prop aircraft has established that in one instance both engines had been operating for some seconds prior to impact and in the other, one engine had been shut down at least some seconds before impact and its exhaust was in the cold working range. These results proved valuable in the analysis of the accident circumstances.

Several piston engine exhaust pipes have been examined with similar positive results. One word of caution-the component, or that portion of it which is to be tested, must, for at least part of its operating cycle, be in the hot-working temperature range.

A further caution is necessary if the exhaust pipe from one cylinder of a piston engine is chosen for study. It may be that this one cylinder was inoperative, while all the others were working correctly! The condition of sparking plugs and other evidence may assist in resolving such a possibility.

Further development of the technique is possible by taking one sample close to the cylinder where it has been established that operating temperatures are in the hot working range and another from a tail pipe where the temperature of the metal under some operating conditions falls within the cold working temperature range. This latter portion of pipe may operate in the hot-working temperature range at medium to high powers yet fall below that temperature at idle or low-power. The combination of the two sets of results may allow a high-power or low-power engine operating condition to be determined.

There is scope for further refinement of the technique by the establishment of component operating temperatures and cooling rates following engine shut down.

About the Author

Mr. Walley joined the Airworthiness Branch, Power Plant Section of the Australian Department of Civil Aviation in 1960. In 1966 he transferred to the Department's Air Safety Investigation Branch to form the Engineering Section of that Branch.

In 1973 the Department of Civil Aviation amalgamated with the Department of Shipping and Transport to form the Department of Transport but the functions of the Air Safety Investigation Branch remained unchanged in the new Department.

Since 1966 Mr. Whalley has been involved in the investigation of every major civil aircraft accident in Australia and New Guinea.

Flight Data Recorders For USAF Fighter/Attack/Trainer Aircraft

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ABSTRACT

The USAF Director of Aerospace Safety recently submitted a Statement of Need (SON) for a Flight Data Recorder (FDR) compatible with fighter/attack/trainer aircraft. Although the need for FDRs has been recognized by the USAF for some time, the size/weight/cost of existing systems limited their application to large transport-type aircraft. This SON acknowledges recent advances in solid state technology which offer quantum reductions in size and increases capability at what appears to be acceptable cost.

A review of F-16 and A-10 mishap experience shows the type of data typically necessary to clearly establish causal factors. Areas where these data could not be retrieved through conventional investigative techniques and the impact of the missing data are discussed. FDR application to fighter/attack/trainer aircraft will probably differ significantly from its role in larger aircraft. The differences in expected crash and post-crash environments will drive us toward different design solutions (crash vs. fire resistance vs. ejectable). The parameters to be recorded, intervals at which they are sampled and how long they are saved will have to reflect not only the differences in the systems, but the way they are flown (mishap causes often relate to tactics). In addition, the differences among fighter/attack/trainer aircraft will present some challenging problems for an FDR if it is to be compatible with the various aircraft in that group (F-16 is fly-by-wire vs. A-10's cable and push rods).

The lack of mishap data often masks mishap causes and negates the purpose of mishap investigation-prevention of future mishaps for like causes. Advances in technology offer the promise of expanding FDRs into the fighter/attack/trainer aircraft areas. But they will only provide the right answers if we design them to ask the right question and hold on to the answers until we need them.

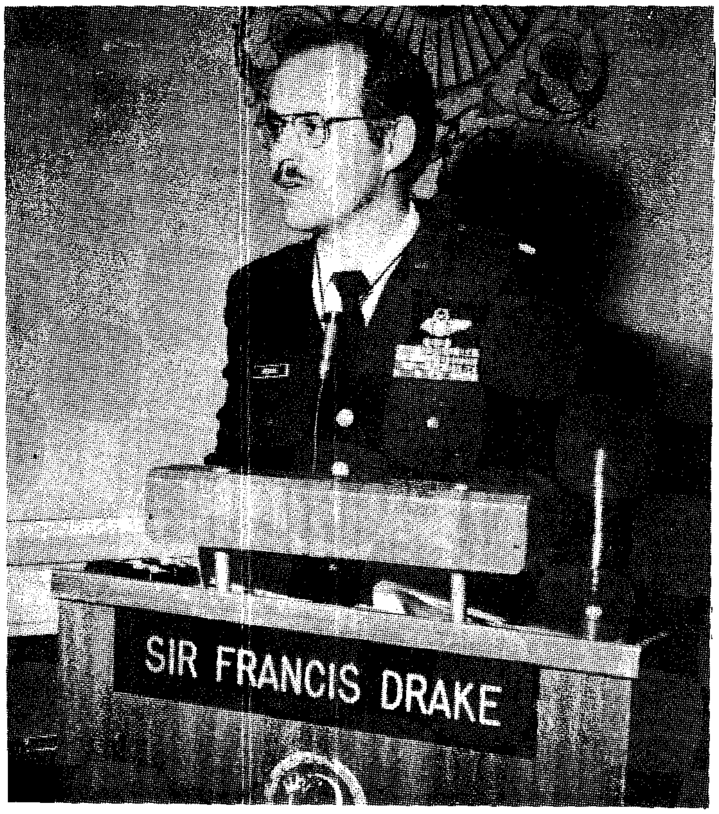
History

Policy. On the sixteenth of June, 1973, General John D. Ryan, then Air Force Chief of Staff, established the current USAF policy concerning Flight Data Recorders (FDRs). This policy puts the Air Force on the record as needing FDRs in all our aircraft. It also recognizes that needs are tempered by resources: dollars, weight and space, and although we need FDRs, we may not be able to afford them for all aircraft. In the past, we have not been able to afford FDRs in our fighter, attack and trainer aircraft. Too big, too heavy, too expensive. But that is changing. The Air Force is taking a close look at the cost effectiveness of FDRs in our fighter, attack and trainer aircraft.

The policy established by General Ryan states that FDRs should be installed on all aircraft entering initial production after the first of July 1974. Deviations to this policy must be fully justified and approved by Headquarters Air Force. The conditions necessary for approval of deviations are clearly specified. First, the lack of a data recorder could not seriously jeopardize missions of national importance. In addition, the installation would have to be shown as either not cost effective, or having such space/weight penalties that it would significantly degrade the mission capabilities of the aircraft. These last items, cost and space/weight, are what did-in data recorders on our latest generation of fighter/attack aircraft, the F-15, F-16 and the A-10.

The 1973 policy letter also states that provisions for data recorders should be addressed during the design of new aircraft. It was intended that this, along with maximum standardization of equipment, would keep costs down to a minimum. So much for Air Force policy.

The Need. Today the Air Force has data recorders in many of its larger aircraft. There are plans to replace the older foil-type recorders in the C-141 with newer digital



systems and preliminary plans to install digital systems in our C-130s. The recorders used in our big birds are essentially the same as those used by commercial aviation. But you don't see any of these systems in our smaller fighter, attack and training machines.

In many ways, data recorders have more potential in the fighter/attack safety arena. We lose more of these types than any of the others. Of the 83 aircraft destroyed in mishaps during 1979, 68, more than 80 percent, were from the fighter/attack group. The fighter/attack destroyed aircraft rate per flying hour was almost three times the Air Force average. It was almost thirty times higher than the rate for our cargo aircraft. Their accidents also tend to involve more operation factors: tactics, loss of control and collision, both with the ground and with other aircraft. When mishaps of these types occur, virtually all the evidence goes up in smoke, especially if the crew doesn't survive. It's not surprising that fighter/attack accidents account for most of the accidents in which the cause could not be determined.

The A-10, F-15 and F-16. None of this is news to the safety folks working the fighter/attack area. The requirement to record volatile accident information through a survivable data recorder was evaluated during the development of the F-15 and the A-10. Unfortunately, the state of the art did not allow a small enough, light enough, cheap enough design. Data recorders were also an issue during the F-16's development. Although the first block of F-16s do not have any hardened data recording equipment dedicated to accident investigation, later model F-16s will include features which are designed to save some data for accident investigators. When compared to the data contained in current digital systems, the data are somewhat limited. The recorded data centers on the fly-by-wire flight control system and gives information on the status of its built-in-test (BIT) system. In addition, angle-of-attack, airspeed and altitude information keyed to a time reference are provided. All of this is pumped into nonvolatile memory chips which, although not fire hardened, are impact hardened. Survivability is further enhanced by redundant chips, one set in the flight control hardware and the other on the ejection seat. The maximum time recorded on this sytem can be up to 2 hours. Although this equipment will provide significantly improved accident investigation capability, it still falls short of our needs.

FDR Statement of Need (SON)

On the twenty-ninth of August, 1979, Brig. Gen. Garry A. Willard, then the Air Force's Director of Aerospace Safety, signed a Statement of Need (SON) for a flight data recorder compatible with Air Force fighter/attack and trainer aircraft. The SON cited the lack of parametric data as a factor which often masks accident causes. Without clearly identifiable causes, the reason for our whole accident investigation program - prevention of future mishaps for like causes - is seriously impaired. The findings and recommendations of our mishap boards may lack the credibility to convince senior officers and to drive firm, timely corrective action. Lack of data recorders in our fighter/attack aircraft is deterring our accident prevention program. Those 68 fighter and attack aircraft we lost last year represent about three squadrons. How many of those accidents were repeats which could have been prevented if the cause had been clearly identified the first time around? We'll never know for sure. All too often mishap investigations do turn up previously unknown failure modes which seem to fit the circumstances surrounding previous accidents. The pilot of a fighter delays his pull out of a steep dive; he ejects too late, at too high a speed, and is killed. The evidence is destroyed when the jet hits the ground. The mishap board, lacking any concrete clues, concludes the pilot misjudged his altitude until too late. During a later mishap investigation, a failure mode which limits elevator authority is discovered. Could it have caused the first accident too?

New technology. The SON points out that although the space/weight restrictions of older data recorder systems were used to justify their absence in our newest fighter and attack aircraft, recent advances in solid state technology appear to provide a way around previous restrictions. Life cycle costs of the next generation FDRs should also be significantly less than today's.

More valuable aircraft. In a time when acquisition plans identify fighter buys in quantities of hundreds, not thousands or tens of thousands, the loss of several aircraft to the same cause is a loss of our capability that can't be accepted. The loss of a single fighter today not only represents a greater dollar value, it represents a much higher proportion of our combat resources. This, coupled with the complexity of today's aircraft, presents our investigators with a formidable challenge.

FY 1981 Budget Proposals

	FY 80 & prior	FY 81	FY 82	FY 83	FY 84	FY 85	After FY 85	Total
A-10	627	60	46	46	46	-	-	825
F-15	639	30	30	30	-	-	-	729
F-16	425	180	120	120	120	120	303	1,388

Source: *Aerospace Daily*, 29 July 1980

More complex aircraft. A very large percentage of our fighter/attack aircraft mishaps end up, literally, as smoking holes. Not much to work with in the way of mechanical reconstruction. Less if the actual cause was a stray electron, a temporary restriction in the flight controls or a pilot whose attention was distracted momentarily by the electron, a stiff stick or a difficult tactical situation. The Air Force's accident rate declined steadily during the first two-and-a-half decades of its existence. However, it's been roughly stable for the past decade. We eliminated most of the easy answers 10 years ago. We'll need help to start the rate moving down again.

Parameters. The SON signed by General Willard comes with a list of parameters to be recorded. About half of the parameters provide indications concerning the aircraft's velocity vector, its attitude and how the pilot was trying to control them. Because of the high incidence of operations-related factors in fighter/attack aircraft crashes, clearly establishing what the pilot was trying to make the aircraft do and how the aircraft was responding is extremely important. The A-10, F-15 and F-16 can generate extremely high rates of turn, at times over 20 degrees per second. Max roll rates would water your eyes. Sampling rates may be critical, limiting factors.

Flight Data Recorder Parameter List

The following parameters are mandatory data items for use in mishap investigation:

Angle-of-attack	Vertical Velocity
Altitude	Heading
Normal load factor	Engine RPM
Roll rate	Engine EGT
Calibrated airspeed	Engine fuel flow
Yaw rate	Hydraulic pressure
Pitch rate	Utility hydraulic pressure
Elevator position	Generator output
Aileron position	Inverter output
Rudder position	Oil pressure
Bank angle	Fuel quantity
Pitch attitude	

Given storage capacity, the following parameters are highly desirable for inclusion:

Sideslip angle	Flap position
Throttle position	Landing gear position
Afterburner (range, nozzle position)	Speed brake position
Rudder pedal (position or force)	Oil quantity
Stick (position or force)	Air Data Computer Status
Mach number	Fire Control Systems Status

The other half of the parameter list is related to systems operation. How were those systems which normally respond to pilot inputs responding to those inputs? E.g., elevator position vs. fore/aft stick position or engine RPM vs. throttle position. How were those systems which operate independently of the pilot functioning? E.g., hydraulic pressure, oil pressure and electrical power. If last year's mishap boards had that data, I'm sure our corrective actions would be more effective.

Request for Proposal

The SON, however, is not a contract specification, and we were still a long way from black boxes in our jets. This winter, the Aeronautical Systems Division (ASD) of the Air Force Systems Command issued a Request for Proposal (RFP) for a study effort to validate and further define Air Force needs concerning a flight data recorder. When contracts for the studies were signed last month, we made another step forward.

A-10 and F-16 form baseline. The statement of work defines several areas for evaluation. First of all, the A-10 and F-16 were identified as baselines. Maximum space/weight criteria and available locations are to be developed for each aircraft. Parameters lists, sampling rates and storage time requirements based on Air Force accident experience will be developed and used to determine memory size. Since the systems and mission profiles of the A-10 and the F-16 are vastly different, there should be some challenging tradeoffs made in this area. The data available for pick up and transmission, as well as the data desired, may vary widely between two lists.

Survivability requirements. How to ensure maximum survivability of the memory device will also be a key issue. Although the SON leaned toward an impact- and fire-hardened, nonejectable module, we are open to any good ideas. A complete review of the survivability issue is in order. From the applicability of the existing standard TSO-C51A to the potential of an ejectable or even frangible device, the survivability issue needs a complete review.

Standardization. The cost benefits of standardization with other programs, larger Air Force aircraft, or even the other services will be evaluated. Standardization could be for the entire system or individual modules.

Development plan and draft specification. After a complete review of the state-of-the-art technology for memory devices is completed and documented, a recommended development plan and a draft specification are to be delivered to the Air Force. The final reports are due eight months after contract award, or early April 1981. Since study contracts were awarded to three companies, all with slightly different approaches to the problem, we expect to see some different slants to the proposed solutions.

AFISC study

In order to get a better feel for the problems the contractors would experience, we initiated a study of our own. We limited ourselves to that portion of the study we felt comfortable with, primarily definition of those requirements that were needed and often not available to our mishap boards.

Air Force mishap reporting procedures use the "preponderance of evidence" rule. Thus, it is not necessary for a board to prove, beyond all reasonable doubt, each cause of an accident. In addition, we use "all cause" methodology and don't attempt to decide which cause is primary and which is secondary. Instead, all causes are listed chronologically. Lastly, it is possible for a mishap not to be identified as cause undetermined, even when one or more of the causes *are* undetermined. For instance, one factor in a recent accident was loss of control for the pitch attitude of the aircraft. But although the exact cause of the loss of control was undetermined (the board couldn't determine if it was a jam or a system malfunction), the accident is not listed under the "cause undetermined" column. With these facts in mind, let's take a look at the records for destroyed A-10s.

A-10 destroyed aircraft experience. We have lost, as of August 1, 1980, seventeen A-10s. Nine were categorized as "collision with the ground." Four involved loss of control, two more involved fire, and two others had both engines flame out.

Potential Flight Data Recorder Utility
During Actual A-10 Destroyed Aircraft Accidents

	Potential FDR Utility	Collision with ground	Loss of control	Fire	Fuel Starvation	Engine failure/ flameout
Destroyed	Low	2	1	1	1	1
A-10s	Mid	3	1	-	-	1
	High	4	2	1	1	-

A-10 collision with ground. During the nine categorized as "collision with the ground," only one of the pilots survived. He ejected when he thought his aircraft could not clear a ridgeline. Additional evidence was unnecessary in only two cases; movie film of the accident sequence was available.

In the other seven accident investigations, questions were left unanswered. In three of the seven cases, a data recorder could have provided basic flight path information, making the board's job simpler and giving their findings and recommendations more credibility. The remaining four investigations suffered significantly from the lack of a data recorder. It's important to point out that the only survivor in the "collision with the ground" category is in this last group.

A-10 loss of control. Three pilots survived the four loss of control accidents. Additional data would have been extremely useful on two of the accidents.

A-10 fire and flameout. Of the two accidents involving fire, one board could not come up with a cause for the fire. Although the pilot survived the accident, he was injured and could not recall the details of the accident. Data concerning systems operation might have provided the clue the board needed. The boards investigating the two flameout accidents identified the cause of both. However, one board had unanswered questions concerning unsuccessful restart attempts which might have been resolved if a data recorder were functioning.

Uncertainty. Although none of these 17 mishaps was classified as "cause undetermined," in four cases the final report listed at least one causal factor as undetermined. The findings of three other mishap boards were questioned during the review cycle indicating a lack of confidence in their findings. Eleven of the 17 investigative reports contained a significant amount of uncertainty. A data recorder clearly would be an extremely valuable tool when investigating these A-10 accidents.

At this point, while this information is still fresh, I'd like to mention a phenomenon discussed in some investigative texts. They caution that when you go over a problem-associated hypothesis many times, you may begin to believe it as fact. We, the Air Force, use the "preponderance of evidence" rule in our investigations. We have to. It's the best we have. But when "the best we have" goes into the computer, it tends to become regarded by some as "the truth and nothing but." This is a real problem, but one which can be minimized through installation of FDRs.

FDRs and hazardous events. One last point before leaving the A-10. The accident chain stretches from its roots in what we call hazards through a number of intermediate events up to the catastrophic accident. So far, I've discussed the catastrophic accident, the destroyed aircraft, and how we can use the data recorder to prevent future occurrences of like mishaps. But the data recorder can also be used to prevent some of those catastrophic events before the first one ever occurs. For example, the A-10 has had a number of single-engine flameouts. Because the engine stalls are often unnoticed until well after they actually occur, we still don't have a good handle on when and how they're happening. With two engines, a single-engine failure is no big thing. But sooner or later we are likely to lose both of them. If the pilot is at low altitude, he's in serious trouble. If information concerning those incidents were available from a data recorder, we might be a lot closer to a solution. This is just one example of the type of intermittent failure or hazardous event whose fingerprints are elusive and hard to catch. They exist in all of our aircraft; flight control twitches and engine burps are the ones that haunt me. At the wrong time they can ruin your day. When you have them at altitude, you want them fixed before you fly again, not signed off by maintenance as "could not duplicate." The data recorder may provide a means of alleviating these problems before they become accidents.

Recording time. The memory of the fighter/attack/trainer data recorder will be short. Definitely shorter than normal mission lengths. The SON states 30 minutes as a minimum length. If the data recorder is going to have the capability to capture incidents which don't result in a crash but still should be tracked down, we need a way to retain portions of the memory after they would normally be erased and written over.

The Air Force Flight Dynamics Lab at Wright-Patterson does a lot of work for accident boards. It has been their experience that data storage for the last five minutes of flight preceding aircraft impact would have been sufficient to answer the vast majority of questions they received from mishap boards. Five minutes may have been cutting it a little close for some of these accidents, but it appears that even a 30-minute memory could allow room to preserve some inflight data when the pilot thinks it's necessary. Push a button and you store the last 5 to 10 minutes' data until the maintenance or safety guys look at it.

F-16 experience. You might be wondering why I'm taking so long getting around to the F-16. Actually, it's because there's not much to talk about. Of the five production models we have lost since the Fighting Falcon came on board, there is a relatively high degree of confidence in the board findings.

Crash survivability. Fighter/attack aircraft crashes often end in the total destruction of the aircraft. This is especially true in collision-with-the-ground and loss-of-control accidents, the types that account for a large portion of our losses. The problems associated with ensuring maximum survival potential are, therefore, significant. Traditional solutions involve beefing up the module to ride out the crash, hopefully in some "cushioned" area like the tail, or ejecting the module when a crash is sensed. It is possible that neither of these solutions alone will be adequate.

TSO requirements may not prove adequate for the high speed and impact angles experienced during fighter/attack aircraft crashes. Increased armor will cost in dollars and weight. Locating the unit in a remote location would add additional wiring, again running up weight, complexity and costs. Ejectable systems activated by crash loads would have to contend with crashes that often consume the aircraft in less than a tenth of a second. The F-16 approach described earlier provides another alternate.

A large percentage of fighter crashes are preceded by aircrew ejections. By utilizing the ejection sequence to get the module out of the aircraft, the problem is greatly simplified. However, although the module is ejected most of the time, the remaining third of the accidents are often the ones about which we know the least. The pilot went in with the aircraft. A slight variation to the F-16 approach may improve the odds of a successful recovery.

Ejection Initiated During Destroyed Aircraft Accidents

	Ejection Initiated	Ejection No Initiated	Percentage
A-10	10	7	59
F-15	12	4	75
F-16	6	1	85
Total	28	12	70

Placing the memory module in a location where it departs as part of the normal ejection sequence and also is subjected to minimum crash loads when ejection is not initiated may be possible. Mounting the unit on the canopy, or in a manner so that the departing canopy will separate it from the aircraft, would significantly reduce the severity of the crash environment. The canopy is relatively loosely attached to the aircraft and normally separates during the initial phases of the crash. The canopy rail, though often in pieces, is not normally subjected to the crushing loads experienced by the center of the fuselage. Since this location is also central to almost all of the data to be collected, extensive rewiring would be eliminated. A canopy-mounted system may, however, warrant locator devices, both land and underwater. The cost effectiveness of all reasonable survivability features will have to be thoroughly reviewed.

Conclusion

The importance of FDRs to accident investigation cannot be denied. The lack of mishap data has masked mishap causes and negated the purpose of many mishap investigations - prevention of future mishaps for like causes. Our tactical air forces are well aware of these limitations imposed on its accident investigators. However, today's technology provides the capability to develop an FDR compatible with fighter/attack aircraft requirements. With this added advantage we can quickly and confidently establish causes and start the accident curve moving down again. There are still problems to be solved: how best to ensure survival of the data recorded; what data will be most vital to the accident boards; how to achieve maximum standardization and still meet the needs of the individual aircraft within the tactical air forces and our trainer aircraft. The need for flexibility may be the biggest problem of all. Our destroyed aircraft rates are a function of both the hardware (the jets) and how they are flown (pilot and mission). These factors vary not only from aircraft to aircraft, they vary over time. Missions change. Tactics change. And the jets change. They get older, and they get modified. A truly effective FDR would have the flexibility to change too, and provide us with answers to questions we don't need to ask today. We may have the technology to build an FDR which can unmask causal factors now missed by the boards. But we will still have to figure out how best to put that technology to use - to get the most needed information at the lowest possible price - the most accident protection per dollar, pound and cubic inch.

About the Author

Lt. Col. Sweginnis is Chief, Developing Systems Engineering Branch, System Safety and Engineering Division, Headquarters Air Force Inspection and Safety Center. He holds a B.S. in Aeronautical Engineering from New York University and an M.S. in Engineering Management from Southern Methodist University. A licensed safety engineer, he has been active in various USAF System Safety programs since 1973. He has participated in numerous fighter/attack aircraft mishap investigations, and is a command pilot with combat fighter experience.

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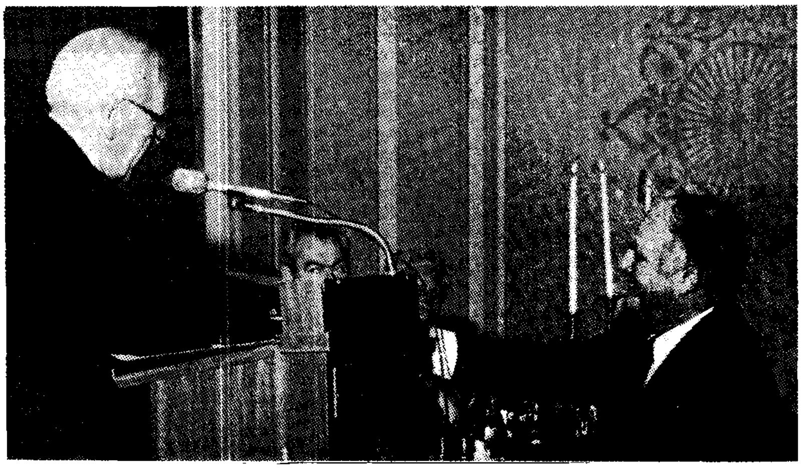

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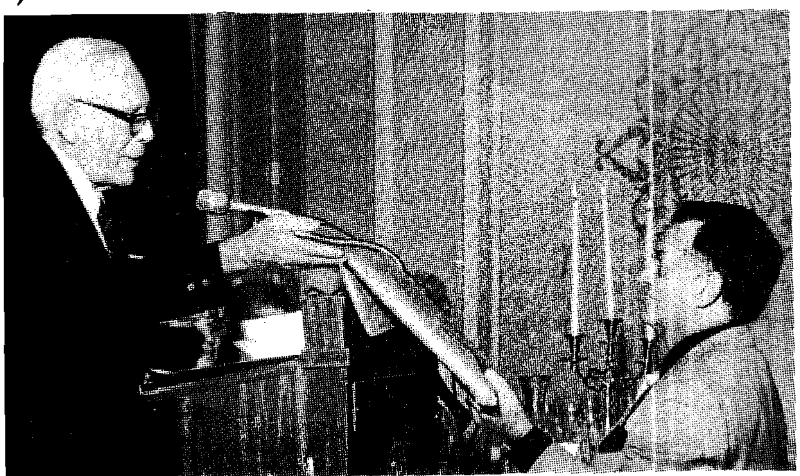

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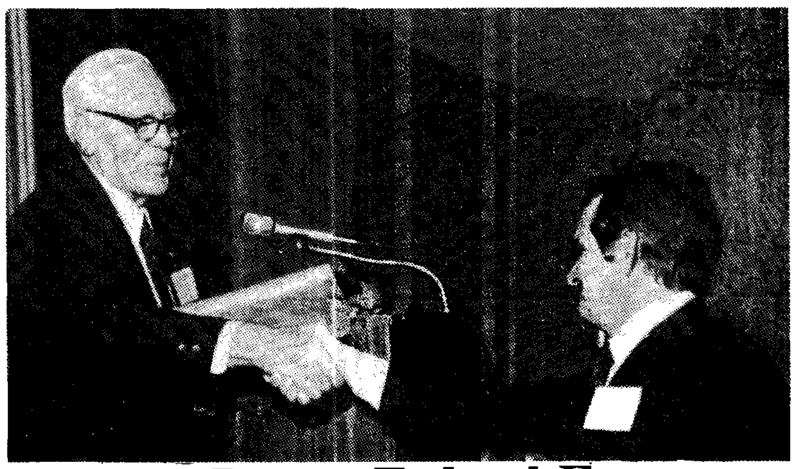

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