INCORPORATED AIR SAFETY INVESTIGATORS AUGUST 31, 1964

forum

The International Society of Air Safety Investigators

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PROCEEDINGS
of the
EIGHTH INTERNATIONAL SEMINAR

3 - 6 OCTOBER 1977

MACUTO SHERATON HOTEL
CARABALLEDA D.F.
VENEZUELA

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INTERNATIONAL SOCIETY OF
AIR SAFETY INVESTIGATORS

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THE INTERNATIONAL SOCIETY OF
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PREFACE

The International Society of Air Safety Investigators was organized exclusively to promote the development of improved accident investigation procedures through lectures, displays, and presentations, and by the exchange of information.

In furtherance of this objective, it is intended to exchange ideas, experiences and information regarding the art of aircraft accident investigation, and disseminate findings to the public, in order to increase the safety of flight.

These PROCEEDINGS include a compilation of the papers presented at the Annual Seminar, and are intended solely for the purpose of aircraft accident prevention. The views and opinions expressed in the PROCEEDINGS are those of the authors, and do not necessarily reflect the views of the Society.

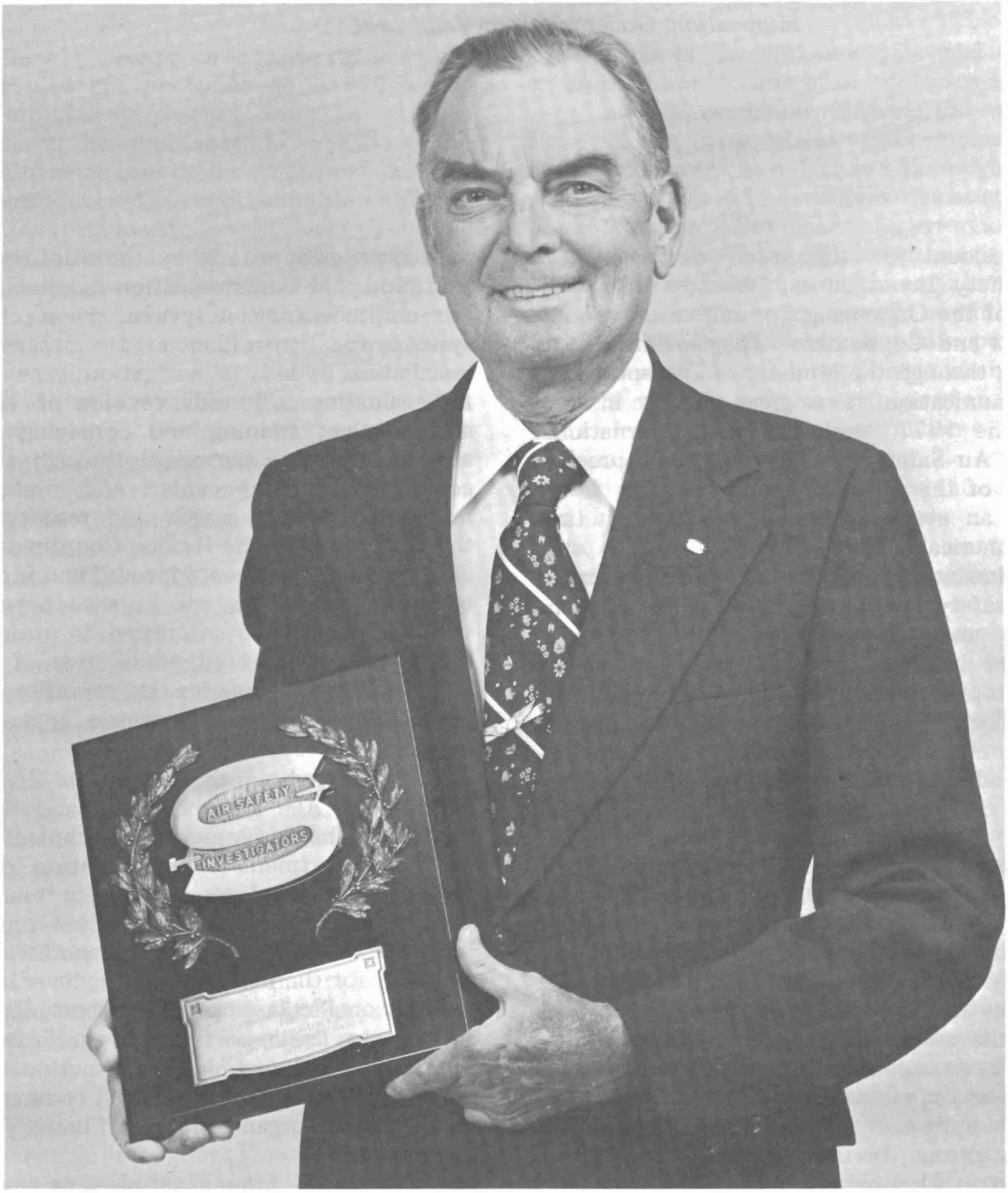
ACKNOWLEDGMENT

The International Society of Air Safety Investigators is deeply grateful for the support given to this Seminar by the Government of Venezuela and the Venezuelan Ministry of Communications and Transportation—Dr. Jesus Vivas Casanova, Minister.

TABLE OF CONTENTS

International Society of Air Safety Investigators

AWARD



The International Society of Air Safety Investigators presented its first **Jerome F. Lederer Award for Technical Excellence in Aircraft Accident Investigation** to Mr. Samuel M. Phillips of the United States Army Agency for Aviation Safety, Fort Rucker, AL., at the Eighth Annual Seminar in Caracas, Venezuela.

The award was established in honor of Jerome F. Lederer, whose efforts in the field of aviation safety are world renowned. Mr. Lederer is a past president of the Flight Safety Foundation, and former Director of Safety for the National Aeronautics and Space Administration during the early manned space flights. Mr. Lederer is now President Emeritus of the Flight Safety Foundation.

Mr. Phillips was selected for the award because of his extensive experience and demonstrated ability in successfully investigating and reporting complex aircraft accidents. His experience spans 26 years and more than 400 accident investigations. He was cited as one of few investigators capable of investigating accidents in both rotary wing and fixed wing aircraft. During his 14 year tenure with the US Army Agency for Aviation Safety he has written the Army's regulations for aviation safety, accident prevention programs and aircraft accident investigation and reporting.

OPENING ADDRESS

Presented by Dr. Jesus Alvarez Fernandez, Deputy Minister of Transportation and Communication, Government of Venezuela.

Mr. President of the International Society of Air Safety Investigators, Directors of ISASI, Members of the Organizing Committee of Seminar '77, Ladies and Gentlemen: The Government of Venezuela, through the Ministry of Transportation and Communication, takes great pleasure in inaugurating the 1977 Seminar of the International Society of Air Safety Investigators. We appreciate the honor of the selection of our country for so important an event, celebrated for the first time in Latin America.

We understand that the fundamental purpose of all air safety investigations is to determine the conditions and circumstances which cause an accident or incident, with the object of identifying appropriate measures to avoid repetition. The investigator's efforts contribute to the important determination of the conditions and circumstances leading to the survival, or not, of the occupants of the aircraft in the case of a violent accident. Your difficult, delicate and complex mission has the purpose of fostering the adoption of corrective measures. It is not to punish, understanding that the determination of fault and responsibility is not included in the task of experts in charge of investigating aircraft accidents. Without doubt, that function is properly a responsibility of the authorities of the interested states. However, it is sometimes possible to determine clear acts or omissions on the part of identified persons or entities. Any evidence of this type should not change the findings of the investigation with regard to what originally caused the accident, irrespective of the personalities involved.

The ISASI, whose 1977 Seminar begins today, is a Society dedicated by its founders in 1963 to the delicate mission of promoting all aspects of air safety by the interchange of experiences and technology among air safety investigators the world over. Thus it is of special significance to announce the support of the Venezuelan government should you decide to establish an ISASI chapter in this country. Along with safety, there have been great efforts by the Ministry of Transportation and Communication to establish, within our national aviation system, the most advanced systems for controlling airspace; renovation and installation of aids to navigation; new equipment for evaluating radio aids; revision of the national airport plan; training and certifying operations and maintenance personnel through a new civil aeronautics training center; and implementing a national plan for search and rescue, of which the first phase — the Rescue Coordination Center at Maiquetia—has been approved and is on the way to realization. This will be a cooperative effort with other entities interested in promoting air safety among the contiguous areas of the Caribbean and South America, by arrangement among the rescue coordination centers adjacent to the region of Venezuela.

At the same time, the Directorate-General of the Section of Air Transportation and Transit has expanded the assignment of technical personnel to the Department of Investigation of aviation incidents and accidents, along with the Director of Civil Aviation. Featured in those programs for immediate action is the incorporation of preparation for the new ICAO guidelines; elaborating the national catastrophic accident plan, projects relating to the reporting of significant aviation documents and technical information, deviations from normal, and air safety procedures for institutions and organizations affiliated with civil aviation.

Ladies and Gentlemen, it gives us great pleasure to acknowledge the presence of such distinguished personalities in the field of International Air Safety Investigation, with the certainty that the deliberations which will begin today will contribute to increasing the level of confidence in the aviation industry. In the name of the Minister of Transportation and Communication, Ing. Jesus E. Vivas Casanova, we extend a cordial welcome, with our wishes that you will enjoy the hospitality of this wide and generous land.

LA AVIACION EN LAS MINAS DIAMANTIFERAS DE VENEZUELA

CAPTAIN Otto Hohn K.
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CARACAS, VENEZUELA 106

Venezuela, país situado en el norte de la América del Sur, con una población de 12.500 habitantes, de infinidad de paisajes, desde las selvas y desiertos, hasta las montañas de más de 5000 metros de altura, es uno de los países más importantes en la producción y exportación de petróleo. Igualmente, exporta hierro.

Políticamente está dividido en 20 Estados, 2 Territorios Federales y 1 Distrito Federal. Entre estos Estados se encuentra el Estado Bolivar, con una extensión de 238.000 Km^2 y aproximadamente tie ne una población de 400.000 habitantes. En este Estado se encuentran las minas de Diamantes, así como también las de Hierro.

Precisamente, por su gran extensión de terreno, no existen buenas vías de comunicación; por esa razón el 90%del traslado de personal y alimentos se hace por vía aérea.

En los años 1969 y 1970 fueron descubiertas varias minas de Diamante, (cabe mencionar que el minero no paga impuesto al Gobierno, lo hacen los compradores). Al grito de DIAMANTE, se volcaron más de 25,000 personas hacia las zonas donde se habían descubierto las piedras preciosas. Esto trajo como consecuencia el problema del traslado y así los primeros mineros construyeron pequenas pistas de aterrizaje de unos 400 a 500 metros, a fin de que pudieran aterrizar pequeñas aeronaves de aero-taxi.

Para poder satisfacer la demanda, se fundaron varias compañías de aero-taxis, las cuales tienen su base en Ciudad Bolívar, capital del Estado. Estas aeronaves son en su mayoría monomotores (Cessna 180, 185 y 206) y son las encargadas de llevar pasajeros, alimentos e implementos de trabajo a las minas. También habían aviones bimotores de tipo Twin Bonanza, Dornier y hasta DC-3.

A consecuencia de la gran cantidad de personas que comenzaron a instalarse en la selva, cerca de las minas, comenzó también a circular gran cantidad de dinero, lo cual trajo consigo una ola criminal, por lo que las autoridades tuvieron que intervenir para mantener el orden. Asimismo, hubo intervención del Ministerio de Comunicaciones, en cuanto a las pistas de aterrizaje, con el fin de que no hubieran violaciones de leyes y reglamentos. Entre estas pistas se encontraban las llamadas: Tiro Loco, El Milagro, La Salvación, etc., nombres puestos por los propios mineros y pilotos. La Dirección de Aeronáutica Civil, después de inspeccionar estas pistas, ordenó cerrarlas por la inseguridad que presentaban, en especial la de Tiro Loco, la cual terminaba en un barranco, lo que ocasionó varios accidentes.

Se pueden enumerar más de 50 accidentes, algunos leves, otros fatales. Las principales causes de los accidentes se debieron a la inseguridad que presentaban las pistas rústicas demasiado cortas, por sobrecarga, fallas mecánicas, errores del piloto en cuanto a precaución para los aterrizajes.

En muchas ocasiones, los comerciantes de las minas necesitaban su mercancía urgentemente, y para ello les pagaban extra al piloto para que les diera prioridad, y como los pilotos también tenían encargas de low mineros, esto ocasionaba que el avión despegaba con el peso máximo o muchas veces sobrecargado.

Otro factor que influyó en los accidentes fue que las aeronaves volaban desde el amanecer hasta el anochecer, por lo que el mantenimiento tenća que hacerse de noche, improvisado y con rapidéz.

A todos estos factores se sumaba el cansancio de los pilotos. La Directión de Aeronáutica Civil, trató de que se cumpliera esta regalamento, pero los pilotos burlaban esta disposición, despegando de pistas cercanas a Ciudad Bolívar. Todos estos factores ocasionaron el cierre de las pistas.

Al Gobierno Estatal se le presentó el problema de que habían más de 20,000 personas en estas minas sin poder recibir alimentos ni asistencia ("médica"), porque no habían vías de acceso a la zona, debido a lo lejos y a los innumerables ríos que circundan esa región. Solucionar el problema por medio de helicópteros, era también imposible, porque se necesitaban más de una docena.

Durante este tiempo se logró construir una pista de 600 metros, un poco irregular, pero allí podían aterrizar los DC-3, y luego una compañía grande de Aerotaxis comenzó a operar esta pista con aviones DC-3, haciendo después el traslado dentro de las minas en helicópteros de turbina, ya que el aeropuerto quedaba a unas 5 millas. Pero tampoco esto fue suficiente para la gran demanda de alimentos y otras cosas que necesitaban los mineros.

Para la construcción de esta pista se presentaron muchos inconvenientes por la inclemencia del tiempo, lluvias, que hacían los trabajos muy lentos. Los mineros reclamaron al Gobernador del Estado e incluso llegaron a secuestrar dos aeronaves. El Gobernador se vió en la necesidad de permitir que se siguieran operando las pistas pequeñas, hasta que estuviera construída la otra.

Finalmente, el Presidente de la República nombró una Comisión a nivel presidencial, con el fin de solucionar todos estos problemas. Se encontró que el 60% de los mineros eran extranjeros que habían entrado al país ilegalmente, obsesionados por los diamantes. Cabe mencionar que la ley en Venezuela dáderechos a explotar a los venezolanos nacidos en el país, pero no a los extranjeros. Se dió el caso, en varias oportunidades, que aviones extranjeros aterrizaban en sabanas cercanas a las minas, y compraban los diamantes, burlando a las autoridades y al impuesto nacional que había que pagar.

La vida en estas minas era sumamente costosa, ya que todos los materiales de construcción, utensilios, víveres, y lo más imprescindible, tenía que ser transportado por vía aérea; podrían imaginarse lo que había que pagar por comida o bebidas. A consecuencia de esto, la mayoría de los mineros, a pesar de haber conseguido buenos y caros diamantes, se quedaron sin nada, ya que tenían que venderlos a los compradores, casi siempre por lo que habían consumido, ya que el comerciante les daba a crédito tanto los utensilios como la comida, y cuando el minero encontraba los diamantes tenía que venderlos al mismo comerciante, en pago de lo que le habían dado. Así que los que salían ganando eran los compradores.

Durante esta época hubo decenas de accidentes, desde el famoso DC-3 hasta los Cessna 180, incluyendo helicópteros. Los siniestros eran tan grandes que las mismas compañías de seguro, en sus pólizas, excluían las pistas de las minas, por peligrosas.

Finalmente, para el año 1975 se terminó de construir la carretera a Guaniamo y una pista de 1,000 metros de largo. Con estas construcciones termina una época de aventura de la aviación y se regulariza el transporte aéreo en la zona. Actualmente, el 90% de la carga es enviada por tierra.

LE VOL EN MONTAGNE
VFR FLIGHT IN THE MOUNTAINS

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Le but de cet exposé est de mettre en évidence quelques problémes relatifs á la sécurité des vols VFR en montagne, notamment les expériences faites dans ce domaine en Suisse.

Plus de la moitié du territoire suisse est situé dans la chaîne des Alpes. Ce massif montagneux, orienté d'est en ouest, a une largeur variant entre 70 et 100 milles nautiques. Il comporte de nombreux sommets d'une hauteur supérieure à 10,000 pieds, les plus hauts se situant entre 13,000 et 15,000 pieds.

De par sa situation géographique, le territoire suisse est l'objet, particulièrement pendant la saison touristique, d'un important trafic VFR nord-sud, à destination des aérodromes de Sion, Samedan, Locarno, Ascona et Lugano, ou en transit pour les pays du bassin méditteranéen.

Les conditions météorologiques caractéristiques du massif alpin sont une nébulosité fréquente ou des régimes de vent susceptibles d'engendrer de violents rabattants et une forte turbulence.

En effet, le vent en terrain montagneux subit immanquablement les influences du relief. Si la surface du sol n'est pas trop tourmentée, un courant modéré qui remonte une pente n'est pas ou peu perturbé. En revanche, lorsqu'il redescend le versant opposé, il suit rarement le profil du terrain mais engendre de la turbulence et des rabattants dont l'intensité et la forme peuvent étre trés variables. Par vent fort, les filets d'air décollent franchement du relief aprés le passage d'une crête. Ils continuent leur ascension dans le prolongement de la pente, créant parfois au-dessous des tourbillons ou des rotors souvent trés dangereux pour la navigation aérienne.

L'action du relief ne se limite pas seulement aux couches voisines du sol. Dans certaines conditions, les couches supérieures de l'atmosphère sont également perturbées. Des courants ondulatoires peuvent se former entraînant la formation d'altocumulus caractéristiques de forme lenticulaire.

Lorsque des masses d'air humides franchissent une haute chaîne de montagne, l'humidité relative de ces masses augmente avec leur ascension, provoquant d'importantes précipitations sous forme de pluie ou de neige. Débarrassées de la plus grande partie de leur humidité ces masses d'air redescendent le versant opposé où souffle alors un vent sec et chaud souvent très turbulent, notamment dans les grandes vallées.

Mais même par beau temps, l'ensoleillement des pentes pendant la journée et le rayonnement du sol pendant la nuit peuvent engendrer des mouvements circulatoires importants; au cours de la matinée la couche d'air au voisinage des pentes se réchauffe au contact du sol. Devenu plus léger que l'air environnant, cet air monte et donne naissance à des ascendances. En fin d,après-midi, l'insolation diminue et le sol se refroidit par rayonnement. A son contact, l'air subit une baisse de température et un courant inverse s'établit.

Les conditions météorologiques et la diminution de puissance des moteurs d'avions légers en air raréfié ne permettent pas toujours un survol en ligne directe du massif alpin. Il faut donc souvent choisir un itinéraire passant par les vallées et les cols.

Les difficultés que rencontre un pilote non familiarisé avec le vol en montagne sont multiples. Abstraction faite des problèms de navigation ét des difficultés d'ordre métórologique, il éprouvera une certaine appréhension à voler à proximité d'un relief accidenté, entouré de montagnes plus élevées que l'altitude à laquelle il se trouve. La notion des distances verticales et horizontales lui fera souvent défaut. L'absence d'horizon naturel exigera de lui une attention soutenue afin de conserver une assiette de vol normale.

Plusieurs accidents dus à l'imprévoyance ou à la méconnaissance des risques objectifs du vol en montagne se produisent chaque année. Ces accidents peuvent être groupés en deux catégories: ceux qui sont survenus lors d'une tentative de traversée "on top" et ceux qui se sont produits au cours d'un vol effectué á une altitude inférieure à celle des sommets environnants.

Les accidents du premier groupe concernent les pilotes qui se sont engagés à la limite du plafond pratique de leur avion au-dessus d'une masse nuageuse d'une certaine étendue et qui, n'ayant pu maintenir leur altitude et s'étant fait absorber par celle-ci, perdent la maîtrise de leur appareil ou entrent en collision avec le relief.

Les accidents du deuxiéme groupe réunissent les pilotes qui, voyageant au voisinage du relief, se sont fourvoyés dans un compartment de terrain trop exigu pour évoluer avec une marge de sécurité suffisante. C'est le cas par exemple, du pilote qui remonte une vallée en son milieu et s'apercoit trop tard que le terrain au-dessous de lui monte plus rapidement que son avion ou qui, après avoir franchi un col, constate en amorcant la descente sur le versant opposé que le haut de la vallée est obstrué par un bouchon nuageux.

Ce genre d'infortune se termine généralement soit par un décrochage au cours d'un virage serré effectué à trop faible vitesse, soit par une collision avec le relief ou, dans le meilleur des cas, par un atterrissage en catastrophe dans une région souvent inhospitaliére.

Les enseignements tirés de ces accidents ont permis de dégager un certain nombre de principes que les écoles suisses de pilotage s'efforcent d'inculquer á leurs élèves, notamment au cours d'exercices pratiques de familiarisation au vol alpin.

C'est ainsi qu'on évitera de s'engager dans une vallée sans réserve de hauteur suffisante. On volera le long des pentes et non au milieu de la vallée de facon à pouvoir disposer de toute sa largeur lors d'un demi-tour éventuel.

On vouera une attention particuliére à l'indicateur de vitesse, afin de ne jamais se trouver à la limite du décrochage, notamment au moment d'amorcer un virage à forte inclinaison latérale.

Les cols ne seront pas abordés de face mais obliquement, de manière à permettre à tout moment un dégagement aval, si les conditions météorologiques au voisinage du col ou sur l'autre versant ne sont pas jugées satisfaisantes.

Enfin, le franchissement des cols et des crêtes se fera avec une réserve de hauteur suffisante et si possible en léger piqué, spécialement si l'air est agité.

Soucieuses d'augmenter la sécurité des vols en montagne, les authorités aéronautiques suisses ont pris un certain nombre d'initiatives:

— Publication dans l'AIP suisse d,un chapitre consacré au vol VFR en montagne.
— Diffusion de dépliants illustrés résumant l'essentiel de ce qu'un pilote doit connaître et emporter avant d'entreprendre un vol en montagne. Ces dépliants sont à disposition à tous les aérodromes suisses et les aérodromes douaniers des pays limitrophes.
— Indication d'itinéraires VFR avec altitudes recommandées de franchissement des cols sur la carte aéronautique O ACI, à l'échelle 1:500,000.
— Introduction du système de prévisions météorologiques GAFOR. Ce système, qui complète avantageusement les prévisions de vol usuelles, renseigne sur les conditions de visibilité et de plafond régnant sur les routes classiques de vol á vue en Suisse. Ces prévisions, élaborées jusqu'à quatre fois par jour pour une période de six heures, fractionnée en trois sections de deux heures chacune, retiennent quatre niveaux de praticabilité: Ouvert, Difficile, Critique et X (fermé). Une route est déclarée ouverte si la visibilité est supérieure à 8 km et le plafond supérieur à 2000 pieds au-dessus du niveau de référence. Elle sera considérée comme fermée si la visibilité est inférieure á 2 km et le plafond inférieur à 1000 pieds.
— L'évolution souvent rapide des conditions météorologiques locales au voisinage des aérodromes alpins et les difficultés rencontrées dans l'établissement des radiocommunications VHF air-sol en montagne ont rendu souhaitable l'implantation de stations relais radiophoniques sur certains sommets. Deux stations, érigées l'une au-dessus de Martigny en Valais et l'autre sur le Piz Corvatsch dans

les Grisons, desservent à ce jour les aéroports de Sion et Samedan, permettant ainsi aux pilotes en route vers ces aéroports de recevoir suffisamment tôt tous renseignements susceptibles de les intéresser. Par ailleurs, une station implantée dans la région du col du Lukmanier assure le relais entre Zurich Information et les avions évoluant sur le versant sud des Alpes.

— L'apparition sur le marché de balises radioélectriques de secours ELT a rapidement suscité un grand intérêt dans les milieux aéronautiques suisses. Ces balises à enclenchement manuel ou automatique et alimentation électrique autonome, travaillent sur les fréquences internationales de secours 121.5 et 243 Mc/s. Elles permettent aux avions de recherche spécialement équipés à cet effet de localiser rapidement la position d'un aéronef sinistré.

La présence à bord d,une balise de détresse est obligatoire dans le trafic commercial pour tous les vols VFR non contrôlés. Les avantages évidents de ces appareils, peu encombrants, légers et d'un prix abordable, ont incité l'Office fédéral de l'air à en recommander l'acquisition à tous les propriétaires et exploitants d'avions privés.

Les expériences faites à ce jour en Suisse, bien qu'encourageantes puisque ce matériel a déjà permis de sauver quelques vies humaines, ont néanmoins révélé un pourcentage encore relativement élevé de défaillances.

Trois causes principales sont à l'origine de ces pannes:

1. Impasse technique due au fait qu'en fonctionnement automatique, les balises commercialisées à ce jour ne peuvent être enclenchées que si la direction d'application de la décélération nécessaire à leur mise en marche (env. 5 g) coïncide avec l'orientation du mécanisme d'enclenchement à inertie dont elles sont pourvues.
2. Arrachement de l'antenne à l'impact, consécutif à un montage parfois inadéquat du câble coaxial.
3. Entretien insuffisant (accumulateurs déchargés).

Un accident particulièrement tragique survenu non loin de la frontière suisse a montré également qu'il est indispensable que les pilotes renseignent leurs passagers sur la présence d'une balise de détresse à bord et de les instruire sur la facon de l'utiliser. Un Cessna 177, immatriculé suisse, s'est ècrasé dans les Alpes au retour d'un voyage à l'étranger. L'épave n'a été retrouvée que 3 semaines plus tard. L'enquête a révélé que le pilote avait été tué sur le coup tandis que ses deux passagers avaient survécu l'un 4 jours, l'autre 8 jours avant de mourir d'épuisement. L'avion ètait muni d'une balise de détresse en parfait ètat de fonctionnement, fixée à l'arriére de la cabine. La décélération à l'impact avait été insuffisante pour enclencher automatiquement l'émetteur. Il aurait toutefois suffi d'actionner le balise. De toute évidence, les passagers ignoraient la présence de cet équipment â bord ou la mainére de l'enclencher.

ABSTRACT

The aim of this report is to expose certain problems associated with VFR flights in mountainous areas and more specifically to outline certain experiments in this field which took place in Switzerland.

The Alps make up more than half of Switzerland. This mountain mass, oriented from East to West, is 70 to 100 nautical miles wide. It includes a number of peaks which exceed 12,000 feet and the highest are between 13,000 and 15,000 feet.

Because of its geographical location, Swiss territory is, especially during the tourist season, the scene of very intense North-South VFR traffic heading for the airports of Sion, Samadan, Locarno, Ascona and Lugano or transiting to Italy and the countries of the Mediterranean basin.

A frequent and heavy cloud cover or winds, notably foehn (a warm and dry Swiss wind) which can produce violent wind shifts and strong turbulence are meteorological conditions characteristic of the Alpine mass.

Because of a lack of understanding of the dangers associated with these factors, many accidents occur each year.

Mountain flying, especially in the valleys and crossing passes and crests requires special techniques. Private pilot training in Switzerland takes cognizance of the problem by giving familiarization flights in Alpine flying.

Because of their concern for the security of air traffic in the mountains, the Swiss aeronautical authorities have taken a number of initiatives:

— Distribution of illustrated brochures outlining the minimum information required for a pilot who wishes to fly in the mountains.

— Recommended VFR flight paths with suggested crossing altitudes for the passes are included on the aeronautical map OACI 1:500,000.

— Introduction of the meterological forecast system GAFOR.

— Recommendations for the use of ELT's

— The installation of radio relay stations in the valleys leading to the alpine aerodrome of Sion and Samedan.

MANAGING THE DIFFICULT ACCIDENT INVESTIGATION

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I. PURPOSE

This paper is intended to acquaint the reader with a technique used for investigating accidents and evaluating accident reports that have a high level of complexity either from the viewpoint of many interacting factors or the need to look at every possible aspect of accident causation.

II. BACKGROUND

By their nature aviation accidents have an unusual potential for catastrophe due to speed, environmental influences, number of people involved, and the continual high degree of professional performance expected of some participants.

Similar conditions surround events involving nuclear activities. The Atomic Energy Commission (AEC), now the Energy Resources and Development Administration (ERDA), has always had a good safety record. The nuclear disaster potential has demanded an ever-more effective prevention program to include more effective accident investigation. Accordingly, in 1970 the AEC contracted for the development of an ideal, comprehensive, safety program utilizing every proven state-of-the art technique. By 1972 the Management Oversight and Risk Tree (MORT) analysis was ready for pilot trials. As a result of the trials MORT was adopted by the AEC. A second generation of MORT was now underway and in 1974, after several years of development, modeling, and extensive trials, it was adopted. The new organization, ERDA, saw that MORT could reduce it's accident rate by an order of magnitude within ten years. The system was adopted for use throughout ERDA and by ERDA contractors. MORT was designed to be used as the basis for a complete safety program. Here, however, we are only concerned with MORT as an accident investigation management tool.

III. INTRODUCTION

MORT is used to investigate the elements of management oversight and risk relative to an accident. It is an ideal system for knowing what information to seek after an accident and what aspects of performance to measure that contribute to an accident.

MORT is simply a diagram which arranges accident causes in an orderly and logical manner. It schematically presents an accident analysis using a sort of fault-tree methodology. MORT structures the largely unstructured various approaches to accident investigation. It looks at a hundred events that could be involved in accidents, diagrams 1500 possible accident cause factors and reveals thousands of criteria to judge whether or not there were Less Than Adequate (LTA) actions which in turn could cause an accident.

While MORT is being considered largely as an investigative tool here, it has just as much value as an analytical tool after that investigation is complete and the facts are all in. At that point the accident can be further analyzed, not only for cause factors, but for adequacy of investigation.

Using a MORT work sheet, the investigative process can be given visibility. The investigator or analyst is able to review his findings in relationship to each other and present his analysis pictorially to others. As the diagram is processed additional facts and information become apparent and the analyst can easily document the new information. He is quickly provided additional insight into factors surrounding the accidental event.

IV. THE ANALYSIS PROCESS

The MORT process starts out looking rather simple (Figure 1) and very much like a fault-tree diagram.

When that chart has some names placed on it, as in the case of an accident, it looks something like Figure 2.

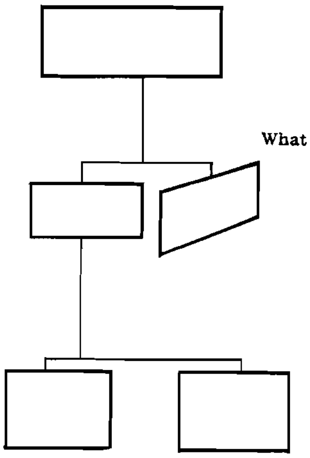
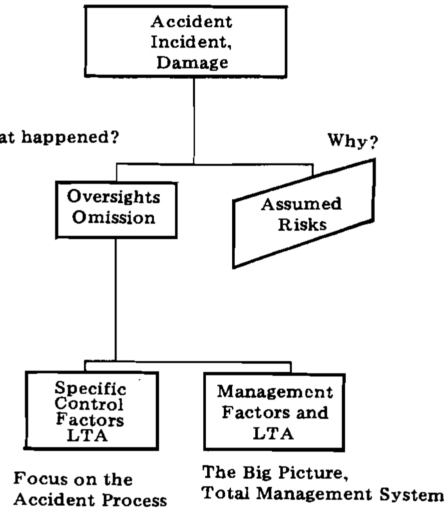


Figure 1



LTA — Less Than Adequate

Figure 2

At the top of the diagram is the event, an accident or incident. The immediate causes of the event can be broken down into two areas—that of oversights and omissions, or assumed risks.

Assumed risks are nearly always present, for example, the decision to take off or enter landing traffic is something of a risk that is readily assumed. This section can be looked at in detail to see specifically what the assumed risks were and if they were appropriate. Were they calculated? Was there a specific decision to assume the risk? Was the decision made by the proper authority? The risk may be low risk, high risk (like taking off into a hurricane), or perhaps the risk was too expensive to correct when weighed against the consequences.

The other area, oversights and omissions, contain all accident cause factors other than assumed risks. Oversights and omissions can nearly always be traced to either "specific control factors" or "management factors," usually both. "Specific control factors" focus on the accident process while management factors cover the big picture, the total system.

Another way of looking at the same diagram is as shown in Figure 3.

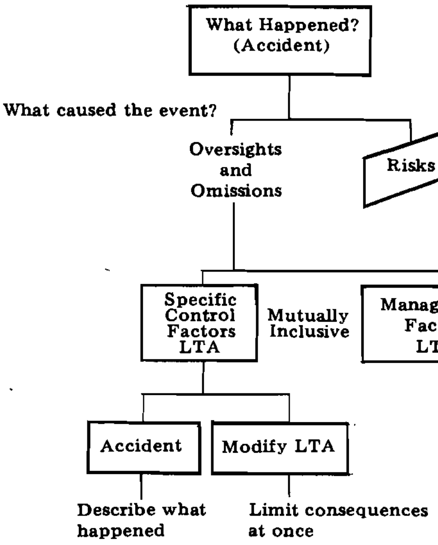


Figure 3.

At the top we want to know "what happened." What brought about our injury?

Next is "what caused the event?" This is the question we are investigating. Since we have discussed assumed risks, let us follow through on "oversights and omissions."

On the next lower level of inquiry we have the same two items as in Figure 2, "control" and "management" factors. Under "control factors" going down to "accidents" we begin to describe what happened.

The term "modify" (amelioration) takes place only after an accident. It refers to the immediate steps taken to prevent further damage or injury such as actions by crash-rescue or firefighting crews. Let us investigate the term "modify" further.

Look now at Figure 4, "Prevention of Second Accident."

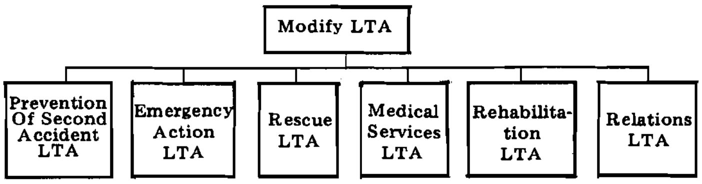


Figure 4.

Was this adequate? Were steps taken to prevent the second accident resulting as a consequence of the first? If not, we have an entire series of blocks to cover this consideration. They are not shown.

"Emergency action" refers to the fire brigade, health physics team, fire department, bomb squad, and other special teams. "Rescue LTA" refers to trapped or immobilized victims, injury to rescuers, and evacuation from the area. "Medical services LTA" covers first aid, medical transport, medical plan, adequate notice of the emergency, personnel and equipment, and distance from the accident to medical facilities. "Rehabilitation" refers to after-action pertaining to both people and objects. For example, how soon did the runway get back into operation or when could the firefighters again get operational? "Relations LTA" means relations with employees, officials, the public and the media.

Take a look at the "accident" block again in Figure 3 and then go to Figure 5.

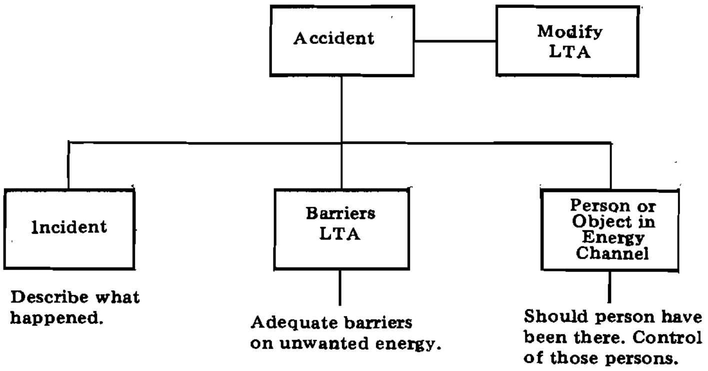


Figure 5.

Expansion of the "accident" block shows us to now be considering "incident," "barriers," and the "energy channel."

"Incident" is merely a description of what happened. It could be a near miss which is often worthy of investigation. "Barriers" means barriers to the energy between the accident and people that might be involved. "Persons and objects in the energy channel" are evaluated to determine their function at the scene and what should have been done about them. If any of these three blocks fit our accident, then they can be considered in detail. Consider the incident block.

Go to Figure 6 for details of "incident."

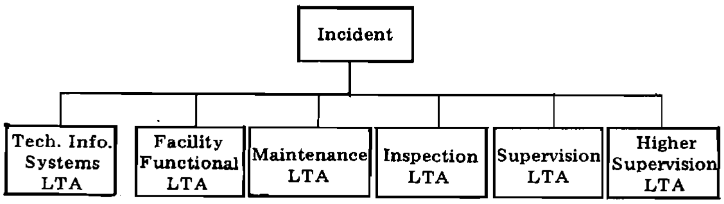


Figure 6

Briefly, some of the things to be considered under "incident" are:

1. "Technical information systems."
2. "Facility functional" meaning ready to use in all respects.
3. "Maintenance" with all the aspects we know so well.
4. "Inspection" which overlaps a little with maintenance.
5. "Supervision" mostly at the first line level of supervision.
6. "Higher level services" which would involve middle or higher level management.

Any of these six factors have many further directions for an indepth investigation. Take "supervision" for instance and look at Figure 7.

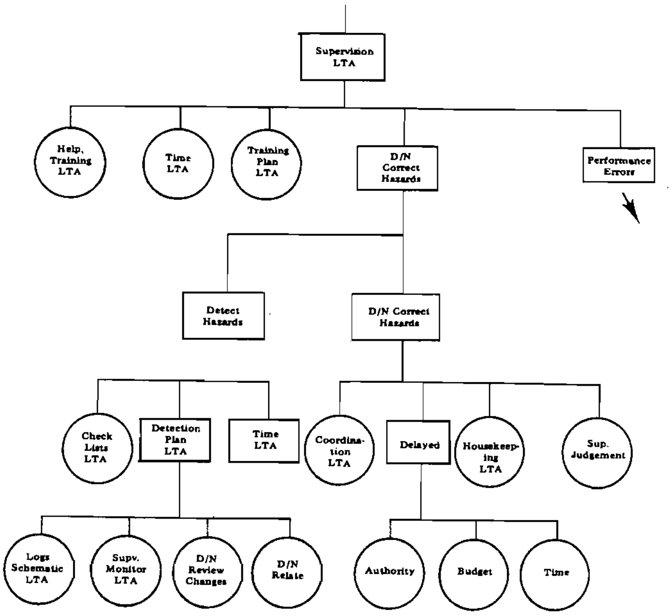


Figure 7

There is not enough time to cover this in detail, but you can see that a thorough consideration of all the blocks would result in an indepth look at hundreds of cause factors. As an example, on Figure 7 notice "performance errors" in the upper right hand corner. Over seventy more blocks provide a detailed analysis of "performance errors."

If we are looking for a detailed analysis of either cause factors or an evaluation of the investigation itself, we have considered only half of the possibilities. We have only looked at control factors. Look again at Figure 3. Notice halfway down on the right the block titled "management factors LTA." A quick look at Figure 8 will show us some of the considerations.

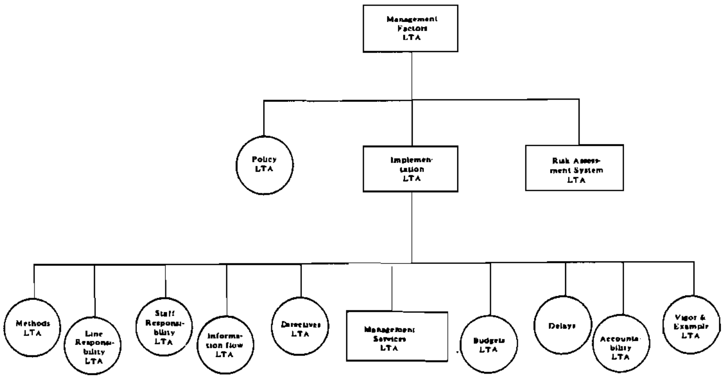


Figure 8

Our MORT diagram or check gives us far more guidance if we want it. In the lower center, notice "management services LTA." There are fifteen additional blocks to look at if this is an appropriate item.

On the center level of Figure 8, you will see a block called "risk assessment system LTA." There are more block items to be covered under that little heading than we have covered in the entire discussion so far. In other words we have barely touched on half of the items that MORT provides us a way to look at in-depth on an investigation.

That is enough of the charts. We have a good idea of how this accident investigation management tool works. No attempt is made here to fully explain the system or make you an expert; only to discuss the possibilities.

MORT is not an easy system, but for a smart person it is not hard. After all, it was advertised as being a management tool for the "difficult investigation."

V. SUMMARY

The MORT process has excellent possibilities for accident prevention purposes. It is a tried and tested system that has already seen extensive use. Because it is systematic and somewhat involved, one should be trained in its use. Such formal training can be received in a few days.

The greatest value of the MORT process for SASI members is:

1. Using MORT to direct and monitor nearly all details of the difficult investigation, and

2. Using MORT to evaluate an already completed investigation for thoroughness and completeness.

Errors and omissions become glaring mistakes under this intensive scrutiny.

MORT is not the perfect solution for accident investigators, but it has been proven hundreds of times in difficult situations. It has been constantly improved and expanded. While not perfect, MORT is probably the most organized and sophisticated of accident investigation techniques.

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INVESTIGATION TECHNIQUES FOR AIRCRAFT FIRES

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The Army's CH-47A (Chinook) is one of the most complex aircraft in the world. This tandem rotor helicopter is powered by two turboshaft engines that develop 2250 SHP each. The engines connect to a combining transmission which drives a common power train to the rotor systems. The control system is hydraulically operated with an electronic stabilization augmentation system. All up weight of this aircraft on a standard day is 33,000 pounds.

One of these aircraft was performing a routine training mission when it became involved in a very complex accident. The investigation of this accident will serve as a vehicle for the discussion of the subject matter of this paper.

The crew consisted of a highly qualified instructor pilot, a rated pilot undergoing transition training and a crew chief. The instructor pilot demonstrated a running takeoff. Everything went normal until the aircraft reached the down wind leg of the traffic pattern. At this point the number one (left) engine began to operate erratically. The instructor pilot ordered the engine secured. This was accomplished satisfactorily by the pilot in training.

The instructor pilot declared an emergency and was given a clearance for a single engine landing. As the aircraft was turning on the final approach, the tower controller saw smoke and flames coming from the aft pylon of the aircraft. He dispatched the fire and crash rescue vehicles and observed the helicopter to rotate to a nose up pitch attitude of about 80 degrees. Shortly thereafter the aircraft impacted on its tail and pitched forward onto the front wheels. Before the aircraft rolled onto its left side the instructor pilot and pilot trainee escaped with minor injuries. The crew chief was fatally injured in the crash.

Fortunately, the local safety officer reached the scene of the accident and took some photographs of the post crash fire which proved very valuable in cause factor analysis as will be shown later.

The aircraft was involved in an extensive post crash fire. This was due largely to the rupture of fuel cells which are located along the sides of the aircraft. At this point in time, the Army had not adopted the crashworthy fuel system.

The aft transmission and rotor system were displaced from their normal position and came to rest on the left side of the aircraft and well forward of its normal location. This was due to the burning away of the support structure during the inflight fire. These components remained in the edge of the post crash fire pattern.

One of the great benefits of taking photographs as soon as possible after the crash occurs is the preservation of evidence that might be moved or destroyed. The oil radiator cooling fan was dislocated from inside the aft pylon and came to rest outside of the ground fire pattern. This part was to play a very important role in the determination of the combustible material that was the fuel for the inflight fire.

The next day after the wreckage had cooled down we were able to get some close up photographs to help determine the temperature of the inflight fire and something about the burn pattern. One of the steel hydraulic actuators that control the rotor head had a hole about four inches long and three inches wide burned through the heavy steel cylinder. This indicated that the inflight fire had reached a temperature in excess of 2700 degrees Fahrenheit. It also indicates that at this point the flame pattern had traveled upward and was concentrated in a relatively small area. The puddled aluminum found on a portion of the aircraft structure attached to the aft transmission is a positive indication that this metal melted in the post crash fire and that the temperatures in this area reached or exceeded the 1200 degree Fahrenheit range, the melting point of aluminum.

Figure 1

The cooling fan mentioned previously was photographed and recovered. There were heavy black deposits on the blades. The fan was immediately sent to a chemical laboratory for analysis. The analysis revealed that the black deposits were the residue of military standard oil number 7808, a synthetic oil used in the transmissions and power plants of Army helicopters of this type. This was the clue as to the fuel for the inflight fire, but there were still a lot of unanswered questions. (Figure 2)

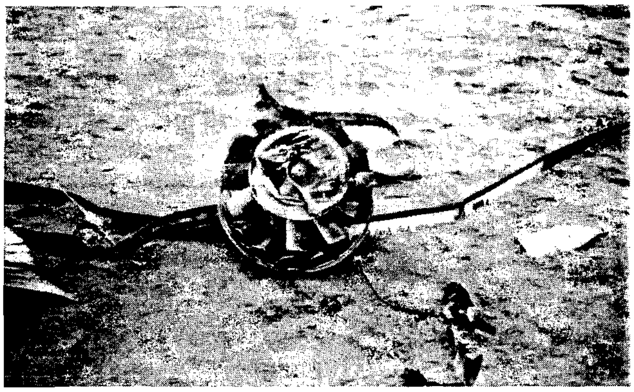

Figure 2

Engineers from the Boeing-Vertol Company were called in to assist in this accident investigation. They were asked to prepare a diagram of the aft pylon of the aircraft and its relationship to the inflight and post crash fire damage. This chart was a great help in the final analysis of the inflight fire pattern and the reasons for it. The diagram clearly shows that the fire pattern traveled aft and up burning the structure that supports the aft transmission. The structure failed and allowed the aft transmission to move upward because of the lift on the rotor system. This movement caused a change in the angle of attack of the blades which reduced the amount of lift on the aft rotor in comparison to the lift on the front rotor. This resulted in the rotation of the helicopter to the extreme nose high attitude just prior to impact.

The witness group turned up some very important information which helped to develop the sequence of events. There were two airborne witnesses in two different aircraft that saw the inflight fire. These witnesses were later flown to the same area from which they made their observations. While in these areas they described again what they had seen. The flight of the CH-47 and the points of observation of the witnesses and the tracks of their two aircraft were plotted on a diagram. The information gained developed the history of the flight from takeoff to the point of impact. The use of such a diagram is an excellent tool for establishing and validating data. For example, a witness in a small helicopter saw white smoke coming from the aft of the aircraft at almost the same point the crew of CH-47 was experiencing engine problems. (Figure 3)

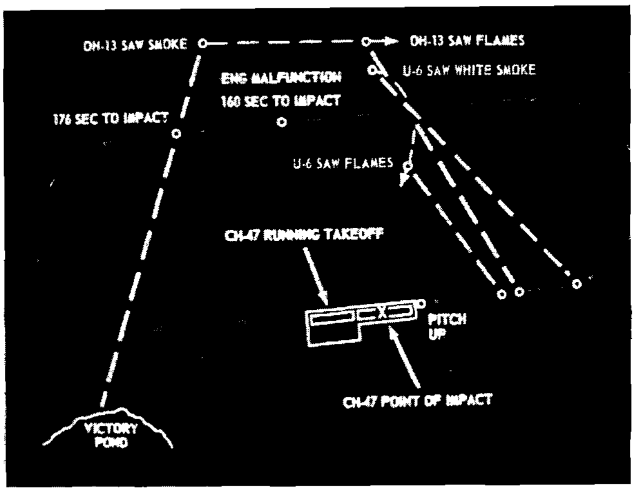

Figure 3

The number one (left) engine was examined to determine its relationship to the aircraft accident. The teardown analysis revealed that the engine had been secured inflight. However, prior to being secured the engine had experienced an overspeed and excessive temperatures. The combination of the high temperature and high RPM caused the failure of the gas producer turbine blades which impacted on the power turbine blades causing heavy damage. The failed blades did not exit the engine case. (Figure 4)

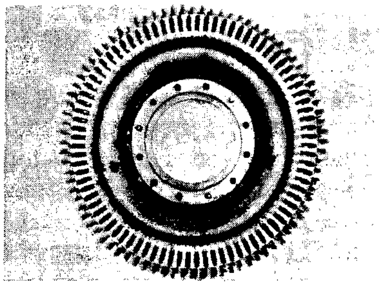

Figure 4

The engine fuel control was examined by disassembly. All parts were determined to be functional and no abnormalities were found that would cause the engine problem. The conclusion was that the engine damage was a result of the inflight fire problem and not a cause.

Examination of the oil radiators and lines that were located in the aft pylon revealed that there were no leaks that could have produced the fuel for the fire. The oil reservoir and pumps were also examined with the same results. There was also no source of ignition in this area of the aircraft.

At this point in time some preliminary analysis was made to determine which direction the investigation should take. The facts revealed the following:

There was an inflight fire—

The 7808 oil was the fuel for the fire—

The number one engine experienced an overspeed and overtemp condition caused by an external source—

Questions still unanswered were:

What was the source of the fuel for the fire?
What was the source of ignition?
What was the source of the engine problem?

Applied logic revealed that the one component that could have an impact on the answer to all three questions was the number one engine transmission. The rationale was that this component used 7808 oil as a lubricant/coolant. It was located in such a position that the loss of oil would impact on the engine. It was not known if this examination would lead to cause of the fire.

Examination of the transmission and its drive shafting revealed that the sprag clutch between the engine and transmission had been damaged. The sprags had rolled over in the cage. This was the result of an engine overspeed in excess of twenty percent of the maximum design RPM. This gave the investigators a feel for the magnitude of the engine overspeed and some of the reasons why. When the sprags rolled over the engine was relieved of the load of driving the power train system. This allowed the engine to run away until it was secured. Further examination of the transmission revealed that the main thrust bearing was partially colored black while the remainder of the bearing was normal in color. The reason for the discoloration was that part of the bearing was submerged in oil during the ground fire. The portion of the bearing outside the oil became very dark in color. This indicated that the amount of oil remaining in the transmission after the engine was shutdown was in excess of the normal amount of residual oil that should have been there. (Figure 5)

Figure 5

The lubricating system for this transmission is a circulating system. The oil is pumped from a reservoir inside the aft pylon through a pressure line to the transmission. It is scavenged through a return line through the oil radiators and then to the reservoir. When the engine is secured only one quart of oil should remain in the engine transmission. Measurement of the oil at the level indicated by the bearing revealed that three quarts of oil remained. The conclusion was that the scavenge system had failed. A test was run to determine what would happen if the scavenge system failed. A mockup of the system was made with a valve in the scavenge line. The valve was to be gradually reduced until it closed. The test was run and shortly after the valve was fully closed on the scavenge line the seal on the drive shaft between the engine transmission and the drive train blew out and the test area was filled with white oil vapors. The test was stopped immediately. The temperature of the oil exceeded 600 degrees and metallurgical checks of the transmission housing revealed that it reached 640 degrees. The conclusion was that this test duplicated what happened to the crashed aircraft. However, no one knew exactly what flow pattern the oil vapors would take when submitted to the same conditions that existed during the flight of the illfated aircraft.

Another test was run to determine what the air flow pattern would be. A red smoke grenade was attached to the number one engine transmission of a test aircraft. With wind conditions the same as those that existed on the day of the crash, the aircraft was flown in an identical pattern as that of the crashed aircraft. When the proper position on the down wind leg was reached the smoke grenade was set off. After the aircraft landed the cowlings and fairlings were removed. It was found that there was a large buildup of red color on the transmission in the front of the engine. The red color was traced inside the fairing and along the drive shaft from the engine transmission to the inside of the aft pylon. Here the cooling fan drew the red smoke through the oil radiators and into the upper support structure of the transmission. This test had proven the theory that the 7808 oil was the fuel for the fire. It also proved the source from which it came and the flow pattern of the fire. (Figures 6, 7 & 8)

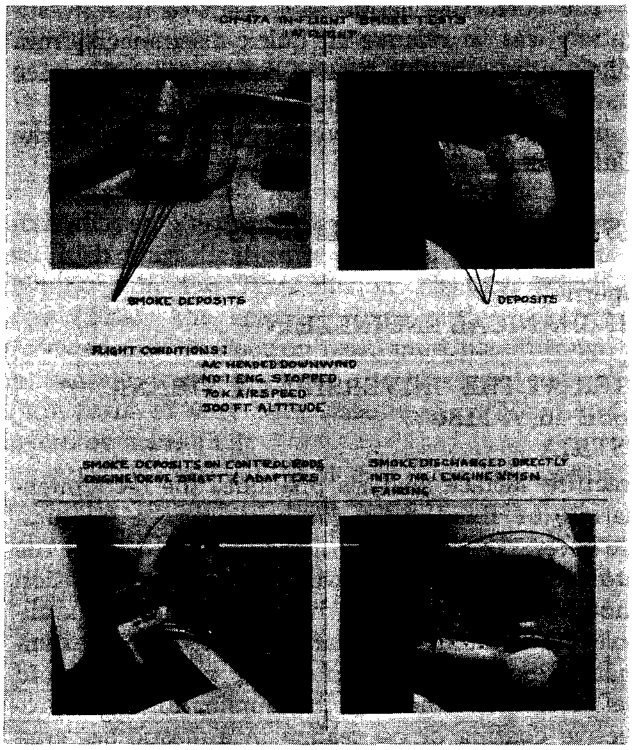

Figure 6

Figure 7

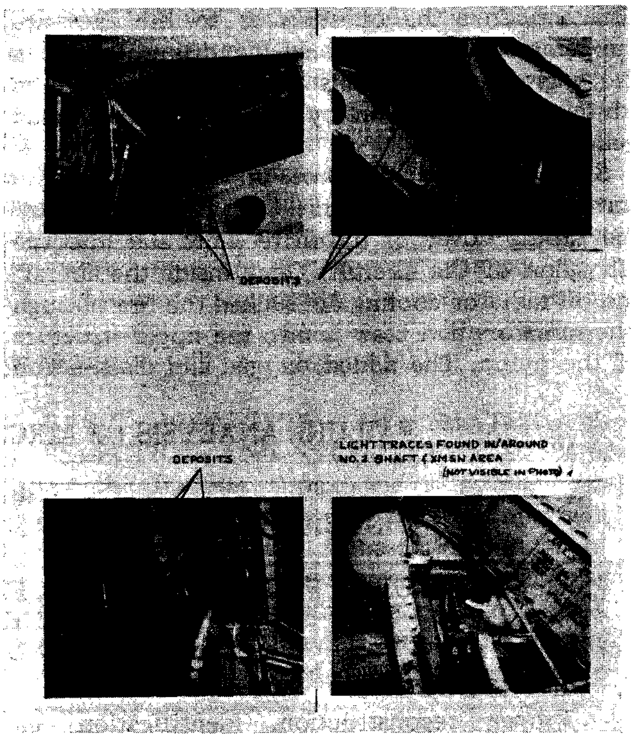

Figure 8

In order to determine the source of ignition a process of elimination and some research and testing were done. Knowing the operating temperatures inside the pylon and all the machinery there assisted in eliminating this area as the ignition source. The hottest object in the area of the white oil vapor was the housing of the engine transmission. Research and tests revealed the following:

7808 oil at room temperature sprayed on metal heated to 917 degrees Fahrenheit will burst into flame.

The oil forms vapors at 310 degrees Fahrenheit.

Oil vapors at 320 degrees Fahrenheit can be ignited by sparks as opposed to open flame.

Oil vapors under pressure at 600 degrees Fahrenheit form a white vapor when released.

Applied logic reveals that as the temperature of the oil vapors rises the temperature at the source of ignition can be reduced to almost equal the temperature of the vapors and fire will result.

The conclusion reached was that a quick disconnect fitting of the oil scavenge line malfunctioned and shut off the scavenge oil flow. The result was the buildup of temperatures in excess of 600 degrees Fahrenheit and sufficient pressure to blow out the drive shaft seal. The escaping hot oil vapors ignited when the vapors came in contact with the outside of the hot transmission housing with sufficient oxygen present to cause combustion.

The above actions created an extremely high temperature in the ambient air being ingested by the engine. This was the cause of the erratic engine operation observed by the pilots. This also answered the question as to the excessive temperature and overspeed condition found in the engine analysis. This also accounted for the white vapor trail seen by the pilot of the small helicopter.

Simultaneously the hot oil vapors and fire traveled from the engine transmission through the fairing cover of the drive shaft and into the aft pylon of the aircraft. Once inside the aircraft the oil radiator cooling fan sucked the fire through the radiators and blew it into the upper structure of the pylon. The added oxygen and distribution of the fire caused by the fan resulted in temperatures sufficient to burn and melt the transmission support structure. This resulted in the movement of the transmission and the out of control condition immediately prior to ground contact.

The corrective action as a result of this investigation was to remove all quick disconnects from all fluid lines in this type of helicopter and replace them with conventional nut type connectors.

This problem has never occurred again in the United States Army.

FAILURE ANALYSIS OF AIRCRAFT STRUCTURAL COMPONENTS

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I. INTRODUCTION

Proper reconstruction, identification and preservation of pieces found on the accident site are the basis of correct failure analyses by specialists. The scope of these analyses is: (1) a clear distinction between in-flight failures and impact damage, (2) reconstruction of the failure sequence, (3) clarification of the circumstances, which led to the primary failure. Structural components failure result either from excessive loads imposed upon a component, poor design and deficient repair, or local decrease of the initial strength of the material through fatigue and/or corrosion effects. The failure modes encountered with aircraft structures comprise static and fatigue failures. Foreign object impact-failure is a specific static failure mode. A static failure is defined as a failure resulting from one distinct overload. Permanent distortion due to local yielding or rupture of the component are its characteristics. The tougher the material, the more considerable yielding will be encountered in the failed area. Repeated loading at stress levels well below the yield stress of the material may cause a cycle-dependent decrease of the allowable stress due to microstructural effects, which result in crack initiation and crack propagation. Once the crack has reached a specific dimension, the final failure occurs in a way similar to static rupture. This type of failure is by far the more frequent one. Careful analysis of the face of the fracture often reveals a lot of information about the sequence of the structural failure, load transfers, and stress concentration.

II. RECOGNITION OF FRACTURE MODE

The diversity of questions associated with fracture surface analysis precludes the recommendation of fixed rules for examining a fracture. However, the first decision in approaching the problem is to decide what specific information should be gained and what techniques are available for obtaining this data. For laboratory examination both mating surfaces, if available, should be preserved either by the application of a protective coating or by sealing in a plastic bag containing a desiccant. The coating applied should be soluble in an organic solvent. Touching the fracture surface with fingers, fitting together the mating surfaces, picking with sharp instruments, any rough mechanical treatment or exposure to corrosive media can wipe out vital information.

The fracture appearance should be documented as early as possible by photographing before any cleaning is attempted. Identification of foreign products on the fracture surface may provide useful informations on factors contributing to the failure. Even the question when and how surface cleaning may be applied has to be checked thoroughly. In general ultrasonic cleaning procedures will be employed.

Laboratory examination of fracture surfaces were usually begun by light-optical aids. A fracture surface must be considered in its entirety. The examination of only one small area may lead to an inaccurate interpretation of the fracture mode. Low-magnification stereomicroscopes provide the depth of focus to guarantee the necessary view to the fracture surface. By these means the location of the fracture origin and the areas for electron microscope analyses can be determined. Features as chevron marks, texture changes or absence of shear lips along the edge, may be guides towards the fracture origin. Higher magnifications demand especially prepared specimens. These metallographic analyses often reveal the specific reason of the crack initiation. That way of analysis represents the first step towards destructive examination. Therefore it must be made sure that all necessary informations from previous investigations are extracted. Viewing a sample in the Scanning Electron Microscope (SEM) requires special techniques of sample preparation. The relatively small samples are mounted in a sample-holder which can be tilted to give different views to the fracture surface. Nonconductive surfaces on the sample must be coated with a thin conductive layer. Very high depth of focus combined with high magnification is an advantage of SEM-technique. In the Transmission Electron Microscope (TEM) the actual fracture surface cannot be viewed. As the electron beam must pass through the sample, replices from the fracture surface in the form of very thin, shadowed carbon films have to be made [1.].

An advantage of SEM and TEM analysis is the ability to provide high magnification stereoscope photographs of the fracture surface. Three dimensional viewing provides the investigator with a clearer understanding of the fracture topography and more quantitative data on the dimensions.

Generally the investigation centers around locating the nucleus of fracture. The ability to trace the fracture direction on a failed component usually depends on whether macroscopic features as chevron marks are identified. However, in absence of macroscopic features, as commonly with shear in thin, ductile materials, TEM analysis of dimple orientation may provide further information. For additional information energy and wave length dispersive X-Ray-Analysis can be used in conjunction with the SEM to identify quantitatively constituents or inclusions on the surface of the sample that may have contributed to the failure. The conventional X-Ray-Analysis yields only qualitative results in this respect.

Fractures in engineering alloys occur by either transgranular or intergranular cracking. Regardless the fracture path several fracture modes were observed. Their recognition allows conclusions on the reason of the failure. A continuously rising load is for the majority of common structural alloys the reason for a mechanism known as microvoid coalescence (dimple rupture). Cleavage stands for a low energy fracture type which propagates along low-index cristallographic planes. Cyclic loaded components show fracture surfaces of the fatigue type. There must be distinguished different stages of fatigue fracture: crack nucleation (activating of slip systems), subcritical crack growth (showing microscopic arrest marks known as striations) transition phase to fast fracture (macroscopic arrest marks) and final separation of parts. However, fatigue fracture surfaces can acquire different appearances than those previously discussed. The alloy, specimen geometry and the external environment stand for a variety of parameters, which exert a strong influence on the fatigue fracture appearance. A systemacy to evaluate structural failure reasons is shown in Fig. 1. Some recent references on the subject may serve as guide for further analysis [2.] [3.]. However, sometimes laboratory testing to create reference-crack-surfaces with simulated load sequences will be indispensable.

III. BASIC CONCEPTS OF MATERIALS SELECTION AND STRUCTURAL DESIGN

As the fracture appearance is strongly influenced by many parameters, some of them will be discussed further on. A basic knowledge of these considerations is indispensable to recognise the different influences which may affect crack propagation tracks. Materials selection in the aircraft industry is based on different, partly contradictory parameters:

(1) Static ultimate strength and stiffness of undamaged, flaw-free material
(2) Fatigue of undamaged, flawed material (safe-life design)
(3) Residual static strength of damaged structure (fail-safe, damage tolerance)
(4) Fatigue of damaged, flawed material (inspection intervals and repair procedures)
(5) Time dependent material behavior (creep, thermal fatigue, stress corrosion, etc).

Hand in hand with these considerations several design concepts for aircraft primary structure were developed:

The Safe-Life design concept requires analyses or testing to show that the probability of any catastrophic fatigue failure is extremely remote as compared with the assumed life of the structure. Modified mission requirements and increasing demands on light-weight structural components to maintain high performance characteristics at minimum weight and cost have introduced modern high strength materials. The use of high strength materials in components where safe-life design has reliably been applied with conventional materials has produced an increase of service failures. These failures today occur in such vital components as landing gears, wing fitting attachments and carry-through structures.

Accident investigation showed that this is because the increase in strength properties mostly brings a considerable loss of toughness of the applied material. One of the advantages of the tough materials previously employed was a big critical flaw size, which could easily be detected by conventional nondestructive inspection (NDI) procedures (Fig. 2). With modern materials, the critical flaw sizes involved are often not detectable by conventional NDI procedures. This question stimulated the studies in fracture toughness of new materials. Proper information on these subjects are now available [4.] They are mostly presented in the form of critical crack-rate (crack propagation per load cycle, mostly the ground-to-air cycle) plotted versus a materials constant (stress intensity factor range).

Where applicable, Fail-Safe design concepts reduced the seriousness of the fracture problem. A Fail-Safe design concept requires that a damaged structure perform satisfactorily until detection and/or remedial activities can be performed. In adoption of this practice some additional items have to be focussed: redundancy of the load path (multiple components), subcritical crack growth prediction techniques (inspection intervals predicted on the basis of crack propagation hypotheses), application of crack stoppers and sufficiently tough material. The Fail-Safe concept was developed as a result of accidents with the first Comet series aircraft in 1954 and effectively provided sufficient damage tolerance so that fatigue cracks or similar damage should be discovered before catastrophic failure occurs (Fig. 3). Consequently the FAA adopted a fail safe standard which requires "that catastrophic failure or excessive structural deformation, that could adversely affect the flight characteristics of the airplane, are not probable after fatigue failure or obvious partial failure of a single principal structural element". This standard has become the primary method of certifying airworthiness of civil aircraft for many years.

IV. RISK ANALYSIS

Available summaries of in-service failures indicate that the main areas of incidences associated with aircraft structure are: primary structure loaded significantly in tension, monolithic rather than redundant structure, main frames, aft fuselage portion, inboard wing main frames, wing plates and skins (fully stressed design). Most of the high strength materials, such as 4340 steel and 7075-T6 aluminium are affected by stress corrosion and residual stress problems. Therefore the basis of a proper risk analysis must contain screening criteria to identify fracture critical components and to concentrate investigation in a successful way (elimination technique). In the design stage of an aircraft assumptions are made about the operating stress spectrum, environmental conditions and materials capabilities. If premature failure of a vital component has occurred, these basic assumptions have to be compared with available data on the actual service conditions and materials capabilities. If premature failure of a vital component has occurred, these basic assumptions have to be compared with available data on the actual service conditions and previous service experience. The risk-analysis uses a profile sheet to rate potential dangers associated with factors involved in material selection, design, manufacturing, assembly and quality assurance [5]. Each factor is assigned a numerical value for its corresponding risk, and the values for each factor are summed to give the total risk for a critical part. Difficulties may arise in quantifying the influence of various local effects, as microstructural discontinuities around holes vs. improper plating for steel parts. Quantification of some risk-factors can be accomplished by the application of fracture-mechanics concepts. A sample risk profile for a main landing gear strut from a transport aircraft is presented in Figure 4. Problems may arise due to low toughness and rapid subcritical flaw growth, related with small critical crack sizes, sensitivity to processing operations, difficulty in detecting small flaws in large, hard-to-handle components.

V. FRACTURE MECHANICS ANALYSIS

Fracture mechanics is a tool to quantify the fracture resistance of a high strength material. Fracture resistance can be defined as the ability of a material to withstand the deleterious effects of cracks, flaws, or notches while under load. These defects may grow in response to service loadings and cause fracture when a critical size is attained. The rate of crack growth depends on the material, environment, stress/strain history of the component, crack geometry and component geometry. The cycle dependent crack growth of a particular material in a specific environment can be described by a single parameter, the stress intensity range (ΔK):

$$\frac{da}{dN} = C\,(\Delta K)^n \qquad \ldots\ldots (1)$$

C and n are empirically determined constants and (ΔK) is defined by

$$\Delta K = \Delta\delta\,\sqrt{\pi .\, a} \qquad \ldots\ldots (2)$$

where $\Delta\delta$ = cyclic stress range, a = depth of a surface crack of the length 2 a. The initial crack depth is taken to be just below the respective NDI capabilities (largest overlooked crack). In a similar way the critical crack depth under static loading can be computed

$$a_K = \frac{1}{\pi}\left(\frac{K}{\delta_W}\right)^2 \qquad \ldots\ldots (3)$$

with K = plane strain fracture toughness, δ_W = maximum tension stress during a ground-air-ground cycle (GAG). The stress intensity range (ΔK), which corresponds to the initial crack depth and the maximum (GAG) stress range ($\Delta\delta$) is computed by Eq. (2.) This value of ΔK is used with constant-amplitude laboratory test data to determine the crack growth rate da/dN as shown in Fig. 5. Each (GAG) gives a crack extension increment. The total number of cycles, required to reach critical crack size, defines the predicted service life. Some further applications, as the calculation of inspection intervals, are summarised in Fig. 5.

VI. APPLICATIONS RELATED TO AIRCRAFT ACCIDENT INVESTIGATION

The previous chapters demonstrated the cycle dependency of the allowable stress in structural components. That means that the allowable stress decreases with increasing number of load cycles. The so-called S-N diagram represents this relation, mostly including certain geometric parameters. Application of these informations on the material of the failed component allows to establish an estimate about the actual allowable local stress in the failed component, provided the previous load history of the airplane including maintenance and repair activities are known. If specific flight load spectra have to be considered in this analysis the amount of numerical analysis becomes tremendous and can only be managed by computer technology. Risk-analysis can help to locate the probable origin of failure by weighting the different risk-value. The five-step analysis from Fig. 1 covers the items: manufacturing detail, service conditions, design quality, strength of components, material specification. The analysis can be accomplished by a try-and-error calculus as the Simplex-Method and represents a generalisation of the elimination-technique [6.]. In general this type of analysis can be made after the first walk-around inspection of the wreckage, provided the necessary data will be available from the manufacturer. It will result in one or more hypotheses on the structural failure which are supposed to have failed first (macro-scale failure analysis). The main disadvantage of such a sophisticated analysis is the fact that the necessary quantitative data often may not be available.

Once the weakest link located and the primary-type fracture found, the fracture topography of the broken component(s) will serve to check the failure hypotheses previously established. Fracture mechanics methodology can support this investigation and sometimes will quantify the results with respect to effective load history and failure sequence (micro-scale failure analysis). Further studies can be directed versus welding and machining quality, substandard material properties, poor heat treatment, stress corrosion cracking or inadequate dimensional properties as contributing factors to the crack initiation. A discussion about the design load criteria is impossible within the confines of this paper. However it will be necessary to check the relevant regulations and design criteria, whenever structural integrity is subject of an investigation program. The following paragraphs contain some practical applications of structural failure analysis.

Fractographic analysis of the fracture surface of a one piece machined spring steel component of a non retractable cantilever main landing gear leg of a JOB 15 disclosed crack initiation due to fretting corrosion in the clamping area of the right leg. The penny-shaped, dark shadowed area in Fig. 6 represents the region of subcritical crack growth. The transition zone and the final fracture is clearly visible. Striation counting and corrosion products in the area of the slow crack propagation indicate very slow crack growth (some hundred landings). Inspection and detection of the cracked area was very difficult.

Risk-analysis of a Cessna 414 landing gear collapse led to the conclusion that during landing compression overloads were produced in components, which were not designed for such loads. SEM and metallographic analyses excluded previous damage of the failed components. Improper rigging procedures during previous maintenance activities were disclosed to be the reason for that failure. Laboratory strength-testing of a similar landing gear proved the results of the fracture analysis.

Four hours after engine overhaul number three connecting rod of a Continental I0-520-L aircraft engine failed. The fatigue fracture surface of the piston pin bearing is shown in Fig. 7. According to manufacturer's instructions the connecting rod was flaw-checked and the bushing was ground to oversize. No cracks were detected by Magnaflux testing. SEM analysis revealed that poor previous machining of the bore was the reason for axial grooves during bushing assembly at the manufacturer. The grooves in the area of highest stress concentration around the bore induced crack nucleation. During 1500 hours of flight subcritical crack growth was very slow due to the low local stress level. The crack length at the time of engine overhaul was below the applied NDI-capabilities. Striations analysis of the transition phase of the crack surface established a proper correlation between the last seven take-offs and the crack-arrest lines. Therefore it became clear, that manufacturing instead of an overhaul defect was the reason for the discussed accident. An example of the striation analysis is shown in Fig. 8.

VII. CONCLUSION

Structural failure analysis represents a successful method to improve aircraft safety. It covers all activities associated with the investigation of failures of structural components. Due to the variety of interacting parameters a successful failure analysis can be accomplished only through the collaboration of several specialists: design, maintenance, operations, metallurgy. The objective of the present discussion was limited to the primary and secondary structure of aircrafts and its lift and control surfaces. Failure analysis in its broadest sense can be applied either to unexpected occurrences (aircraft accidents and incidences) or in a more systematic manner to study the reasons of failures found during scheduled maintenance operations or laboratory testing. The results of such analyses deliver useful guidelines to prevent similar failures.

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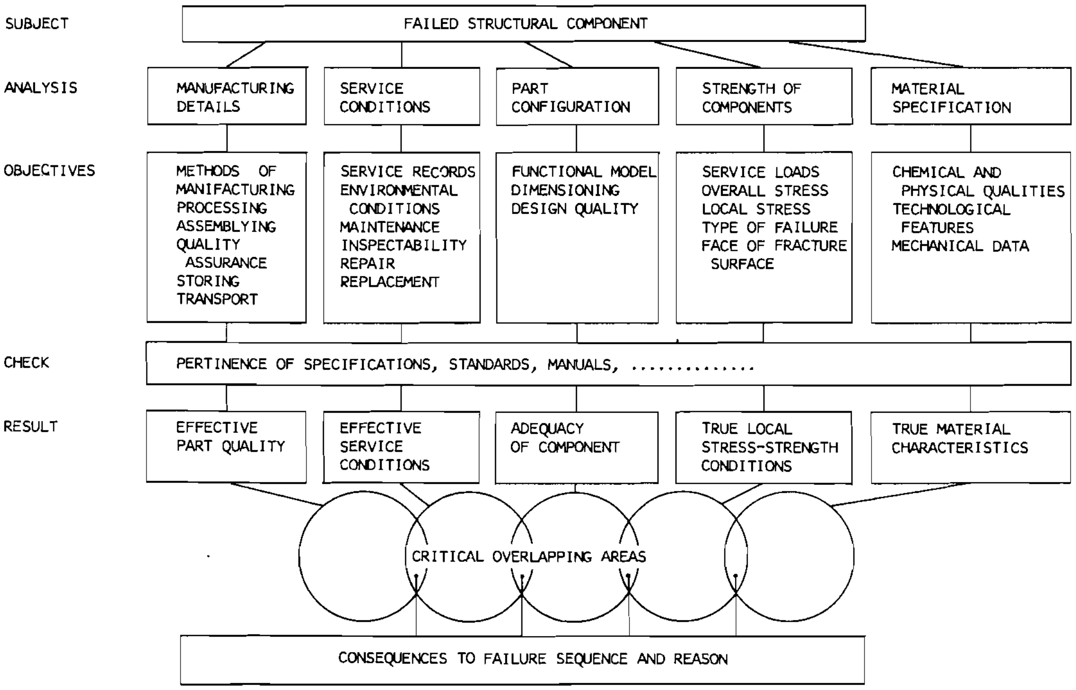


Figure 1: Flow diagram to evaluate the reasons of structural failures

MATERIAL	VISUAL +)	MAGNETIC PARTICLE +)	PENETRANT +)	X-RAY ++)	ULTRASONIC ++)	DELTA ULTRANSONIC ++)
0,25 IN EXTRUSION						
7075-T6511	0,03	...	0,25	0,50	0,25	...
4340 V	0,03	0,30	0,35	0,50	0,20	...
0,020 IN PLATE						
7075-T6	...	...	0,040	...	0,050	...
TI-6AL-4V	...	...	0,032	0,070	0,100	...
0,125 IN PLATE						
7075-T6	...	...	0,030	...	...	...
TI-6AL-4V	...	...	0,050	0,130	0,090	0,034
0,500 IN PLATE						
7075-T6	...	...	...	0,460	0,290	...
TI-6AL-4V	...	...	0,035	...	0,150	0,090

+) SURFACE FLAWS OF KNOWN LOCATION
++) BOTH KNOWN SURFACE FLAWS AND UNKNOWN EMBEDDED FLAWS

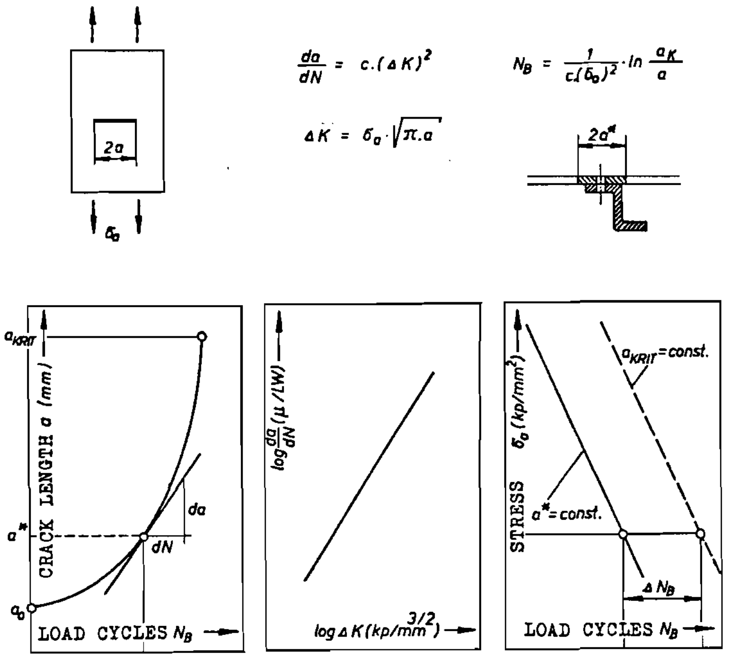
Figure 2: Capabilities of NDI inspection techniques [5.]

DECADE	PROBLEM	FLAW SIZE (APPROXIMATE)	CAUSE	SOLUTIONS
1920	FLAWS IN GLASS	1 MM	INHERENT	PHYSICAL PROPERTIES
1940	WELDED STEEL SHIPS	SEVERAL METERS (INCLUDING HATCH SIZE)	WELDS	METALLURGICAL PROPERTIES ELIMINATE SOURCE OF CRACKS
1950	CIVIL AIRCRAFT	1/2 METER	FATIGUE	REDUNDANCY
1960	SPACECRAFT	1-3 MM	WELDS AND STRESS CORROSION	PROOF TEST
1970	MILITARY AIRCRAFT	5-10 MM (INCLUDING FASTENER)	MANUFACTURING, FATIGUE, CORROSION	LIFE PREDICTION INSPECTION

Figure 3: Milestones in development of fracture mechanics and fail-safe design

ITEM	RISK VALUE		REASON FOR HIGH RISK VALUE
	LOW	HIGH	
MATERIAL			
CHARACTERIZATION	X		4340 STEEL WITH $\sigma_U=1750-1950$ N/MM^2
LIMITATIONS		X	LOW TOUGHNESS
MANUFACTURING SENSITIVITY	X		
MECHANICAL SENSITIVITY		X	NOTCH SENSITIVE
ENVIRONMENTAL SENSITIVITY		X	STRESS CORROSION
AVAILABILITY DEVELOPMENT STATUS	X		
PERTINENCE OF SPECIFICATIONS	X		
DESIGN			
PART CONFIGURATION	X		
MATERIAL ADEQUACY	X		
PROCESSING REQUIREMENTS	X		
PREMATURE FAILURE CAUSES			
STATIC STRESSES	X		
CYCLIC STRESSES		X	HIGHLY STRESSED PART
FRACTURE MECHANISMUS		X	SUBCRITICAL FLAW GROWTH
CORROSION	X		
PROCESSING INDUCED DAMAGE		X	POST HEAT TREAT MACHINING, PLATING
PART QUALIFICATION			
FAIL-SAFE/SAFE-LIFE	X		
DAMAGE TOLERANCE		X	MONOLITHIC PART
SERVICE RECORD		X	HIGH MORTALITY RATE IN SIMILAR PARTS
DAMAGE DETECTION		X	CRITICAL AREAS OBSCURED IN SERVICE
REPAIR/REPLACEMENT EASE	X		
MANUFACTURING			
PLANNING/PROCESS CONTROLS	X		
PROCESSING METHODS			
ADEQUACY FOR PART	X		
POTENTIAL FOR DAMAGE		X	POST HEAT TREAT MACHINING, PLATING
QUALITY REQUIRED	X		
FACILITIES/EQUIPMENT	X		
PERSONNEL TRAINING LEVEL	X		
QUALITY ASSURANCE			
TESTING METHODS			
DEVELOPMENT STATUS	X		
DETECTION LIMITS		X	SMALL CRITICAL FLAW SIZE
INSPECTION OF RAW MATERIAL	X		
PROCESSING/ASSEMBLEY CONTROLS	X		
PART INSPECTION		X	PART SIZE MAKES INSPECTION DIFFICULT

Figure 4: Sample risk profile, main landing gear strut from a transport aircraft



.a(i),N(i) DATA
FROM CONSTANT
AMPLITUDE TEST

⇨

APPLIED CRACK
GROWTH
EQUATION

⇨

EVALUATED
S-N DIAGRAM
a^*... LARGEST
OVERLOOKED
CRACK
ΔN ... INSPEC-
TION INTERVAL

Figure 5: Applications of fracture mechanics on fatigue crack growth data analysis

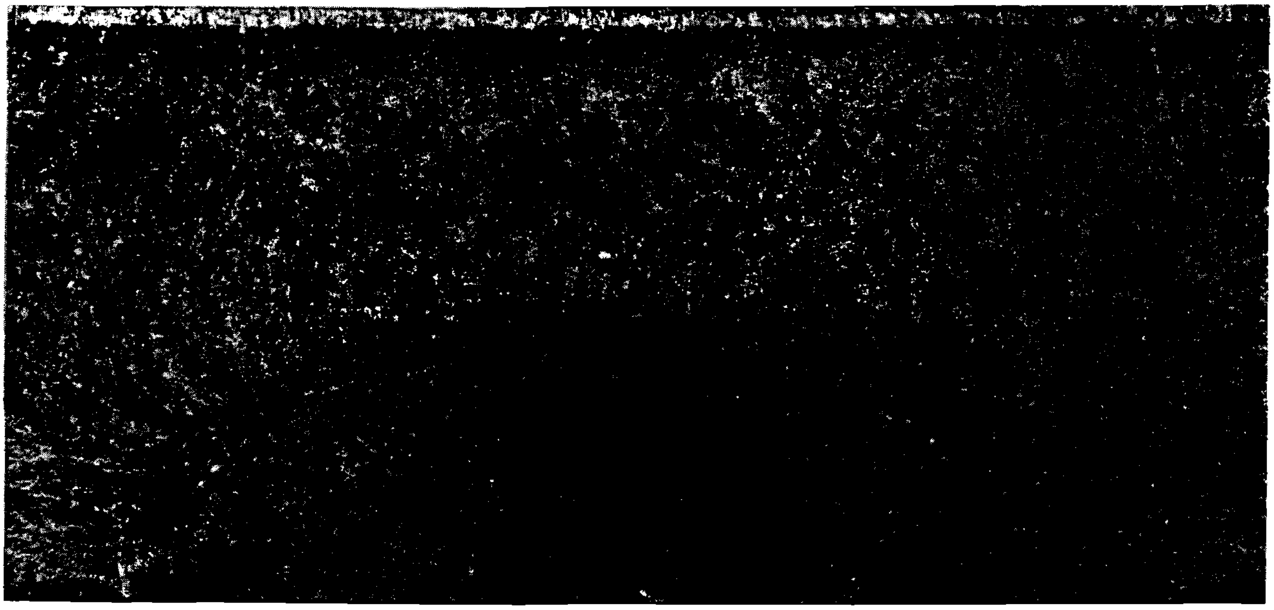


Figure 6: Fracture surface of a one piece machined spring steel component, JOB 15 main landing gear 4X

Figure 7: Fatigue fracture surface of the piston pin bearing of a connecting rod IO-520-L Continental aircraft engine 40X

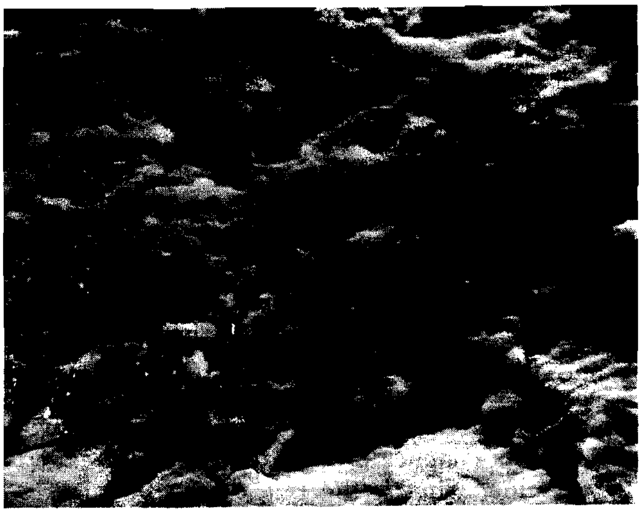


Figure 8: Striation analysis on the fracture surface from Fig. 7 4000X

AIRCRAFT ACCIDENT INVESTIGATION IN THE MARINE ENVIRONMENT

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The task of aircraft accident investigation is basically an exercise in coordination, teamwork, and painstaking expert analysis of on-scene evidence and corroborative data. This evidence, both physical and non-physical, is vital to the investigative analysis process. When this evidence is further amplified by the wealth of flight experience and knowledge, both resident in, and available to, the accident board, the overall result is most often a sound judgement as to "cause." This "cause" finding is normally accompanied by a recommendation as to "cure" in order that further similar occurrences will hopefully be prevented.

The task, however, of aircraft accident investigation in the marine environment, or more directly stated, in the water, can very often be an exercise in futility. This is so quite simply because there is little or no visual physical evidence of the accident.

Those sign posts most familiar to the accident team such as path of impact, debris distribution, and debris field size are not immediately at hand. The ability to be able to identify, plot, and tag parts for analysis, or to merely take photographs and measurements is not available. Obvious physical or visual evidence such as fracture locations, fire damaged parts, or possible pieces which could have come loose and caused the crash are not apparent to be seen by the trained, experienced eyes of the investigative team.

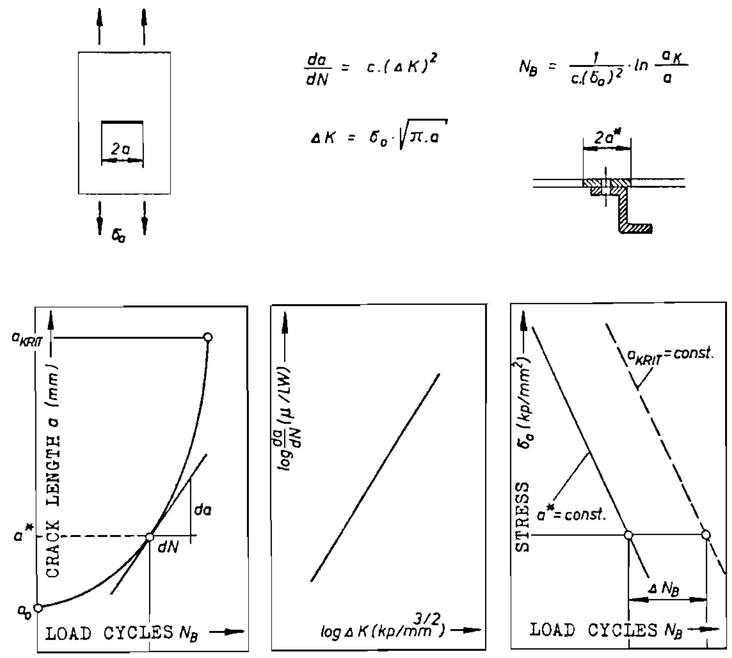
How then does the well developed aircraft accident investigation process proceed? What then does the Accident Board President or Investigator-In-Charge do with the wealth of experience and multi-disciplined talent pool available to him?

Now certainly, some basic investigative steps can be taken—a few of which are witness interviews, ground control personnel interviews, document and records checks, in-flight weather and communication log checks, and so on. In the majority of marine crashes, however, once these initial steps have been followed, the work of the various investigators and team will slowly grind to a halt until further tangible evidence can be located and examined. Herein lies the problem that faces the investigator. SHALL THE INVESTIGATION PROCEED?

This paper *is not intended* to answer that question. It *is intended* to assist the investigator by answering some of the typical questions which have become obvious during the past years. It hopefully will be of assistance to those who may have to address a similar situation in the future.

Some key questions which immediately come to mind are those which appear in the overall decision-making process such as:

(1) Can a determination or finding as to cause be made without the presence of tangible physical evidence?
(2) How critical *is* the determination of cause to the aircraft flight safety program?



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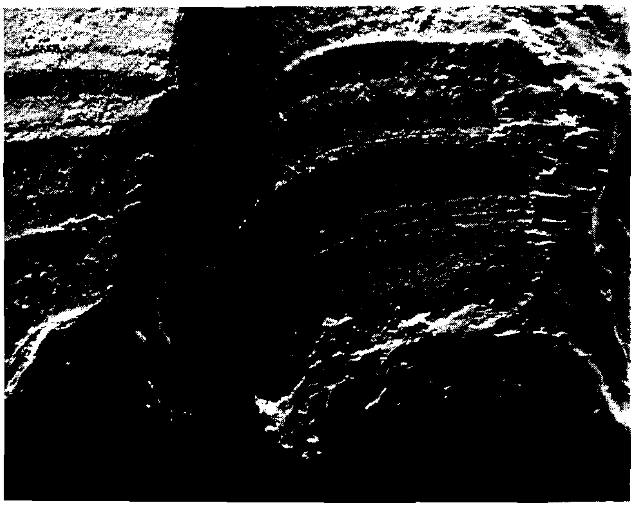

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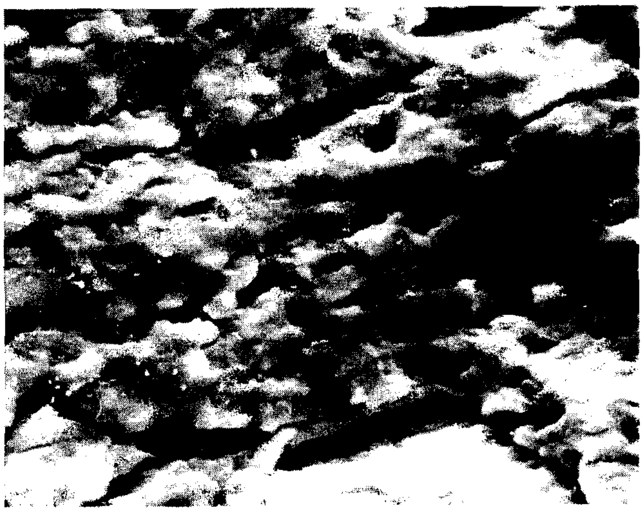

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Some key questions which immediately come to mind are those which appear in the overall decision-making process such as:

(1) Can a determination or finding as to cause be made without the presence of tangible physical evidence?

(2) How critical *is* the determination of cause to the aircraft flight safety program?

(3) What are the probabilities of success—of the search phase and, of course, recovery effort?
(4) A very important one—what is the approximate cost and time required to locate and recover such evidence if it is sorely needed?
(5) Most probably, a final reexamination or trade-off study of the relative importance of such a determination of "cause," when weighed against the cost, time and success figures presented.

Now, let's presuppose a hypothetical case in which an aircraft has been lost over water with little or no evidence present for a team of experts to examine. What is the role of the Board President or Investigator-In-Charge? It would appear at once that the most important first objective would be to determine if the search for location, and recovery of such evidence is vital to finding of "cause." Having made such a determination, and once again presupposing that it is an affirmative one, the investigator must have sufficient factual information available to him to be able to arrive at a decision to proceed with the investigation or not. Alternatively, and perhaps in many cases, he must be able to present this information to his superiors fully supported by such data as cost, time, and probabilities of success. His own judgments and experience as well as those of his team should always be added as a recommendation to assist in the final decision-making process.

The questions which immediately then come to mind, of course, are:

(1) Where does the seasoned land investigator get this information?
(2) To whom does he turn to have made available to him such factual information that he can make a valid judgement?

Unfortunately, the Accident Investigator-In-Charge, the Board President or whoever he may be, will normally be beset by all sorts of advisors immediately following a crash into the sea. Some of this advice will be well meaning and well intentioned. It may also be very misleading. Other advice may be keyed to the commercial aspect, that is, the provision of a multitude of costly equipment, none of which may be suited to the task. Others will be again well meaning, but just not very factual. How then does the land investigator, or the person experienced in land crashes, but perhaps not familiar with marine situations, proceed?

One technique, of course, which can be implemented by most governmental agencies is to have on a consulting or contract basis, a marine expert who can counsel or advise the investigators on a part-time basis, especially when such crashes occur. Another alternative is to have as a marine member, an experienced consultant who is available to travel with accident boards when and if there is a marine crash. The problem here is that he may not always be available, so it is probably best to have one leading member and an alternate provided. A third course of action is to get this type of expertise after-the-fact, or after the investigator has arrived on scene. Here the investigator must determine for himself that while there may not be enough evidence at hand to fully employ the talents of his team members, there is a chance that such evidence might be reasonably collected. This latter suggestion, however, is not recommended unless no other recourse is open to the Investigator-In-Charge. The reason behind this negative suggestion is that the earlier that a marine member of an Accident Board can arrive on scene, the more pertinent is the information that he will be able to collect. Facts tend to get blurred after a few days or weeks. It will always prove better for a marine member to arrive on scene with the first group of investigators.

Not only does an early arrival give the marine investigator a better chance to evaluate the initial information, it gives him more time and wider latitude to select the most proper course of action for recommendation or counsel to the senior member. Further, the presence of a marine member on scene from the beginning acts to protect or insulate the Investigator-In-Charge from those well intentioned free advisors who tend to appear from every direction. His presence, therefore, will not only help in more learned advice to the senior investigator, but will allow the senior investigator to go about those other investigative tasks that can be followed from the outset. At the least, it may permit him to better coordinate the activities of the other members of the team. For example, one of the sub-tasks that must be addressed early on is a list of questions which need to be answered in the event that an offshore search is instituted. Following this, a list of items needs to be made up, whose physical recovery might better help define the accident cause for the Board of Investigators.

Fortunately today, almost all commercial passenger aircraft have acoustical sound sources rigidly attached to both the flight recorder and the cockpit voice recorder. These, of course, depending on their location in the debris would probably be one of the first items sought after by the investigators. Where there are indications of engine malfunctions, air frame malfunctions, or flight control problems, these can be listed in a descending order of importance for possible recovery should the determination be made to press on after the feasibility and success probabilities are analyzed.

Today, deep ocean searches in waters of far greater depths than formerly thought possible can be achieved. There have also been advances made in the acoustic hydrophone field so that the initial location of aircraft debris by the pinpointing of the acoustic sound source is more of a reality today. The TWA crash just a few years ago in the Ionian Sea was a good example. Here in water depths of over 10,000 ft. the pinger, or acoustic noise source, was heard and its location determined. Fortunately in this case, there was apparently enough surface debris to help point to the cause of the tragedy. More recently several military aircraft have also been initially located by virtue of an installed pinger which, while not displaying the debris or its disposition, did lead the underwater search team to an earlier location thereby saving not only valuable time, but valuable dollars.

Based on the best estimate of time required for both the search and recovery phases, it may also be worthwhile for the Investigator-In-Charge to consider a temporary suspension of part of the accident investigation team in order that some of the talents not able to be utilized during this period can be more effectively employed elsewhere. Such personnel as the medical examiner, air frames, or power plant experts may be needed elsewhere in the short term. Certainly if they could be released they might be better employed during the time the search, location and pre-recovery phase is taking place. It probably would be advantageous for the senior member plus one or two other members of the team to remain on scene as the search progresses to review daily findings with the search experts. Very often a great deal of information can be gleaned from records of search sonar. For example, once located, it is fairly easy to define the limits and disposition of debris fields, as well as to point out the larger pieces of wreckage.

In a recent search off Korea, the search team involved was able to almost pinpoint the location in the debris field of an ejection seat that had malfunctioned. Following the location, the seat was photographed and recovered using a remote vehicle. This is not always possible of course, but is pointed out as the type of results that can be obtained when a selective process is employed to utilize the best talents and equipment available.

As we all know, an offshore crash will most probably take place in either the most remote of locations or in an environment at sea where the water is very rough, stormy or deep. It most likely will also occur in an area where the bottom topography does not lend itself to easy location of the debris. Therefore, should a search be decided on, the pre-task analyses becomes a key to the success or failure of the mission.

(1) Where is the best location to look?
(2) What is the best equipment to use?
(3) How can the overall search effort be best employed?

Again, from all of these comes the time and cost estimates which are so important, as well as the probability of success.

Let me counsel here, that a successful search by no means infers that there can be a successful recovery. As in the case of the crash in the Ionian Sea, although the pinger was located, no further actions were undertaken. This stand-down or termination of the effort was for good reason since the capability to search for and recover items from depths of 10,000 ft or more is, for our purposes, non-existent today. Were such a package able to be put together however, it would be prohibitively expensive and extremely time consuming. Therefore, any and all data must be carefully researched before such a mission is authorized to proceed. Just as there are experts used in the fields of air frames, power plants, medicine, etc. so too should an expert, or a person widely experienced in marine matters be utilized for aircraft searches in the water.

Along this vein, it should also be mentioned here that by no means should the volunteer or individual quick response efforts be discounted or discouraged. Very often, especially in the shallower depths or close-in shore environment, the volunteer, quick and enthusiatic response will bring miraculous results. While this type of effort should always be considered and possibly encouraged, there are some caveats to be addressed here. First of all, the question of legality and safety should be looked to with an appreciation towards what may happen to the volunteer should an accident occur, especially the sport diver. Secondly, the question of direction once having found the wreckage, who directs the recovery effort; what is done with the debris; and, of course, the publicity aspect. This again, would probably more come under the purview of the Investigator-In-Charge, but it is mentioned in passing.

As a qualification to this paper, what is being spoken to are the searches where the aircraft has disappeared with little or no trace, and where the location, the bottom, and the seas are demonstrably hostile to the normal type of accident investigation.

Although it has not been addressed before, weather can have a most serious impact on any phase of the overall offshore project. Heavy weather can derogate the sonar records, can prevent the ship from steering an orderly, continuous course and can, of course, cause damage to all of the equipment which must be carried on board. As a case in point, the recent F-14 crash, location and recovery in the Northern waters off Scotland was an excellent example of how weather can cause problems. The weather derogated the search effort to the point where it took six days to find the aircraft instead of two or three. The storms in the area also caused serious navigational inaccuracies and breakdowns, thereby costing the search effort many extra days and many extra dollars in the overall effort.

It is not the purpose of this paper, however, to present a listing of the facts which bear on search and recovery at sea; they are too manifold to consider here. Rather, it is to apprise the members of the various aircraft investigation boards of the problems which they will be faced with when a crash occurs offshore or in the deep ocean.

Once the pre-task analysis has been completed and the various equipment and personnel selected, they will naturally be put to useful work in the water. It will most probably be at this point that frustration sets in for those members of the accident board who are retained on scene, for it is at this point that the expertise and wealth of training available is minimized. Even after the wreckage is located, those investigation board personnel will have to depend on the free flow of communications and exchange of ideas to get the best grasp of how the debris is, where it is, and what must be done next. Once having found and recorded the area of debris, the process becomes an educational or learning phase for these various team members by the communications exchange between those who are best qualified to make the records interpretation (and by this I mean the search team), and those who are best suited to receive and comprehend such information (the investigative team).

Let us assume for the moment that an aircraft is down offshore with a pinger or acoustic noise source attached. If the search is felt to be reasonable and feasible, then step one would probably be to try to locate the pinger source to better define the search area. This area should then be covered by some sort of bottom mapping device which would provide a permanent record for use by both the search analyst and the accident investigation team. Now it may be, having once found the pinger, that the impulse would arise to just go straight out and attempt the recovery. While this sounds like an excellent idea, it may well be that the pinger and its attachment point to the aircraft might have become separated and be lying some distance away from the actual debris in murky water. It has actually happened that the pinger has been found almost half a mile away from the main area of debris. Debris fields have been found that extend for 1000 meters. In the former case it should be noted that divers could not find the debris field even though they had been searching in random circles nearby for a number of days.

So Phase Two in this case would be to obtain a permanent record of how the debris field lies, where the larger pieces are, how big and how high they might be. Then utilizing the free-flow of communications, and probably some sketches of the aircraft, a quite valid determination can be made as to which pieces should be located and recovered within the debris field. Once more it should be stressed that the search analyst or interpreter is more likely to be a greater expert in debris field determination than the accident investigator. This does not come from any super intelligence, just good old fashioned experience. The more experienced the team of searchers are, the better service, the better answers, will be provided the Investigator-In-Charge. Once, of course, the perimeters in the debris field are laid out and the disposition of the wreckage reasonably determined, then a good constructive recovery plan will readily present itself or can more easily be formulated.

The typical recovery process is neither very speedy nor very rewarding in the short term. Work on the sea floor is difficult at best. It is slow and time-consuming and usually very costly. Here too, frustration can set in for those members of the accident team who, having once been advised that the wreckage is found, cannot directly view or directly take part in the recovery process. This is especially true if it is to be a selective one. Again, the communications flow must take place. It may be that diving personnel inexperienced in air frames or aircraft will have to be sent down to examine and select that wreckage most urgently needed. This process can be very time consuming, especially in murky water. And, with the inexperienced personnel just mentioned who may not be able to recognize the pieces sought after, especially after impact damage, the ability to educate these personnel by clear, concise communications is paramount.

Points worthy of mention here are the considerations to use a submersible or an underwater television with video tape prior to any recovery process. If a submersible is used quite often a knowledgeable member of the accident team can be embarked thereby gaining for the entire team a first-hand account of what lies on the bottom from the eyes of an experienced aircraft analyst. This technique has been used several times with very effective results. Actual cases have been in Greenland, offshore Mexico, and, of course, just off Caracas some years ago when the wreckage of a 707 was located. In the Caracas case, it was found that excellent TV visibility was at hand.

Therefore, a complete and thorough survey of the debris field was made using television and video tape with the aircraft experts topside aboard ship viewing the screen. In the cases mentioned in Greenland, a knowledgeable aircraft expert was able to see firsthand the evidence on the bottom, describe the details, what was needed, and recommended how best to go about recovery. Offshore Mexico, in about 5000 feet of water, the same technique was used to great advantage when a Navy fighter aircraft was located. The aircraft expert accompanied the submersible pilot to the bottom where the aircraft was located, photographed, and the parts needed recovered. The aircraft expert provided complete data as to the disposition, number of pieces, sizes, etc.

It would therefore appear very judicious to utilize these services if it is at all possible. This will accelerate the recovery task and make the entire operation more efficient.

In almost every case, some means of visual contact with the bottom should be employed prior to recovery. Helpful commentary and/or judgment from team members, either topside or in the submersible, are most advantageous. It must be remembered carefully that the people who are used to effect the recovery very often know little about aircraft. In the case off Greenland the Chief Engineer of the airline involved was embarked in the submarien, and in several hours furnished more valuable data than the 2-man submarine crew had been able to give in several days. This is not spoken of in any way as a derogation of the submarine crew as to ability, but merely to point out the fact that they had no prior experience in aircraft wreckage recovery.

Going back to the televison and video tape survey, the ability to record the debris field on video tape allows the entire services of the team to be brought to bear to determine which pieces should be recovered first and how best to go about it. It must be remembered again that if diving personnel are utilized their experience in aircraft wreckage, and in handling is minimal at best. So the reverse communication effect must take place. Where formerly the sonar interpretor advised the board, the board, in this instance, can advise the recovery diver.

During the recovery process damage to wreckage sought after should be minimized or hopefully prevented. Again, the free flow of communications will assist either the diver, the submersible personnel, or the remote vehicle operator from further damaging any debris attempted to be lifted from the bottom. Careful pre-recovery preparation can also minimize another cause of damage. This is the damage which occurs after the debris is brought to the surface and exposed to the open air. Without either a thorough fresh water washing or some detergent chemical washing, the salt and air will cause extensive damage to much of the air frame and engine parts. The recovery rigging, whether it be wire, grapnels or chain slings can also cause damage to debris which should be noted at once by the investigators upon surface recovery.

There are many milestones in any aircraft accident investigation. Certainly too, there are milestones in offshore aircraft accident investigations. Some of these, of course, have been noted earlier such as the time, cost, feasibility, and various tradeoffs. Having once made the decision to press on there is another milestone during the search phase which must be faced by the Investigator-In-Charge. This milestone is a question. At what point is the search discontinued purely because of financial or economic reasons? Another milestone to be faced during the recovery phase is at what point is enough wreckage in hand to make a finding or determination?

The Aircraft Investigator-In-Charge faced with an offshore crash does not have the most welcome option of taking his time, or allowing time to proceed. There can be serious damage to debris in the shallower depths where concentrated salts and/or oxygen are present. There can be serious damage to bodies on board due to fish or other organisms. There can be extensive damage to the cockpit voice recorder or flight recorder should they be allowed to remain in the salt water environment for too long a period of time. Therefore, a judgement must be made early on using the criteria mentioned herein to determine whether to proceed with the investigation or not.

This paper, of course, points toward the Accident Investigation Board and is not tailored to the requirements of other activities or exigencies. Certainly were it vital that a search and recovery program be initiated for security or other considerations, the Accident team would benefit from their findings. However, the "decision-tree" faced by an Investigator-In-Charge when involved with a marine crash is a difficult and arduous one. It is hoped that by presenting this food for thought their task may be made less difficult.

THE COCKPIT VOICE RECORDER, ITS CAPABILITIES AND LIMITATIONS

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The air safety investigator, searching for the causes of an accident involving a turbojet aircraft, is becoming more and more dependent upon the data provided by the cockpit voice recorder (CVR). The recorder's capability of directing the investigation toward areas that might be related to the cause can save time and expense for the investigator. As modern aircraft tend toward the increased use of electronics in their onboard system controls, it is becoming more difficult after the accident to research the status of the systems prior to the accident so it is, therefore, imperative that the investigator be aware of the capabilities and limitations of the CVR and be able to relate its record to that of the flight data recorder and other flight profile information sources.

In relation to recording equipment available to the general public, the cockpit voice recorder is a relatively low quality piece of recording equipment. A much better recording of the events in the cockpit can be produced by using a portable recorder that can be purchased for less than $50. The reasons for the quality of the CVR recordings can best be understood by reviewing the development of the equipment.

The cockpit voice recorder was required to be capable of recording the voice sounds from the cockpit and radio channels and to be able to protect those recordings in the event of an accident. At the time of the requirement by the regulatory agencies, there was not a widespread industry enthusiasm for the recorder. This produced a desire to fulfill the regulation at minimum cost. The manufacturers naturally sought to provide a recorder that would be acceptable to the industry and at competitive costs. The costs of developing and certifying a crashworthy recorder are extremely high so to achieve a reasonable price, the recording device in the CVR was apparently given a lesser amount of attention in the original design stages. It should be noted that all of the CVR's produced today meet or exceed the design requirements of FAR 121.359, FAR 25.1457 and TSO C84 but it appears that these requirements are in no way adequate for the purpose of cockpit voice recording. The manufacturers have built and the carriers have installed and operated CVR's that meet the requirements of the regulations but fail to meet the intent. It is interesting to note that very few changes have been made in the CVR, even in light of repeated documentation of their deficiencies.

Operationally, the recorders are operating at a disadvantage because of design. The radio channels of the recorder do a good job because there is no extraneous noise, but the Cockpit Area Microphone (CAM) is being asked to do an almost impossible job.

The Cockpit Area Microphone is generally placed in the overhead instrument panel of the cockpit. Its parabolic area of best reception is directed downward toward the crew. But it is not just directed toward the crew, it is also directed toward some more significant noise makers in the cockpit such as the landing gear handle, flap handle, warning horns, fire bells, trim wheels, speed brake levers and any other noise made in the lower half of the cockpit. It is also placed near the variety of switches on the overhead panel that, when used, make an overpowering noise on the recording, much like that of hitting the microphone with a large stick.

The cockpit speakers can totally overpower all of the other noises in the cockpit if used. It is natural for the crew to turn up the volume of the speakers to a point at which they can hear the speakers above the other cockpit noises. In this way a conversation on the radio from a ground station to another aircraft can totally mask a statement of the recorded aircraft's crew in the cockpit.

With one microphone all of the various noises that are produced in the cockpit must be blended into one sound to be recorded on the CAM channel of the CVR. As an example, at any one time the CVR could be recording on the CAM channel the composite noises of aircraft engines and wind noise, two or more crewmembers talking, radio conversations on the cockpit speakers, the trim wheel turning, switches being thrown and possibly a warning horn or bell. A microphone records by converting the pressure of the combined noise it is receiving into an electronic signal to be recorded. It is, therefore,, not surprising that the final recording is a garbled and distorted reproduction of the events that occurred in the cockpit.

The regulations for the maintenance of the CVR are similar to the requirements for the quality of recording—inadequate and ineffective. It is not unusual for the investigators to receive a tape from an accident on which one or more channels of the tape were inoperative or were recorded with such a level of distortion as to be undecipherable. The build up of the tape oxides on the heads, incorrect tape tension, incorrect adjustment of recording levels and extreme erosion of the recording heads are the most common mechanical problems observed in the subject recorders. Occasionally, a recorder is found to actually have the recording heads or the erase heads misaligned or in the wrong position for recording on the tape. The standard maintenance practice is, when it is performed, simply to check that a signal input to the recorder is recorded. There is no check for the quality of the recording capability.

Therefore, the air safety investigator working with the CVR is faced with the problem of deciphering a tape that was produced by a recorder that was designed as the absolute minimum to accomplish the job and then probably has not been maintained to achieve even that design level of performance.

In the event of an accident, the CVR should be removed from the wreckage area as soon as possible. This is especially true in the case of extensive fire damage. The heat that the tape will receive in its protective case is directly related to the heat of the fire surrounding the recorder and the time of exposure to that heat. The record of tape protection within the CVR is very good, but prolonged heating can produce a loss of information or distortion of the recorded signal.

When the CVR is removed from the wreckage it should be enclosed in a protective packaging and transported by an authorized person to the place at which the tape playback will be made. Under no circumstances should the tape be removed prior to arriving at the recorder laboratory. It is also recommended that the tape be protected from all magnetic and xray devices such as those used in airport security equipment.

In the United States, the National Transportation Safety Board (NTSB) uses the group method of interpreting the voice recorder data. The interested parties that are designated by the NTSB provide the manpower to assist the Board's laboratory technicians in the interpretation. The desired makeup of the committee is of persons that are experienced with the accident aircraft type and with the personality and voices of the crewmembers. This provides an additional insight and familiarity that promotes a better understanding of the recording, because although certain technical procedures are sometimes used, the interpretation of CVR recordings is an art and not a science. Therefore, it is of great assistance to have several committee members that are experienced in the art and technique of CVR accident investigation.

When the original tape is removed from the CVR and prepared for playback, two copies of the original should be made for use by the working group and the original tape then stored in a safe place. Because the recording contains many extraneous noises and considerable distortion, it is imperative that the playback equipment have the optimum retrieval capabilities. One of the most important is to be able to move the playback heads back and forth across the tape to obtain the maximum recorded signal strength so that the playback heads will be in the same position as the recording heads were. Most of the microphone capabilities are in the range of 350 to 3500 hertz. Since the normal range of hearing is so much larger it is imperative that we at least reproduce the data as well as it was recorded. During the interpretation of the recording, it is important that each person listen to the tape and record their own interpretation of the sounds and not be influenced by other members of the group. A hearing bias can occur in which the listener will actually hear whatever has been suggested. If each member of the group will listen to the tape and decide what they think the voices are saying and then compare their notes with the other members of the group to resolve their differences, it will avoid the alteration of recorded voice components when preparing a transcription. As the recording is normally difficult to understand, it is reasonable to record uncertain statements as unintelligible for a misleading comment can throw a whole investigation off track.

After an initial transcription has been made, a report should be made to the investigator-in-charge at the accident site. He can then direct his investigation toward areas of concern and relate his findings to those of the voice recorder and flight recorder groups.

The tapes should be maintained in the closest security and the information derived from the tapes should be considered as classified until the time at which the investigating agency decides it is proper to release the information. The news media and public speculation can distort the statements made on the tape.

Because certain statements contained could be non-pertinent to the aircraft operation and were basically intended as private conversations between crewmembers, it is felt that they may properly be omitted from the transcript. These statements must be considered by the group on their merit and included or omitted according to their relevance. The tape should be permanently retained by the investigating agency in case a further study should become necessary. Above all, it must be remembered that the CVR is an accident investigation tool only.

Outside of recording voice sounds, the CVR can be useful in the recording of other data beyond its original intent. One example is determining engine power settings on aircraft with wing mounted engines. The speed of the N_1 compressor can usually be determined by the identification and tracking of the sound imprint made by the engine. By observing the change of frequency of the N_1 compressor blades rotation, each engine's power output can be determined and related to a profile established by the flight data recorder to provide data for energy analysis or other performance studies that might provide useful in the investigation. These engine power studies are very complex and require sound analysis computers available only in the most sophisticated sound laboratories, such as those of General Electric or the Bell laboratories.

In some accidents, the data from the FDR is unusable or unavailable. In these cases, the CVR can often provide extensive data that will assist in establishing the aircraft's profile and flight path. One simple example would be crew statements concerning crossing intersections or navigational points of reference. A more finite example would be to use the Brush Pen Recorder to visually identify the sound of the passage of a navigational facility, such as an outer marker, and then overlay this with a navigational facility flight check aircraft's recording of the station passage and determine the exact point on the CVR that the aircraft was directly over that position. The profile may then be established by working forward or backwards from that known point in time and position over the ground.

The recorder's timing can be checked by comparing the time between transmissions on CVR with the transmission binary marks on the FDR and by comparison with the Air Traffic Control (ATC) tapes. This provides a timing check on all of the recording equipment used in establishing the aircraft flight profile.

Due to the extreme distortion often experienced in the aircraft wreckage it is often difficult to determine the position of some of the controls prior to the accident. It is, of course, also desirable to establish the sequence of the placement of these controls into certain positions prior to the accident. In some cases, movement of these controls can be identified by their sound pattern signature on the Brush Pen Recorder.

An example would be that the CVR group identifies a sound that is believed to be a flap handle movement. A recording of the flap handle movement into and out of all of the various positions can be made and then a Brush Pen Recorder signature can be made of these sounds. When the test recordings signatures are compared with the accident signature, the actual positioning of the flap handle can be identified by a statement such as "flap selector handle moved from 15 to 30".

There are many other clicks, noises, squeals and sounds that occur in the cockpit and are recorded. Some can be identified and others cannot. Sometimes the sound is distorted by the blending of several noises that might occur simultaneously. But the capability of the CVR to produce evidence that is more extensive than just the recording of voices is a great asset to the air safety investigator. If the investigator-in-charge is familiar with the capabilities and limitations of the recording equipment and the methods and techniques of information retrieval, then he will be much more qualified to interpret the transcript provided to him by his CVR group and will be able to determine what further studies might be required of the CVR tape to support his investigation. It might also be said that he should also be on very familiar terms with his CVR technician and know his qualifications and capabilities in working with the tapes. The technician must be willing to spend long hours with the tape and be imaginative enough to suggest what data can be retrieved by various methods. If the technician doesn't accept the role of the artist-investigator, then the investigator-in-charge must provide the driving forces to avoid losing potential data. The recorded data is not in a simple black and white form, but rather in a jumbled maze that can be as difficult to separate as that of the physical wreckage. It is up to the investigator to separate the clues and be able to support his position by the imaginative use of scientific process on a very difficult piece of evidence.

LESSONS TO BE LEARNED FROM COCKPIT VOICE RECORDERS

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This paper is intended to highlight some of the lessons learned from the often sad experiences of those who have gone before, as derived from the cockpit voice recorder (CVR) as the sole data source. The examples used herein were randomly selected to illustrate the title of the paper, and the reader should not be misled into believing that these are the only lessons to be learned. The examples do, however, represent situations which can be described in a relatively few words, without the need to provide a wealth of background on all of the circumstances which may have had a bearing on the accident.

Early on in the history of the use of CVRs, in 1966, it became evident that it is not a particularly good idea to demonstrate a simulated four-engine flameout approach in a Boeing 720, especially without having established well in advance a safe value of height above airport at which the demonstration will be terminated by either pilot should there be any question in his mind about his or the other pilot's ability to complete a successful landing on the *runway*. Shortly thereafter, there was presented an example of the application of habit reversion, when a Boeing 727 pilot who was currently also flying Martin 404s and F-27s, was faced with a complete brake failure while in the last stage of taxiing into the arrival gate. His instinctive reaction, according to his post-accident remarks recorded on the CVR, was to reach for the emergency brake handle, at its location on the Martin 404. He next reached for it in the location where it is found on the F-27. Finally, as he reached for it in the Boeing 727 (straight ahead and at eye level in front of him) the terminal building was coming into and through his windscreen (as he put it); the aircraft was crashing into the gate extension of the terminal. All of the foregoing transpired over a six-second period, while the airplane was moving at an average of 5 knots.

The following year a lesson was relearned concerning the dangers inherent in the peer group syndrome as applied to training situations. At the same time it was discovered that to practice in an airplane the maneuvers associated with a four-engine transport operating with numbers one and two engines at flight idle, and compounding the situation with three additional emergencies (simulated), could have catastrophic results not only for the occupants of the airplane but also for a considerable number of innocent citizens on the ground as well. After very little reflection it was decided to remove the scene of such training to a flight simulator, as this environment was infinitely more forgiving of any error which might be committed during this exercise.

In 1968, it was decided on the basis of a tragic experience, that when encountering a single hydraulic system failure in a Boeing 707 during the go-around phase of a three-engine ILS approach, one does not shut down *all* hydraulic pumps and thereby cease the accumulation of hydraulic pressure necessary to operate the airplane's rudder boost system. Alternatively, if it becomes necessary so to do, the pilot *must immediately* discontinue the engine power asymetry associated with the three-engine operation, either by advancing the power lever on the retarded engine to a point where thrust is being generated, or retarding thrust on the opposite side of the airplane. Failure to act accordingly *without delay* was shown to have catastrophic consequences.

In 1969, it was learned that a CVR tape will survive without damage for a considerable number of weeks while submerged in sea water, *provided* that air is not allowed to reach the tape after its recovery until the recorder is opened and the tape dried as it is removed for examination. At the same time it was found that it is not the best idea in the world to cause a Boeing 727 to be dispatched with one of its three engine-drived generators inoperative, particularly when a battery-powered standby artificial horizon instrument is not available for use by the crew in the event of the necessity to shut down one of the two remaining engines with operating generators.

In 1970 we learned, through the experiences of an air carrier in a neighboring country, that after missing the only approved instrument approach procedure (an NDB approach) to a back-country airport in hilly terrain because the weather was "below minimums," the reason that a turbo-prop airliner crashed was that the crew was executing a VOR-DME approach of their own design to the reciprocal direction, using navigation signals from a VOR 38 miles distant and DME data from another site 55 miles away. The last conversation on the CVR tape prior to impact consisted of remarks concerning the flags showing on the navigation display, probably due (as remarked) to the shielding effect on the signals of the intervening hills. In view of the circumstances revealed by the CVR examination, no further detailed examination of the wreckage was required, beyond routine verification that no other causal factor existed.

As time progressed it was to be expected that pilots would be improving their professional attitudes and performance, yet 1971 brought the spectacle (that word is chosen in lieu of "example," since it was *not* an example, as that term is normally defined) of a captain executing an instrument approach over water who disregarded *five* specific warnings from his First Officer that the aircraft was descending *well* below minimum authorized altitude with no forward visibility. The predictable result was that a violent head-on encounter ensued between the airplane and a house on the shore 29 feet above airport elevation and about one mile short of the runway. The house was not declared the victor of this encounter, but, then again, neither was the deceased captain nor any of the passengers.

1972 brought the realization, among other miscellany, that a sweet-sounding "C" chord cannot truly be called an aural alerting or warning signal for an altitude alerting system on a wide-body jet aircraft. Although the accident to which reference is made had a multitude of interlocking causal factors, one of them was the inadequacy of the aural signal warning the crew that the airplane had deviated from its assigned altitude.

Throughout all of the years of the existence of CVR records there have been produced repeated examples of aircrews who, either with or in the absence of warning messages from external sources, proceed into weather conditions which are or should be observed by them on their weather *avoidance* radar (emphasis supplied intentionally) to be potentially (or even most likely) hazardous to their safety and that of those in their charge.

Most of the lessons learned have been put to their appropriate use; i.e., corrective action of a permanent nature was taken in regard to practice, procedure, checklist, equipment, etc., so as to preclude recurrence of a similar accident. Only the examples cited in the foregoing paragraph continue to occur, and occur, and occur, each occasion with marked similarity to its predecessors.

Where do we go from here?

COPING WITH NEW TECHNOLOGY IN THE REALM OF FLIGHT RECORDERS

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In many countries of the world, large aircraft in air carrier operations and in air taxi operations must be equipped with an approved flight data recorder (FDR) and a cockpit voice recorder (CVR). In the United States, any aircraft type certificated after September 30, 1969, that is required to carry an FDR must be equipped with the expanded-parameter type known as the digital flight data recorder or DFDR [1].

As new-design large aircraft come into production and use, the DFDR will replace the foil-medium FDR as the required data recorder. Thus, the on-scene investigator must be able to recognize a damaged or burned DFDR and be knowledgeable in how to prepare it for transfer to a readout facility. This paper contains photographs and diagrams of new and damaged DFDR's and tape enclosures, and lists the steps that the on-scene investigator should follow from the time he finds the DFDR, or portions thereof, until he has prepared it for shipment to a readout facility.

Several additional aspects of the new technology in flight recorders are also discussed.

I. WHAT TO LOOK FOR

Flight recorders (CVR, FDR, DFDR) are all painted bright yellow or red or bright orange, and may be marked "FLIGHT RECORDER - DO NOT OPEN" in several languages. However, they may not retain their bright colors in the event of a fire. Hence, the investigator must be able to recognize a flight recorder by its size and shape alone.

This was made graphically evident at the site of the KLM-Pan American B-747 collision at Tenerife in the Canary Islands on March 27, 1977. The investigation team reported that they had found two CVR's and one DFDR — the other DFDR could not be located. The DFDR from the Pan American B-747 was not burned, and so was recognized; it was manufactured by the Lockheed Aircraft Service Company (LAS). The DFDR from the KLM B-747, however, had been burned and had suffered severe physical deformation. It was gray in color and the front panel was missing so that the crash-proof tape container was exposed. Since it was manufactured by Sundstrand Data Control (SDC), its interior was totally different from the LAS DFDR.

The team had found the SDC DFDR, compared it to the LAS DFDR, and assumed it was not the box they were seeking — this, even though "FLIGHT DATA RECORDER - DO NOT OPEN" was written on the sides of the case in English and in French. Granted, the box was charred and gray, but the print was readable albeit faded.

In telephone conversations with the on-site investigation team, the Washington-based NTSB Laboratory Services staff was reasonably sure that they had, indeed, found the KLM DFDR. We asked them to send the box to the U.S. with the other recorders so we could confirm our hypothesis. When the recorders arrived at the laboratory, it was immediately evident that all the recorders had been found.

The major manufacturers of DFDR's are LAS and SDC in the United States, Leigh Instruments in Canada, Plessey Avionics in Great Britain, and Schlumberger in France. Figures 1 through 13 show photographs and interior diagrams of assorted DFDR's. Photographs are in black and white both to save reproduction costs and to do away with the myth that all flight recorders will be orange or yellow or red after an accident.

Figures 14 through 18 show photographs of DFDR's recovered from aircraft crash sites. An experienced investigator should be able to recognize these as DFDR's.

U.S. Federal Aviation Regulations require that:

> "Each nonejectable record container [none are ejectable on U.S. commercial aircraft] must be located . . .as far aft as practicable, but need not be aft of the pressurized compartment, and may not be where aft-mounted engines may crush the container upon impact." [2]

Exactly where the DFDR is located varies with the aircraft manufacturer, model, and operator. U.S. manufactured aircraft carrying DFDR's generally carry SDC or LAS DFDR's.

CVR's, FDR's, and DFDR's may also be found in some general aviation aircraft, particularly business jets. Investigators at the site of general aviation accidents involving small but sophisticated aircraft should not overlook the possibility that these may carry flight recorders. If you have time before leaving for the scene of such an accident, it is a good idea to have someone telephone the operator/owner of the aircraft and find out if it was equipped with recording devices, and if so where they are/were located.

II. HOW TO PREPARE THE RECORDER FOR TRANSFER TO A READOUT FACILITY

DFDR's are magnetic tape recorders, as are CVR's. Hence, the same rules apply to both.

a. Protect the recorder from strong magnetic fields. Remember that an X-ray transformer at an airport security station gate may damage your data. If you mail the recorder or tape, mark the package "MAGNETIC TAPE WITH CRITICAL DATA. DO NOT EXPOSE TO X-RAYS OR PENETRATING RADIATION."

b. Exercise care in handling and packing the recorder or parts thereof.

c. Never, never open the recorder. Do not allow anyone to remove the tapes under any circumstances.

d. If the recorder is undamaged, use a shipping container obtained from the operator involved.

e. Should the case be broken, DO NOT remove the tape from the unit. Wrap the entire unit and its contents in polyethylene or similar material or heavy paper before packaging for shipment.

f. If the tape reels are separated from the unit, wrap them in paper or polyethylene before applying sealing tape. NEVER apply sealing tape directly to the recording medium. DO NOT remove the recording medium from the reels or enclosure.

g. If the tape is found separated from the recorder, never crinkle it. Carefully wrap it on a spool or round block of wood or cardboard. Wrap this in polyethylene or paper and pack carefully. NEVER stuff the tape randomly into a box or container. Data are easily degraded; creases and crinkles can cause electronic noise and errors.

h. If the recorder is from the site of a major accident, get it to the readout facility by the fastest means possible. If it is from the site of a minor accident or incident (in the U.S.) where speed is not essential, ship it by certified mail to:

National Transportation Safety Board
Bureau of Technology, TE-60
Washington, D.C. 20594

Include a brief statement of the circumstances, location, and other pertinent facts regarding the accident. When accepting custody of the recorders, execute an NTSB Form 6120.15, and enclose one copy in the shipping container. This will supply information as to where the unit is to be returned, as well as formalizing the Bureau's receipt of this material.

i. If the recorder is found in water, do not attempt to dry it.
   (1) SALT WATER: rinse in fresh water, then arrange to ship the recorder *immersed in water* to the readout facility in a watertight container. Make sure the recorder stays immersed in water until it can reach the lab. Pack it very securely. This is no joke . . . .
   (2) FRESH WATER; ship as above. NOTE: ship by the fastest means available.

All requests for flight and voice recorder readouts in the U.S. should be coordinated with the appropriate NTSB laboratory prior to shipping the recording medium/recorder. Call 202-426-3980 and ask for the Chief, Laboratory Services Division. Describe:

(1) the state of the recorder(s).
(2) what happened in relation to how much data you feel must be read out. NOTE: limit what you ask for. It takes several days, at least, to transcribe one-half hour of a CVR tape. On FDR, ask yourself if you really need a full readout of all parameters (e.g., if you have a turbulence incident, a g's readout might suffice).

Remember: let the experts be the judge as to whether the medium is readable or not. Get it to a readout facility as soon as possible in the state you've found it. *Never* open a recorder or cut a tape.

III. THE READOUT PROCESS

What do the experts do with the DFDR or parts thereof that are sent to the readout facility? A little background may be helpful.

The DFDR records digital information on magnetic tape which is crash and fire protected [3]. The DFDR stores numerical data on magnetic tape as opposed to the FDR which stores engraved oscillographic traces on a foil medium. A list of U.S. mandatory DFDR parameters, their ranges, accuracies, and maximum recording intervals is given in Appendix A. A sampling of regulations on DFDR's from other countries is given in reference [4]. The DFDR is capable of recording as many as 90 to 100 parameters, and many carriers take advantage of this capacity, especially those outside the U.S. The DFDR stores 25 hours of flight data on a continuously-running magnetic tape. Data older than these are erased as new data are recorded.

DFDR's can only be read out at a base station, remote (hopefully) from the crash site. There are relatively few such facilities in the world today. One such facility exists at the NTSB laboratory in Washington, D. C.

At NTSB the tapes are first played on special electronic hardware that amplifies the recorded signal, shapes it, recognizes the synchronization words, puts the data stream into computer compatible format, and records it on 9-track computer tape.

NTSB's data reduction station is currently in the process of being upgraded. We recently increased our PDP-11/40 mini-computer storage capacity from 28-K core to 128-K, added a second disk drive unit, a line printer, an 8-channel analog strip chart recorder, and improved synchronization recognition circuitry. These supplement the older peripherals: a keyboard terminal, an electrostatic printer-plotter, two 9-track magnetic tape units, a high-speed paper tape reader and punch, and hardware specifically designed for the flight recorder laboratory. Specialized hardware includes two DFDR readers (so that the 1/4-inch tapes from each of the two U.S. DFDR manufacturers can be transcribed to 9-track computer tapes without being removed from their crash-proof containers), a reel-to-reel tape deck (so that a 1/4-inch tape can be played in the normal manner if it becomes necessary to remove it from a damaged DFDR), a computer interface (to reformat the Harvard biphase data stream into computer compatible format), and an FDR interface (for getting X-Y coordinate data from the foil recorder reader into the computer).

The signal from the DFDR tape is transcribed to a 9-track computer tape using the NTSB's data reduction station. The transcription process is begun by looking for a sync word. (There are four sync words that repeat in sequence. A sync word is the signal for the start of a 1-second block of data called a subframe). When one is found, the system in normal sync mode expects the next sequential sync word 1 second later, that is, 768 bits later (64 words x 12 bits per word). Meanwhile, data from the subframe are preserved. If the next sequential sync word is found, the transcription continues. If the next sequential sync word is not found, the data just transcribed are flagged (an asterisk in the data printout) to indicate that these data are questionable.

After a transcription tape is generated, it is played back on a 9-track tape machine that feeds the information to the computer. A program is called from disk which converts the taped data in raw form (numbers from 0 to 4095 for 12-bit words) into the parameter values originally transmitted to the recording system by the aircraft sensors. The program called depends upon the airline and type aircraft.

The numbers recorded on the DFDR tape are scaled data, and not necessarily the parameter values themselves. For example, heading on the American Airlines DC-10 is obtained from the raw data value (x) by multiplying by the scale factor 360/4096.

Thus, a heading of 240° will be recorded as the base 10 number $x = 2731$ (the 12-bit number representing x is a binary (base 2) 101010101011 or an octal (base 8) 5253).

The scaling equation is usually not so simple, and depends on the specific parameter, the type flight data acquisition unit used by the airline, and the type sensors installed in the aircraft.

The end result of a normal readout is a second-by-second listing of the data for as much of a given flight or flights as desired (the so-called engineering units printout), as well as a plot of all or selected data parameters versus time. The DFDR group chairman's factual report for an aircraft accident always contains the engineering units printout and a plot. DFDR data in NTSB accident reports are usually presented in graphical form.

Additional details regarding tape format, problems encountered with digital recording systems, and the like may be found in reference [5].

IV. SPECIAL PROCESSING OF DFDR DATA

Several techniques have been used to obtain data in difficult circumstances, such as when severe vibration causes the tape speed to vary outside the normal range limits, thus causing loss of sync.

The NTSB hardware has the following features (supplied by Lockheed Aircraft Service Co.):

a: "Supersync" or the super-synchronization mode of operation wherein acquisition of any *one* sync word causes an "in-sync" condition. In addition, prior to the end of the subframe, a "window" is opened which enables the circuit to look for the next sync word up to 8 bits early (normal sync mode requires *two sequential* sync words spaced exactly 768 bits apart).

b. a wideband filter that can be switched into the circuit to aid in recovering data that exhibit large-amplitude frequency modulations.

c. a "bit dump" mode of operation which permits the transfer of a continuous stream of data bits from the DFDR tape directly to computer core memory regardless of sync condition. Once a switch is enabled, data transfer begins immediately upon the system's recognition of a single subframe #1 sync word, and continues until 12,000 bits have been stored in computer memory.

The data so stored can then be processed. The NTSB software, developed by IKONIX, Inc., allows several modes of processing. The bit stream may be listed on the line printer in serial binary format (see Figure 19-a) or in 12-bit octal format (Figure 19-b). Presentation of the data in octal format also includes a search of the bit stream for all occurrences of any preselected set of 4 patterns, each of them of up to 12 bits in length (for example, the 4 sync words — or any other data pattern). These options are very useful in attempts to recover data from subframes that are out of synchronization; there have been instances where the first part of the subframe was faulty because of initial crash impact or whatever, but the latter part was good. By searching for certain bit patterns that were known to occur in mid subframe, part of the data could be reconstructed from the bit dump.

The software also includes a correlation option where one section of data can be compared to another using an approximation to the statistical cross-correlation function. A total of 180 values of the function are computed for 12 bit shifts.

There are two additional techniques that are available to aid in obtaining DFDR data in difficult situations, namely, DFDR waveform analysis and magnetic pattern analysis.

d. Waveform Analysis: A recording oscillograph, which writes with a beam of light on sensitive paper, is capable of generating a picture of the actual waveform of the data stream from the DFDR tape. See Figure 20. An experienced technician knows how to interpret the waveform (see Figure 21) and can decide whether or not a certain section of the data is good by the shape of the waveform.

The readout electronics is sensitive to waveshape also. If the signal is distorted enough in amplitude or in periodicity in a given area of the tape, two separate bit dumps give two different results in that area. Obviously, data must be reproducible to be valid.

Recording oscillograph traces have been used in conjunction with bit dumps to determine which sections of data were valid and which invalid.

The waveform from the oscillographic trace is first analyzed by assigning either a "O" or a "1" to a number of properly-shaped bits. The tape is then run through the bit dump analysis using the search pattern taken from the oscillogram. In this way, a common starting point is established. It is then easy to select areas where data are valid or invalid. The next step is to search for certain bit patterns that are known to occur in mid-subframe, for example, the five most significant bits of the current flap setting. These bit patterns act as identifiers that help to separate one parameter from another so that the valid part of the data can be used to reconstruct engineering units values.

Waveform analysis is very laborious and time consuming, and is only used in extreme cases.

e. Magnetic Pattern Analysis: the second technique is really a check to see if any data signal at all has been recorded on the DFDR tape. The tape is dipped in a material which renders the bit pattern visible, yet does not harm the tape in any way. If it is desired to preserve the pattern, clear mending tape can be applied to the DFDR tape and the magnetic pattern carefully lifted off. Such patterns are shown in Figure 22.

To conclude this section on special processing techniques, I want to describe a technique that is currently being studied to see if the DFDR is at all helpful in detecting and identifying lightning strikes on aircraft. In the one case studied so far, the results were negative, but no general conclusions can be reached until more data can be collected on aircraft involved in known lightning strikes.

An Air New Zealand DC-10 was struck by lightning in the nose area while departing LAX on January 5, 1977. The air-conditioning doors light annunciated on the flight engineer's panel and moderate vibration was experienced. Loss of an air-conditioning door was suspected. An emergency was declared and approximately 44,490 KGS of fuel dumped prior to making a normal landing. Inspection revealed that the No. 1 and No. 2 air-conditioning pack doors had departed the airplane.

An NTSB investigator requested that Air New Zealand send the flight recorder tape to Washington so that the effect of a known lightning strike on the aircraft as reflected by data from the DFDR could be studied. The tape was forwarded to the NTSB flight recorder laboratory.

The air-conditioning doors light is part of the DC-10 master caution system; the DFDR data indicate that the master caution illuminated. The master caution ON signal was taken to be the reference point for the occurrence of the lightning strike.

Three types of tape analyses were run, and all showed that the DFDR behaved normally before, during, and after the strike. No unusual spikes or signals were found within this region of the tape, nor did the recorder lose synchronization in this region. The three tests were:

Generation of strip chart readouts of 14 parameters versus time for the entire flight,

Generation of a transcription tape and engineering units printouts of all parameters in the region of interest,

Generation of oscillographic traces of the data stream from the DFDR tape in the region of interest.

Both types of oscillographic traces were made (with and without horizontal sweep) as shown in Figure 20. The "Mark" was called by watching the Master Caution binary on the strip chart recorder as the oscillogram and strip chart were run simultaneously. When the Master Caution binary went on, "Mark" was called and the oscillogram marked by a second party.

No unusual spikes or signals were found on the oscillographic traces. Since the tape is normally driven into magnetic saturation in non-transition areas of the bit pattern, a spike that rises above the bit level is unlikely. However, the possibility of unusual lightning-generated signals on other tapes cannot be entirely dismissed.

V. A NEW IDEA IN FLIGHT RECORDERS

There is no present requirement for flight recorders on large corporate aircraft, although NTSB Chairman Webster B. Todd, Jr. stated in a press conference in October 1976 that he planned to ask the full Safety Board to make a recommendation to the FAA that would require voice and flight data recorders on all corporate jets. Several aviation publications including *Business and Commercial Aviation* and *Professional Pilot* have supported such a requirement [6,7].

Some owner/operators of corporate aircraft have objected to the proposed requirement because they feel it places an unnecessary economic burden on them, both in the initial hardware investment and in the maintenance costs. Also, present recording systems are rather bulky and heavy.

There is hope, however. With present avionics technology advancing at a rapid pace thanks to the use of microprocessors [8,9], the outlook for an inexpensive, lightweight, compact, and maintenance-free digital crash recording system is good.

A very small digital crash recorder is being developed by Hamilton Standard of Windsor Locks, Connecticut, under contract with the U.S. Army. This system is to use a microprocessor to decide which data should be stored and when, and a nonvolatile solid-state memory instead of recording tape. Because no recording tape is used, the system will be virtually maintenance-free. Projected costs are 25 percent lower than present digital systems, with volume and weight over 80 percent less. This system will not meet the requirements of the FAR's for 25-hour storage capacity, but it has exciting possibilities for use in corporate aircraft.

The question arises as to how much the recording system can be minimized in terms of cost, weight, size, and data storage capacity, and still be acceptable to both NTSB and FAA for use in corporate aircraft.

Storage capacity of Hamilton Standard's new recorder is limited to several thousand 16-bit words, but the microprocessor allows "smart" recording. For example, instead of blindly recording a sample of each parameter at regular time intervals (as is done in the present system), an incremental value ΔP could be programmed for each parameter, so that a value of the parameter and the time of occurrence would be recorded only when the parameter value changed by $\pm\Delta P$. One could also program the unit to record local maxima and minima (and times of occurrence) of certain critical parameters, such as tri-axis accelerations, rather than waste memory space by recording at fixed intervals. Algorithms for the microprocessor are currently under study.

The advantages of a solid-state recording medium over magnetic tape in an aircraft recorder are: (1) there are no tape transport mechanisms and other moving parts to jam or fail, (2) there are no magnetic heads to wear out or get dirty, (3) there is less susceptibility to vibration because there is no tape/head contact to disrupt.

VI. A MODEST PROPOSAL

Ordinary solid-state memory elements, such as are contained in automatic flight control systems and navigation receivers, remember the mode or frequency selected only so long as power is applied to the system. When power is interrupted, the data are lost. Hence, necessary data cannot be obtained by examining solid-state avionics circuits after an aircraft accident once power has been removed.

How many times have you as an investigator wished you could have known which flight director/autopilot modes were last selected, or which navigation facility was being used at the time of an air crash? This information is generally not recorded on the DFDR tape, even assuming that the aircraft was equipped with a DFDR.

We now have solid-state memory components that are nonvolatile, that is, these components retain information in memory even after power is lost, so that reapplication of power allows continued operation in the same state as previously. Such a nonvolatile solid-state memory is the basis of the Hamilton Standard tapeless DFDR, as well as certain hand-held calculators now on the market.

I suspect that the storage method proposed in the new DFDR might be modified and adopted for use in the manufacture of avionics and communications equipment. In this way, the information as to the state of these components immediately before a crash will be retained upon the loss of aircraft electrical power.

VII. CONCLUSION

The practical thrust of this paper is to show the on-scene investigator photographs and diagrams of digital flight data recorders, both new and damaged, so as to develop his ability to identify such devices in the post-crash situation. Section 2 is devoted to preparing the recorder for transfer to a readout facility. Hopefully, the average investigator will become familiar with these portions of the paper.

What can be gained from the DFDR data? A lot of information, as evidence by the list of U.S. mandatory parameters given in Appendix A. A description of the readout process is given for the more curious investigator in Section 3. Section 4 describes special processing of DFDR data, Section 5, a tapeless DFDR currently under development. Section 6 presents a proposal that nonvolatile solid-state components be used in avionics and communications equipment.

VIII. REFERENCES

1. 14 CFR, 121.343 (U.S. Code of Federal Regulations, Title 14, Part 121, Paragraph 121.343), December 31, 1964, as amended.
2. 14 CFR, 25.1457, December 24, 1964, as amended.
3. 14 CFR, 37.150, November 17, 1964, as amended.
4. C. A. Roberts, *The Flight Data Recorder and the NTSB's New Data Reduction Station*, 5th Annual International Seminar, SASI, Washington, D. C., October 1974.
5. C. A. Roberts, *The Status of Flight Recorders in Modern Aircraft*, Journal of Air Law and Commerce, Air Law Symposium Issue (March 3-5, 1977, Dallas, Texas), Volume 43, No. 2.
6. R. N. Aarons, Hardware/Software - "CVR's and FDR's" Business and Commercial Aviation, Volume 39, No. 5, November 1976.
7. A. W. Scott, Position and Hold - *Wiretapping the Corporate Cockpit?*, Professional Pilot, Volume 10, No. 12, December 1976.
8. J. Terry, *Microprocessors Are Key to New Digital COM/NAV/IDENT Designs*, ICAO Bulleting, Volume 32, No. 3, March 1977.
9. P. J. Klass, *Future Avionics Trends Emerge*, Aviation Week and Space Technology, Volume 106, No. 12, March 21, 1977.

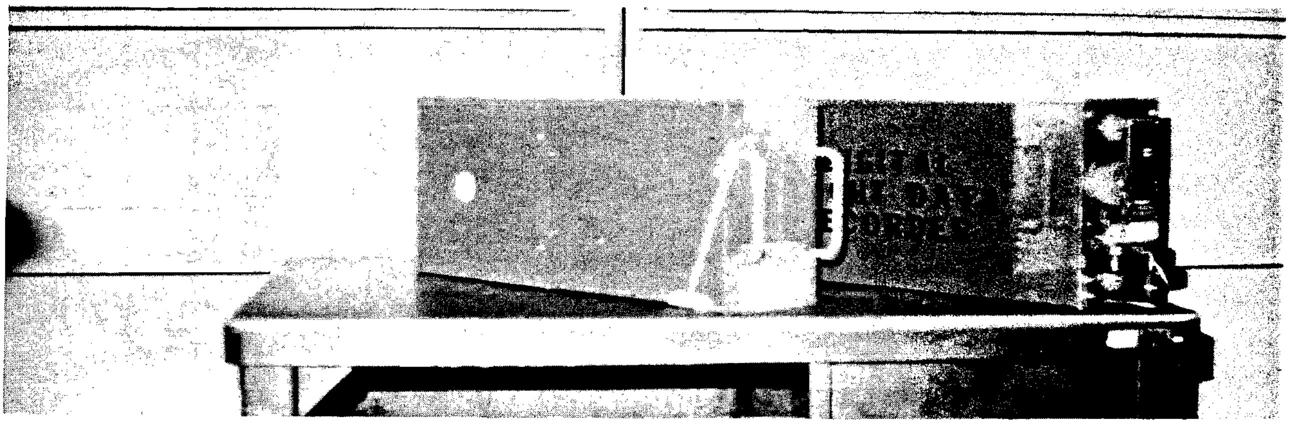


Figure 1: U.S. Manufactured DFDR's: (Left) Lockheed Aircraft Service Co. (LAS) Model 209 DFDR. (Right) Sundstrand Data Control (SDC) Model 573A DFDR. Both are packaged in 1/2 ATR long frames; boxes measure 5x8x21 inches (12.7 x 20.3 x 53.3 cm.).

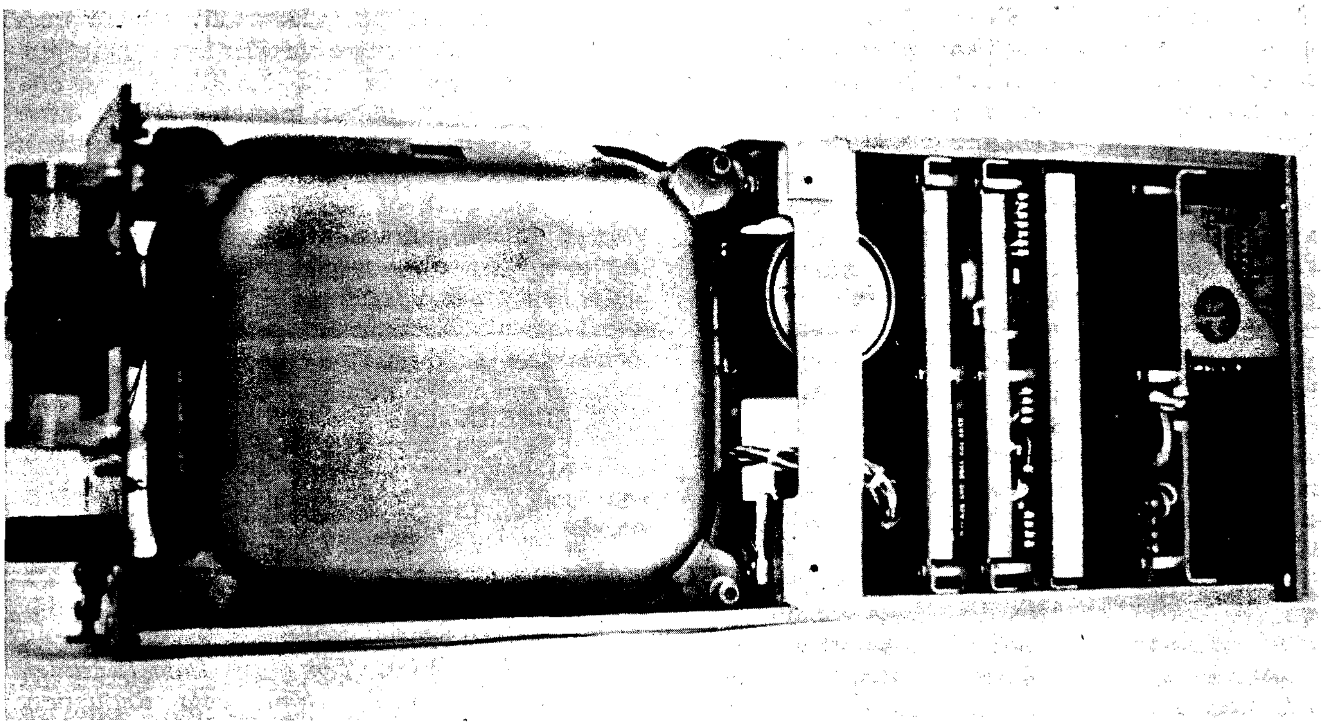
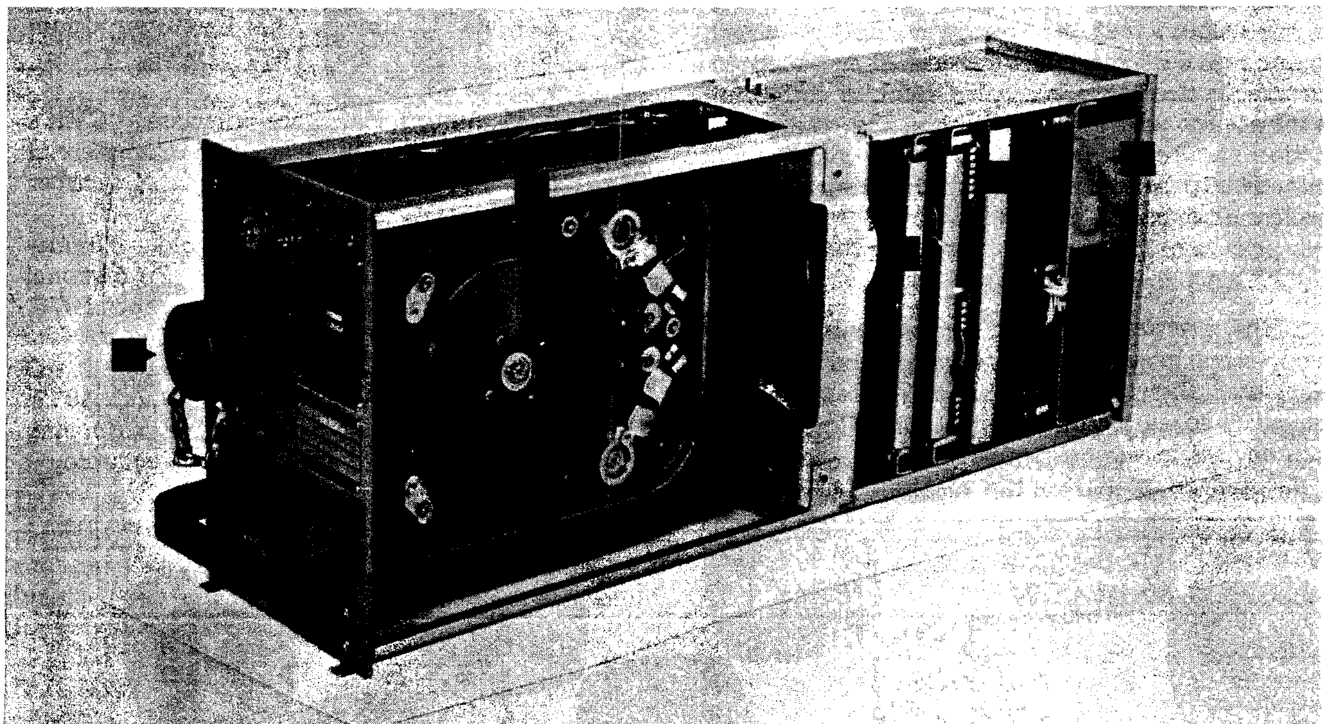


Figure 2: SDC 573A DFDR with dust cover removed. Note the crash-protected tape enclosure that occupies the left half of the recorder. This part contains the data tape and must be recovered from the wreckage.



Sundstrand Digital Flight Data Recorder, Model 573A. (1) Vicalloy Magnetic Tape, (2) Magnetic Heads, (3) Dual Capstan Drive and Negator Springs, (4) Tape Reels, (5) Integrated Recorder Electronics, (6) BOT/EOT* Sensing, (7) Tape Protective Enclosure, (8) Internal Shock Mounts, (9) Status Indicator, (10) ATE** Connector, (11) Power Supply, (12) Drive Motor.

*Beginning of Tape/End of Tape

** Automatic Test Equipment

Figure 3: SDC 573A DFDR showing details of the interior. Recording tape is 800 ft. long and 1/4 inch wide and is made of a metal called Vicalloy. (Photo from SDC promotional brochure.)

LOCKHEED AIRCRAFT SERVICE COMPANY
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

OVERHAUL MANUAL
DIGITAL FLIGHT DATA RECORDER
PART NUMBER 10077A500-103

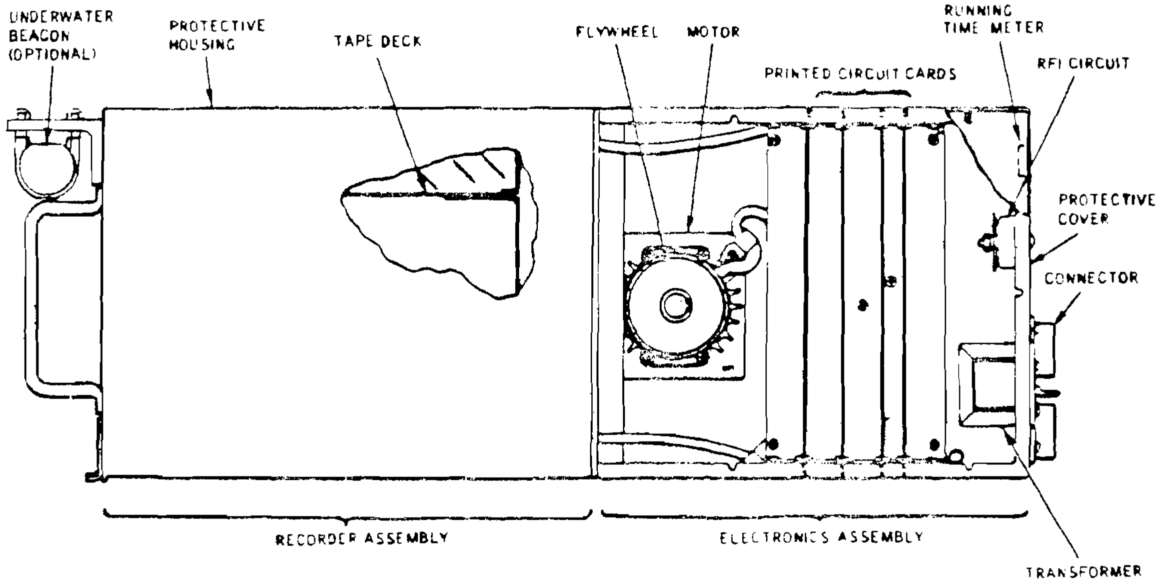


Figure 4: Cut-away drawing of LAS model 209 DFDR

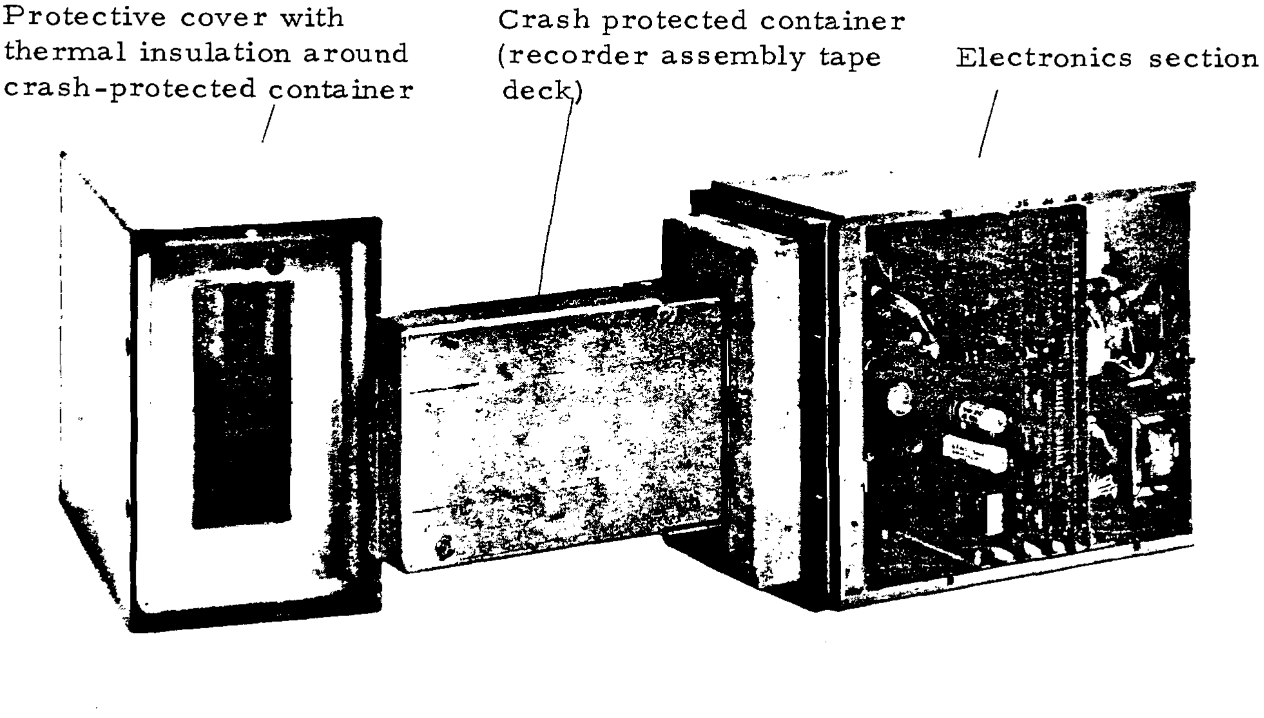


Figure 5: LAS model 209 DFDR major assemblies

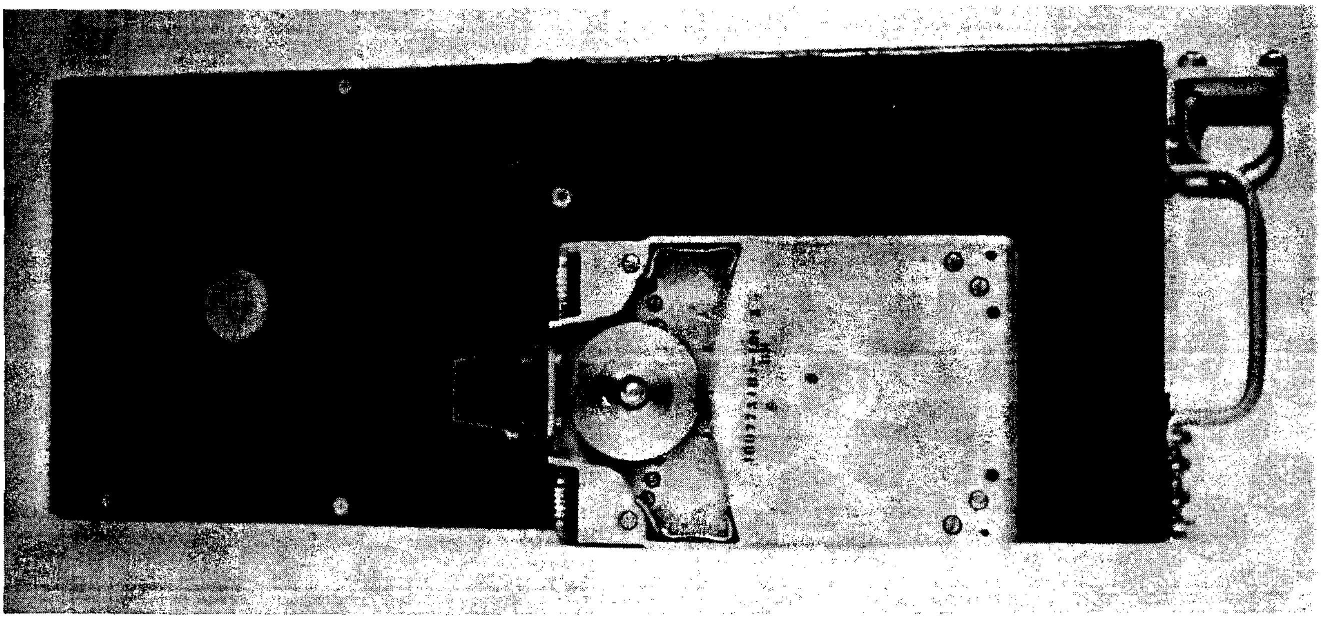


Figure 6: LAS 209 DFDR. The crash-protected tape enclosure was removed from the recorder, after which the recorder was reassembled. The enclosure is in the foreground, the DFDR case behind it.

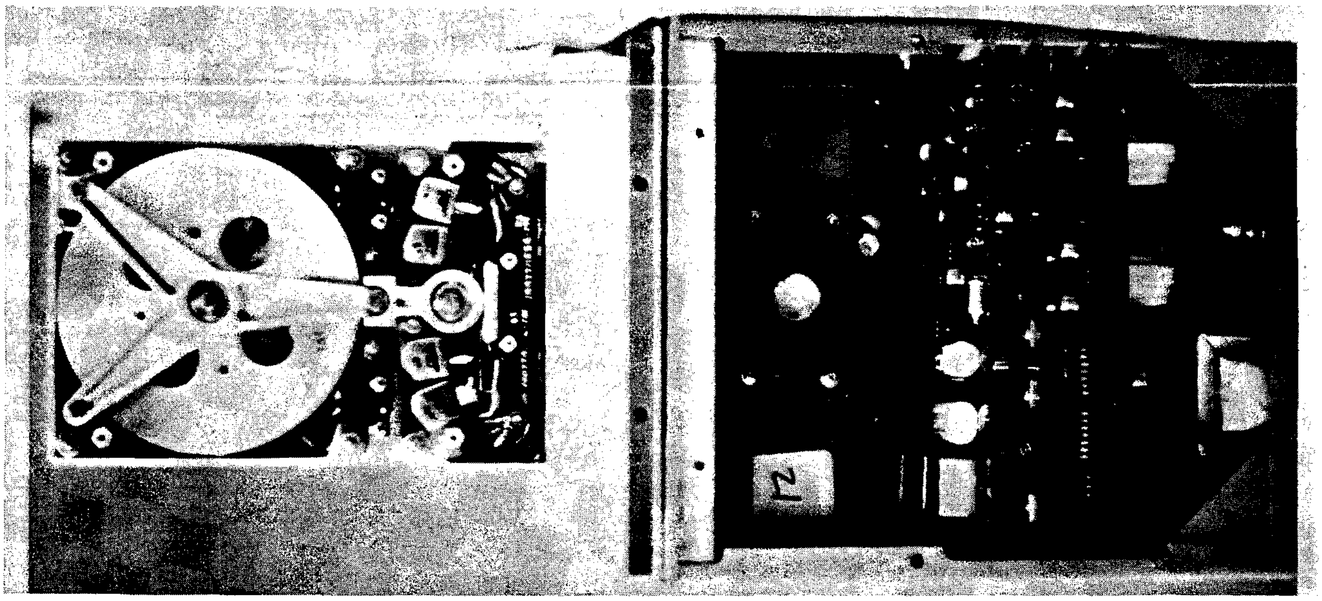


Figure 7: LAS 209 DFDR showing a view similar to that in Figure 5 except that the crash-protected enclosure cover has been removed and the top tape reel and magnetic recording heads are visible. Recording tape is 1100 ft. long and 1/4 inch wide made of a mylar-based material.

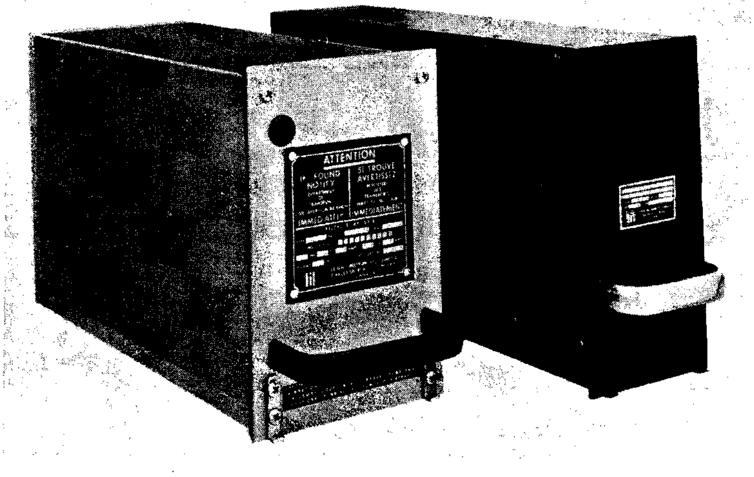
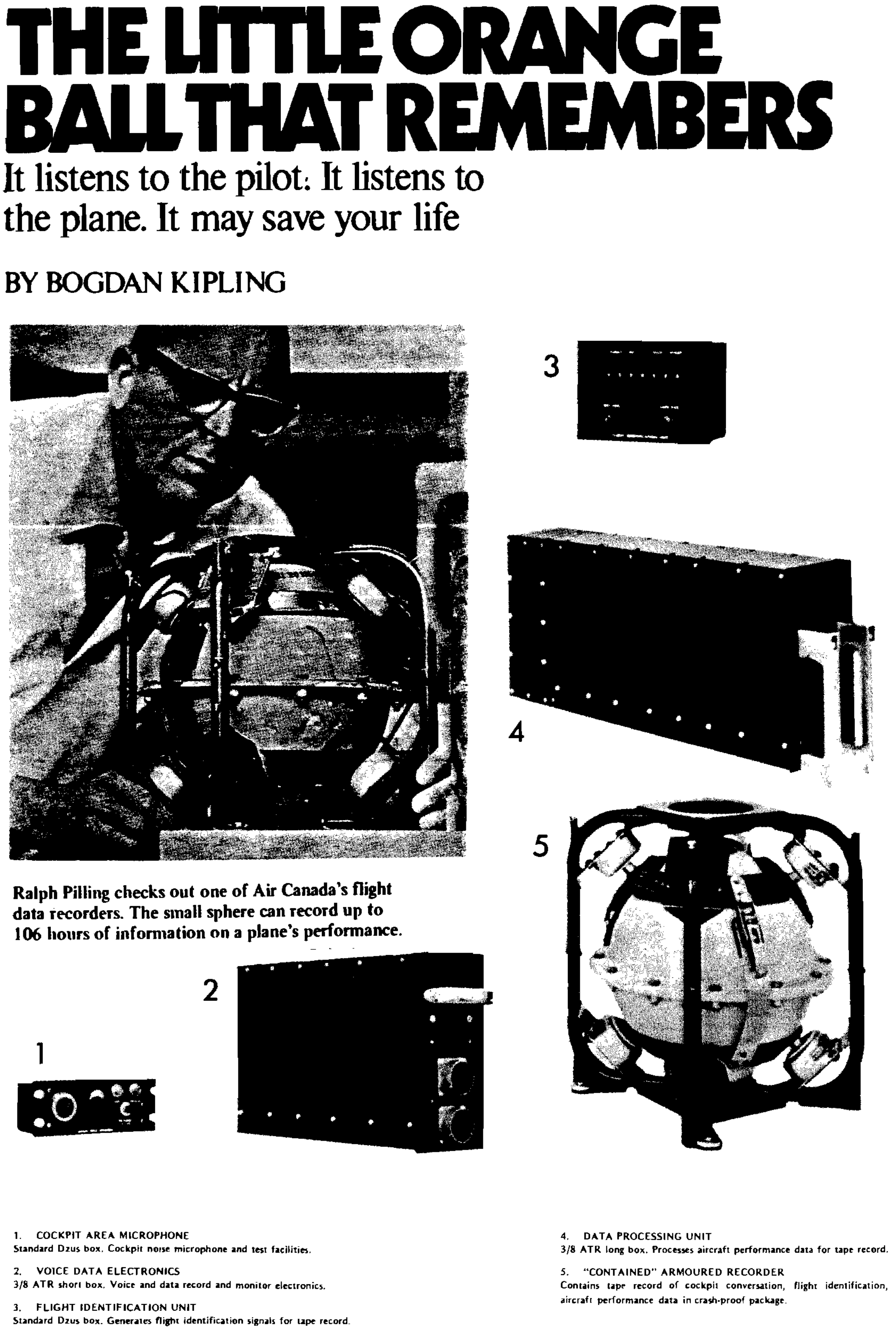


Figure 8: Leigh Flight Data Recorder System, FDRS-38. DFDR at left is a 1/2-ATR short box (5 x 8 x 12.5 inches) and contains the magnetic tape. The box at right is an electronic unit and need not be recovered. (Photo from Leigh Promotional Brochure.)



THE LITTLE ORANGE BALL THAT REMEMBERS

It listens to the pilot: It listens to the plane. It may save your life

BY BOGDAN KIPLING

Ralph Pilling checks out one of Air Canada's flight data recorders. The small sphere can record up to 106 hours of information on a plane's performance.

1. COCKPIT AREA MICROPHONE
Standard Dzus box. Cockpit noise microphone and test facilities.

2. VOICE DATA ELECTRONICS
3/8 ATR short box. Voice and data record and monitor electronics.

3. FLIGHT IDENTIFICATION UNIT
Standard Dzus box. Generates flight identification signals for tape record.

4. DATA PROCESSING UNIT
3/8 ATR long box. Processes aircraft performance data for tape record.

5. "CONTAINED" ARMOURED RECORDER
Contains tape record of cockpit conversation, flight identification, aircraft performance data in crash-proof package.

Figure 9: Leigh FDRS-37/106 Combined DFDR and CVR recording system. Only the spherical recorder need be recovered. (Photo from Leigh Promotional Brochure.)

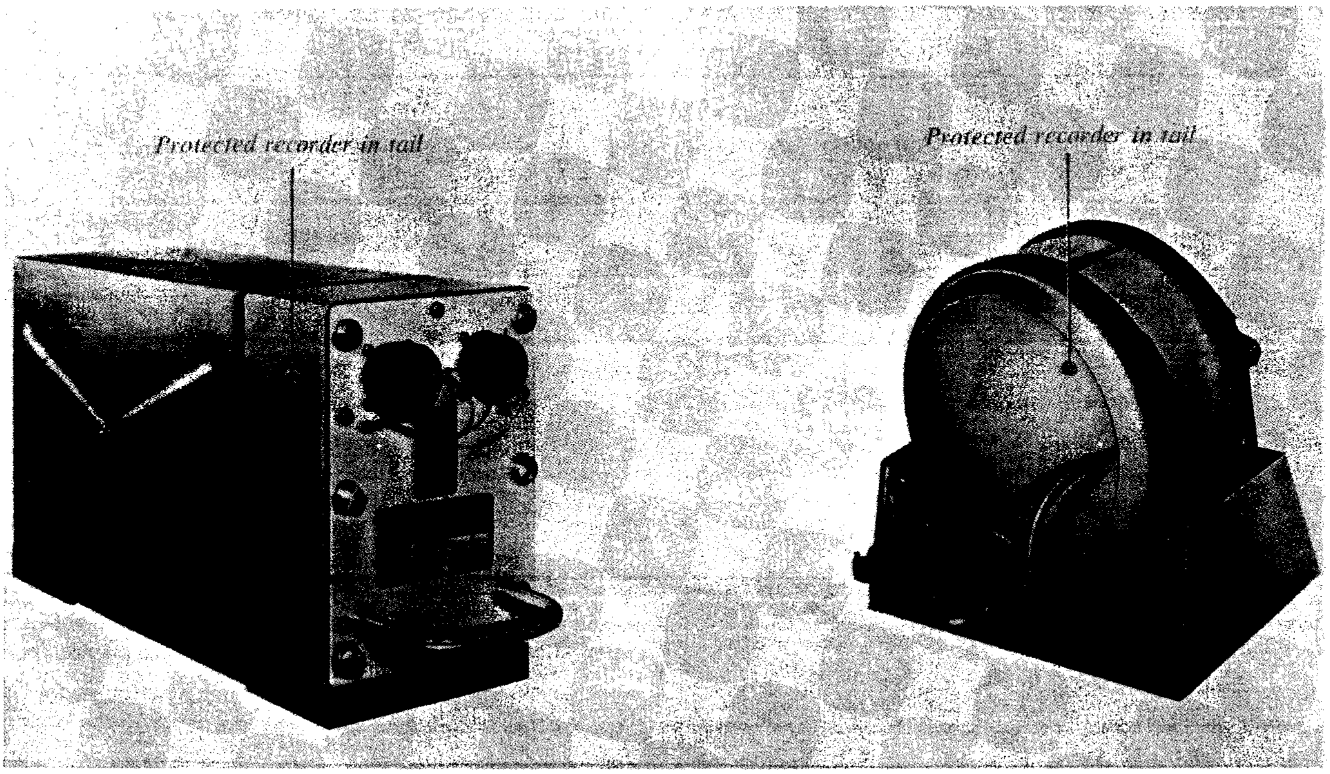


Figure 10: Plessey DFDR's. At left is the Plessey PV740 DFDR; at right is Plessey PV 726A DFDR, a crash-protected wire (not tape) recorder. (Photo from Plessey Promotional Brochure.)

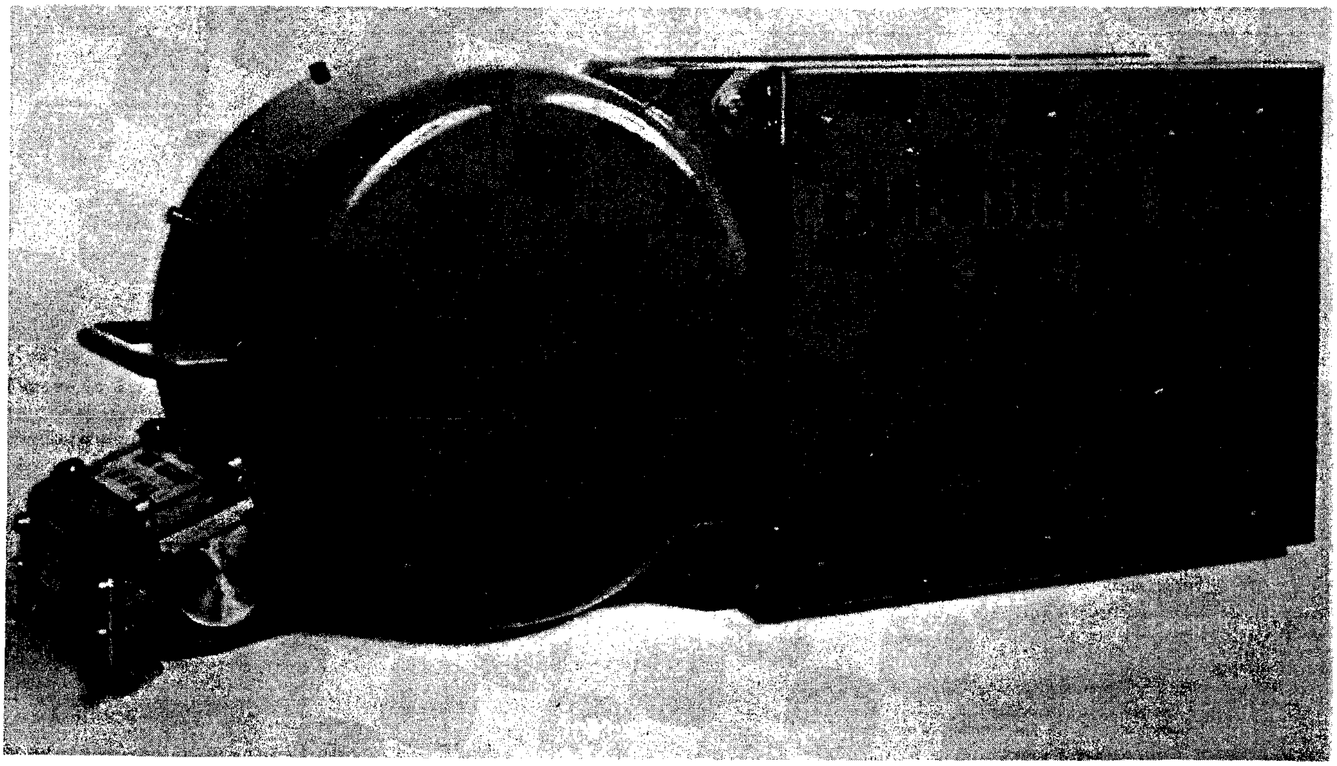


Figure 11: Schlumberger PE 6573 DFDR. This recorder is packaged in a 1/2 ATR long frame and uses polyimide recording tape. (Photo from Schlumberger Promotional Brochure.)

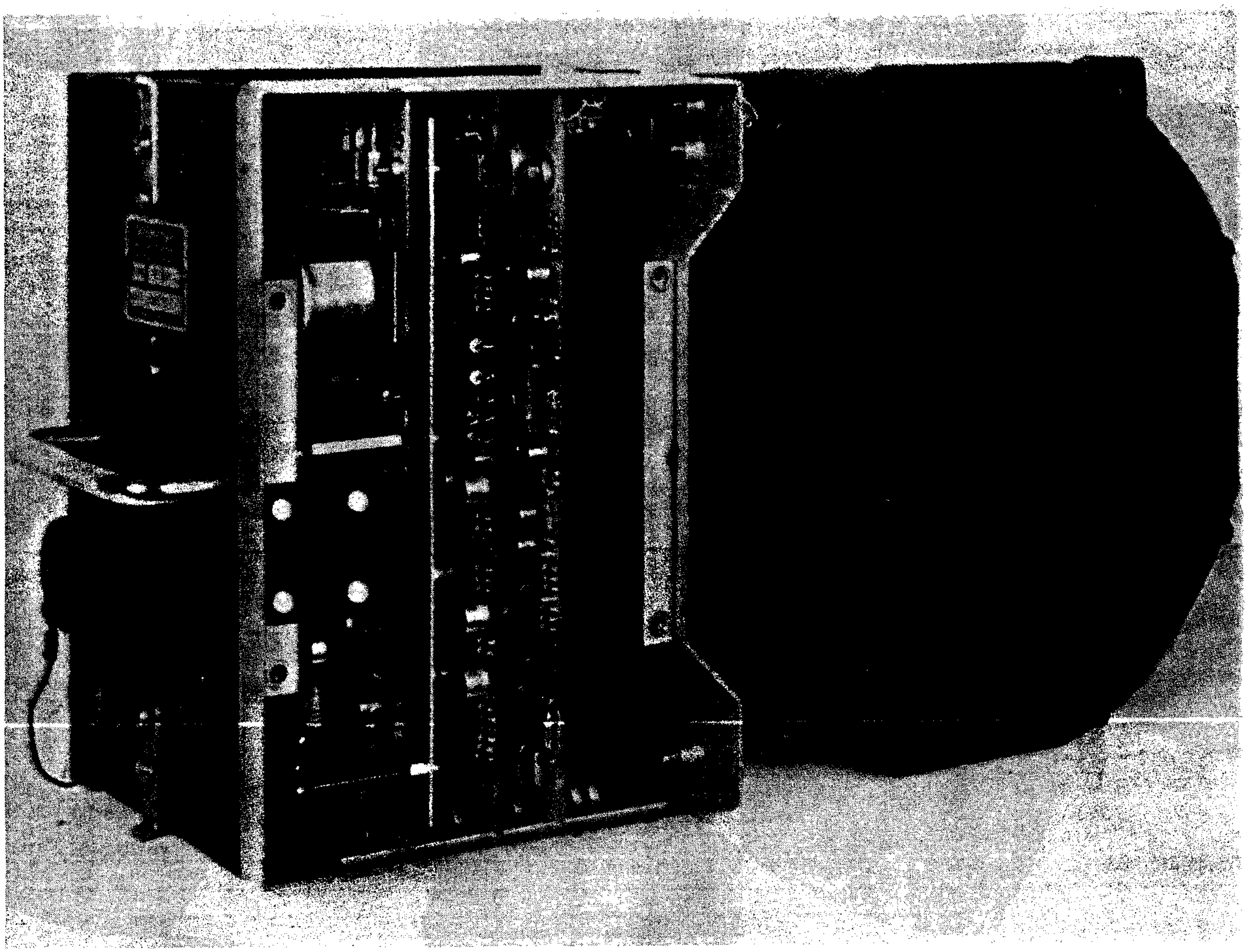


Figure 12: Schlumberger PE 6010 lightweight DFDR. This recorder is designed for use on smaller aircraft; the weight saving is obtained by reducing the crash-penetration requirement (hence, the unit does not meet all specifications for use in air transport category aircraft). (Photo from Schlumberger Promotional Brochure.)

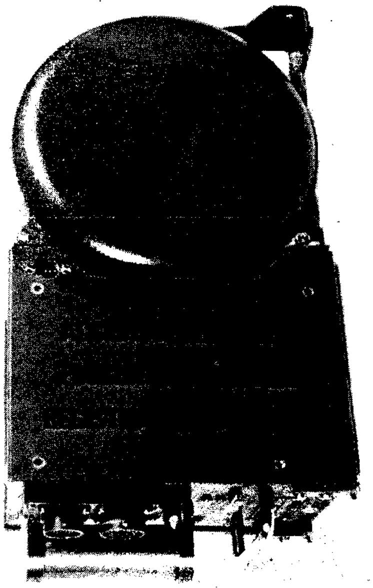


Figure 13: Schlumberger PE 6015 flight-test combined DFDR and CVR. This unit records one hour of digital data and 30 minutes of voice data. It is designed to meet certain flight-test requirements (it has a higher data rate than other models), and does not meet the 25-hour storage requirement for use in air transport category aircraft. (Photo from Schlumberger Promotional Brochure.)

Figure 14: Crash-protected container from SDC DFDR aboard Turkish Airlines DC-10 aircraft that crashed near Paris, France on March 3, 1974. (Container was wrapped in transparent tape for shipment to the U.S.)

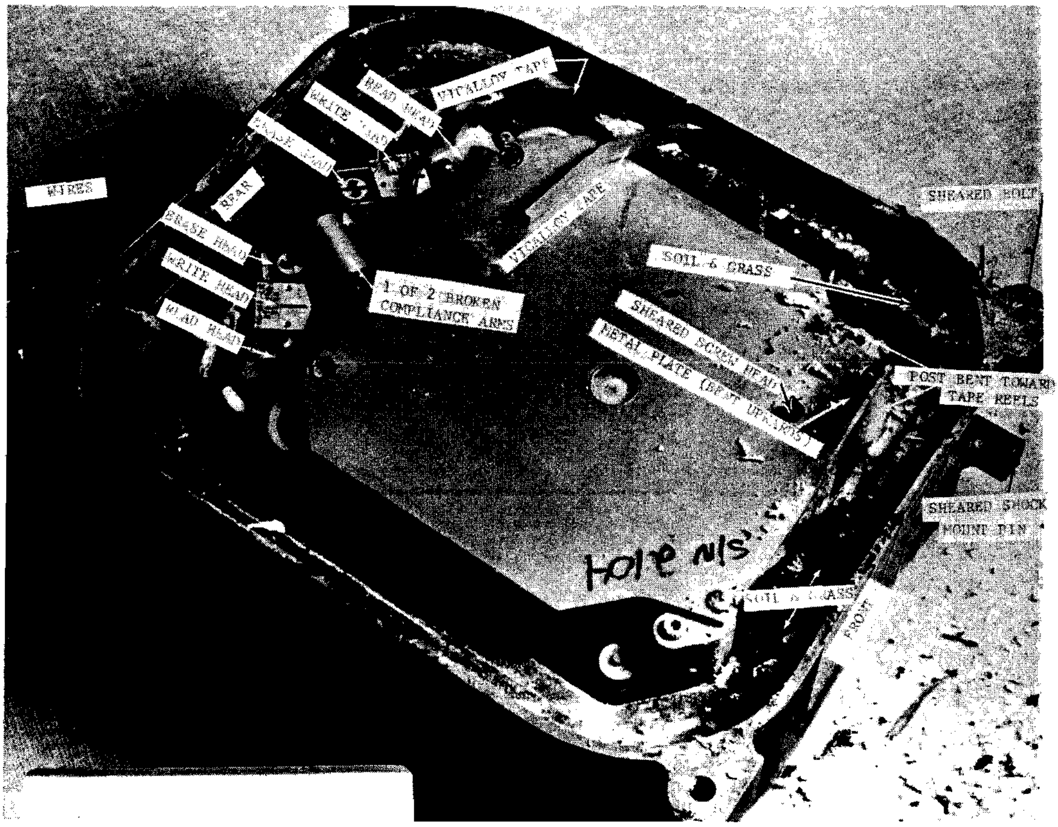


Figure 15: Crash-proof container of Figure 14 with top cover removed. Beneath the tape-reel cover plate shown in the photograph are the tape reels depicted in Figure 3.

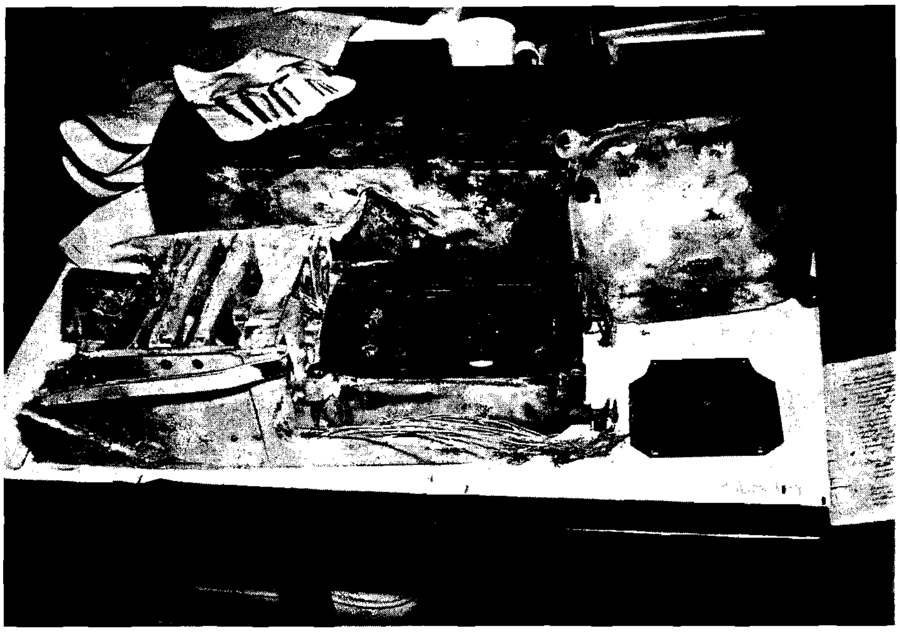


Figure 16: SDC DFDR aboard the Air France B-747 that burned on the ground at Bombay, India, on June 12, 1975. At rear of the photograph is the exterior cover of the recorder, no longer orange in color. In front of the cover is the electronics section and the opened crash-protected container, the top cover of the crash-protected container, and the tape-reel cover plate. The DFDR from the KLM B-747 at Tenerife was in similar condition, although not as badly burned.

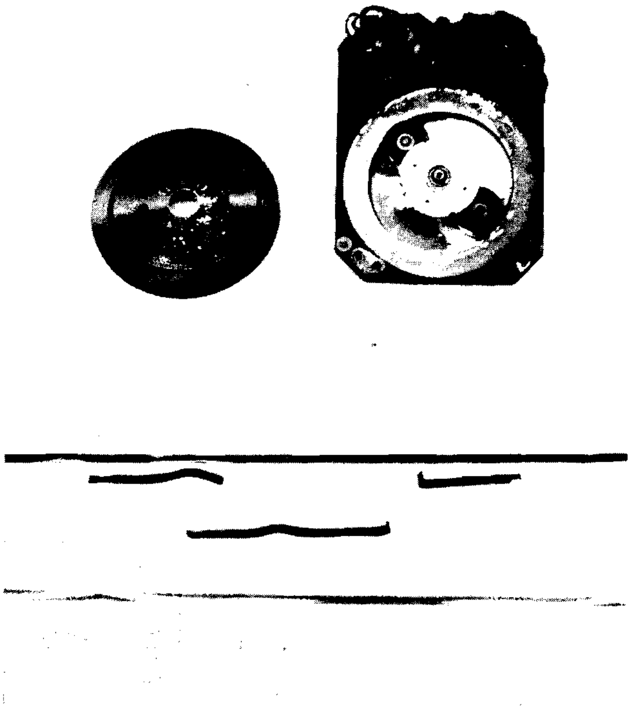


Figure 17: The tape deck and sections of recording tape from the DFDR shown in Figure 16. All pertinent data were recovered from this tape.

Figure 18: Schlumberger recorder after an accident: the tape deck remained intact within its mechanical and thermal protection. (Photo from Schlumberger Promotional Brochure.)

LEAST SIGNIFICANT BIT

MOST SIG. BIT

```
NTSB BIT DUMP TRANSCRIPTION PROGRAM

000000000000 100010001001 010101001111 110100101110 000000001001 101010000001 011111111111 111101110001 111000000000 00
0000000000 110011001011 000010000001 011011101110 110111110000 110110100001 010100100001 110011111111 110010001001 0110
00010110 111111111111 100110000001 011111111111 010110101000 010000000001 011000101011 000000000000 111111111111 011001
100000 111011101110 110000000000 011010100001 111111111111 100010101010 001010001001 010000110111 111000110111 11111111
1111 100000000001 010000000000 111111111110 111101110001 000000000000 110011001011 000000000000 110111101110 1010111011
10 010110100001 100111111111 111111111111 011010001001 111101100000 000000000000 011110100011 111111111111 111111111101
 011100000001 001100101011 000000000000 111111111111 010000110111 110111101110 010000110111 110110100001 111011111111

000111011010 110010001001 010101001111 111000101110 111101001001 011100000001 010000000001 110001110001 111000000000 00
0000000000 111011001011 100010000001 011011101110 000000000000 111010100001 011100100001 111011111111 110010001001 1111
11100110 111111111111 101011111111 011111111111 110000110111 011000000001 001100101011 000000000000 111111111111 010001
100000 111011101110 111111111111 011010100001 111111111111 110000101010 110010001001 000000000000 001000000000 00000000
0000 000000000001 010111111111 111111111110 111101110001 000000000000 111011001011 000000000000 110111101110 1001111011
10 010110100001 000111111111 010000000001 110010001001 111101100000 101011100011 001011100011 111111111111 100101110011
 000100000001 101100101011 000000000000 111111111111 000000000000 110111101110 000000000000 110110100001 101011111111

111000100101 011010001001 011001001111 111111001110 000001101001 010100000001 011111111111 110001110001 111000000000 00
0000000000 111011001011 100010000001 010111101110 001111110000 110110100001 000001100001 111011111111 001010001001 1001
11100110 111111111111 000110000001 011111111111 000000000000 011100000001 101100101011 000000000000 111111111111 010101
100000 110111101110 111001011001 010110100001 111111111111 111001001010 001010001001 100000110111 101000110111 11111111
1111 100000000001 010000000000 111111111110 110101110001 000000000000 111011001011 000000000000 110111101110 0001000111
10 010110100001 111011111111 111111111111 011010001001 111101100000 000000000000 000000111101 111111111111 110011111101
 010000000001 100100101011 000000000000 111111111111 010000110111 111011101110 010000110111 110110100001 011011111111

000111011011 111010001001,010101001111 110000101110 111010011001 110100000001 010000000001 111101110001 110000000000 00
0000000000 111011001011 000010000001 011011101110 000000000000 111010100001 110011000001 111011111111 011010001001 1000
11100110 111111111111 101011111111 011111111111 000000000000 111100000001 101100101011 000000000000 111111111111 010001
100000 110011101110 111111111111 010110100001 111111111111 001101000000 101010001001 000000000000 001000000000 11110001
0111 010000000001 010111111111 111111111110 111101110001 000000000000 110011001011 000000000000 110011101110 0100001011
10 011010100001 010111111111 000000000001 111010001001 111101100000 010101100011 000000000000 111111111111 000000110011
 100100000001 001000101011 000000000000 111111111111 000000000000 110011101110 100000110111 111110100001 010111111111

111000100100 111010001001 011001001111 111111001110 001010111001 010010000001 011111111111 111011110001 110000000000 00
0000000000 110011001011 000010000001 010011101110 001111110000 111001100001 001101111110 111011111111 101010001001 0001
01100110 000000000000 100110000001 011111111111 100001101000 110000000001 111100101011 000000000000 111111111111 011001
100000 111011101110 111111111111 010001100001 111111111111 101001101010 101010001001 100000110111 101000110111 11111111
1111 010000000001 010000000000 111111111110 110011110001 000000000000 110011001011 000000000000 111011101110 0010111101
10 010001100001 111111111111 111111111111 111010001001 111101100000 000000000000 011110100011.111111111111 111111111101
 100010000001 010100101011 000000000000 111111111111 010000110111 111011101110 010000110111 110001100001 010111111111
```

(a)

```
                                   NTSB BIT DUMP TRANSCRIPTION PROGRAM

  1:      0  4421  7452  3513  4400  4025  7776  4357     7     0  6463  4020  3566   373  4133  4112
 17:   7763  4423  3206  7777  4031  7776   532  4002  6506     0  7777   146  3567     3  4126  7777
 33:   2521  4424  7302  7307  7777  4001     2  3777  4357     0  6463     0  3573  3565  4132  7771
 49:   7777  4426   157     0  6136  7777  5777  4016  6514     0  7777  7302  3573  7302  4133  7767
 65:   2670  4423  7452  3507  4457  4016  4002  4343     7     0  6467  4021  3566     0  4127  4116
 81:   7767  4423  3177  7777  7765  7776  7303  4006  6514     0  7777   142  3567  7777  4126  7777
 97:   2503  4423     0     4     0  4000  7772  3777  4357     0  6467     0  3573  3571  4132  7770
113:   4002  4423   157  6165  6164  7777  6351  4010  6515     0  7777     0  3573     0  4133  7765
129:   5107  4426  7446  3477  4540  4012  7776  4343     7     0  6467  4021  3572   374  4133  4140
145:   7767  4424  3171  7777  4030  7776     0  4016  6515     0  7777   152  3573  4647  4132  7777
161:   2447  4424  7301  7305  7777  4001     2  3777  4353     0  6467     0  3573  3610  4132  7767
177:   7777  4426   157     0  5700  7777  5763  4002  6511     0  7777  7302  3567  7302  4133  7766
193:   6670  4427  7452  3503  4627  4013  4002  4357     3     0  6467  4020  3566     0  4127  4002
209:   7767  4426  3161  7777  7765  7776     0  4017  6515     0  7777   142  3563  7777  4132  7777
225:     54  4425     0     4  7217  4002  7772  3777  4357     0  6463     0  3563  3502  4126  7772
241:   4000  4427   157  6152     0  7777  6300  4011  6504     0  7777     0  3563  7301  4137  7772
257:   1107  4427  7446  3477  4724  4022  7776  4367     3     0  6463  4020  3562   374  4147  3254
273:   7767  4425  3150     0  4031  7776   541  4002  6517     0  7777   146  3567  7777  4142  7777
289:   2545  4425  7301  7305  7777  4002     2  3777  4363     0  6467     0  3567  3364  4147  7777
305:   7777  4427   157     0  6136  7777  5777  4021  6512     0  7777  7302  3547  7302  4141  7772
321:   2670  4425  7446  3467  5030  4020  4002  4357     3     0  6467  4020  3566     0  4140  4010
337:   7777  4426  3142     0  7766  7776  7302  4002  6521     0  7777   142  3567     3  4136  7777
353:   2516  4427     0     4     0  4002  7772  3777  4357     0  6467     0  3567  3471  4136  7772
369:   4000  4427   163  6175  6166  7777  6340  4011  6521     0  7777     0  3567     0  4133  7770
385:   5107  4432  7446  3467  5130  4012  7776  4343     3     0  6473  4020  3572   374  4127  4035
401:     13  4432  3132  7777  4031  7776     0  4016  6521     0  7777   146  3573  5707  4116  7777
417:   2465  4432  7301  7305  7777  4001     2  3777  4353     0  6473     0  3567  3504  4116  7777
433:   7777  4432   163     0  5701  7777  5753  4001  6520     0  7777  7302  3573  7302  4112  7771
449:   6670  4431  7446  3467  5221  4012  4002  4353     3     0  6473  4020  3572     0  4112  4021
465:     17  4434  3126     0  7766  7776     0  4016  6520     0  7777   142  3567     3  4112  7777
481:     55  4432     0     4  7217  4000  7772  3777  4357     0  6473     0  3567  3501  4112  7772
497:   4001  4432   163  6154     0  7777  6306  4006  6522     0  7777     0  3567  7302  4113  7770
513:   1107  4431  7446  3467  5305  4021  7776  4367     3     0  6473  4020  3566   373  4117  4021
529:     23  4433  3120  7777  4031  7776   551  4006  6522     0  7777   146  3567  7777  4116  7777
545:   2553  4434  7301  7305  7777  4001     2  3777  4357     0  6473     0  3572  3451  4116  7774
561:   7777  4435   163     0  6137  7777  5761  4017  6523     0  7777  7303  3567  7302  4123  7772
577:   2670  4432  7446  3467  5365  4026  4002  4373     3     0  6473  4020  3566     0  4123  4001
593:     27  4433  3111     0  7766  7776  7303  4002  6523     0  7777   142  3567     3  4122  7777
609:   2537  4432     0     4     0  4001  7772  3777  4403     0  6473     0  3563  3466  4116  7774
625:   4001  4427   163  6170  6163  7777  6277  4017  6522     0  7777     0  3557     0  4123  7771
641:   5107  4426  7446  3477  5443  4014  7776  4363     3     0  6467  4021  3546   373  4123  4052
```

(b)

Figure 19: Bit stream from bit dump mode of operation in (a) serial binary format; (b) 12-bit octal format.

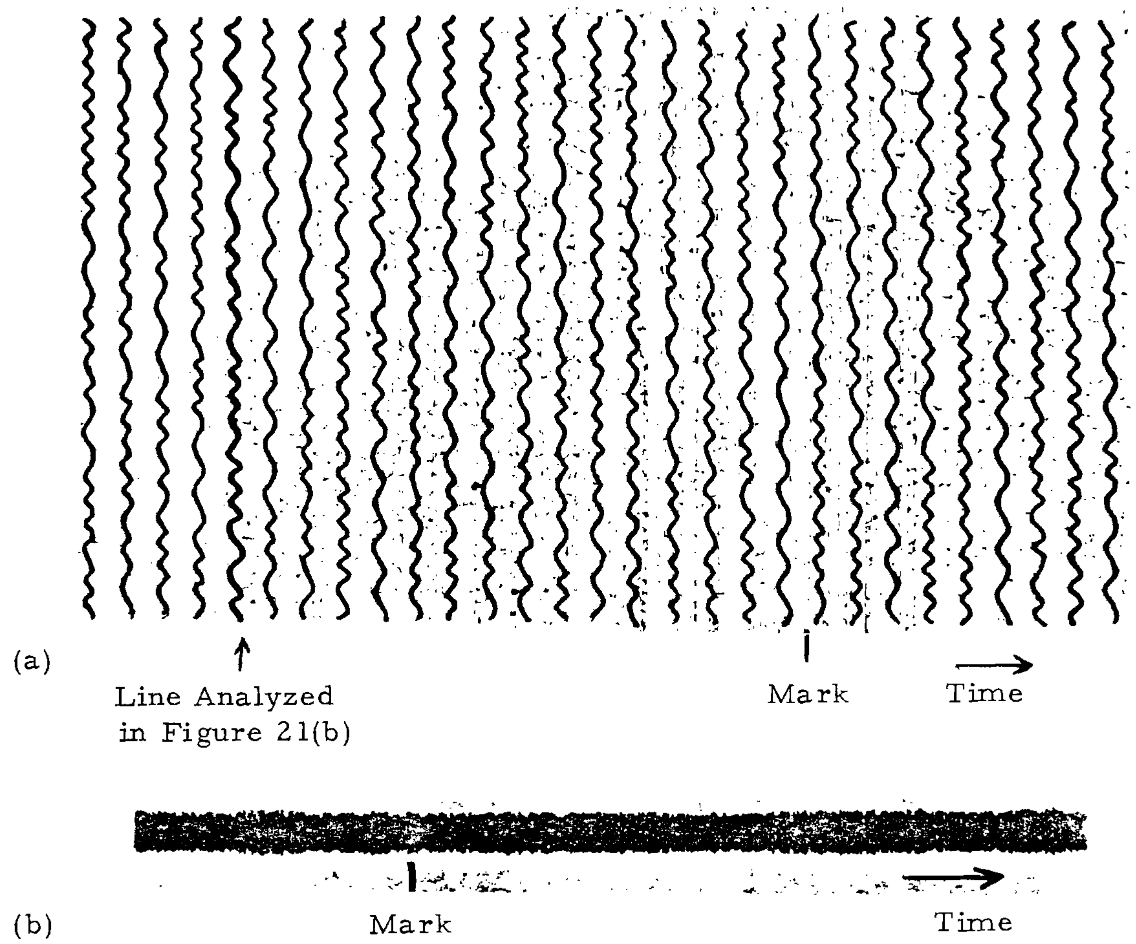


Figure 20: DFDR waveforms from recording oscillograph trace. (a) With sweep generator operating; (b) Without sweep generator.

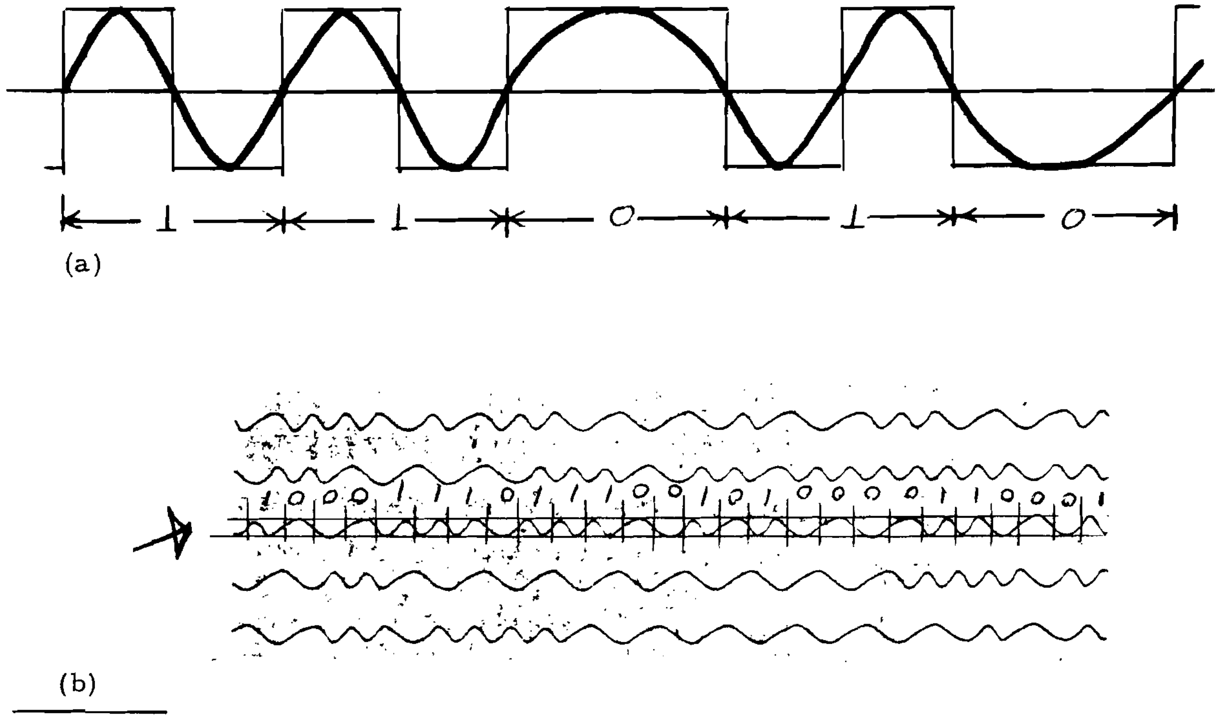


Figure 21: A "1" occurs if the pulse changes polarity half-way through the bit period. A "0" occurs if no polarity change occurs; (b) Manual interpretation of one line from Figure 20(a).

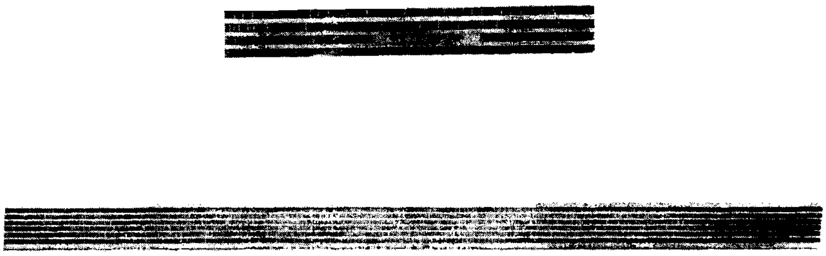


Figure 22: Magnetic pattern from (top) a 4-track SDC DFDR tape and (bottom) a 6-track LAS DFDR tape.

APPENDIX A

AIRCRAFT FLIGHT RECORDER SPECIFICATIONS AS DEFINED IN FAR PART 121, APPENDIX B (AMENDMENT 121-66, EFFECTIVE SEPTEMBER 18, 1970)

Information	Range	Accuracy, minimum (recorder and readout)	Recording interval, maximum (seconds)
Time		±0.125% per hour, except accuracy need not exceed ±4 seconds.	60.
Altitude	-1,000 ft. to max. certificated altitude of aircraft	±100 to ±700 ft. (see Table I TSO-C51a; FAR §37.150).	1.
Airspeed	100 to 450 KIAS or 100 KIAS to 1. V_D whichever is greater	±10 knots at room temp. ±12 knots at low temp. (see Table III, TSO-C51a; FAR §37.150).	1.
Vertical Acceleration	-3 g to +6g	±0.2g stabilized, ±10% transient (see TSO-C51a).	0.25 (or 1 sec. in which ± peaks are recorded).
Heading	360°	±2°	1.
Pitch Attitude	±75°	±2°	1.
Roll Attitude	±180°	±2°	1.
Lateral Acceleration (in lieu of sideslip angle).	±1.0g	±0.5g stabilized ±10% transient	0.25 (or 1 sec. in which ± peaks are recorded).
Sideslip Angle (in lieu of Lateral Acceleration).	±30°	±2°	0.5.
Radio Transmitter Keying	On — Off		1.
Pitch Trim Position	Full range	±1° or ±5% whichever is greater	2.
Control Column or Pitch Control Surface Position	Full range	±2°	1.
Control Wheel or Lateral Control Surface Position	Full range	±2°	1.
Rudder Pedal or Yaw Control Surface Position	Full range	±2°	0.5.
Thrust of Each Engine	Full range forward	±2%	4.
Position of Each Thrust Reverser	Stowed and Full Reverse		4.

Appendix A (Continued)

Trailing Edge Flap or . . . . . . Cockpit Flap Control Position	.Full range (or each discrete position)	±3°	2.
Leading Edge Flap or . . . . . Cockpit Flap Control Position	.Each discrete position		2.
Angle of Attack . . . . (If recorded directly)	.-20° to +40°	±1	0.5

FROM SCRIBE TO DATA – OSCILLOGRAPHIC FLIGHT DATA RECORDER

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INTRODUCTION

The importance of the flight recorder plot in assisting to determine the probable cause of an accident or incident has been very well established, but do all investigators extract the maximum information available from graphs? The answer is no. It has been my experience that this apparent inability is due primarily to a lack of understanding of the process, the recorder, the tape, the graph and its limitations. To initiate the necessary corrective actions, I offer you a review of the oscillographic flight recorder, data reduction process, and samples of information available from the final plot.

SPECIFICATIONS–UNITED STATES

The requirements for this type of recorder are set forth in Federal Aviation Regulation 121.343 and the specifications are listed in FAR 121, Appendix B. (Appendix I)

The data recorded is time, altitude, indicated air speed, vertical acceleration ("G" force), heading and radio transmission (time). All flight recorders must have attached to them, or adjacent to them, an underwater locating device. All aircraft require an indicator within the cockpit which illuminates if the movement of the tape stops during the required operation period. The oscillographic recorder is the most common type used–in United States commercial aviation alone it presently represents approximately 85% of the total.

THE RECORDER

The recorder has a self-contained speed and altitude sensor, a remote mounted vertical acceleration sensor, located within the aircraft's center of gravity limits, and a self-contained timing device. Heading information is normally supplied from the first officer's compass system. Radio transmission time is recorded only when the aircraft is transmitting to traffic control.

There are two types of oscillographic recorders used. The principles of recording are the same; each signal source drives a stylus which embosses or etches the foil. The foil (tape) speed is 6" per hour, thus establishing the time base. The combination of the tape movement in "X" axis in conjunction with the stylus movements in the "y" axis gives us the oscillographic presentation. Time intervals in minutes, as well as the reference line, are traced during all operations. All dimensions are measured from the reference line.

The spherically shaped Lockheed Model 109-C uses an aluminum foil, 2½ inches wide and capable of 200 hours of recording. The recording is continuous and only one side of the tape can be used. The styli are offset, thus requiring an overlay to obtain values of the parameters referenced to a fixed-time line, or a minicomputer can be programmed to perform the same function (figure 1).

The other type of recorders, such as the Sundstrand F-542, or the Fairchild 5424, use a stainless steel tape 5" wide, capable of 400 hours of operation for each side. The styli have diamond heads which engrave the required parameters at one second intervals. The curve consists of a series of one-second dashes. The fixed-time reference for all parameters lies on the datum line that is perpendicular to the reference line.

These recorders are basically mechanical devices and, like all such devices, a maintenance program is required. Recognizing that the units are subjected to normal wear, vibration, etc., the maintenance program must provide a means to ascertain that the position of the styli is within designed dimensions. The manufacturers' conversion charts, which are used to convert inches to a parameter value, are based on the premise that the position of the styli is within its designed dimension.

To determine precise styli positioning and its related parameter value it is common practice in the U.S. that, subsequent to a shop maintenance action, a calibration chart be made during the final operational inspection. Signals from shop standards are used to actuate the styli for a series of specific parameter values (altitude, knots, etc.). The foil is removed and the values are noted on the foil at the respective points. The foil now has a set of calibrated values. It is dated and the serial number of the recorder is added and kept in file until the next calibration. It becomes the reference chart for the particular recorder for tape readout purposes.

DATA REDUCTION

The data reduction process begins with the retrieval of the recorder. Its bright orange color and its location in the aft section of the aircraft localizes the search area. Extract the complete unit from the aircraft and examine its general condition and:

- If the recorder has been submerged in salt water immediate immersion in fresh water for a 24-hour period will retard salt water corrosion.
- If the recorder has not been subjected to fire or impact damage and it is deemed necessary to remove the cassette, have it done by an experienced person. The foil can also be rolled onto one spool. Foil should always be transported or shipped wound on the spool.
- If the recorder has been subjected to heat or impact damage, it should not be disturbed. Forward the unit to the reading facility.

All shipped components should be properly packaged and always include the make, model, and serial number.

The data reduction facility requires three pieces of equipment: a flat table or platen to hold the foil securely; an optical instrument with sufficient magnification; and a means to measure the magnitude of the traces in both the "x" and "y" axes. A ten-powered magnifying glass, using an appropriate machinist scale or an overlay, is generally sufficient for cursory or nondetailed analysis.

Accident or incident plots require more details; accordingly, the data reduction system must have greater precision. The mounted tape should be covered with nonglaring glass. This will not only keep the tape flat, it will also reduce light reflections. A microscope with cross hairs and a magnification factor of about 35 is sufficient to distinguish one-second marks. Means should be provided to read the value of "x" and "y" points in increments of ± 0.001 inches and the recording of such dimensional changes. The tape or microscope can be moved. In either case, all movements should maintain the required accuracy. Any deviations can cause errors in the correlation between the value of the parameters referenced to a specific time. It is also desirable to have provisions for photographing the tape through the microscope.

The importance of being able to read in increments of 0.001 inches is evident, realizing that the tape recording speed is six inches per hour. This represents a rate of 0.00166+ inches per second. An aircraft landing at 150 knots has an approximate speed of 240 feet per second. The U.S. National Transportation Safety Board (NTSB) has adopted a tape speed of 0.0016 inches per second for all its data reductions. In addition, some recorder manufacturers identify "y" values to 0.001 of an inch.

The first step in the process is to readout the calibration tape. The tape, properly mounted, should be aligned with the horizontal cross hair of the microscope, thus establishing the zero reference point. Using the zero reference as the starting point, measure the distance from there to the points identified on the tape. Note and record the value of "x/y" in 0.001 inches and its respective value in feet, knots, or whichever is applicable. This completes the analysis of the calibration curve. The tape is removed and the aircraft tape is mounted. The mounted tape should be smooth and devoid of dirt and kinks. The section to be read is located; the reference line is aligned with the cross hair, and the zero reference point for both the "x" and "y" axes is established. It is good practice to make a cursory inspection of the tape, particularly for alignment purposes. If corrections are necessary, make the corrections before proceeding. Starting from the zeropoint, remembering that the "x" axis represents time and the "y" axis represents the value of the particular parameter, move to the selected parameter, recording the change in value of the "x" and "y". Continue the reading for this particular parameter to the end, tabulating all points where the value has changed. The same procedure should be followed for all other parameters.

Upon completing the point-to-point readout, add or subtract the offset value for those tapes whose recording is offset. Normally, offset recording is associated only with the "x" axis, the time base. Now all "y" values can be converted to parameter values using the manufacturers, conversion tables, and the "x" values to second.

Check the values of the parameter obtained with those obtained from the calibration table.

If a correction is necessary, make the necessary adjustments to the plotting data. As an example, if the data obtained from the calibration tape shows that 1" in the "y" axis represents 150 knots and 2" represents 280 knots, whereas the tape indicates 140 knots and 305 knots, respectively, a correction curve must be plotted from which more representative values may be obtained.

The altitude sensors cannot be corrected for barometric changes. To compensate, obtain the pressure reading converted to feet from the last takeoff airport (as close to the departure time as possible). Compare this reading with the reading obtained from the recorder during the same departure. The difference, if any, must be computed into the final plot.

The accuracy of the heading information can be confirmed by comparing the tape data with the published heading of either the last takeoff runway or landing runway.

The plot should be scaled to the needs. If all "x" readings are taken in seconds, the time line should be in seconds for maximum accuracy.

At times it may be found that the final plot appears to be, to a degree, unreasonable. In such cases it becomes necessary to readout the data from previous flight. Comparing these additional readings with the plot in question will normally indicate if the discrepancy was inherent to the recorder, or if the plot represents the actual conditions.

The cycle is completed when the investigator receives the plot. It provides him with values at some particular point in time. Combining these values and relating them to known factors, he is able to extract significant and meaningful information which assists him in his task.

As an example of some of the data that can be extracted from plot, let us examine Illustrative Plot, Fig. 2:

- The vertical acceleration, or "G" forces, shows that the aircraft experienced slight to moderate turbulence at about the 27-seconds point. At 47 seconds there is an increase in "G" followed by a decrease in speed and the altitude is below the runway. This represents the point of landing. The high "G" excursion at the 58-seconds point shows the point of impact—note the sharp decrease in speed.
- The heading line shows course changes between 7 and 39 seconds. It can indicate a crosswind, poor piloting, or poor autopilot operation. Additional investigation is necessary. Comparing the craft's heading on landing with the published runway heading verifies the accuracy of the heading trace.
- At the 10-seconds point note the normal increase in airspeed with a decrease in altitude.
- At 47 seconds it appears that the aircraft landed below the runway. This is normal; it is the result of pressure compression between the aircraft's wings and the ground. Note that the pressure is normalized as the aircraft continues its ground roll. The rollout altitude is the same as the altitude of the runway, verifying the accuracy of the trace.
- We know airspeed and time from which we can calculate distance and rate.
- Radio transmission marks which can be time-referenced to the voice recorder permit a time correlation of aircraft performance with activities within the cockpit.

CONCLUSIONS

In conclusion, I have but one statement to make—get better acquainted with the system; understand the readout techniques and practices; analyze the final plot for clues that may reflect abnormal conditions and, in return, the system will better assist you in your investigative tasks.

FEDERAL AIR REGULATION FAR 121, APPENDIX B

Information	Range	Accuracy, minimum (Recorder and readout)	Recording Interval maximum (seconds)
Time		±0.125% per hour except accuracy need not exceed ±4 seconds	60
Altitude	-1000 to maximum certificated altitude of aircraft	± 100 to ± 700 feet (See table I TSO-C51a; FAR 37.150)	1
Airspeed	100 to 450 KIAS or 100 KIAS to 1.0_{vp}, whichever is greater	± 10 knots at room temp., ± 12 knots at low temp. (See table III, TSO C51a; FAR Section 37.150)	1
Vertical acceleration	-3g to +6g	± .2g stablized, ± 10% transient (see TSO-C51a)	0.25 (or 1 second in which ± peaks are recorded)
Heading	360 degrees	± 2 degrees	1

NOTE: FAR 37.150 (TSO-C51a) contains the minimum performance standards for the aircraft flight recorder. Ref. U.S. Code Federal Regulations 14, Aeronautics and Space—Part 37—Technical Standard Order Authorization

APPENDIX I

THE SUBJECTIVITY OF FLIGHT DATA RECORDER READOUTS

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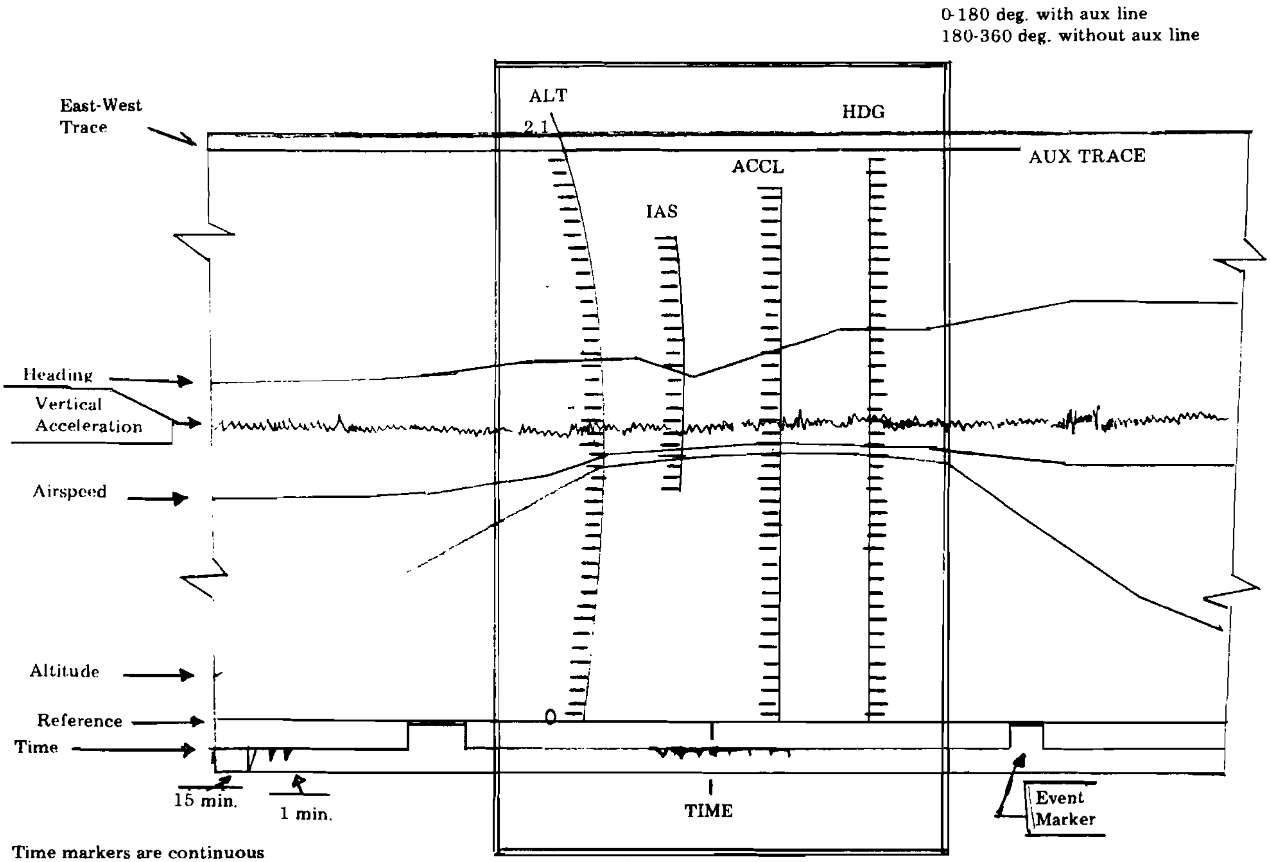
I. INTRODUCTION

As most of you are aware, two "black box" recording devices are required by many regulatory authorities on large commercial air transport aircraft. One is a Cockpit Voice Recorder for recording voice conversations, and the other is a Flight Data Recorder which records aircraft flight parameters. Two types of Flight Data Recorders are in use today; the foil (FDR) and digital (DFDR).



Time markers are continuous

Note: The value of the grid marks on the overlay are not included on this sample. (Normal increment —.01")

OVERLAY & FOIL

ILLUSTRATIVE PLOT

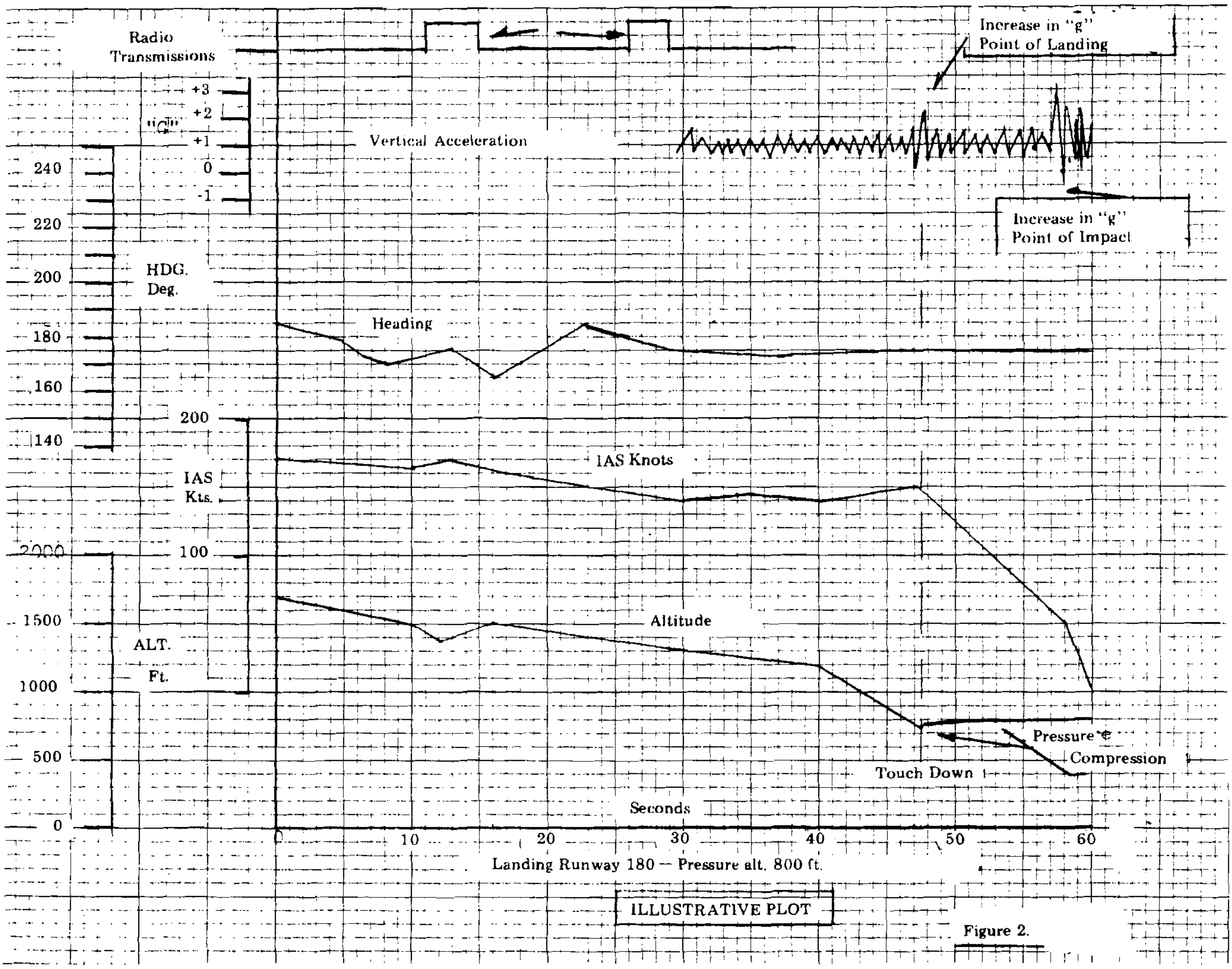
Figure 1

The foil type recorders are installed on most pre-wide-body trunk carrier aircraft. My discussion will focus on the technical aspects of transcribing FDR recorder data.

II. THE MECHANICS OF FOIL RECORDERS

The recorder system consists of a housing which contains the electronics, motor drives, scribe arms and altitude/airspeed diaphragms, an externally mounted accelerometer and a removable magazine containing the recording medium (Fig. 1). Also shown is the trip and date encoder which is a manually selectable input device for providing flight identification logic to the recorder.

Operationally, recording is accomplished by the periodic depression of diamond-tipped scribes onto a moving metal tape (Fig. 2). When powered, individual parameter sensors position the scribe



ILLUSTRATIVE PLOT

Figure 2.

arms prior to contact with the tape. The contact sample rate is generally controlled by the number of lobes on a constant speed cam mechanism which drives the scribes against the tape. The required sample rate varies between countries, but most are at least ten per second for vertical acceleration and one per second for all other parameters.

The standard U.S. FAR required parameters (for large jet and turbo-prop aircraft having an original type certificate prior to September 30, 1969) are altitude, airspeed, heading, vertical acceleration, time and closure of the radio microphone switch. Optional recorder configurations can provide for up to ten parameters. Figure 3 illustrates some of the design variations between recorders manufactured in the United States. The parameter accuracies vary between models, but all must meet FAR 121.343 Appendix B requirements.

III. PARAMETER SIGNAL SOURCES

- Altitude/Airspeed
  The recorder contains individual altitude and airspeed diaphragms which may be driven by any pair of the aircraft's pitot and static sources. The recorded altitude information is totally independent of the barometric setting of the altimeters.
- Heading
  The aircraft compass system is usually the source of magnetic heading information A voltage signal is fed to the recorder heading servo.
- Vertical Acceleration
  A vertical accelerometer of the type shown in Fig. 1 is mounted close to the aircraft's center of gravity. The acceleration range is typically -3G to +6G.
- Radio Transmissions
  The aircraft communication system provides signal coincident with a radio transmission from any one of the cockpit microphones.

IV. THE RECORDED TAPE FORMAT

The relative positions of the parameters on a Sundstrand tape, as an example, are shown in Fig. 4. Notice that under magnification, the heading, airspeed and altitude traces become a segmented series of oval shaped marks. These are the contact points of the knife edge scribe tips with the tape. The vertical acceleration scribe is distinct in that it has a point tip which results in the appearance of a continuous line in the Sundstrand recorder due to the 10 per second sample rate.

The reference line which appears along the lower edge of the tape serves a dual purpose. First, it provides a common reference point from which the measurement of all parameters can be determined. Second, it records the flight identification as received from the trip and date encoder. Examples of this are shown in Fig. 5.

V. FLIGHT RECORDER CALIBRATION

Every recorder receives a calibration check when it is overhauled or undergoes other scribe or transducer related shop servicing. A calibration tape is made at that time using simulated parameter inputs (Fig. 6). Each step shown is a manufacturer's recommended calibration point. This calibration data is necessary to determine the unique input/output response curves associated with each recorder, as the precise response of *each scribe* to known values of input voltages or pressure must be known. Calibration tape readout is accomplished using a precision microscope instrument mounted on a calibrated movable X - Y Table (Fig. 7). Vertical measurements are made from the reference line to each of the steps on the tape. These data points are then used to develop the response curves shown in Figures 8 and 9. These curves display the nonlinear relationships of input pressure to scribe recording position. The altitude calibration and the resulting response curve is based on a 29.92 inches of mercury sea level standard day pressure. Similar curves are developed for heading and vertical acceleration. These curves are used to convert the reference line-to-parameter readings from the subject flight tape into units of feet, knots, degrees and acceleration.

VI. FLIGHT TAPE TRANSCRIPTION PROCESS

The subject flight is first identified through the trip and date encoding. In Fig. 10, reading from right to left, the pulse groupings are independently summed as was illustrated in Fig. 5. Here, we read Flight 324 of the 16th. When flight identification is confirmed, the segment of the flight to be reviewed is positioned on the X - Y Table and measurements made to *selected* scribe marks. Vertical (parameter value) measurements are taken relative to the reference line and horizontal (time) measurements are made relative to a preselected starting point. Obviously, it is unnecessary and impractical to read every data sample. If more than two scribe marks lie on a straight line, it is only necessary to read the first and last.

As an example, let's assume that Flight 324 encountered turbulence during descent into Miami (KMIA). In practice, we would probably only be interested in reviewing several minutes before and after the incident. For illustration purposes, however, we will consider the entire approach from start to descent. Figure 11 is an expanded view of the altitude parameter. The data samples selected for readout are indicated by an asterisk and are numbered. These selected points are not unique and would differ somewhat between individuals reading the tape. X and Y measurements of these points are tabulated. Assuming the flight was operating in a standard day pressure environment, the Y readings are converted into values of altitude feet using the altitude calibration curve (Fig. 9). The X readings are converted to time in one of several ways depending on the recorder type.

In Sundstrand and Lockheed recorders, time is recorded in one-minute intervals, as shown on Fig. 10. For data-points falling within these intervals, the one-minute spacing is measured and a linear interpolation applied to the subject data points, i.e., 1/2 space = 30 seconds.

The Fairchild recorder contains an internal precision frequency generator which controls the speed of a synchronous tape drive motor. For this reason, no time marks are annotated, and the tape is assumed to travel linearly at 6 inches per hour. The X measurements are converted accordingly, (.001 in. = .6 sec.). A tabulation of the X - Y readout for altitude is shown in Fig. 12. The other parameters are read in a similar fashion. These data may then be plotted in a format and scale selected by the analyst.

VII. REQUIRED DATA READOUT CONSIDERATIONS

Unfortunately, most recorded foil tapes fall short of the "ideal" illustrated in Fig. 10. Corrections must be applied to compensate for scribe position errors, tape speed variations and differences from the 29.92 standard-day atmospheric pressure. Subjective interpretations are necessary when pitot/static airflow disturbances cause erroneous airspeed and altitude scribe deflections. These effects are frequently observed in turbulence encounters and during takeoffs and landings:

- Scribe Position Errors

  Errors in the scribe positions may be either along-track or cross-track. Along-track errors are depicted in Fig. 13. These are mechanical offsets which effect the *time* relationship between parameter recordings. These offsets are determined by reading the X positions of the last scribe mark recorded for all parameters. A vertical line across the tape, perpendicular to the reference line, should pass through all marks identically. A bias correction must be applied to the tabulated X readings to compensate for any misalignment.

  Cross-track errors are determined by comparing various *known* flight parameter conditions to the values actually recorded. In the case of airspeed, the value prior to takeoff is measured. Any reading other than zero is applied as a plus or minus correction. For altitude, the reading on takeoff or landing is checked and compared to the known field elevation. An appropriate correction is applied. The barometric pressure at the time of the flight must also be considered in the correction. The recorded takeoff or landing heading is compared to the known runway headings and a correction applied accordingly. The checkpoint for vertical acceleration is +1G when the aircraft is stationary on the ground or is in smooth level flight.

  These cross-track error corrections must be applied *before* the tabulated X - Y readings are converted into parameter units by the use of the calibration tape. This is accomplished as illustrated in Fig. 14. Notice that the airspeed curves are not parallel. Each data point used to develop the original curve is shifted horizontally by the amount of the difference of the zero airspeed readings as discussed above. The X - Y conversions are now performed using the corrected curves. In reality, the calibration tape serves only to describe the *shape* of the parameter response functions.

- Tape Speed Errors

  A typical altitude recording might appear as shown in Fig. 15. The effects of tape speed variations called "stitching" are evident here. This results in groupings of multiple data samples periodically separated by gaps. This is caused by hysteresis in the tape tension mechanism which allows slack in the tape for short periods of time. The only valid data points, relative to time, are those occurring when the tape tension is restored. These points are numbered. The data is artificially smoothed in this manner and the confidence level of the final transcription plot must be judged accordingly.

  The "stitch" patterns and the corresponding valid update points are usually recognizable in the altitude and airspeed recordings, but are difficult to positively identify in the heading trace. This is partially due to the fact that heading changes occur more rapidly and often reverse directions. It is often impossible to identify the valid update points for vertical acceleration. In cases of severe stitching, only the peak G values are read. An approximation of the relative time of occurrence must suffice. This also applies to radio transmissions which is a continuous trace with no data gaps.

- Pitot Static Source Errors
  Pitot static airflow disturbances can occur in turbulence and give the appearance of data scattering as shown in Fig. 15. Under these conditions, it is not possible to determine with absolute certainty which altitude or airspeed data points are valid. Generally, if one data point stands alone significantly greater or less than the previous and following ones, it is considered invalid. Extenuating circumstances may alter this logic in certain cases.

  Notice also that the altitude trace shows the aircraft as having descended below ground level during landing. This is caused by an increase in air pressure around the static ports that results from a combination of the aircraft's altitude and proximity to the ground. It is commonly called "ground effect." The resulting trace is read and plotted as shown, even though the aircraft did not, in fact, follow this flight path. In conjunction with other related incident data, this gives an indication of the aircraft's landing flare and the magnitude of the resulting air cushion. The aircraft's final rate of descent is indeterminable due to this effect. The lowest valid altitude scribe that can legitmately be used for descent rate calculations varies, but readings below 50 feet above the ground are definitely questionable.

- Barometric Pressure Environment
  As mentioned earlier, the altitude recording is referenced to the standard day barometric setting of 29.92 inches of mercury sea level pressure. The altitude calibration curve must be shifted to compensate for the reported pressure at the time of the incident. The mathematical difference between the reported and the standard barometric pressures for the elevation in question is multiplied by 925 feet. For example, if the reported pressure was 30.28, then the difference is .36 and the correction would be 925 X .36 = 333 feet. This means that the recorder was showing the aircraft to be 333 feet *lower* than it actually was. The method of applying this correction is shown in Fig. 16.

  First, the 333 feet is applied to vertically offset the calibration point that is closest to the subject flight's Y altitude reading when on the ground. The resulting horizontal offset from the 29.92 curve is then applied to all other calibration points and a new corrected (30.28) curve drawn. If the reported pressure was less than 29.92, the correction curve would be below the 29.92 curve.

VIII. SUMMARY

It is evident that the accurate determination of an aircraft's performance based on recorded FDR information is difficult to accomplish even under ideal recording conditions. By the very nature of most incidents and accidents, unusual situations that sometimes exceed the capabilities of the recording system can occur. The quantitative effects of numerous variables, and their relative impact on the flight parameter recordings, is subject to the interpretive processes of the readout analyst. While the analytical techniques followed in the transcription process are technically valid, the final profile plot should not be considered an *exact* duplication of the subject flight. It remains a very useful investigative tool and indeed, represents the best data available. It is important for the Air Safety Community to recognize the accuracy tolerances associated with this data and be cognizant that unknown environmental factors may have had an adverse impact on the recordings.

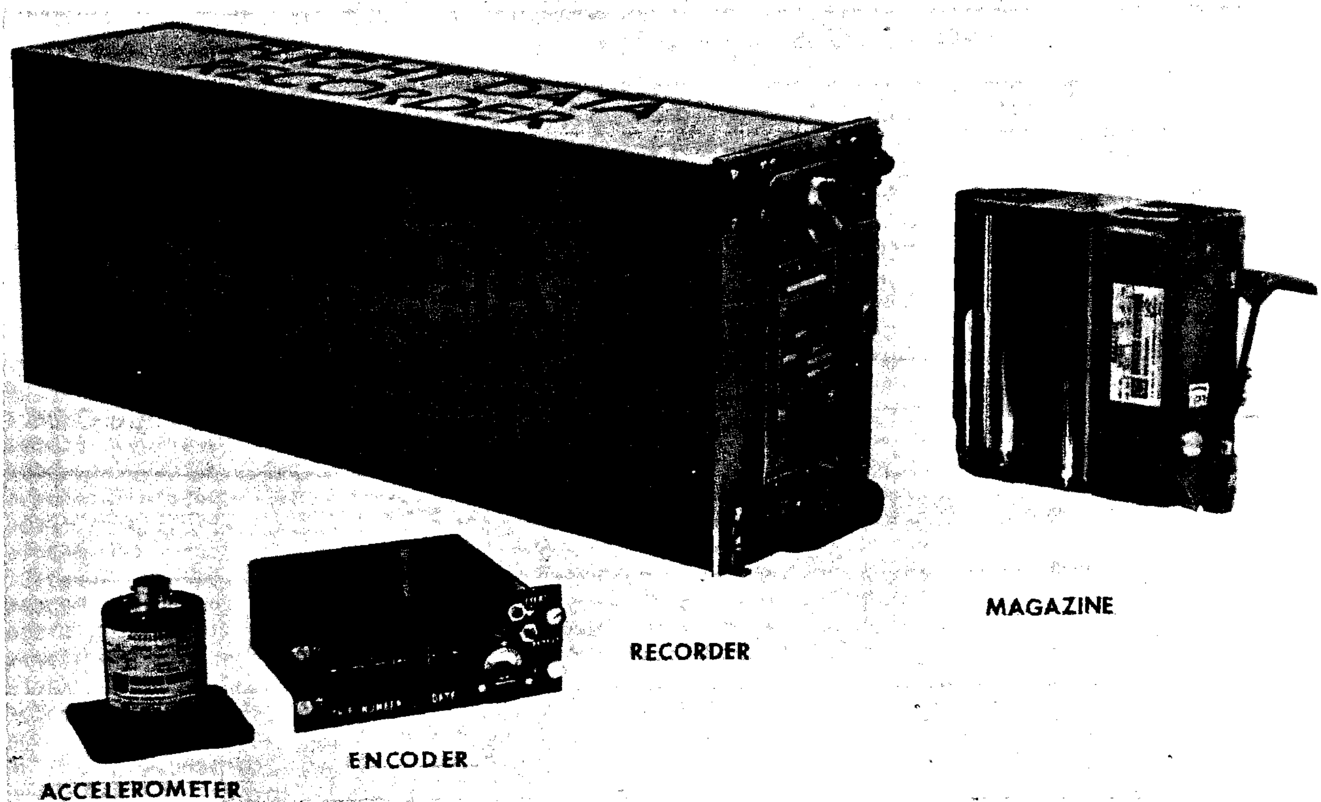


FIG 1 FLIGHT DATA RECORDER SYSTEM

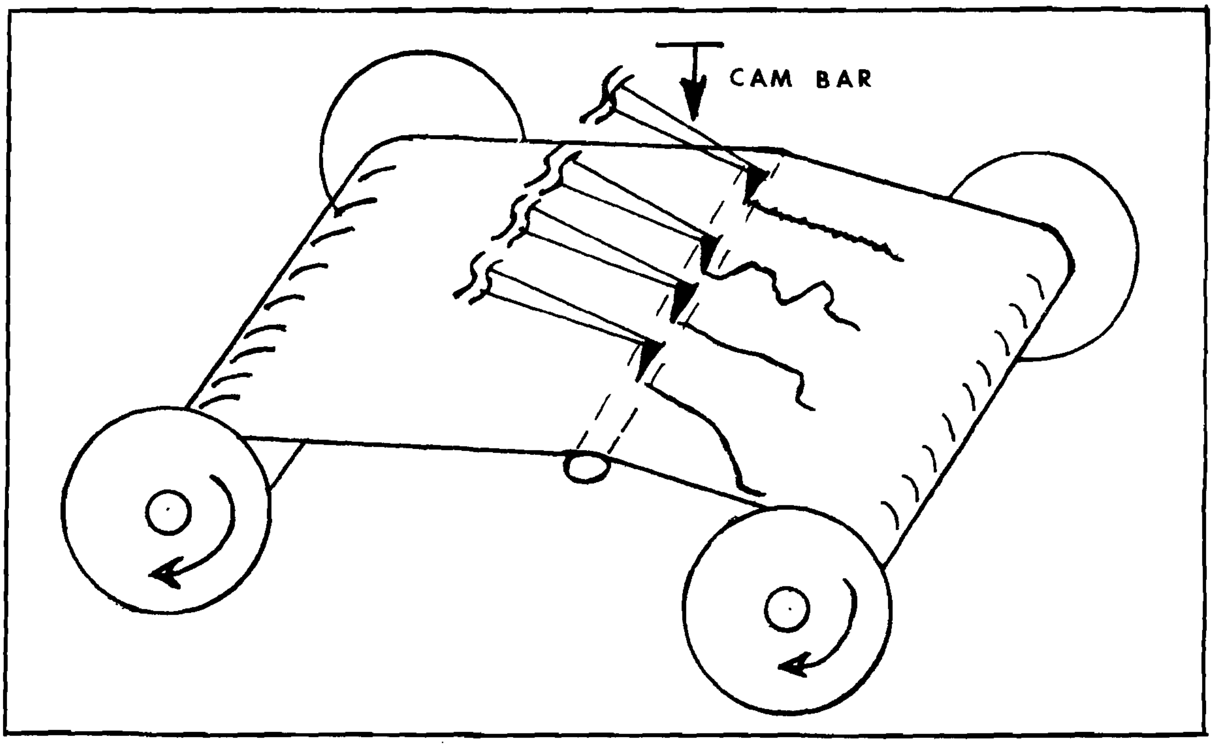


FIG 2 RECORDING MECHANISM

Manufacturer	PARAMETERS/SAMPLE RATES						TAPE SPEED	RECORDING MEDIUM
	ALT	A/S	HDG	VERT ACC	MIKE KEY	TIME		
Sundstrand	1/Sec	1/Sec	1/Sec	10/Sec	Continuous	1/Min	6 In/Hr	Stainless Steel
Fairchild	1/Sec	1/Sec	1/Sec	Continuous	Continuous	Constant Speed	6 In/Hr	Stainless Steel
Lockheed	Continuous					1/Min	Variable	Aluminum

FIG 3 FOIL RECORDER DESIGN VARIATIONS

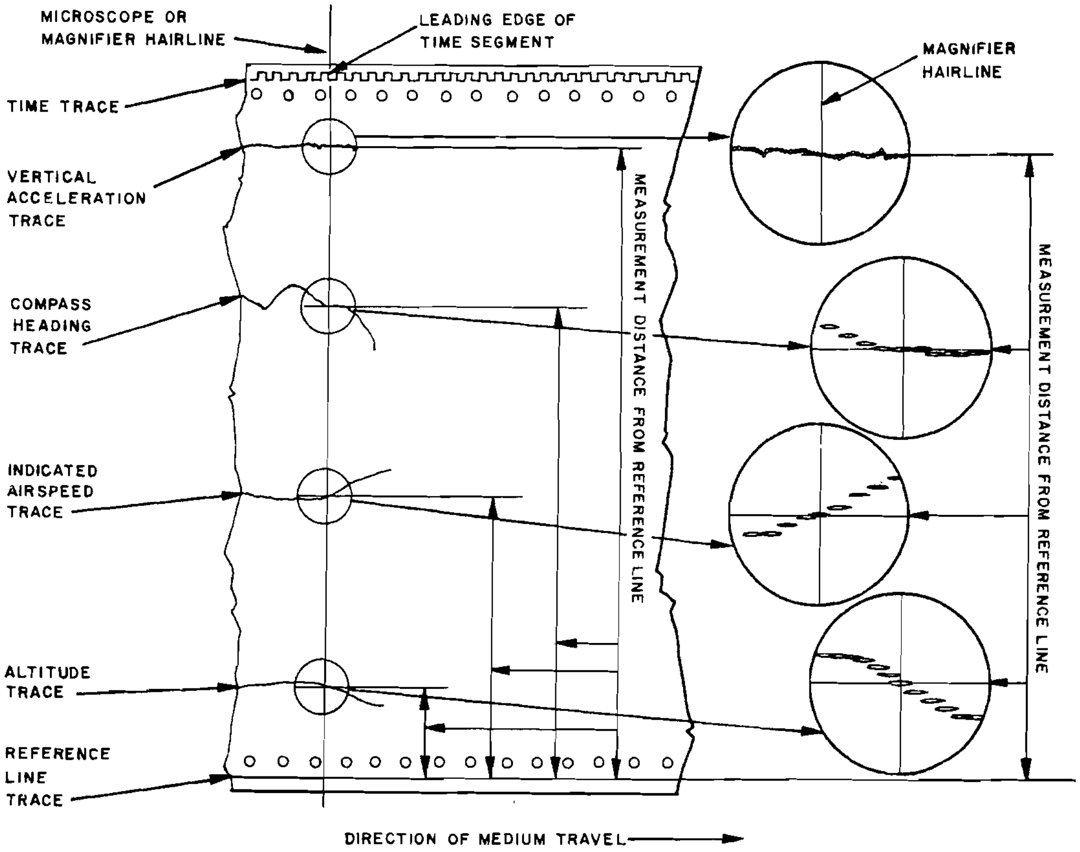


FIG 4 PARAMETER LOCATIONS

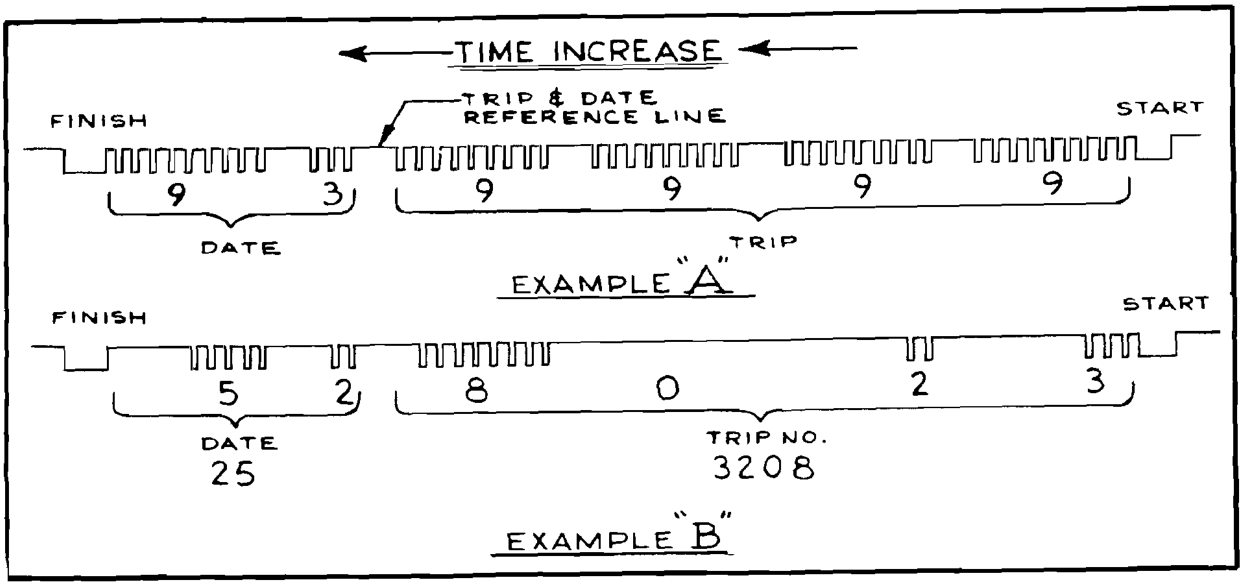


FIG 5 TRIP AND DATE ENCODING

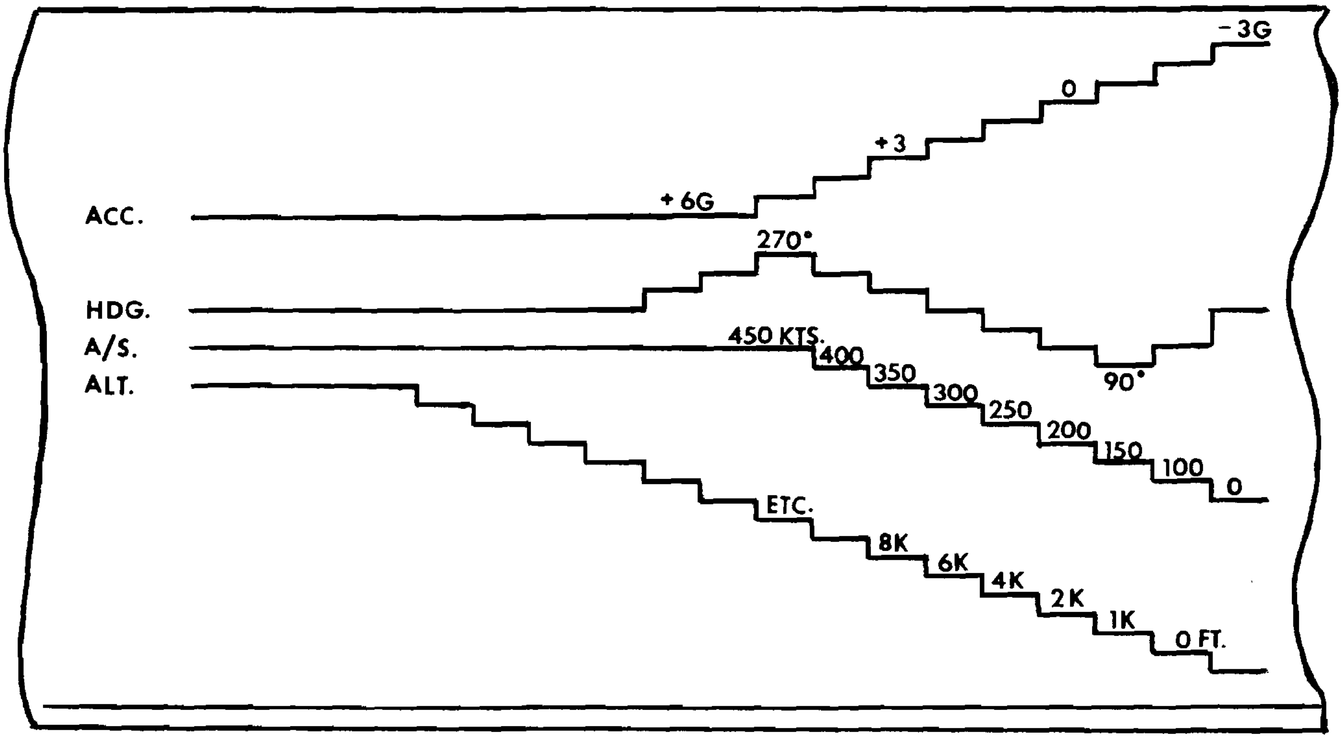


FIG 6 TYPICAL CALIBRATION TAPE

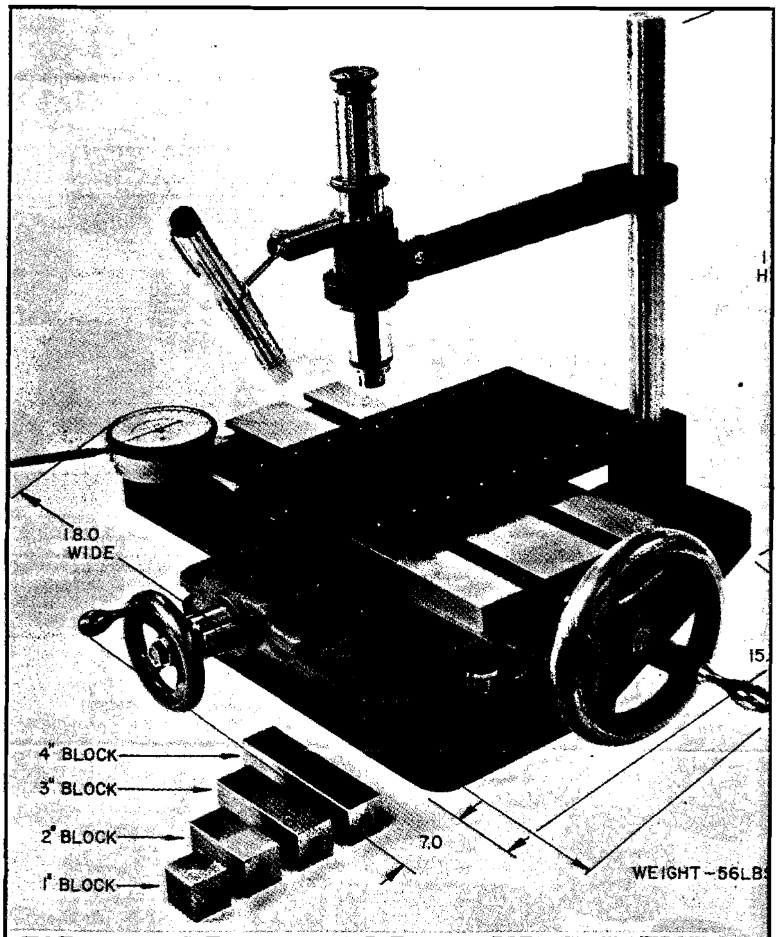


FIG 7 RECORD READOUT INSTRUMENT

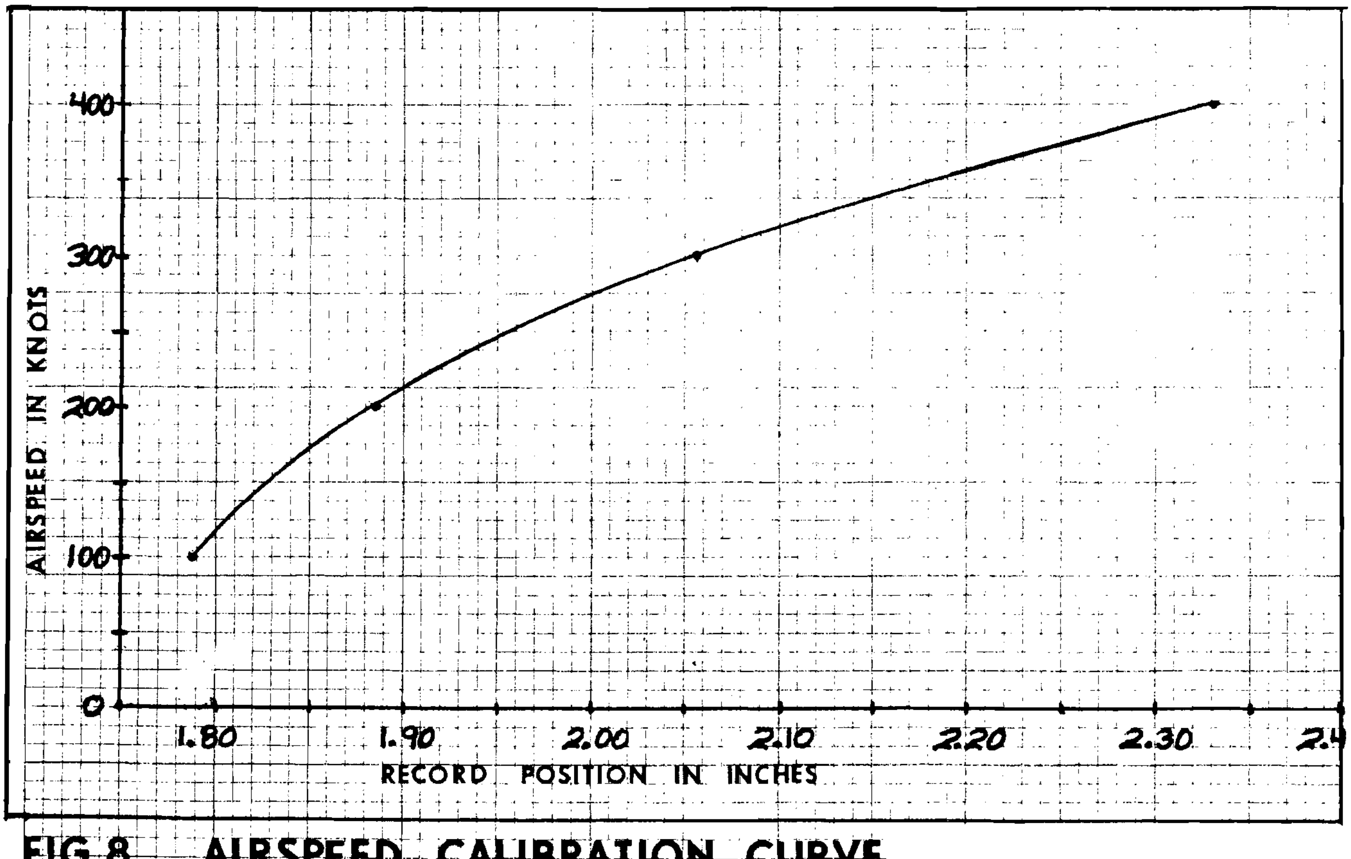


FIG 8 AIRSPEED CALIBRATION CURVE

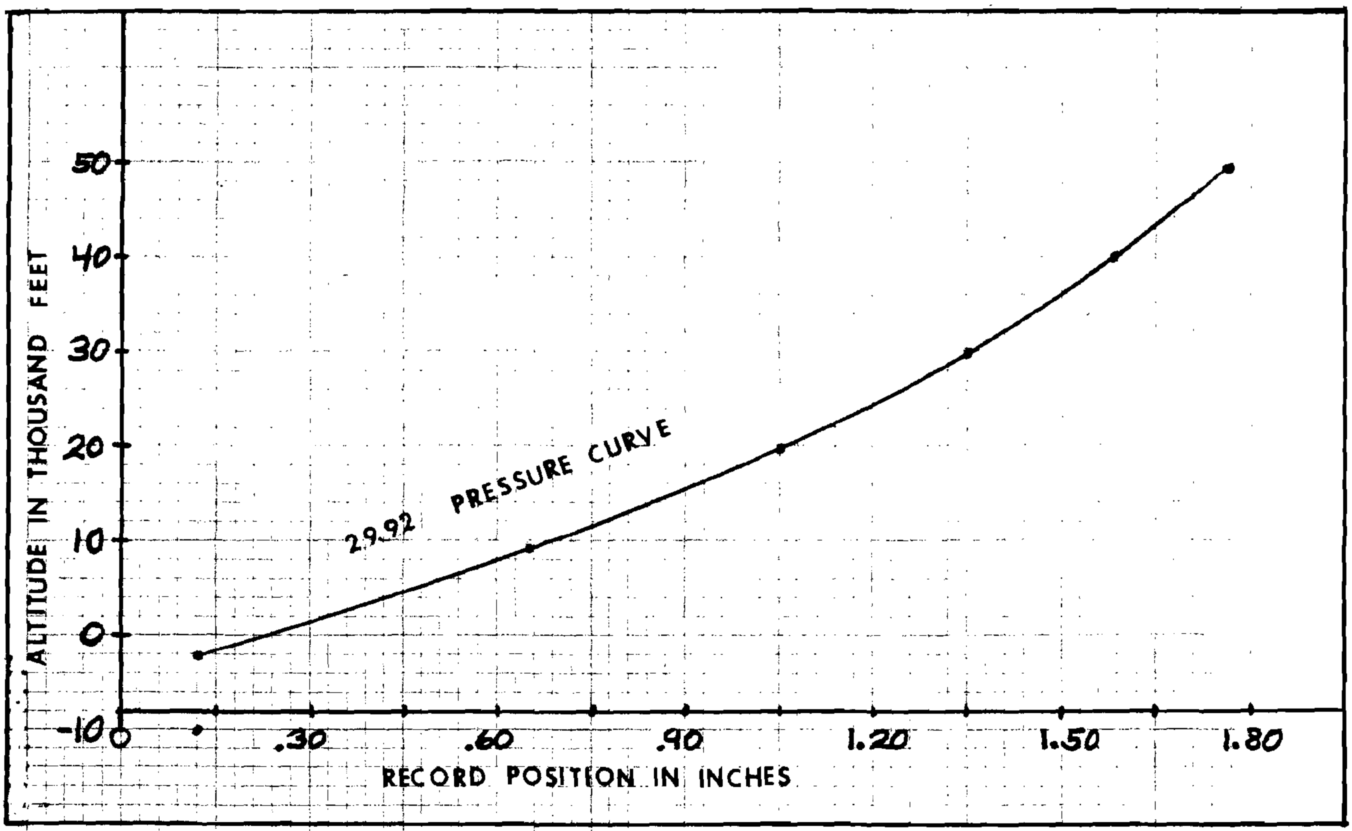


FIG 9 ALTITUDE CALIBRATION CURVE

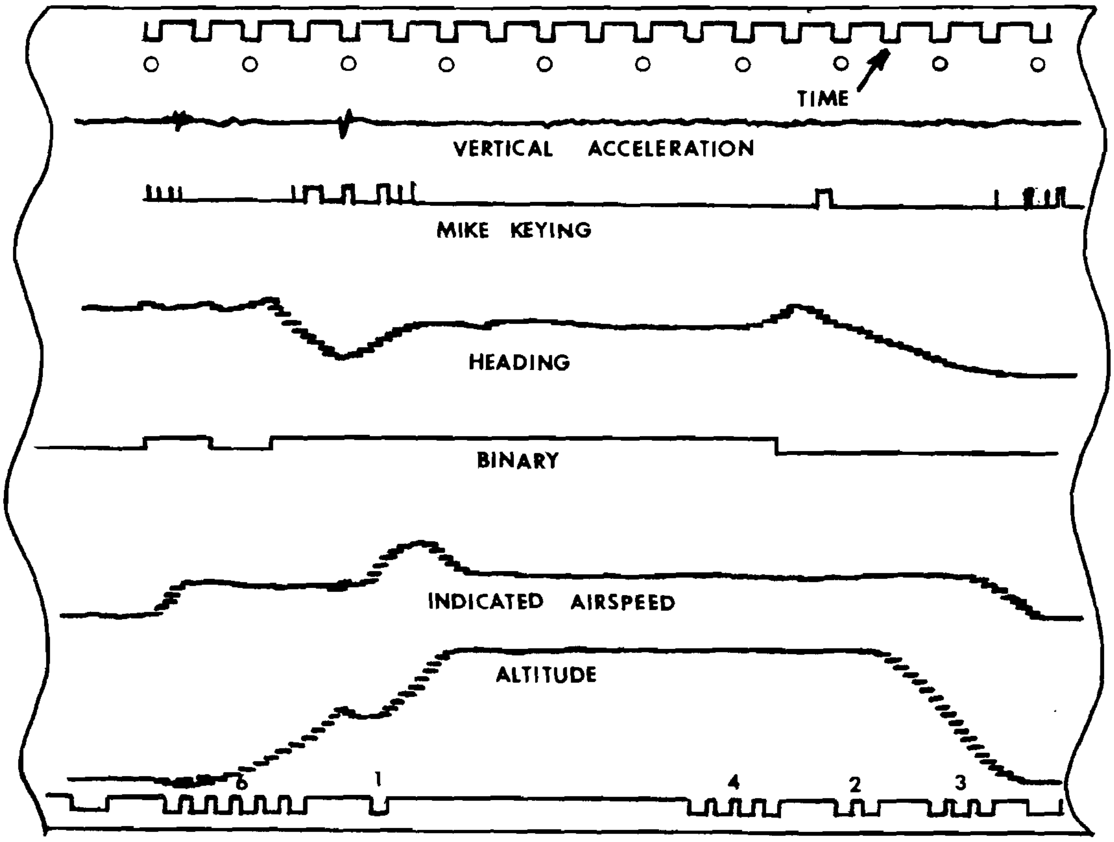


FIG 10 SAMPLE FLIGHT TAPE

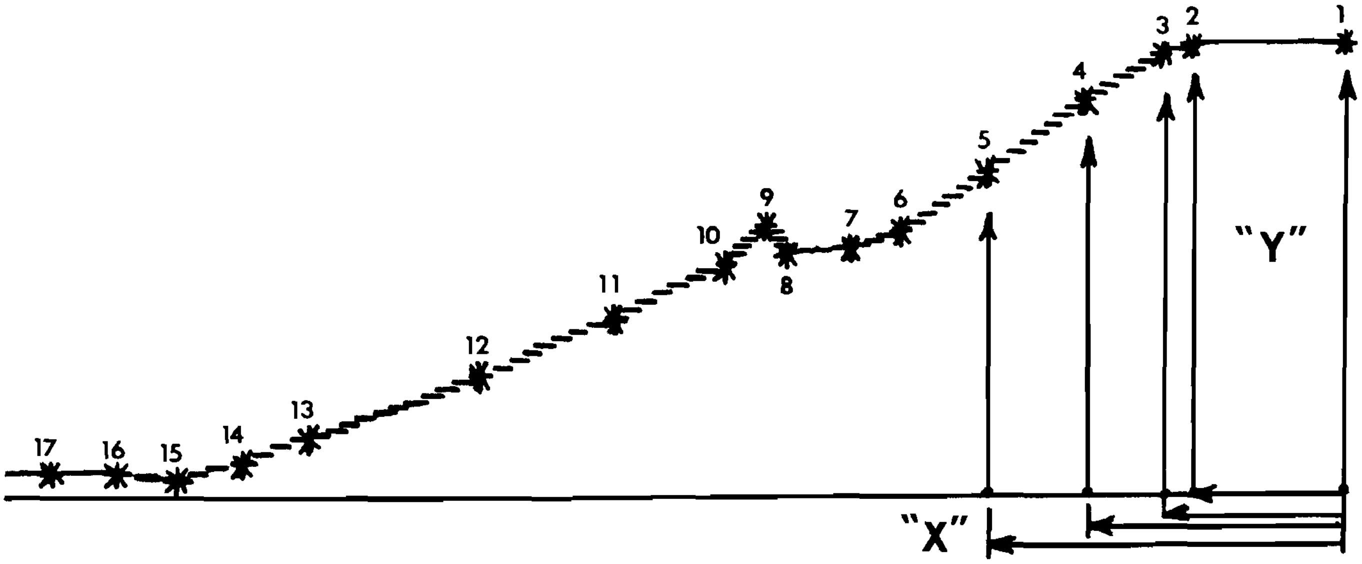


FIG 11 ALTITUDE RECORDING

DATA POINT	- ALTITUDE -			
	Y READING		X READING	
	Inches	Feet	Inches	Time (sec.)
# 1	.204	1450	000	0
# 2	.204	1450	.065	39
# 3	.201	1400	.075	45
# 4	.192	1210	.145	87
# 5	.177	890	.220	132
# 6	.168	700	.295	177
# 7	.165	630	.315	189
Etc.	--	--	--	--

FIG 12 TABULATED X-Y VALUES

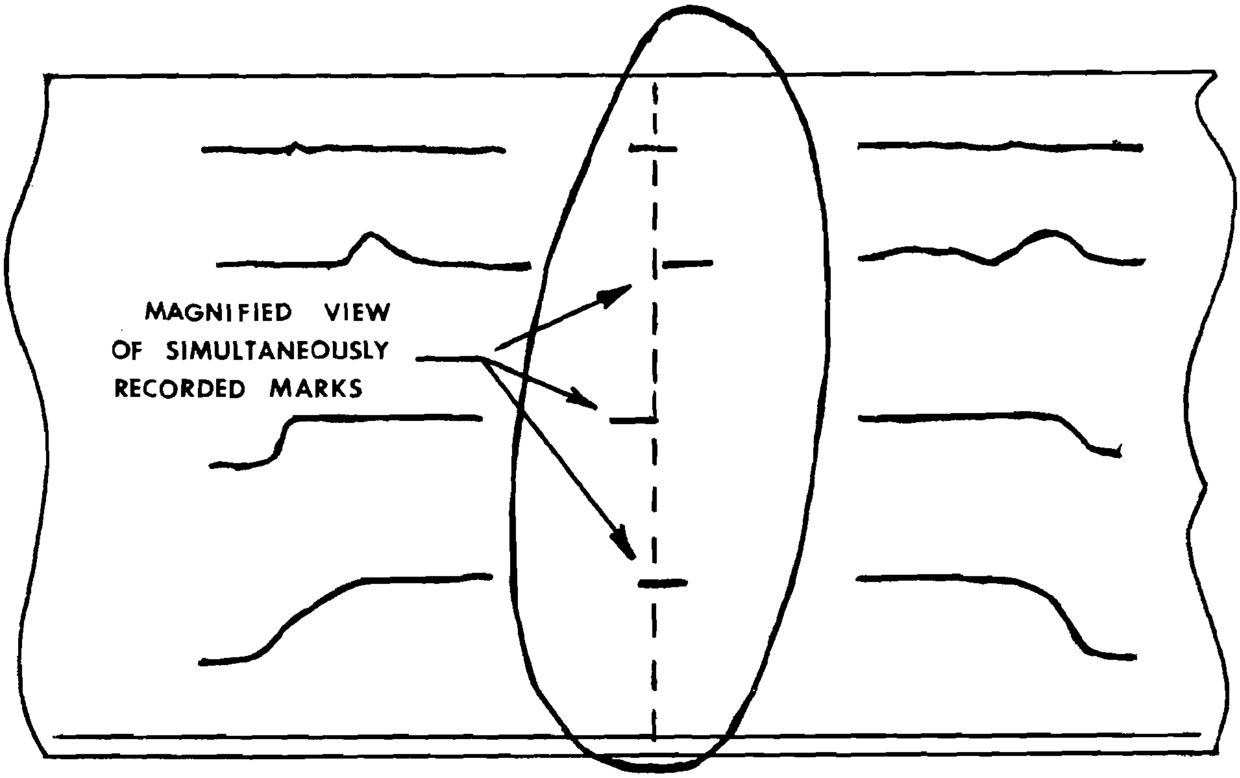


FIG 13 EXAMPLE OF ALONG-TRACK SCRIBE ERRORS

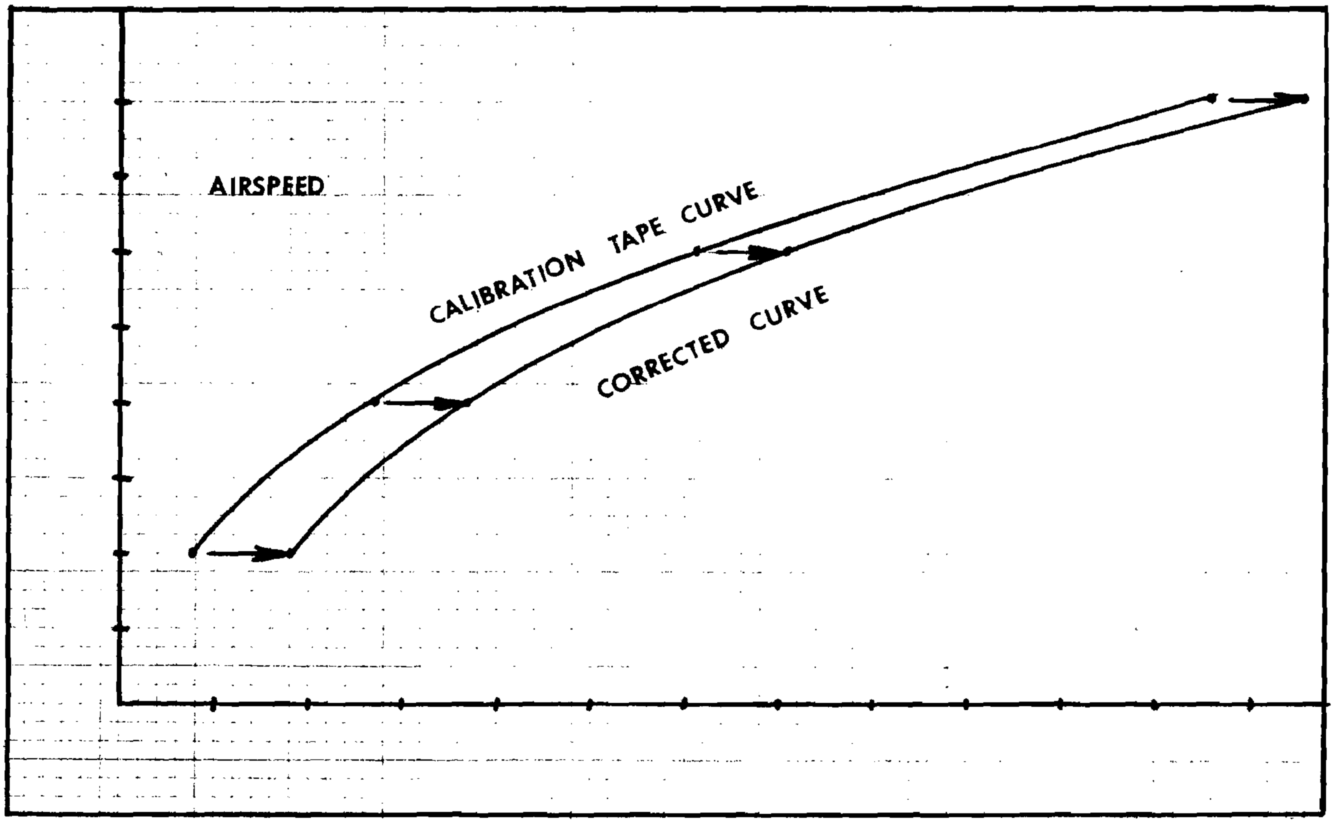


FIG 14 CROSS-TRACK SCRIBE ERROR CORRECTION

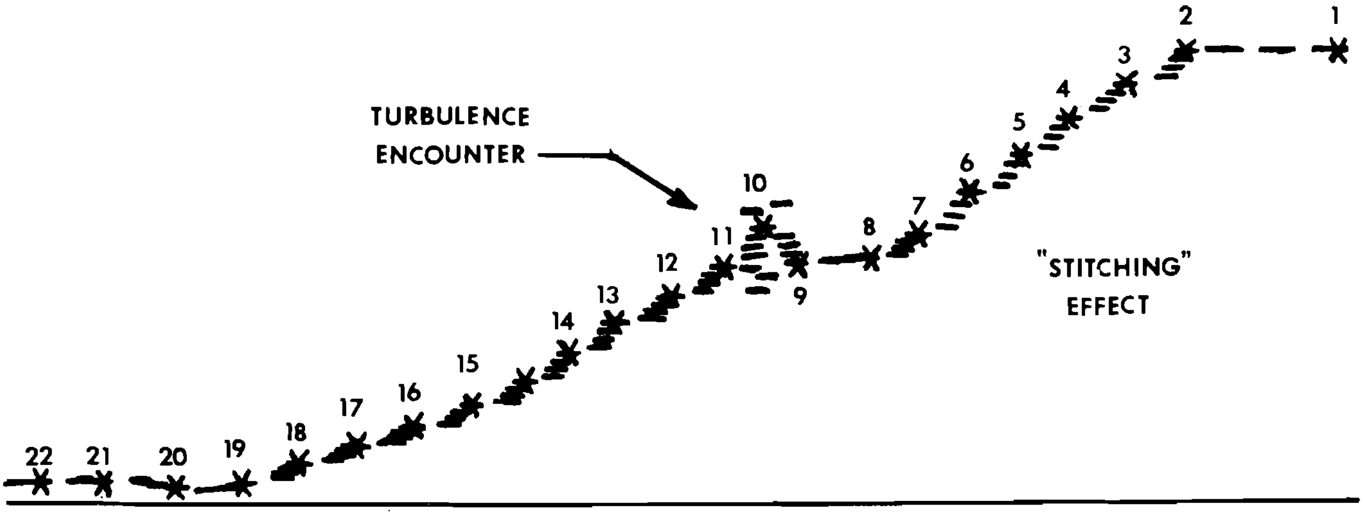


FIG 15 TYPICAL ALTITUDE RECORDING

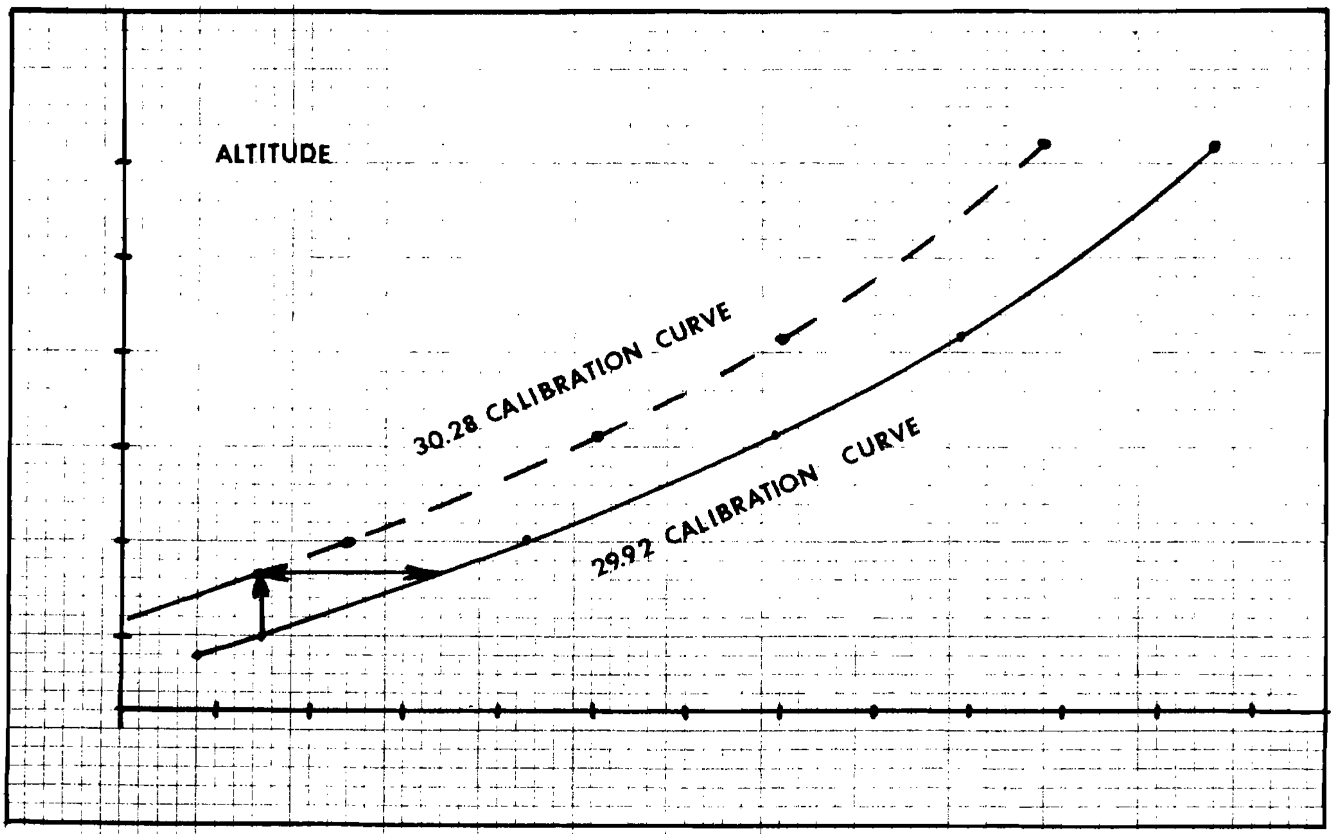


FIG 16 ALTITUDE BAROMETRIC CORRECTION

THE IMPACT OF FLY-BY-WIRE (AND OTHER COMPUTER-CONTROLLED SYSTEMS) ON AIRCRAFT ACCIDENT INVESTIGATIONS

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Air safety investigators traditionally have specialized in the fields of aerodynamics, structures and powerplants, and more recently in weather, human factors, crashworthiness and operations control. However, with the exception of systems which relate to the more traditional areas of investigation; for example, radio communications, air traffic control and weather radar, radar altimeters, flight instruments and flight data recorders, little attention has been given to developing expertise for investigating electronics systems or subsystems as major contributors to aircraft accidents. The reason is simple and logical: until recently there have been few, if any, electronic systems or subsystems which possessed the capability for precipitating — of their own accord — substantial cause for an accident. There have always been a large number of "nuisance" malfunctions of electronics systems which inconvenienced aircrews, some to the point of substantial hazard. But they were nuisances; procedures existed by which the aircrews could, and did complete the flight successfully.

Advancing technology has brought us to the point where aircraft systems are no longer straightforward interactions among mechanically traceable linkages. The pilot in the cockpit is no longer connected physically to the moveable aerodynamic surfaces of the airframe, or the fuel controls on the engines. He no longer manipulates cables, pushrods and other mechanical items directly. In today's newest high-technology aircraft he manipulates potentiometers, transducers and other analog electronic subsystems. Welcome to the age of the electron, and prepare for its impact on your role as an investigator.

Let's start by looking at a pitch control system in its simplest form, one in which you no doubt have considerable familiarity (Figure 1):

The pilot pulls back on the stick, putting tension on the cable. The tension is transformed through the elevator horn into a rotational force about the hinge points which moves the elevator to a trailing-edge-up position. Push forward on the stick and opposite action results. If you were faced with determining the cause for loss of pitch control in an aircraft incorporating this type of system, your search is going to be quite straightforward: the stick may have broken, the cable may be broken or jammed in a sheave, the elevator horn may be broken, or the elevator physically jammed. In any case, the success of your search lies in finding the physical evidence of the failure.

Now let's look at a schematic diagram of the pitch control system from a "state-of-the-art" aircraft (Figure 2):

Try to trace the path between the stick and the stabilizer actuator. If you can understand the normal operation you're better than most of us. Each of the blocks on this diagram represents a "black box" full of electronics. The connecting paths are not mechanical cables. Nor are they single wires. They are wire bundles which carry electrons through the system with the eventual goal of assuring that the position to which the pilot manipulates the "stick position transducers" will ultimately be correctly duplicated by the "stabilizer position transducers."

Some years ago, when I was learning to be an instructor, my mentor advised me: "When they ask you how it works, tell 'em it works good." Unfortunately, my experience has shown that a great many electronics designers' attitudes toward us more simple-minded folks seems to be similar. If you're like me, you know that if you put two electrons into the same room they try to get as far away from each other as possible. We have to learn more than that if we are to learn to find the causes of accidents involving malfunctions of fly-by-wire and other computer-controlled systems.

One accident which occurred last year achieved instant notoriety because it happened in front of international television news cameras. An F-14 fighter literally drove off the edge of the flight deck of the aircraft carrier KENNEDY in the North Sea. We made world wide television news history that night. You can well imagine the pressure to find the cause.

Fortunately the crew ejected successfully before the plane went over the side. We started with the pilot's recollections. He had taxied forward to a position near the catapult. A technician started to remove the safety pins from the plane's weap-

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The comments expressed herein are the opinions of the author, and in no way reflect or represent official policy of the Naval Air Systems Command, the United States Navy, Department of Defense, or any other official United States government agency.

ons. As a result, both the pilot and the weapon systems operator (in the rear cockpit) had their hands on their helmets. (As a safety precaution to prevent inadvertent switch actuation, aircrews are required to keep their hands where they can be seen from the ground when ground personnel are working around the external weapons.) As the pilot sat there with his hands on his helmet he heard the engine RPM increase and felt the aircraft start to move forward. As soon as he realized what was happening he attempted to retard the throttles to idle. He pulled, but they felt as though they were already against the idle stops. He stood on the brakes, but with both wheels locked and the RPM gauges reading 94% the aircraft slid accelerating toward the deck edge. Less than 100 feet from the edge, with no immediate alternative in sight, the pilot initiated command ejection of both crewmen.

The challenge of the investigation lay in identifying a condition in which the engines could advance from idle to 94% RPM by themselves. Initial analysis addressed the normal operation of the fuel control. In the F-14, the pilot manipulates the throttles, which in turn position the input shafts to the throttle amplifier (Figure 3).

That box in turn schedules the throttle computer, which programs the fuel control according to a number of sampled variables, including air density, temperature, fuel density, Mach number and aircraft configuration. It appeared that a malfunction in that system could cause the results which were experienced. Parallel to the system analysis, the maintenance member of the accident board reviewed the maintenance history of the aircraft and components. Among all the irrelevant items he found one that was significant: a few weeks previously the throttle computer which was installed on the aircraft had experienced an uncommanded Built-in-Test cycle activation during a ground run to check the engine trim. The throttle computer's historical data card revealed that it had experienced four separate uncommanded Built-in-Test (BIT) cycles in the previous six months. After each occurrence it had been removed and tested thoroughly. Each time, no malfunction could be duplicated, and it had been returned to service in a "Ready-for-Issue" condition.

The next step was to identify the characteristics of the BIT cycle to determine how it might have affected the aircraft in a way to lead to the accident conditions. Research revealed that the BIT cycle is a complex self-test process within the throttle computer program, in which the computer runs itself through a number of functional operations to determine whether it is operating correctly. (Physicians refer to the process as "self-diagnosis".) Normally the BIT process is used by ground maintenance personnel during troubleshooting of malfunctions, or for testing system operation. Once the BIT cycle is initiated the computer automatically operates through the full functional test schedule. At one point in the cycle, the computer runs the throttles forward to a nominal mid-range power setting, about 95% RPM. To avoid interrupting the test by inadvertent movement of the throttle levers, they are clamped in position. It takes forty pounds of breakout force to overcome the locks and move the throttles.

It all started to fit together. Somehow the throttle computer's BIT cycle had started. While the pilot had his hands and eyes directed elsewhere, the throttles were moved forward to the mid-range RPM setting by the BIT program. When the pilot realized the increased RPM, he tried to retard the throttles. Unaware of the forty-pound breakout force requirement, he thought they were against the stops. He didn't remember actually looking at the positions of the throttles, but under the circumstances - sliding along the deck toward the edge - I suspect he probably didn't take the time. He did what we all would have done after perceiving an extremis situation: he got out fast!

We never did find out what caused the BIT cycle to start. To my knowledge the engineers are still playing with the throttle computer. But even if we had the wreckage to inspect at the time, the chance of finding the physical evidence of the initiating malfunction would have been very slight, because Rule #1 for investigating this type of accident is:

> "Malufunctioning Electrons will not be found in the Wreckage"

One of the major frustration of this type of accident is that the only fully supportable conclusion will be a probable cause. In this case, that electromagnetic interference, from an undetermined source either internal or external to the aircraft, induced sufficient current in an unknown place to initiate the throttle computer's BIT cycle. The case was closed, leaving behind a large number of highly dissatisfied designers, project managers, investigators and operators. On the surface this had been a relatively simple, straightforward investigation. Yet the outcome might have been quite different had we not found the maintenance records, or had they been incomplete or inaccurate. In the end we were only able to discover what happened, not why.

I like to define Rule #2 for fly-by-wire accidents as:

> "Computer Systems rarely leave physical evidence of Malfunction"

You find effects, not causes. The next example demonstrates more vividly the difficulties which you can expect to encounter.

After a routine flight, the aircraft arrived at its destination airport. The pilot performed a conservative 45-degree-bank break turn to the downwind leg. After 120 degrees of turn the pilot applied opposite controls to roll out. There was no response to any control movement. No warning lights were lit on the cockpit annunciator panel. Despite full opposite stick and rudder the aircraft maintained its altitude. As the airspeed slowed the nose started to fall through without responding to back stick. In less than ten seconds the aircraft had assumed a 30-degree left-wing-down, 30-degree nose-down attitude, descending through 800 feet AGL. Perceiving a non-recoverable situation the crew ejected, successfully.

The accident presented us with a real puzzle. It appeared as though a power loss to the fly-by-wire system "froze" the control surfaces at their last position. Yet the system contains an automatic load-switching provision that transfers the system load to an alternate power source if normal power is interrupted. If that, too, fails, a backup mechanical system provides adequate controllability for normal flight maneuvers. The manufacturer started an immediate investigation in parallel with the Navy's, attempting to determine possible sources of a malfunction which could generate the symptoms which had been experienced. While the investigations were proceeding, all operators were advised of the details of the accident as we knew them. Within a few days we were advised that another squadron had experienced a control malfunction in a similar aircraft which might in some way be related. The difference was that the crew had managed to get the second aircraft back safely. The pilot was interviewed and developed the following scenario:

After takeoff and climbout through an overcast, the pilot was established in a level 30-degree banked turn at 6500 feet MSL. While established in the turn the aircraft rolled rapidly to a 60-degree bank, and the nose dropped to 30-degrees below the horizon. The pilot got no response to any control movements. The master caution light and numerous annunciator panel warning lights were illuminated. As the aircraft entered the top of the overcast at 3500 feet the pilot told his crewman to prepare for ejection. In a final effort to recover, the pilot applied full afterburner on the down-wing engine. The asymmetric power brought the aircraft nose up into a semi-controlled climb, and as the aircraft accelerated through 300KIAS cockpit control authority returned. The pilot leveled the aircraft at 6500 feet and waited for his vital signs to return to near normal. A wingman joined him, inspected the aircraft, and reported that everything looked "clean." With some control authority restored, the pilot turned his attention to the annunciator panel, where numerous warning lights announced multiple malfunctions of the Stability Augmentation System (SAS) and Automatic Flight Control System (AFCS). None of the systems failures could be reset by normal procedures. The wingman reported that the spoilers, which are the primary lateral control surfaces in the fly-by-wire system, were not operating. The pilot assumed that a substantial portion of the AFCS system was inoperative, and prepared to bring the aircraft back aboard the carrier in the manual flight mode. When he attempted to lower the flaps they remained up. At five miles on his straight-in approach he felt a major trim change, and the wingman reported that the inboard (landing) flaps had extended. As the aircraft approached the stern of the ship the left wing dropped 20 degrees. Unable to correct with the inoperative spoilers, the pilot corrected with asymmetric power to stop the wing-drop. The aircraft's hook caught the last arresting gear cable. The crew parked the aircraft - and went off on two weeks' leave.

The maintenance crew had a well-documented set of symptoms when they started their work on the aircraft. But when they applied power to start their troubleshooting they could find no trace of a malfunction.

Back at the factory the contractor's engineers had run into a series of dead-ends in their design analyses. They finally decided to attempt to duplicate the fault on their aircraft systems simulator - the "Iron Bird". After four months of trial and error they uncovered possible answers. But before we attempt to analyze them, let's look first at the characteristics of the electrical distribution system to the AFCS as it was designed. (Figure 4)

Normal electrical power is distributed via 115VAC single-phase feeders. By specification the system must provide uninterrupted service during "normal" transients. Large load-switching transients, such as those which might be caused by high-current accessories such as hydraulic pumps, are assumed to lie within a ±50 volt envelope and recover to normal within 500 milliseconds. Small load-switching transients are assumed to lie within an envelope smaller than ±30 volts and recover within 100 milliseconds. An undervoltage delay of 50 milliseconds at 0 volts and 7 seconds at (up to) 102 volts provides time for "burn-out" of phase-to-ground or phase-to-phase short circuits, respectively, after which the automatic bus-switching provision transfers the AFCS from its normal generator source of power to the other generator.

The contractor's simulations revealed two failure modes which had not been anticipated before. In the first case (Figure 5) a steady state of 60V (within the normal envelope) was set. The AFCS responded, but more slowly than normally. The system voltage was dropped to 42.5V. The pitch SAS dropped out, and the control commands migrated to a zero-deflection status. More significant was the complete absence of illumination of any warning lights on the cockpit annunciator panel. The undervoltage condition could be held for up to ten seconds, and after system voltage was restored to the normal 115V the AFCS restored itself to normal operation, except for the pitch SAS - which could be reset manually.

In the second case (Figure 6) a steady state of 45V was set to establish the nonresponsive control condition experienced in Case 1. The voltage was then failed to zero for 15 milliseconds - not long enough to trip the automatic bus switchover. The results were dramatic: not only did the pitch SAS and roll SAS drop out, but the annunciator panel lit up "like a Christmas Tree" with the following warning lights illuminated:

Roll SAS 1
Roll SAS 2
Spoilers
Pitch SAS 1
Pitch SAS 2
Mach Trim
Yaw SAS OUT
Yaw SAS OP
Auto Pilot
Rudder Authority
Lateral Authority

The most significant difference from Case 1 was that all AFCS functions remained locked out following restoration of normal system voltage. Later it was discovered that the lockout could be overcome by interrupting feeder power, either by pulling and resetting the feeder circuit breaker or by shutting down the aircraft. Now we knew why the troubleshooting technicians could never find any symptoms.

The results of the contractor's analyses are shown on the composite graph in Figure 7. Between 95 and 60V the AFCS operated, but control commands and control surface deflections were slower than normal. Below 35V but above 0V the AFCS commands are essentially zero, resulting in neutral commands to the aerodynamic surfaces. The real problem area lies between about 35 and 60V, where cockpit control inputs command totally unpredictable responses from the AFCS and the control surfaces. Finally, a zero-voltage transient lasting less than 50 milliseconds, coupled with an initial steady-state undervoltage in the indeterminate or neutral range will result in total AFCS lockout, preventing automatic system restoration when power returns to normal. The AFCS can be restored only by interrupting all power for more than 50 milliseconds, then reapplying normal voltage.

Having found the results of the problem from the operators' point of view, we were able to devise corrective action for aircrews faced with loss-of-control symptoms. We have not yet discovered what caused the undervoltage conditions in the first place. The contractor spent four months of simulation experiments to come up with the results you see here. We may never find the underlying cause, but be willing to settle for controlling the symptoms.

The results of the analysis enabled me to formulate Rule #3:

> "Computer-controlled Systems often fix themselves after a malfunction"

Unless a means exists for recording anomalies and malfunctions as they occur, the investigator will have no evidence of their occurrence other than the aircrew's narrative of the effects which were observable to them.

At this point I suspect that many of you are ready to return to the days of wood, wire and canvas, where an investigator could expect to find positive evidence of a definite cause in the wreckage. I suspect that similar emotions were evoked when jet engines first came into use. Advancing technology is a fact of life, and a major factor in our professional existence. We can overcome these latest technological complexities the same way we have overcome them in the past - by research and determination.

One source of hope exists for the investigator: incorporation of recording systems which will capture the volatile electronic excursions for future reference. I believe that an advanced recording system, which will permit retrieval and reconstruction of electronic anomalies, is essential to permit early identification of real sources of the problems before they generate catastrophic situations beyond the capabilities of the aircrews. Until they become standard outfitting, we will be faced with long, difficult and sometimes painful tasks of analysis to determine probabilities by inferential logic.

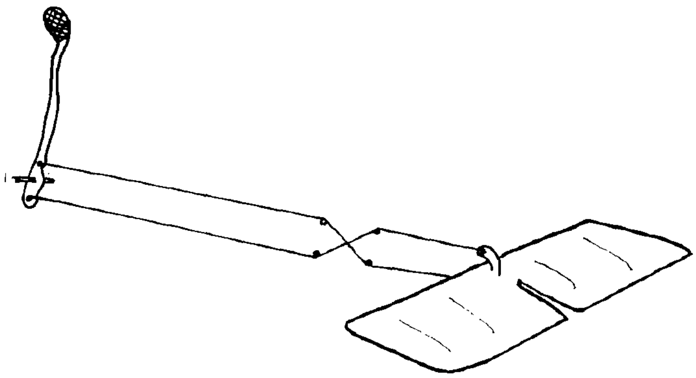

FIGURE 1

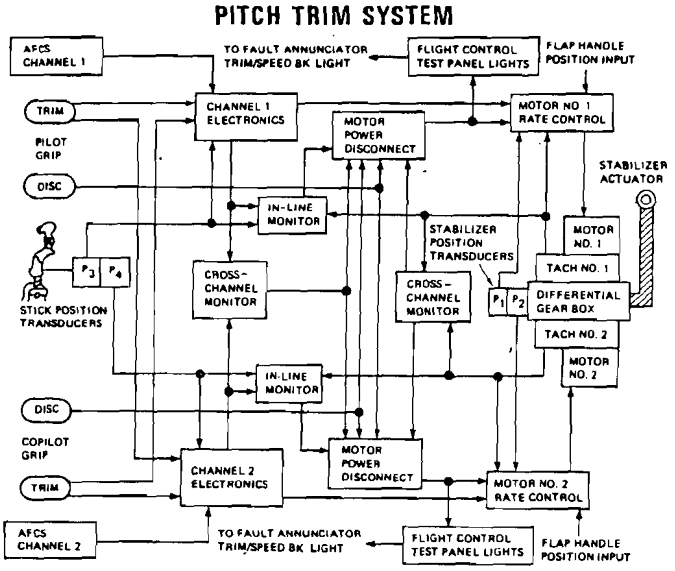

FIGURE 2

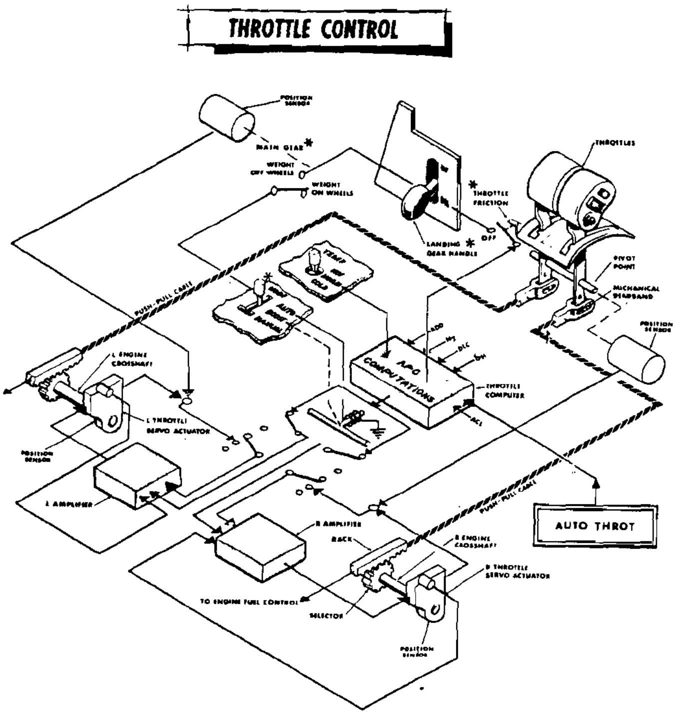

FIGURE 3

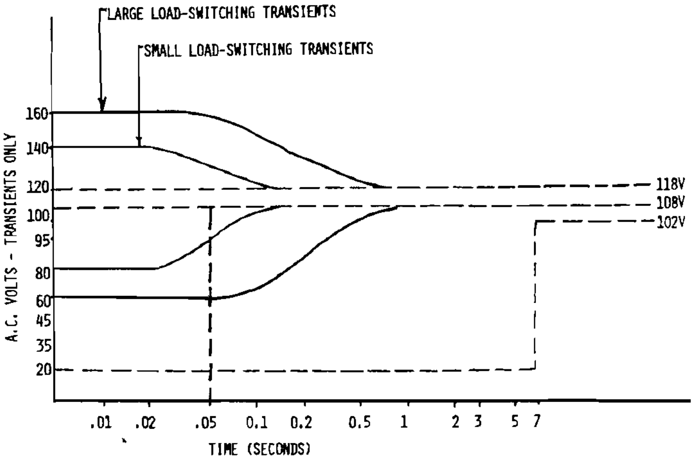

FIGURE 4

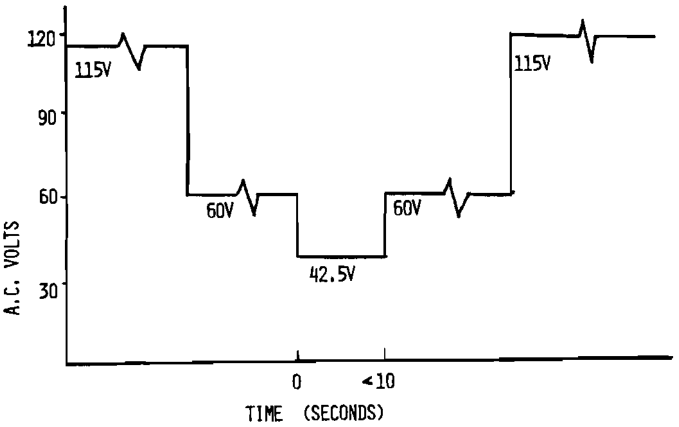

FIGURE 5

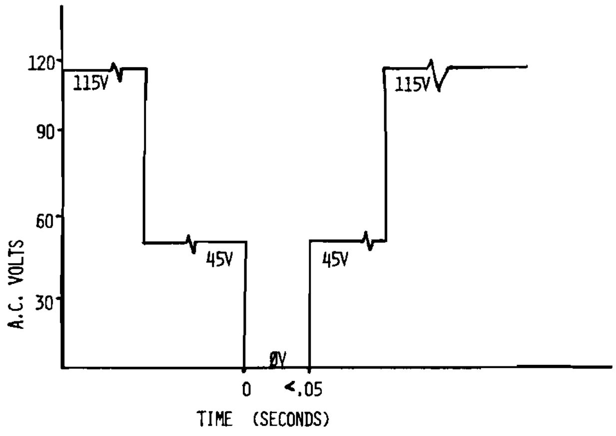

FIGURE 6

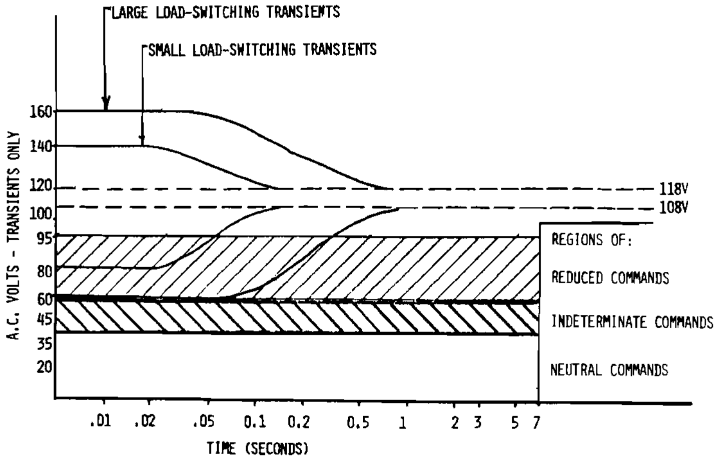

FIGURE 7

THE LAW, FEDERAL SAFETY REGULATIONS, AND SAFETY ARE NOT AND NEED NOT BE MUTUALLY EXCLUSIVE

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Having read each and every paper given at each SASI Symposium, and having given what was considered a controversial paper at last year's symposium it became obvious to me that the majority of the members of the S.A.S.I. feel that the injection of the adversary system into aircraft accident investigation has had a deleterious (the hysterical would say disastrous) effect on the promotion of aviation safety and safety in general.

The feeling is that the attorney's role is simply to represent a client in order to win enormous judgments against defendants who have the ability to pay such as the manufacturer, the insurance companies, the airline, or the government without regard to the promotion of aviation safety. Often times the slow moving judicial process does drag out investigation in that it ties up FAA and NTSB personnel in time consuming judicial duties such as appearing for depositions, answering interrogatories, providing information under the Freedom of Information Act, and occasionally being required to actually testify in the courtroom.

Admittedly to these persons so burdened it is natural to feel that they could better be utilizing their time elsewhere. Further, often times the attorneys conclusion of what happened, and what caused a certain accident may differ materially from the conclusion arrived at in the accident investigator's report. So while it is not a personal attack on the investigator's professional work; it may be necessary for the attorney to attempt to impeach the investigator's conclusions and findings of fact. As a result when an attorney interjects his presence into an aircraft investigation his actions are often viewed as hostile towards the smooth workings of the professional aircraft investigating agencies.

Add to this an attorney who himself is not truthfully familiar with aviation, and it may appear by the questions he asks that they seem to be poorly worded, time consuming to answer, and irrelevant to the accident at hand. Further, the attorney may ask questions that you as an investigator have no way of answering, as you didn't conduct that portion of the investigation, thus to you the attorney appears foolish.

However, there are valid reasons that the attorney is doing what he is doing. The *Rules of Evidence* vary from state to state which are all more conservative than the *Federal Rules of Evidence*. Many of the seemingly irrelevant questions are being asked so as to lay the ground work for them to be introduced into evidence in a courtroom. Thus an attorney might read an accident report to you sentence by sentence, in question form asking you if that sentence is correct. As an investigator you think "My gosh that's what I wrote, of course it's right." You think of your watch and wish you were elsewhere. In truth and in fact the attorney is simply getting the accident report into a form that is introduced into evidence. The point is that the law often requires round about methods to get to the point.

But what of the results. If the attorneys contentions are perceived as correct by the court the widow or the disabled will receive a money decision to enable the widow to continue a lifestyle with some certainty and attorney will be rewarded both pecuniarily and with prestige. The manufacturer and insurer will lick their wounds and wonder aloud if it was fair to have a hot shot attorney sharpshoot or Monday morning quarterback their product. Eventually the consumer will pay as the costs of insurance and the product goes up. The manufacturer would have you believe that they are being unfairly treated, as they point to federal regulatory agencies, and state righteously "look fellas we're already meeting a very high standard of safety, by meeting Federal regulations and inspections previous to being issued airworthiness certificates for our product."

In truth and in fact we do have two agencies that regulate, direct, investigate and make recommendations to our aviation industries. On a scale compared with many nations it is probably efficient and the standard the world can look to. However, it is slow to move, and at times indecisive because as we all realize, federal bureaucracies are political entities to an extent and economic and ecological considerations and impacts are necessarily weighed against safety considerations often times with safety a secondary consideration. Obviously there is no one here who would argue if we could have good drainage, long grooved runways and CAT II ILS to every airport served by aircarriers that we wouldn't have a safer operation but there is a cost factor. Noise abatement climbs and two segment approaches are direct tradeoffs with safety being comprised for ecology impact considerations.

But the purpose of this paper was to say that perhaps the end result, safety enhancement can be facilitated by the judicial process. In a discussion last year between General Caldera and Tom Davis, the President, Elect of the American-Trial Lawyers, Tom explained that it would be a far stronger case at law to handle a case in which a previously recognized defect was the cause of a second accident, especially if the manufacturer after notice of the defect did nothing to correct it. Thus, Mr. Davis said that an enlightened manufacturer would strive to correct defects as soon as it got notice of the defect no matter how the defect was discovered (an investigator, a lawyer, a supplier, a customer, the FAA, the NTSB, whatever). A changed or an improved product is not an admission of negligence of a previously defective product. Believe me a defective product can easily be shown by the state of the art and what competitors and the government were doing at the time of manufacture.

A product known as Everclear, an almost pure drinking alcohol, is more volatile than gasoline. When it is shipped the truck carrying it is required to post flammable warning signs. When a case of it is delivered the box is required to have warning labels. When a quart of it was retailed there were no such labels. A newly opened restaurant utilized it to serve flaming dishes. Needless to say, it created a Molotov cocktail, and after the waitress who was dreadfully burned teamed with a trial lawyer they were compensated, and within weeks each and every bottle of Everclear now sold contains a strong warning that the contents are very flammable.

A teenage boy to impress his girlfriend picked up a bottle of that splash on lotion that so many of the superstars use. Apparently he felt the more he used the better he would smell. Either while dousing himself or immediately after he lit a cigarette with a lighter he became a human torch. The contents of this bottle contains a very high content of alcohol. I feel certain that in the very near future you will see warning labels on such products. In the meantime tell your teenage sons to use toothpastes and roll ons or better don't smoke.

A three year old boy picked up and sucked upon a paper towel that had been utilized to apply and then wipe window cleaner. The product is commercially well known. To the basic ammonia they have added a pretty blue color and a perfume to kill the smell. Noticeably the perfume and other additives makes the mixture more palatable than plain ammonia. Eighteen hours later the little boy was dead. If I have anything to say about it this company should pay, and there will be child proof bottle caps and warning labels. In the meantime have your wife use Bon Ami and water.

The twin push pull Cessna 337 has been involved in over 15 rear engine out take off attempt accidents. In 1965 they had an engine fail light installed. Because Part 23 of the FAR's didn't require such a light they removed it in 1966 and subsequent models do not have such a device. The Chairman of the NTSB sent a letter urging the FAA to require such a light but it was not acted upon. The loss of the rear engine cannot be readily heard, felt in yaw, or seen. The engine instruments in this single piloted aircraft are on the far side of a radio panel in front of the co-pilot. The airplane's performance is marginal rear engine out, prop unfeathered, gear down.

A large settlement with Cessna was accomplished when the trial date approached. The very next year's model had a rear view mirror so mounted that the pilot may now see operation of the rear propellor and view the engine for fire, smoke, or leaks. I do fervently hope for Cessna's sake that the same accident doesn't happen again at night, because they forgot to put a light out there.

Currently a Major Manufacturer of General Aviation Aircraft is creating pretty interiors for his aircraft of plastic fabrics. He has a duty to utilize at least flame resistant materials, which can be defined that the materials will extinguish themselves within safe limits after the heat source is removed. The FAA has a duty to police these manufacturers to see that they are following the requirements for certification. In the facts at hand the aircraft interior caught fire and in the minutes it took to attempt a crash landing the passenger was badly burned and the pilot died. Our chemist says that of ten swatches of different material taken from aboard the aircraft none were even flame resistant while some were extremely flame enlarging.

Demonstration (see attached photos)

The same polymer plastics chemist says that these same polymer plastics utilized on this aircraft could have been made at least flame retardant by the addition of additives that would have only cost pocket change per pound.

I am sure that in this case that this attorney and his dead and disabled client have done more for safety than the Regulatory Agency that shouldn't have allowed this to happen or the accident investigator whose report focused on the cause of the fire rather than its unbelievable rapid spread and expansion.

In several cases that I have been involved with we have spent large sums of money finding and utilizing the very newest technologies and sciences some never before utilized in an airplane crash investigation.

For instance in one case a voice print analyser with wide scale scan 0 to 2,000 cps in combination with an IBM computer displayed the pilots voice communications with the tower.

It had been thought that the pilot was under the influence of alcohol because of a wrongly administered blood alcohol test. The nurse had used an alcohol swab and the equipment used to test the blood couldn't discriminate between isopropyl or drinking alcohol.

Certain words from the voice print analyser tapes were compared with other recorded words uttered by the pilot on tape when it was known that he had not been drinking. From this comparison it was evident that the pilot's capabilities were in fact not impaired. The NTSB reopened the file on reviewing evidence of the bad blood test and voice print material and deleted all references to the blood alcohol reading. To my knowledge this was the first usage of this new scientific evidence into a proceeding and it was first introduced by a lawyer.

This new device considerably more sophisticated than the simple voice print identifier can be used to (1) identify the voice; (2) tell whether the voice is affected by alcohol and can differentiate between drug and alcohol effects. Anxiety and fatigue can be picked up by a trained operator and it can be used to tell if a witness is telling the truth when he is answering questions as his anxiety level materially increases when telling an untruth.

In the case at hand we were able to determine that the failure or emergency situation had begun earlier than when the pilot actually verbalized it as the tapes showed increased anxiety in a normal transmission prior to the pilot actually verbalizing his emergency condition.

This is an example of the usage of the newest technology that adds probative value to an investigators search for the truth even though it is not currently accepted as scientific evidence in a court of law.

Aviation safety is enhanced in the long run every time a dedicated attorney is able to show the public the real cause of an aviation accident. The fact that the manufacturer or negligent party must pay a large settlement should only act as the discipline to be expected for failure to meet reasonable standards of conduct or engineering design. For each and every pilot, crewmember or passenger the name of the game is to be afforded a flight in a reasonably safe vehicle that keeps its take offs and landings in a one to one ratio. Lawyers who work in the personal injury areas of litigations see the results of the accidents in terms of the frightfully injured, the burned, and the widows. When the law provides an avenue for compensation it is the duty of the lawyer to pursue that course. It is absurd however to believe that the lawyer is actively making aviation less safe. On the contrary he is protecting the consumer, the flying public. Realize for an instant that perhaps lawyers had something to do with the engineering decisions of many major companies to:

(1) install roll bars on tractors as at least optionally available equipment.

(2) to redesign certain filler caps and necks on vehicle gas tanks.

(3) to move gas tanks on certain vehicles from bumper areas to more protected crashworthy areas.

(4) to show the need for firewalls of steel between gas tanks and passenger compartments.

(5) redesign lawnmowers so they are less likely to throw objects.

(6) the installation of innumerable stop lights, stop or yield signs and railroad crossing warnings.

(7) the redesign of certain aircraft fuel systems.

In many instances in searching for expert witnesses (I do not believe in using those persons who make their living by testifying) I have found a willingness by those people who are known to be the foremost in their technology to come forward and to testify. Many have expressed a frustration at the inertia of the business community to accept and utilize the existing technologies available to them. These experts look at the court as the last forum available to them to institute changes for safety that should have been accomplished through normal channels.

In conclusion that portion of the world above the ground and below the stratosphere is regularly traveled by mankind. It is a fact of life that the law of the land accompanies man on that journey. It is and should be the fervent hope and goal of all attorneys, investigators, safety engineers and SASI members that the trip will be a safe one.

Photo No. 1
Swatch of Interior
Material at ignition

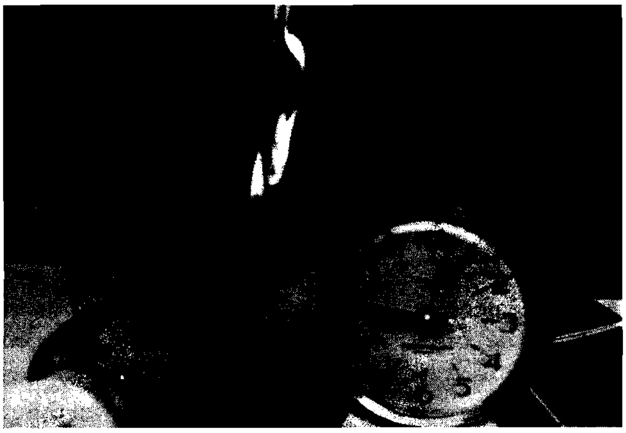

Photo No. 2
Swatch of Interior
Material heat source
removed + 15 seconds

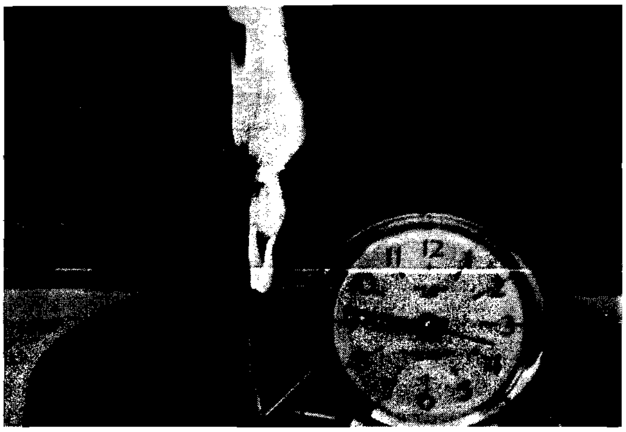

Photo No. 3
Swatch of Material
at + 30 seconds

Note: To meet minimum standards the material should extinguish when ignition source is removed

SUBJECTIVE AND LEGAL ASPECTS OF THE AIR TRAFFIC CONTROLLER'S INTRODUCTION TO ACCIDENT INVESTIGATIONS AND PROCEEDINGS

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The objective of this paper is to demonstrate, or disclose, some of the subjective and legal considerations set in motion at the onset of the investigatory processes following an aircraft accident in the United States. The scope of the paper is limited to the role of the air traffic controller whose involvement, if any, in the accident is but the initial element in investigative and legal processes which may, from the standpoint of his perspective, dwarf his rather ministerial involvement in the happening of an accident. He, the controller, will be caught up, sequentially, in the post-accident investigation, the National Transportation Safety Board hearing process, the discovery phase of litigation and, potentially, the actual trial on liability.

The objective of air traffic control is to provide for the safe, orderly, and expeditious movement of air traffic. An objective analysis of performance, following an accident, should be circumscribed by the identification of duty, as it relates to prescribed procedures, in the provision of instructions, clearances, and information necessary for the conduct of safe flight. It is not difficult to obtain, for reconstruction purposes, all of the objective information available to a controller, nor to determine his actions pursuant to such information. There are available tape recordings which identify, sequentially, each action taken with respect to the accident aircraft or any others subject to the control of the individual; the cockpit voice recorder which discloses the reaction of the flight crew to instructions, clearances, or information; and, subject to the limitations of the system, computer data which will reveal, relatively speaking, the time, position and altitude of the accident aircraft with respect to the geographical occurrence of the accident. The only element remaining, or potentially ascertainable, is the state of mind of the controller and, potentially, the rational or logical processes of his mind during the sequential events immediately preceding the accident. Considering the difficult, sometimes ambiguous or anomalous nature of the air traffic control function we will attempt to examine the interaction of the individual and the potential benefit to be derived from the inclusion of the controller in the investigative and legal processes. We shall keep in mind the objective aspect of the investigation, which is to ascertain cause, the subjective assessments which are made to test the system, and the legal objective, which is to determine fault. If it could be said that any of these objectives could be obtained without the assistance and involvement of the controller, there would be little to discuss. Likewise, if the objectives could be realized in a nonpartisan atmosphere, with wholly objective proceedings, there would be little impact upon the individual. Unfortunately, this is not the case. The processes are set in motion at the time of the accident and are, unfortunately, not again at rest for months, or even years. The controller has no advance training or preparation in dealing with the events that follow.

Immediately following the happening of an accident operative procedures result in the collection of the objective information or evidence available in the facility. Tapes are removed, equipment settings recorded, strips collected, and weather information marshalled; also, the controller is relieved from his position to assist in this effort and to initiate his efforts to prepare a statement. At this stage the subjective elements begin to appear, the atmosphere in the tower changes; the crisp, businesslike, sometimes noisy, sometimes jocular setting becomes one of somber quietude under the impact or realization of disaster; the involved controllers' interactions with others are changed, he is treated like one who had a death in the family. They don't know what the facts are, the extent of involvement, if any, and they don't know what could be said, or fear to say it, for it might be construed as improper solicitude. The statement which must be prepared presents the potential for anxiety because of the fear of later contradiction by recorded or computer information which will be collected. There is the concern for notoriety, and the immediate and unquenchable thirst of management and other elements, including the media, for information, and the introduction to evaluators, investigators, and lawyers. On the legal side there is to be learned and accepted the difference between fact, conclusion, speculation, conjecture, inference, and the infinite distinctions and interpretations available under regulations and procedures. The realization that completion of a report is not the end, but rather the beginning, is present and its impact can be assessed only on an individual basis. It soon becomes evident that, even in the simplest case, the reporting of facts by different individuals create issues rather than resolve them.

In the typical air carrier case there is dispatched, from Washington, a representative of the Air Traffic Service who will assist in coordinating the activities necessary to transcribe the various tapes, whether those of the center, approach, or tower facilities. His function is, initially, to ascertain the procedures which may come under question, and assist, if necessary, in the preparation of the necessary air traffic package. Also, an attorney from the Office of the Chief Counsel will represent the agency, at the scene, and as spokesman at the NTSB hearing. He will, on the scene, provide appropriate legal review of all evidence coming into possession of the FAA, legal clearance of statements, documents and transcripts, and brief FAA personnel on their conduct and responsibilities in the presentation of testimony and evidence at formal or informal interviews or hearings.

Approximately 6 to 8 weeks following the happening of the accident, a public safety hearing is convened by the National Transportation Safety Board. Parties are named, including the FAA, Professional Air Traffic Controllers Association, the Air Carrier, Air Line Pilots Association, the manufacturer of the aircraft or component parts, the National Weather Service, or other interested parties including, occasionally, Aviation Consumer Action groups. Witnesses are designated for appearance before the hearing. It is provided that such hearings are purely fact finding proceedings, that there are no formal pleadings or issues and no adverse parties, [2] and that it is not an adjudicatory hearing. It is evident, however, that most of the facts are already known, having been made a part of the record through inclusion as exhibits or as a part of the separate group reports. As a consequence, the quest appears to be directed towards the perspective, or weight to be given, to the salient facts. It is also a time when hypotheses, or reasoning processes, which lead to a conclusion are tested against the known facts. Finally, it is an opportunity for the parties to exhibit their adversary contentions. A time for partisans to vie for attention or sympathy, or to compete for exoneration or the blame of others.

The final elements of involvement include the protracted litigation procedures, pretrial discovery and trial. The pretrial phase includes the complaint or allegations, study of accident reports, air traffic control procedures and the deposition testimony of fact witnesses and experts. In this phase the controller may find himself interrogated on the soundness or reasonableness of procedures, the scope of his function or duty, and then tested against the perspective of the adversary parties interpretation of the facts, procedures and his performance. In this process interrogation over a period of several weeks is not unusual. Eventually the process is completed and the controller may appear as a witness before the court and jury. Conflicting, or separate claims may require several trials. Throughout the entire period, from the first informal interview, consistency is necessary to avoid inference or insinuation of self interest or deceit.

What are the pressures, and how do they affect the participants? In the field investigation stage, as we have said, there is the element of the unknown, the introduction to proceedings and processes beyond the comprehension of the ordinary controller. In advance of the public hearing the controller becomes aware of the contentions of the parties, or partisans as the case may be, through hearsay and rumor, agency representatives and the attorney acting as spokesman. He finds it difficult to accept the extremes of interpretation, or the stringent compliance expected in a dynamic constantly changing environment. In the atmosphere of preparation for the hearing, and in the hearing itself, the controller undergoes, depending upon the individual, some degree of fear or anxiety. This is due, primarily, to the atmosphere generated by the inquisitors in the investigative process, the media, and the industry where conflicting interpretations of procedures or duty arise. In this anomalous situation the controller, who has not authored the procedures or practices, but merely uses them, realizes that he will be expected to justify, from the standpoint of logic and reason, procedures which have been established at the policy-making level of the government. The controller, faced with this task, may be an extrovert, a leader, and articulate, or he may be inarticulate and subject to stage fright. He may be hopelessly at sea in the realm of public debate, but may be forced to cope, in a public forum, with "but for" logic.

The "but for" approach usually hypothesizes a truism, such as: If you had warned would you have expected the pilot to act? The principal element in the hypothesis is the precatory, or wishful act or a multitude of different acts, any one of which, on the basis of hope or expectation, might have been performed by the controller under the most extreme, or most remote standard of foresight or insight. Once the extreme is accepted the hypothesis becomes a truism, an obvious statement. If the controller resists the tactic of the interrogator, or partisan as the case may be, by refusing to join in the hypothetical, which in reality is speculation and conjecture, it leaves the question hanging with its intended insinuation. If the witness accepts the hypothesis, he must also accept the inference that but for the failure to do something, which was not done, there would have been no accident. Thus coincidentally, he must also accept the inference that, with foresight, he might have acted differently, and there would have been no accident. Thus, we call it a double bind, the controller is placed in the paradoxical position of stating that with foresight he might have been able to prevent the accident.

In the litigation phase the problems are even more complex. It is more difficult to preserve the thread of consistency. The facts have been repeated a countless number of times, at least once or twice under oath. It seems to be the objective of lawyers to undermine the credibility of the witness. The most used tactics are the attempts to demonstrate inconsistency, inaccuracy or self interest. These may be superficially innocuous but have an intimidating effect upon witnesses. The most popular is that of endless interrogation which will afford, ultimately, an opportunity to demonstrate inconsistency. The exchange which follows occurred, in trial, after a cross-examination of a controller which resulted in apparent inconsistencies:

Q: When you were shown various testimony from the transcript of the NTSB hearing, there were several times that you said you didn't remember. Were you saying that the transcript was wrong?

A: No, I am not saying that the transcript was wrong. I may have said those things, but as far as I can remember, I can't recall saying those things, that is all. I didn't say I didn't say them. I just can't recall having said them.

Q: Can you tell us so the judge and jury would have some understanding of what happens and what did happen in this case, can you tell us what the setting of the NTSB hearing was?

A: You mean like —

Q: Where it was, what it was like, give us a description, if you can, if you remember.

A: Well, it was held in . . . , I believe it is, in the . . . , in the function room and I recall that you go down a hall, turn left and there was a function room. As I went in the function room—by the way, I took my daughter with me for a little comfort, so to speak—and as I walked into the room, there were lot of chairs, a lot of people standing around and I happened to notice some of the local television personalities standing all around, milling around, so my daughter and I went over to the right side of the room and sat down, and I looked at the makeup of where I had to sit and there was more or less a stage or platform and below that was a table and a microphone and after I was called, I sat down at the stage. After I was called up, I sat down at this stage. I think there were four men off my right, overlooking me, sitting at the table with the microphone, plus the lights shining where I was sitting. The lights were so bright that you could barely tell if someone was behind the lights. More or less, like a theater or something, like you were on stage, and there were guys walking around grinding cameras, taking photographs, and then you are sitting there. There are about four or five people in front of you and God only knows how many were on my left because I didn't dare to look to my left. Then after they asked my name, what I did, and my certificates, then they started firing questions at me from all angles, guys walking around, winding cameras, guys kneeling at their feet snapping pictures, and one thing I distinctly remember about that hearing, my daughter went with me and I remember she was sitting off my left and behind me and I happened to look behind me at her and she looked kind of sad and I thought to myself, "Why did I bring her in a mess like this," because she was seeing her father getting eaten to pieces, torn to pieces by all these people firing questions at me, so I had to maintain some kind of composure. I thought to myself, "After 17 years of working my head off, it all ends up to this, a big show on a stage with your daughter looking at you getting eaten alive by these guys," and I remember thinking of my daughter sitting there and looking at her and somebody fired two or three questions at me and I just answered them because I made up my mind from that time, I said, "Look, I am sitting here telling the truth, tell it as I can and get out of here." I looked at my daughter. Some guy fired some question at me. I said, "Yes." I wasn't even thinking about that, and then before the end of the proceedings, these guys off my right, that they asked some question I recall, "How many times have you seen an aircraft turned on inside the outer marker," so in my whole experience at . . . I have seen maybe one time at the most, and whoever he was, I don't know who the fellow was, I just wanted to get the heck out of there. He asked, " How many times have you seen it?" I said, "Jesus, I don't know." He said, " Often?" I knew it wasn't often. I said, "No." He said, "Once in awhile?" I said, "No." Then I remember his voice inflection, he said, "Well, occasionally?" "Well," I said, "that must be the answer." I said, "Yes, occasionally," just to get the heck out of there, and I hope no one ever has to go through the experience that I went through, like a big side show.

Q: Did you hear applause from time to time?

A: Yes, to top all this off, a couple of the questions that were asked, it was more or less like having a rooting section. I answered a couple of questions or something and I heard applause. That is when I was looking at my daughter, you know, and that is when I thought, I said, "It all ends like this, a big side show."

It is apparent that his testimony, or recollection, was influenced by his responsiveness in a foreign environment. We should, then, question the relevance of testimony which can be misleading or distorted by the subjective post-accident circumstances.

Others, in the legal field, have commented upon the impact of these proceedings upon the individual, such as F. Lee Bailey in his new book, where he related a discussion had with a former government attorney:

> . . . but he made one point that I could not have agreed with more. That was the effect of the complicated and complex trial procedure on the air traffic controller who may or may not have been at fault. It pleased me to see that a government lawyer, a former government lawyer, had seen way back then that the controllers were under an unnatural amount of pressure.
>
> As [he] put it, "I never did feel that the individual controller was the snag in the system, not by any stretch of the imagination. . . . The controller is subjected to the massive publicity, the amount of time that's involved in preparing a case, and all of that has to give most people a feeling of second guessing, perhaps even guilt feelings, whether they were warranted or not.
>
> "I could see this in the faces of these people, working with them, having a drink with them afterwards, trying to get them squared away on how to cope with a very skilled lawyer, that their confidence was shaken. And the sad thing is that the confidence is what makes them able to do this extremely unusual, high-pressure job."

The spectrum of potential pressure ranges from the obvious and minimal to the extreme and remote. Though not anticipated in our system of justice the extreme influence may be represented by the potential for conviction and punishment. Or there may be the potential of being held personally liable in the litigation. In the recent trial of the controllers acting the sequence of events which led to a mid-air collision near Zagreb, Yugoslavia, an attorney representing some of the decedents made an eloquent appeal, before the criminal tribunal, on behalf of the controllers. He articulated the perversity of focusing upon the individual:

> They, as I shall endeavor to show, are themselves victims of a system.
>
> * * *
>
> . . . an internationally used . . . and integrated system, the excellence, and it needs to be said that it is excellent, which is, obviously enough, only undermined by its own complexity and shortcomings.
>
> * * *
>
> It is interesting to observe that in the final analysis it is, contrary to popular belief, more productive to recognize the failure of the system . . . than to blame an individual . . .
>
> * * *
>
> I suggest that we must, as a responsible society, differentiate between simple human error, [and] culpable negligence, [or] recklessness. . . .
>
> * * *
>
> I do not subscribe to the view of some American lawyers who equate human failure to an act of negligence . . . . people concerned with aircraft are not negligent, human failures are not usually blameworthy as they stem from insufficiency of knowledge or skill or foresight.
>
> * * *
>
> I do not imagine that even with understanding one can overcome human frailty . . . .
>
> * * *
>
> . . . decisions made under the pressure of fast moving and momentous events may not always be the best or most efficient.
>
> * * *
>
> Decisions in these circumstances can only be safe provided they require the minimum of consideration in thinking time and calculation, they should follow simple and practical patterns and should be accepted by a known preplanned pattern of operations within a relatively simple standardized system - simplicity and standardization is a recognized necessity and a constantly recurring theme in all aspects of air operations. There are many aspects of current air traffic control which fail to satisfy these requirements and each represents special difficulties for the controller. The need for a common language for aviation is readily apparent and I believe is accepted by this Court: is it, however, I wonder, accepted by this Court that it is a sad fact of life that incoming messages do not reach us at convenient intervals but

> arrive irregularly and often just at the wrong time? This fact, which has been medically proven, is critical in this case because research has shown that man possesses only a single decision making channel and all information must be passed sequentially through this channel - for example, if two items of information arrive at the brain at the same time, one must wait until the other is processed.

There are many recurrent issues, or themes, which arise in the aftermath of disaster. Probably the most prominent is that of the division of authority, between the pilot and controller. In recent discussion at an Aviation Review Conference one commentator stated that

> . . . it appears that prior to an accident, people want to keep the controller out of the cockpit, but after a crash and the litigation that flows from it, they are the first ones to point the finger at the controller and try to bring him back into the cockpit. [5]

Where such issues arise, and we do not attempt here to resolve them, it should be recognized that they cannot be resolved by examining, in a single accident investigation, the infinite possibilities which might have been available to the individual. In fact, it may be that to carry such quests to the extreme could have a derogating effect on the alternatives now available in the system. If the people in the system perceive the imposition of liability without fault, will it produce that subjective attitude or mental perspective which will make them unable, or unwilling, to engage in judicious and innovative action in order to resolve operational problems? It has been said that the potential for liability may exhibit sound judgment. [6] And, in a recent observation by an airline captain:

> in an increasing number of recent accidents the National Transportation Safety Board has found controllers to be casual factors. Could it be that the real trend developing is an attitude of complacency and a decline of skepticism on the part of pilots?[7]

It is evident that the controller will be caught up in the torturous and inexorable processes, both quasi legal and legal, from which there is no escape. It is evident that the experience will have some impact in his life and in his profession. What, if anything, can be done to achieve the necessary goals while continuing to recognize the limitations of the individual? First, from the investigation standpoint we should recognize the limited value of the direct and personal input of the controller. There is no area, from the investigative standpoint, where the objective factual information obtainable can be so exact. When the controller adds his perspective, the reasons why, there is no reason to go further. There is no reason for the controller to answer to the imponderables which can be postulated with the comfort of hindsight, or the luxury of time. Second, we should recognize that the real issue is, how did the controller perform in the real world of air traffic control? Last, we should recognize that determinations of cause should not depend upon the performance of the involved individuals under interrogation or in debate.

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VISIBILITY STUDIES OF MID-AIR COLLISIONS

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I. INTRODUCTION

The probable cause of this accident was the failure of both flight crews to detect visually the other aircraft in sufficient time to initiate evasive action. To reach such a conclusion following a mid-air collision accident, the flight path geometry must be developed and the cockpit window configuration analyzed to determine if the flight crews had an opportunity to detect visually the other aircraft.

Many factors affect the flight crews' ability to detect another aircraft which might be on a collision course with their aircraft. The aircraft size, closure speed, contrast between aircraft and background, haze, smoke, sun position, window configuration and cleanliness of the windows will affect the ability to detect the other aircraft. The crews' scanning techniques and time sharing of attention between the inside and outside of the cockpit will have a significant effect on the probability of detection.

For the period 1957 through 1976 there were 490 mid-air collision accidents in U.S. Civil Aviation resulting in 1120 fatalities. The National Transportation Safety Board figures published on May 12, 1977, show that the majority of these accidents, namely 428, involved general aviation aircraft to general aviation aircraft.

It can be expected that the air safety investigator (ASI) will someday be confronted with the investigation of a mid-air collision. The investigator should be able to reconstruct the flight paths of each aircraft and determine whether the pilots or the flight crews had an opportunity to detect visually the other aircraft. This paper deals with the mechanics of making such determinations.

II. DEVELOPMENT OF THE FLIGHT PATHS

There are many sources of information available to the ASI which can assist him in the reconstruction of the flight paths. Detailed information on the aircraft's altitude, airspeed, headings, airport departure time, intended destination, times over known geographic locations, etc., should be obtained from the surviving crew members, if any. Of course, if there are surviving crew members, information should be ascertained as to the scanning techniques utilized, whether or not the crew actually saw the other aircraft and what the heading and position of the sighted aircraft was at the time of sighting.

The data obtained from the surviving crew members would be most reliable with the possible exception of the information regarding the scanning techniques. This information could be self serving and the ASI could expect the crew to overestimate the amount of time that they were engaged in outside observations.

Surviving passengers should be interviewed to obtain similar information on the aircraft flight path. Unless the passenger was knowledgeable with respect to aviation, and in a position to observe the aircraft instrumentation, the information obtained would not be as reliable as that provided by the flight crew. The air carrier passenger would have little, if any, usable information. Such passengers could provide information with respect to the aircraft attitude climbing or descending, level flight or turning, sun position and cloud cover. Estimated speeds and altitudes would be unreliable unless announced by the flight crew over the public address system.

Ground eye witnesses should be interviewed with respect to their observations. Although the eye witness will usually estimate speed and altitude of the aircraft, these estimates are not too reliable. If possible, have the eye witness provide you with the angle from his vantage point to the position of the aircraft as he observed it. This should be done at the location from which the witness made the observations. Through triangulation you can determine the approximate height of the aircraft.

The ground observer can provide information on the direction of flight, whether evasive action was taken, the approximate speed of the aircraft, the sound of power application, the position of the sun, clouds and the visibility conditions at the time.

If either or both aircraft were being controlled by an air traffic controller, then the controller should be interviewed. The controller could provide information regarding the speed, altitude, heading and position of the aircraft being controlled. All conversations between the aircraft flight crew and the controller are recorded. The tapes should be reviewed to obtain the aircraft speed, heading and altitude information.

The controller quite often will observe aircraft on the radar scope which he is not controlling and will be able to provide the position and heading of these aircraft. If the controller provided traffic advisories to any aircraft involving the ones in the collision, positions of the aircraft might be obtained.

The controller's observations and the information obtained from the air traffic control tapes might be the most accurate information available on a general aviation aircraft, especially if the flight crew did not survive. The best information for the accurate reconstruction of the aircraft's flight path can be obtained from the flight data recorder if one is installed in the aircraft. The recorder will provide indicated air speeds, headings and altitudes in relation to time of flight. From these data and the winds and temperatures aloft, an accurate ground track can be developed.

Physical evidence is available to the ASI which should not be overlooked. If the aircraft were not consumed by fire, telltale scratch marks can be found and measured on each aircraft. From these scratches the relative heading, speeds, angles of impact, and closure speeds can be calculated. For an explanation of this technique, see Appendix II, "Mid-Air Collision Analysis", ICAO Manual of Aircraft Accident Investigation, Fourth Edition - 1970. It must be remembered that these calculations may only be applicable to the final impact, since evasive action taken just before impact will modity the scratch mark patterns.

All of the information gathered from the flight crew, passengers, eye witnesses, air traffic controllers, flight data recorders, and physical evidence at the crash scene must be analyzed by the ASI. These data might very well be, and usually are, somewhat conflicting. The aircraft flight manual can provide speeds, rates of climb, and bank angles for each aircraft.

From this analysis the flight paths are constructed and visual angles from each aircraft are measured.

Let us assume that two aircraft are approaching an uncontrolled airport with the intention of landing on Runway 18. Both aircraft were observed from the ground. Aircraft A was observed to be making a straight in approach while Aircraft B turned left onto final from the base leg. The aircraft collided when Aircraft B rolled out on his final heading. Aircraft B crashed while Aircraft A maintained control and was landed safely.

During an interview the pilot of Aircraft A indicated that he started his approach five miles out and that he maintained an airspeed of 90 mph and a rate of descent of 600 feet per minute. He indicated that he never saw Aircraft B until they collided. His recount of his approach, airspeed, and rate of descent were consistent with the eye witnesses' accounts and the aircraft owners manual regarding approach speeds.

The pilot in Aircraft B was fatally injured. Eye witnesses reported that the aircraft was level and flying on a heading of about 270 degrees until he made a steep turn to the left to a heading of 180 degrees. It was learned that the pilot of Aircraft B had about 100 hours total flight time and was practicing touch and go landings.

From the scratch marks on the airplane, it was calculated that Aircraft A was overtaking Aircraft B, and that if A's speed was 90 mph, B's speed was 65 mph. The impact angle was 10 degrees with Aircraft A to the right of Aircraft B.

Figure 1 depicts the calculated ground tracks of the two aircraft and computed ranges, bearings and elevation angles. The ground tracks were developed in a no wind atmosphere. Had wind been included, the aircraft speeds would have been modified to account for the wind component along the flight path. Additionally, a cross wind would have resulted in a crab angle which would have to be accounted for in the bearing angles.

The following data was used to construct the paths of each aircraft:

Aircraft A

Speed	90 miles per hour
Heading	180 degrees
Descent	600 feet per minute
Deck angle	-5 degrees

1.467 x mph = fps
1.467 x 90 = 132 fps
132 x 5 = 660 feet per 5 seconds

Aircraft B

Speed	65 mph
Initial heading	279 degrees
Final heading	180 degrees
Level flight	
Deck angle	0 degrees

1.467 x mph = fps
1.467 x 65 = 95 fps
95 x 5 = 475 feet per 5 seconds

Radius of turn $= \dfrac{V^2}{11.26 \tan \measuredangle}$

V in knots = 0.8684 x mph
V = 0.8684 x 65
= 56.54

$\measuredangle$ = bank angle = 20 degrees

$\therefore R = \dfrac{56.54^2}{11.26 \tan 20 \text{ degrees}}$

R = 778 feet

III. COCKPIT WINDOW CONFIGURATIONS

The window configuration of the cockpit for U.S. manufactured transport category airplanes and general aviation airplanes is governed by the provisions of Parts 25 and 23 of the Federal Aviation Regulations respectively. Although these regulations are worded differently, it is essentially required that the pilot's view be sufficiently extensive, clear and undistorted for safe operation of the airplane. To determine whether these general objectives are met in transport category airplane, the FAA utilities the policies contained in Civil Aeronautics Manual (CAM) 4b which contains the angular vision to be made available to the pilots. Although these visual angles are not mandatory, the CAM 4b criteria are utilized to determine the adequacy of the actual configuration.

In order to provide the pilot with the best opportunity to detect the other aircraft, as much unobstructed vision should be provided as possible. There are, however, certain other factors which must be considered in the design of the cockpit window areas such as pressurization strength, location of essential instruments, glare, bird-proofing and heating. Each of these tend to compromise the size of the cockpit windows.

The most accurate and convenient method for the air safety investigator to determine the pilot's visual angles is through the utilization of binocular photographs. To the author's knowledge, there is only one camera specifically designed to provide binocular photographs of cockpit interiors which permit accurate measurements of the visual angles from the pilot's position. The camera is located and used by the National Aviation Facilities Experimental Center (NAFEC) of the Federal Aviation Administration at Atlantic City, New Jersey.

This unique camera has two lenses separated to simulate the distance between the eyes of the pilot. The camera is motor driven so that it will rotate at a constant speed through 360 degrees. The film advances at a speed to provide a panoramic view of the cockpit window configuration. Superimposed on the negative is a grid depicting five degree increments to permit angular measurement of the windows.

The camera is placed in the pilot's seat with the two lenses positioned to correspond to the pilot's design eye position. This position is designated by the aircraft manufacturer and is utilized by him to measure the position of the instruments, equipment and visual angles in the original cockpit layout. The camera is rotated through a sufficient arc to permit a photograph of all of the cockpit windows.

Examples of photographs taken by the binocular camera are shown in Attachment 1 and 2. It will be noted that in the center of the pilot's windshield there is a cross depicting the design eye position. From this point all visual angles are measured in both the horizontal and vertical planes. The grid which is superimposed on such photographs is always in 5 degree increments unless otherwise specified. The dark areas are posts and aircraft structure which obstruct the outside view of the pilot. The shaded area on each side of the post is the outside area which can be seen by only the left eye. The post blocks out the right eye's vision. Similarly, the right shaded area is the area viewed only by the right eye.

By using the photographs applicable to Aircrafts A and B in our visibility problem, Figures 2 and 3 were drawn. The visual angles calculated in Figure 1 were plotted on the window configurations. One can observe from Figure 2 that Airplane B can be seen in the pilot's left hand window during the entire approach up to the last few seconds before impact. Similarly, in Figure 3 it will be noted that Aircraft A can be seen by the pilot through the copilot's windshield up to 15 seconds before impact. The left turn by Aircraft B caused the target, Aircraft A, to disappear from the pilot's view.

IV. LIMITATIONS OF VISUAL STUDIES

As previously mentioned, the accuracy of the calculated flight paths of aircraft involved in a mid-air collision is only as good as the information available to the air safety investigator. The accuracy of information varies from that provided by a digital flight recorder to merely a flight plan filed prior to take-off. A judgment must be made by the investigator as to how much credence is to be placed on the particular study.

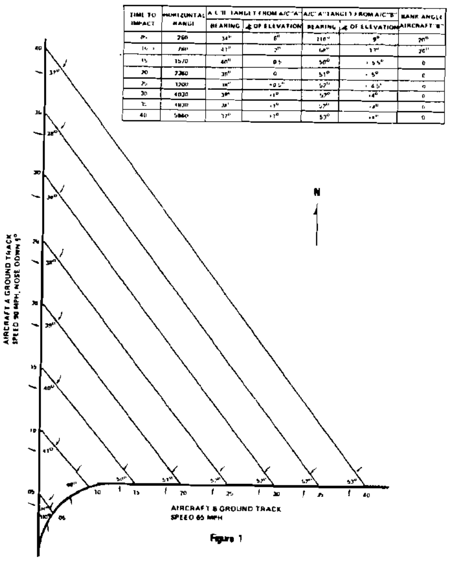
The visual angles provided by the cockpit window, although precisely measured, are only applicable to the pilot when his eyes are positioned at the design eye position. A movement forward or aft will effect these visual angles.

The studies will provide a basis, however, to show which, if either, pilot had an opportunity to see the other aircraft in time to avoid the collision.

V. RECOMMENDATION

It is recommended that the air safety investigator conduct a visibility study in each mid-air collision to provide a basis for the determination of probable cause.

COMPUTED RANGES, BEARINGS AND ELEVATION ANGLES



TIME TO IMPACT	HORIZONTAL RANGE	A/C "B" TARGET FROM A/C "A"		A/C "A" TARGET FROM A/C "B"		BANK ANGLE AIRCRAFT "B"
		BEARING	∡ OF ELEVATION	BEARING	∡ OF ELEVATION	
[illegible]	260	34°	6°	110°	9°	20°
[illegible]	700	41°	2°	64°	13°	20°
15	1570	40°	0.5	50°	+5.5°	0
20	2360	39°	0	51°	+5°	0
25	3200	38°	+0.5°	52°	+4.5°	0
30	4030	38°	+1°	52°	+4°	0
35	4830	38°	+1°	52°	+4°	0
40	5660	37°	+1°	53°	+4°	0

Figure 1

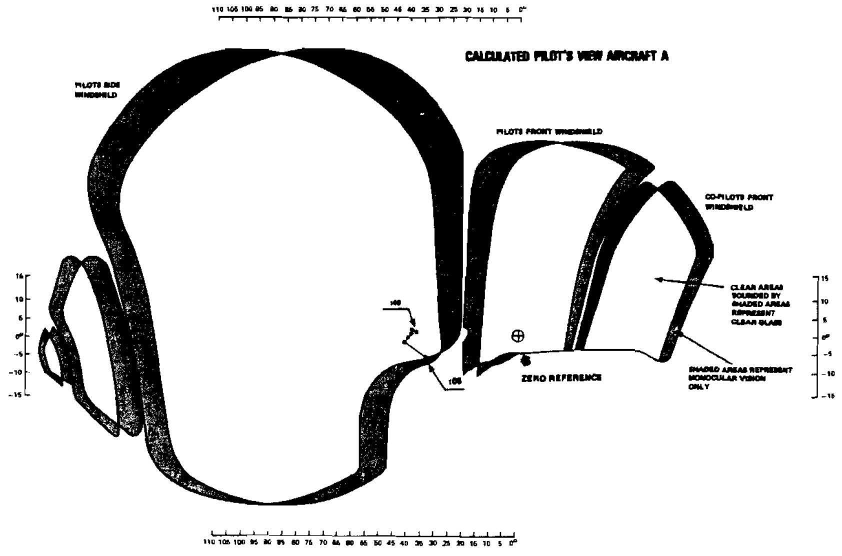


Figure 2

CALCULATED PILOT S VIEW AIRCRAFT B PILOTS

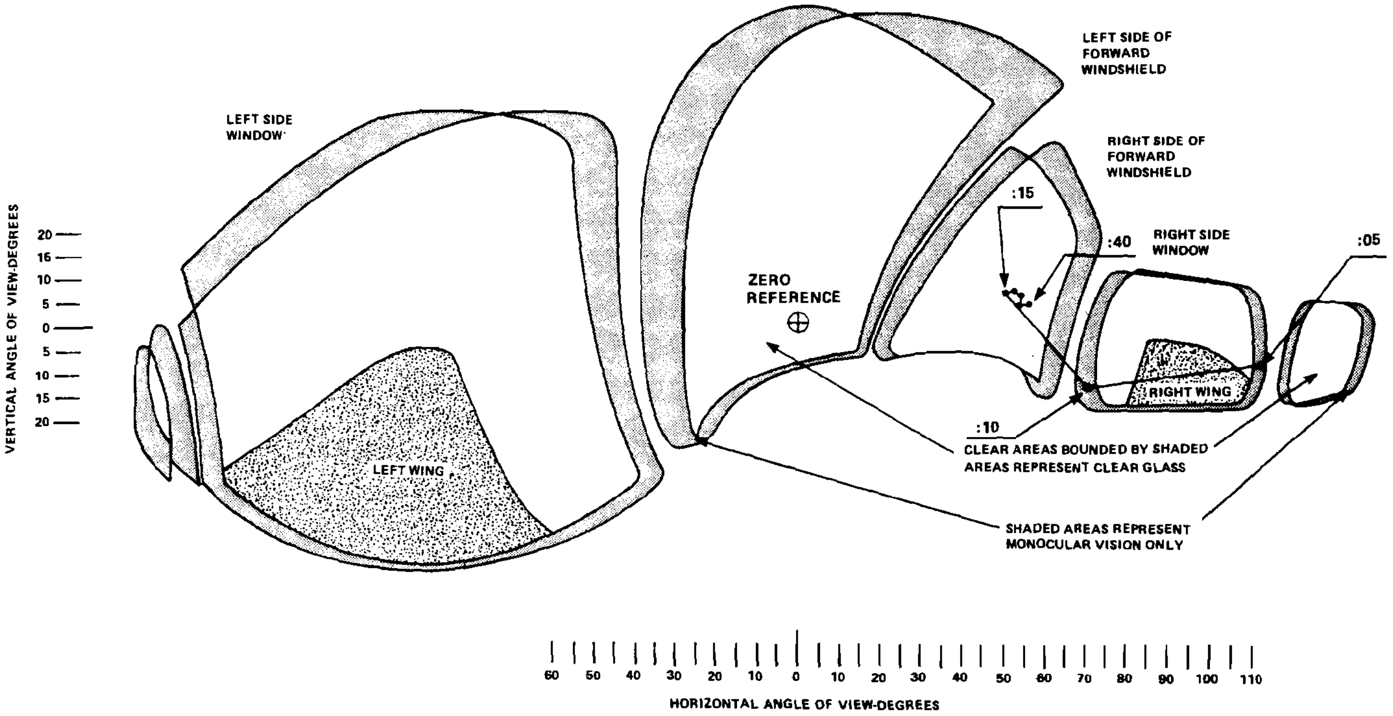
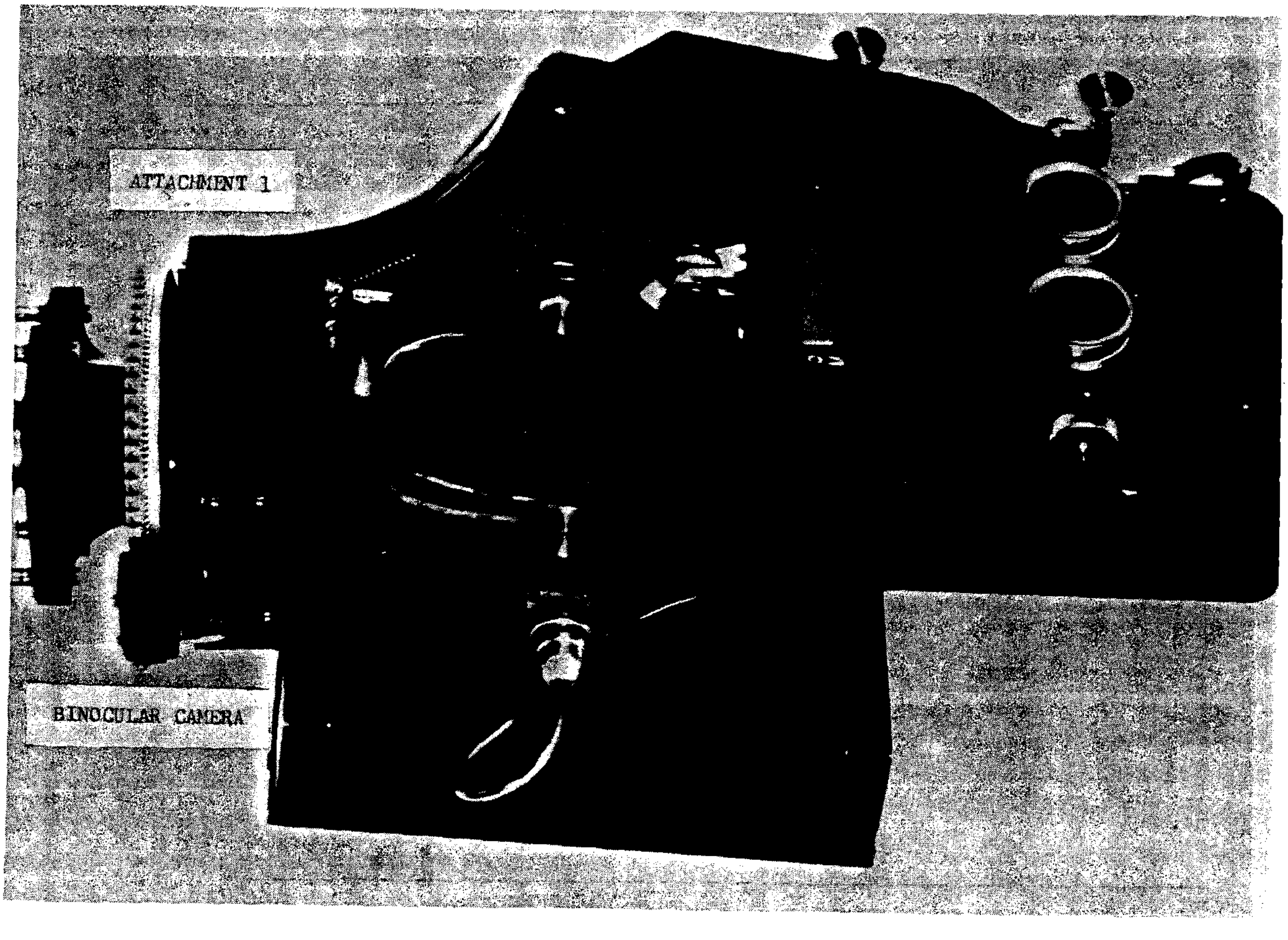


Figure 3



ATTACHMENT 2

A TYPICAL EXAMPLE OF COCKPIT VISIBILITY TAKEN WITH THE BINOCULAR CAMERA. THIS AUTOMATICALLY RECORDS COCKPIT VISIBILITY AS THE EYES SEE IT, PLACING DEGREE MARKS ON THE FILM DIRECTLY IN INCREMENTS OF 5° HORIZONTALLY AND VERTICALLY.

ATTACHMENT 3

BINOCULAR CAMERA PHOTOGRAPH

THE ACCREDITED REPRESENTATIVE

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A review of procedures for investigating accidents reveals that little is known, or has been written about, the functions of the accredited representative, the responsibilities of his advisors, or the relationship between the accredited representative and the investigator-in-charge. The actions of an investigator-in-charge are meant to be accommodating and helpful, but sometimes are contrary to the role of the accredited representative as defined by Annex 13 of ICAO. I have been guilty of these breaches of procedures simply because I was not as knowledgeable of the recommended procedures for the accredited representative as an investigator-in-charge should have been. However, the best teacher is the experience of attempting to correct or apologize for your own good intentions even though they turned out to be eggheaded mistakes.

The investigation of the Pan American World Airways, Boeing 707-321 accident on the island of Bali, Indonesia, illustrates the role of the accredited representative, and how it differs from the role I normally held—Investigator-in-Charge. I was the United States accredited representative, and I hope that this saga of my adventures—and mis-adventures—may throw some light on the differences between the roles of the IIC and the accredited representative.

The accident at Bali presented several extremely difficult logistic and technical problems. (The technical problems were basically local custom problems, but no less real or difficult to handle by the investigator-in-charge or were of the type wherein the accredited representative could not be of assistance.)

Pan American Flight 812 was a scheduled international flight from Hong Kong to Sydney, with an en route stop at Denpasar, Bali. The flight departed Hong Kong at 1108Z, with an estimated en route time of 4 hours 23 minutes. The flight was routine except for difficulty in establishing radio contact with Bali approach control. Communications were established and the flight was cleared to descend from its cruising flight level of 350 to flight level 100. The flight contacted Bali Tower at flight level 110 and requested a lower altitude; seconds later, it reported over the station. This report was made at 1519; although a corrected ETA of 1527Z had been reported a few minutes before the aircraft began to descend. The 8-minute early arrival should have been a cue to the crew to verify their position. The flight was cleared to descend to 2,500 feet and landing instructions for runway 09 were issued. Shortly before 1527Z , the crew reported level at 2,500 feet and were instructed to report the runway in sight. At 1527, the crew asked, "Hey Tower, what's your visibility out there now." This was the last radio transmission from the aircraft. The wreckage was found on the north slope of the mountains about 37 nm northwest of the airport at the 3,000-foot level. The flightpath through the trees indicated a direction of flight of 155° to 160° and a 15° to 25° noseup attitude.

The search and rescue effort was directed by Indonesian military, and although the troops reached the scene, the almost total disintegration of the aircraft and its occupants, as well as the rugged terrain between the scene and the nearest road, made it almost impossible to recover the bodies. As it turned out, had the bodies been recovered, it would have created one of the local difficulties I referred to earlier.

The customs and beliefs of the local villages would have caused a real turmoil if the remains of passengers had been transported through their area. There is a local belief that the "spirit" of the dead could be so attracted to a village that it would remain there, thus becoming an added responsibility to that particular village for the rest of eternity and very possibly cause disruption and turmoil among its own departed spirits.

Because of the extremely rugged terrain, the almost total disintegration of the aircraft, and the circumstances surrounding an early descent, the wreckage was examined on the site. To do so, the investigators had to camp on the ridge line above the wreckage and the climb down to the wreckage site. A large portion of the available daylight was spent climbing up and down.

A concentrated effort was made to recover the cockpit voice and flight data recorders.

The recorders were not located by the first "expedition" to the site. I should mention here that all trips to the site were under the control of the military and they made the decisions as to when the investigators could work, what tasks could be accomplished, and what undertakings were too dangerous and would not be allowed.

The feasibility of using explosives to blast a helipad on the ridge above the wreckage was explored. This plan had to be abandoned because the local villagers were afraid we would disturb the mountain "spirits" with the blasting and that after our departure these spirits would take revenge on the villages.

Based on the investigators' reports, the aircraft had impacted on a ravine cut upslope of about 45°. The aircraft disintegrated, and with a few exceptions—a wing section and two engines—the separate pieces slid (tail first) down one of the ravines to a ledge where it piled (layer fashion) into one large heap. Pieces, such as main landing gears and engines which were too heavy to carry, had to be moved with some type of mechanical advantage tools.

A second expedition was organized, and tools, such as come alongs, pulleys, ropes, chains, saws, cutting torches, food, and shelter for 10 days were assembled. Along with the military escort and local porters, who could make the trip barefoot in about 3 hours carrying 75 lbs. of gear, the investigators went to the site with the intention of "unstacking" the wreckage layer by. layer, pulling it to the edge of the ledge, and after inspecting it, letting gravity move it out of the way. The plan was feasible, and, although risky, it could have been carried out if the investigators were very careful. All this planning, procurement, and labor to get to the site was for naught.

After all components of the expedition were in position, the Major in charge of the military escort said, "No," and that was the end of the project.

About 90 days later, after the wreckage had been released, permission was obtained from the Indonesian Government in Jakarta for a private "expedition" to go to the site and carry out the original plan. They went to the site with six local laborers and in 8 days they unlayered the wreckage, dug into the soft loam and decaying leaves, and recovered the CVR and FDR.

The recorders were read out at the NTSB labs in Washington with representatives of the Indonesian investigation team in attendance.

The CVR revealed that, following the problem connected with establishing radio contact with the Bali Approach Control, the crew identified being overhead the airport by the swing of one of the two ADF's that were tuned to the NDB on the airport. The comment that "one's swinging, the other decided to wait," followed by the overhead report and the commencement of the approach descent, indicates the crew's actions.

The descent flightpath derived by a computer-generated plot was in error, because in making up the cards for the computer, someone, the keypunch operator or someone, entered an extra digit in one card and this cancelled several heading changes. This error was not noticed until much later; however, this mistake would only move the start of the descent a mile or so to the west and the descent would still have been made behind the mountains.

It is interesting to note that the VOR referred to by the crew is about 6 nm south, or beyond the airport from the direction PA812 was approaching. The VOR was operating but it was not being used by the crew of PA812.

Now, to the subject matter of this presentation—the functions of the accredited representative. The accredited representative is assured of receiving all the facts, conditions, and circumstances developed during the investigation. This does not mean he has any right to investigate on his own or to gather any information not provided to him by the investigator-in-charge. If he, the accredited representative, has technical advisors, these persons may be assigned to working groups at the pleasure of the investigator-in-charge. In the previously discussed case the U.S. contingent consisted of:

1 -	Accredited Representative
4 -	NTSB specialists (systems, operations, human factors and structures)
1 -	FAA Representative
10 -	Pan American Employees
4 -	Air Line Pilot's Association Members
2 -	Air Line Dispatchers Association Members
4 -	Boeing Aircraft Employees
5 -	FBI Identification Experts

The investigator-in-charge put U.S. representatives on various groups and arranged for a selected group of investigators to climb to the site.

These advisors were then under the direct functional control of their group leader (chairman) and must provide any assistance they possibly can to that group. They must report any observations they make to their group leader and carry out his instructions in all tasks. Naturally, they are obligated to keep the accredited representative appraised of their findings but the investigation has top priority.

The accredited representative is the only person that can deliver any technical information to the investigation. It is his responsibility to gather and deliver any cogent manufacturing data, operating procedures, or any other official material requested by the investigator-in-charge. That is why he usually has advisors from the manufacturers, the rulemaking organization, or the certificating agency in his contingent at the investigation. The investigator-in-charge should rely on the accredited representative to supply him with the official answers to any question he may have.

Upon completion of the field phase, all correspondence with the parent organization of any advisor (i.e., manufacturer) should be communicated through the accredited representative. He knows the manufacturer and was appointed to make sure timely and accurate responses to legitimate requests are fulfilled. He cannot perform this function unless the requests are funneled through him and, unfortunately, delays or nonresponsive answers may result to the detriment of the investigation if direct line communication is utilized.

The accredited representative can and must be the key to answering the needs of the investigator-in-charge. Also, it should be recognized that the role of the advisor to the accredited representative is specifically defined in Annex 13 to the Convention and should be respected. Even though the advisor's expertise is used by a group during the field phase, any written data, document, or test results should be coordinated through the accredited representative.

The accredited representative is the only one who can furnish the official documents of his advisors findings used by the investigator-in-charge in the preparation of the final report of the accident.

COMPLACENCY - IT KILLS AND DATA WITHOUT TEARS

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I. INTRODUCTION

While all accidents are the result of "human error", it gets to be a problem as to which human in the long line of people associated with an aircraft accident; from those who mined the raw materials, designed the parts and systems, machined and assembled the components and entire aircraft, inspected and approved the aircraft, its systems and manner of operation, to the individual crew members at the controls at the time of the accident, should be charged with the responsibility of a particular accident.

Being pilots the authors have always hesitated to immediately lay the blame for the accident on the crew, but they have done so when the investigation revealed that the crew was a fault and have issued reports which indicated that "pilot error" was the primary causal factor in the accident. To our knowledge the pilot representatives are the only group that have ever issued a report on an accident and found their product to be at fault.

In recent years it has become harder and harder to justify conduct of some pilots in their aircraft prior to an accident and it is believed that complacency rather than any other cause is the major cause of pilot involvement.

II. DISCUSSION - PART I

Complacency is defined as:

> "Contented to a fault; marked by sometimes unwarranted, uncritical, and irritating satisfaction and pleasure at one's personality, accomplishments, or situation.
>
> Marked by or as if by unruffled or blase satisfaction about the security of one's own position or by careless acceptance of events around one: disinclined to act, to change or to guard.
>
> The quality or state of being satisfied: A calm sense of well being and security; satisfaction or self-satisfaction accompanied by unawareness of actual danger or deficiencies."[1]

Probably the first pilot error accident that can be charged to complacency, and certainly the first recorded airborne accident would be the accident involving Icarus. Greek mythology records that Icarus, after being imprisoned by Minos, escaped into the air with wings his father, Daedalus, had fashioned of feathers and attached to his shoulders with wax.

Ignoring the advice and warnings of his father, Icarus flew too high and too near the heat of the sun which melted the wax and he fell into the sea.

> "a calm sense of well being and security—unaware of actual danger."

Certainly things didn't stop there.

A review of General Aviation Accident statistics in the U.S. for 1965 [2] and 1975 [3] indicates that while fewer accidents were reported in 1975, accident causal factors that can be placed in a complacency classification have with one exception increased.

1965		1975
5196	Total Accidents	4158
538	Fatal Accidents	660
4658	Non-Fatal Accidents	3498
592	Pilot Cause — Fatal	575 (87.12%)
3929	Pilot Cause — Non-Fatal	2848 (81.42%)

Note: Change in definition of "Accident" on 1 January 1968 results in a lower number of accidents being reported after that date.

In this ten year period the "Cause/Factor Table" [2] & [3] was expanded from a 46 line "Pilot in Command Detailed Cause/Factor" table in 1965 to a 64 line table in 1975, however the expansion was only to provide more detail in certain areas. The following area were unchanged and provide some interesting information. (Only cause information is reported here.)

	Accident Type			
	Fatal		Non-Fatal	
Cause	1965	1975	1965	1975
Diverted Attention from Operating A/C	5	26	31	85
Failed to see and avoid other A/C	13	19	33	50
Failed to see & avoid objects or obstructions	15	42	165	183
Failed to follow approved Procedures, Directions, etc.	3	28	4	79
Inadequate Pre-Flight Preparation and/or Planning	41	51	202	385
Inadequate Supervision of Flight	4	7	134	94
Exercised Poor Judgment	67	33	113	252

While the total number of accidents reported in 1975 decreased 20 percent from that reported in 1965, in only two (2) of the above 28 areas was any decrease recorded.

1. Inadequate Supervision of Flight decreased in Non-Fatal accidents, and,
2. Exercised Poor Judgement decreased in Fatal Accidents

Expressed another way, while the total number of reported accidents declined 20 percent from 1965 to 1975, the seven referenced cause areas increased in Fatal Accidents from 27 percent in 1965 to 31 percent in 1975 and in Non-Fatal Accidents from 14.6 percent in 1965 to 31 percent in 1975, during the same time period.

It is to be noted that none of the "Pilot in Command" Cause areas reviewed would present any problem in their eradication and yet if they could be eliminated almost one-third of all the reported accidents in 1975 would not have happened.

An examination of the same seven "Pilot in Command" cause areas in all United States Air Carrier aircraft accidents reveals that 16 percent of all Fatal Accidents and 17 percent of all Non-Fatal Accidents in the 1964-1969 period could just as easily been avoided. [4]

Dr. Robert E. Yanowitch, points out that an individual, or the cockpit crew working as a team, is basically an information processor. The final phase of this processing system deals with performing or not performing some physical action based on the three phases (1) Perception, (2) Comprehension, (3) Decision and thus the resulting action [5]

Using the definition of Complacency, if "Perception" is removed by "unwarranted, uncritical and irritating satisfaction of one's own personality, accomplishment or situation" or "blase satisfaction about the security of one's own position" or by "unawareness of actual dangers or deficiencies" it makes no difference as to the ability of the individual or cockpit crew to Comprehend, Make Decisions or Act. If they do not perceive they cannot act.

Dr. James E. Crane, states "Monotony and boredom can lead to absentmindness. This situation suggests an aimless wandering of the mind away from the immediate situation. It often implies an habitual tendency. One of the major airlines is concerned about this problem in a certain category of their pilots. The profile describes a well entrenched airman with about 12,000 hours flying the 707, with his family coming along well and a business on the side. The novelty of flying is a thing of the past; there is almost an air of overconfidence." [6]

A readout of the Cockpit Voice Recorder of an aircarrier accident in December 1972 reveals that the crew spent all of the time enroute in discussions of matters that were in no way concerned with their trip. As Dr. Yanowitch puts it "trivia". The crew became so engrossed in their conversation that as the situation deteriorated to the point that the aircraft crossed the Final Approach Fix too high and too fast, and continued descent below the Minimum Descent Altitude, the crew was unable to respond to the situation and the aircraft crashed short of the runway. In this accident none of the cockpit crew utilized their shoulder harnesses, a compulsory Check List Item. While it made little difference to the First and Second Officers, in the Captain's case there is an excellent likelihood that he would have survived the accident had he used his shoulder harness.

> "or by careless acceptance of events around one: disinclined to act, to change or to guard."

Again an approach was made to the Miami airport. When the nose gear indicator light failed to operate the approach was abandoned and a clearance was received to maintain 3,000 feet above sea level and hold west of the airport while efforts were made to determine the malfunction. Review of the Cockpit Voice Recorder readout and the Flight Data Recorder reveals two persons went below the cockpit floor to check the gear extension visually, while the Captain and First Officer flew the aircraft on the auto-pilot. Depending on the auto-pilot to fly the airplane the Captain and First Officer attempted to remove the faulty light's cover. With all the faith in the auto-pilot no one was flying the airplane, which through failures in the Altitude Hold mode, started a gradual descent.

Even a query from the Miami tower controller was insufficient to arouse the crew that something had changed. The Controller's use of improper phraseology indicates a great deal of "uncritical and irritating satisfaction and pleasure at one's own personality, accomplishments, or situation." The aircraft crashed in the Everglades.

> "by, or as if by, unruffled or blase satisfaction about the security of one's own position or by careless acceptance of events."

A DC-9 taxies out for an easy thirty-five minute flight to Charlotte, North Carolina. A review of the CVR reveals a constant flow of conversation between the crew members. A total of 366 line items are listed in the CVR readout for this period of just less than 34 minutes. While the crew did accomplish all the required Check Lists, it also manages to cover a long list of irrelevant material and in the process both crew members fail to hear the sound of the 1000 foot radio altimeter alert which sounded 1 minute and 17 seconds prior to contact with the ground.

> "blase satisfaction about the security of one's own position";
> "accompanied by unawareness of actual danger or deficiencies."

In July 1976, two Piper PA-28 aircraft are flying at 6,000 feet on the same airway. One was flying southwest under Instrument Flight Rules. The other was flying northeast under Visual Flight Rules. The sky was clear and visibility unlimited. The aircraft were destroyed and the crews and passengers killed in a head-on collision. [7]

> "disinclined to act, to change or to guard. . . . .satisfaction or self-satisfaction accompanied by unawareness of actual danger or deficiencies."

The tendency for complacency is not limited to the Cockpit. Discussions with Flight Managers of a major airline, as to why disciplinary action was not taken against a reported case of non-standard cockpit procedures, brought forth the reply that the Company realized the problem and closely monitored it on Enroute Checks, but disciplinary action, other than discussion and notation, was not taken because "the Air Line Pilot's Association would be on our necks in a minute." Even if this fear was valid, the failure to act is unjustified, and while the Air Line Pilot's Association may have many faults the defense of a member guilty of unsafe conduct cannot be said to be one of them.

Another Flight Manager testified that the required Enroute Flight Checks are "merely exercises." [8]

Regulatory Agencies, while generally doing an excellent job, continually remind each other of deficiencies in their programs. The National Transportation Safety Board has issued a long list of Safety Recommendations to the Federal Aviation Administration pointing out areas of concern uncovered in the NTSB's accident investigations. Some recommendations cover areas of several years, standing. Both agencies fail at times to act with sufficient speed on recommendations from other members of the aviation community. A specific example is ALPA's long standing recommendation that a standby, independently powered, artificial horizon be required in all jet aircraft. It was necessary to have a B-727 crash into Santa Monica Bay before this recommendation became a requirement.

Some responsibility for such accidents must be accepted by the Air Line Pilot's Association. While ALPA put forth many strong arguments for such an aritifical horizon, its complacement attitude on the subject permitted the continued operation of the aircraft without the requested installation. A refusal to fly the aircraft until the units had been installed would have prevented the accident.

It is interesting to note that the Regulatory Agencies are beginning to take steps to require better cockpit discipline. While it may be argued that a pilot that does not abide by the rules is not of necessity complacent, such actions certainly fall within three of the seven Causal areas under discussion. It is disappointing to note that in two reported incidents the Federal Aviation Administration waited until one pilot had accumulated 23 alleged violations and cited the prior violation history of the second pilot before removing them from the cockpit. [9]

Air Carrier operators must place more rigid emphasis on the use of Enroute Flight and other checks, and in cases of repeated notation of non-standard methods of operation the pilot should be given the opportunity to be retrained in the area of concern. If such retraining proves ineffective the pilot must be removed from the cockpit.

The pilots themselves must undertake to upgrade their own awareness while in the cockpit. Dr. Crane points out that,

> "Unnecessary conversations at the wrong time can be controlled easily by the Captain. Banish from the cockpit during critical times (take-off, landing and approach) all non-crew members. Brief the crew that the social hour will begin after the flight terminates." [6]

ALPA has a program of Professional Standard's Committees which has seldom been used. The composition and purpose of this committee could easily be changed to provide a positive factor to increase awareness and reduce complacency in the cockpit.

Each of the other pilot segments of the aviation community has its own representing organization, which can and must mount a campaign to eliminate complacency from their cockpits.

Any pilot failing to respond to efforts to eliminate his complacency must be removed from the cockpit.

Reduction to zero in the seven previously listed Cause areas would require only that the pilot in command be more aware of what he is doing. Nothing more. No engineering changes; no regulatory changes; nothing other than to be more aware and less complacent. Maybe less satisfied is a better way of saying it but no matter how it is said, if it could be accomplished almost one-third of all General Aviation Accidents and 16 percent to 17 percent of the Air Carrier accidents in the U.S. could be avoided.

We in the aviation community must do something, if only to learn, for we have not learned from our past accidents. In December of 1972 a DC-9 took off in heavy fog at O'Hare International Airport and struck a Convair 880 taxiing across the runway. In March of 1977 a B-747 took off in fog at Tenerife, Canary Islands and struck a B-747 taxiing on the runway. In five years we didn't learn a thing.

> "The quality or state of being satisfied: a calm sense of well being and security: satisfaction or self-satisfaction accompanied by unawareness of actual dangers or deficiencies."

DATA WITHOUT TEARS - PART II

A rapid review of the statistics compiled by different international bodies (I.C.A.O., I.A.T.A., N.T.S.B., etc.) indicates that the causes of accidents attributable to the fallibility of flight personnel varies from a figure of 51 percent to a high of 75 percent, depending upon one's estimate of human error.

Two interesting theories are basic in the minds of those who attempt to explain the reasons why such a large percentage of incidents are attributable to a highly qualified group like that of pilots.

The first theory is discussed in a technical report prepared by the Office of Aviation Medicine of the F.A.A. and deals with the subject of "The Aircraft as an Instrument of Self-destruction". This theory holds that the relationship between the man and his machine is such that the machine may be thought of as an extension of the man himself during operations.

The second theory is that of the inevitability on the part of the human operator to commit errors. Generalized this theory is Murphy's Law, a law which is given its spirit through perception.

Experience has proven that investigation of random events such as aircraft accidents produces results more ameniable in the correction of the mechanical aspects as opposed to "The Operational Aspects of Human Behavior" (Orlady 1966). Human behavior broadens the task immeasurably and complacency is but a single factor. When we are confronted with such a behavior the best we seem to be able to do is recommend against it and exhort concerning it. Some suitable antonyms for complacency are: bothered, uneasy, agitated, perturbed and upset. I can't imagine recommending any of these as the constant attitude to be held by air crew members. What we should develop is an attitude of healthy concern among all who function in our aviation system.

Franklin's Poor Richard is often quoted concerning error and forgiveness. This maxim is an excellent case in point since it is not in its complete form as most often quoted. Used this way you and I are lead to a different perception, a perception which is convenient for the one using it. The maxim fully stated adds "but to persist in erring is devilish".

The key word here, naturally, is persist.

Bruggink in his "The Last Line of Defense" (1975) speaks of various role players in the aviation system. People within one common role fulfill their role expectations differently from those in another common role and yet these roles must merge at some point to transact. It is interesting to ask different role players at the end of a shift or at the termination of a flight how they viewed the role that day and how they feel they did in the role and also how the others in transacting roles fulfilled theirs. We usually find it to be true that individuals who face common role obligations can generally fulfill them and it is also true that the theory of institutional integration is correct as an orienting idea; people generally want to do what it is they are supposed to do, and this is what society needs to have done in order to continue. I propose we are, or should be, in the business of enabling every role player to meet the highest expectations that accrue to their roles.

No one I know in this industry persists in error. Persistence implies total disregard for proven professional behavior and yet we find persistent error within the system which those professionals must cope with by adjusting. This to me is tantamount to "lais'sez' faire" control of the aviation system. For example, I recently re-read a paper on wind shear published in 1968. In it data from other, earlier studies, was mentioned. The point is that the article was accurate and complete by today's standards yet a number of years passed before wind shear was accepted seriously as an accident cause. During that same reading I was struck by the fact, in still another article, that misreading of the altimeter has been a persistent problem for over thirty years and yet treatment of the problem is now no different than it was. Further, accidents fatal and nearly so induced by pitot system malfunction span many years and they are far too numerous to mention. Yet they have not happened frequently enough as to be called other than random; that is, of course, if we are satisfied we know of all occurrences.

Error that is random and error that is persistent when committed by individuals, I believe, have been shown to be quite different. An error was once thought of as an honest but incorrect behavior attributable to lack of training, sensitivity or even incapacity. Of late however error of any type has taken on a different cast. Error has come to have the connotation wrongness, wrongness akin to sin and sin we know is bad.

Let's examine that in the light of six thousand years of Judeo-Christian history. By the end of the first four thousand years of that history law was a strangle hold on life, a deadweight of punctilious requirements which ordinary people did not attempt to cope with. This was not life as life was meant to be lived and its yoke was broken. Two thousand years more might seem to demonstrate that we really didn't learn from the first four or that perhaps man cannot be trusted to himself.

It is important to recognize, as law and regulation are made more complex, error committed as a result of that complexity is the fodder of the self-generating nature of that system. That is why the first system failed. The solution and the message is that error should be used as a means to learn. Correction in all of that history is meant for learning and not for punishment.

We can witness all this at work in a microcosm of society today, the educational system. A teacher teaches and then tests. If a student can disgorge that information letter perfect the teacher and the system are satisfied. Should the opposite be the case there is frequently an attempt to make the student feel his error is not only wrong but that it is bad, ergo, he is bad. This is just one more place where God and man part company since, you see, God hates sin and wants to see it eliminated; he does not hate the sinner, in fact, he seems to tolerate a great deal of it while men learn.

This is not calculated to create a dilema since it seemingly calls for moral judgments. Nothing could be farther from the truth and I mean that sincerely. We all feel quite comfortable when we purport to be totally objective. But there are those who treat the world around them as if it were an objective system they can manipulate at will for purposes that pertain to themselves. There is the cult of objectivity in the behavioral sciences and also in those administrative capacities that involve making decisions about people and their merit. They rely, they say, on verifiable and quantifiable fact rather on feelings, wishes, guesses, or ethical and empathetical resonances, or scales of value. It is not hard to see from this that adhering to an objective standard is itself making a value judgement. Objectivists may start by modestly confining their discourse to what is verifiable and quantifiable but there is a native tendency to slip from this into denying that there is anything else; that is going from objectivity to reductionism in one easy step. A man's behavior can best be understood as a result of an open exchange.

What I have attempted to point out in this discussion is that the acceptable tools of the trade which are used to obtain information from error makers are not up to doing the kind of job we would like. It could be that they are the correct tools being applied improperly. We devilishly persist in the use of punishment for error since error no matter where we find it, will be judged first. Regulations have not resolved the questions nor have they changed behavior. As a result of this and because it has gone for such a long time, just about every one is accomplished at covering up. Thus our ability to uncover anything but the most obvious and to examine it in open exchange is so completely diminished as to be almost useless. The American philosopher George Santayana extends to us a key when he says, "Those who cannot remember the past are doomed to repeat it." The matter of concern here, for us, is that often it is a case of 'will not' as opposed to 'cannot'.

The complexity of open exchange does not only have its roots in the past, it is also involved with a man's very nature. This becomes immediately apparent when one considers the perceptions of various role players, keeping in mind that a role player and his role are inseparable once assigned. Each role player contributes his knowledge, attitudes, skills and habits (K.A.S.H.) to the role. Once he behaves in his role it adds to that KASH. The very difficult part is this, these attributes are hidden away in the recesses of his brain bank and like a good banker he is comfortable when you are close enough to permit transactions, but he gets terribly nervous if you attempt to get into the vault.

You have no sure way of knowing his KASH value if he won't allow it, but then in the light of the company you keep, can he trust you? What it evolves to simply is this, he is not what he perceives himself to be. He is not what you perceive him to be. He is what he perceives you perceive him to be.

As I mentioned earlier safety regulations and their enforcement seem to be calculated so that people will change their behavior and then the system will be safer. Policy makers tend to suffer from some sort of chronic myopia with regard to the rules they promulgate and much of that myopia comes from the fact that they choose their advisors for irrelevant reasons. The idea that a rule will change anyone is just not true. There are three ways to change people: brain surgery, psychoanalysis and religious conversion. None of us is qualified to attempt the use of any of these methods and were we, would it have an effect on flying safety? C. F. Kettering while addressing a group of helicopter design engineers in the winter of 1949 was asked what advice he could give them. His prompt answer was, "Simplicate and add lightness". That was good advice then and it is good advice now. We must reduce the gap between the separate and complex worlds of the knowledge makers and the policy makers so that we can raise a generation in our industry who will not hesitate to report system error to the end the system or they themselves will be better for it.

The method I believe is within our grasp. The Air Safety Reporting System is the first step in the direction of a non-punitive approach permitting the open exchange of safety information. It is my hope that you will all embrace this program and foster its concept. Nothing is perfect but that is why we assess and modify programs and activities and that is why I urge you to examine the data produced by this program, work with it, question it and contribute. It is hard to imagine the wealth of information in real time that could be generated if indeed the error rate of one per every two segments of commercial operations is a realistic estimate.

The day every one accepts the fact that information relative to system error can and should be given impunity is the day the accident investigator will become as lonesome as the Maytag repairman.

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