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PREFACE

The Society of Air Safety Investigators is 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.

The PROCEEDINGS of the Society 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.

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THE AIR TRAFFIC CONTROLLER IN AIRCRAFT ACCIDENT INVESTIGATION

Evolutionary developments in the aviation industry in the last fifteen years have brought about a significant and inevitable shift of responsibilities for air safety from the flight crew to the air traffic controller. Technical advances have occurred which have resulted in increased responsibilities for controllers and as a result of this evolution the participation of air traffic controllers in accident investigation on the same basis as that at present enjoyed by pilots is now a practical necessity. Because of this there now is an urgent need for such organizations as MOT in Canada, and DOT, FAA, and those universities offering training in this field to design and conduct courses specifically for Air Traffic Controllers.

LE ROLE DU CONTROLEUR DE LA CIRCULATION AERIENNE DANS LES ENQUETES SUR ACCIDENT D'AVIATION.

GENERALITES

Les progrès réalisés par l'industrie de l'aviation depuis une quinzaine d'années ont inévitablement amené à attribuer aux contrôleurs de la circulation aérienne bon nombre de responsabilités qui incombaient jusque là aux membres d'équipage en matière de sécurité aérienne. Il est donc nécessaire en pratique que les contrôleurs participent aux enquêtes sur accident au même titre que les pilotes. C'est pourquoi le MDT du Canada, le DOT et la FAA des Etats-Unis, ainsi que les universités qui forment du personnel en ce domaine programment plus spécialement leurs cours à l'intention des contrôleurs de la circulation aérienne.

PAPEL DEL CONTROLADOR DE TRANSITO AEREO EN LOS ACCIDENTES Y SU INVESTIGACION

La evolución de la aeronáutica en los últimos tres lustros ha traido un cambio importante e inevitable: muchas responsabilidades han pasado de los tripulantes a los controladores debido al progreso de la técnica, y éstos debían participar en la investigación en la misma medida que los pilotos. Por ese motivo, el MOT de Canadá, el DOT y la FAA, así como las universidades, han concebido cursos para los controladores de tránsito aéreo.

Эволюционные изменения в авиационной индустрии за последние пятнадцать лет привели к значительной и неизбежной смене ответственности за безопасность полетов от летного экипажа к диспетчеру воздушного движения. Произошел технический прогресс, который привел к повышенной ответственности для диспетчеров и, как результат этой эволюции, участие диспетчеров воздушного движения в расследовании происшествий на той же основе как это осуществляется в настоящее время пилотами, является практической необходимостью. Ввиду этого сейчас существует срочная необходимость в таких организациях как МОТ в Канаде, ДОТ и ФАА и в таких университетах, которые предлагают обучение в этой области для разработки и проведения курсов специально для диспетчеров воздушного движения.

DISCREDITING AIRCRAFT ACCIDENT INVESTIGATION

Most aircraft accident investigators are technically qualified to investigate an aircraft accident and analyze the evidence. They experience no difficulty in orally explaining what caused the accident. Unfortunately, an oral description is not all that is required; there is the inevitable accident report. Many investigators discredit the accident investigation with their report by not following rules of usage, grammar or spelling. This paper contains extracts from accident reports and illustrates how an accident investigation may be discredited by the written word.

LACUNES QUI PEUVENT DISCREDITER UNE ENQUETE SUR ACCIDENT D'AVIATION.

La plupart des enquêteurs possèdent toutes les qualifications techniques pour enquêter sur un accident d'aviation et analyser les indices recueillis. Ils n'éprouvent aucune difficulté à exposer verbalement les causes de l'accident. Malheureusement, ils ne peuvent pas se soustraire à la nécessité de présenter leur rapport par écrit. Nombre d'enquêtes sur accident se trouvent discréditées parce que le rapport d'accident ne respecte pas les bons usages, les règles grammaticales ou l'orthographe. L'auteur présente des extraits de rapports d'accident qui illustrent ce genre d'erreurs.

COMO PUEDE DESPRESTIGIARSE LA INVESTIGACION DE ACCIDENTES

La mayoría de los investigadores de accidentes tienen la competencia necesaria y no les es difícil explicar verbalmente las causas de un accidente. Lamentablemente, no es eso lo único que se les exige, es necesario además redactar un informe. Muchos investigadores desprestigian su profesión, redactando un informe que infringe las normas de gramática, estilo y ortografía. En esta nota se dan algunas ilustraciones de la forma en que puede desprestigiarse la investigación por un texto mal redactado.

ДИСКРЕДИТОВАНИЕ РАССЛЕДОВАНИЯ АВИАЦИОННЫХ ПРОИСШЕСТВИЙ

Большинство расследований авиационных происшествий в техническом отношении квалифицированы для расследования авиационного происшествия и анализа очевидностей. Они не испытывают никаких трудностей при устном объяснении того, что вызвало происшествие. К сожалению, устное описание - не все, что требуется; существует еще неизбежный доклад о происшествии. Многие расследователи дискредитируют расследование происшествий в своих докладах, не следуя правилам употребления, грамматики или правописания. Настоящий документ содержит выдержки из докладов по расследованию происшествий и иллюстраций как расследование происшествия может быть дискредитировано посредством письменного изложения.

THE ROLE OF LITIGATION IN US AIR SAFETY INVESTIGATION

This paper discusses a source of aircraft accident investigative data which is sometimes disregarded or neglected. Litigation investigation frequently entails extensive studies which go beyond the realm of the initial government investigation. This process sometimes reveals substantial accident related information which if used appropriately would be invaluable to a safety program. There is a requirement to develop a system whereby this information would be more readily available to all.

LE ROLE DES PROCES DANS LES ENQUETES DE SECURITE AERIENNE AUX ETATS-UNIS.

L'auteur évoque une source souvent négligée de données dans le domaine des enquêtes sur les accidents d'aviation. Les enquêtes effectuées lors d'un procès sont souvent poussées bien au-delà des moyens dont disposait l'enquête officielle initiale. Ce processus permet parfois d'obtenir des renseignements dont l'utilisation rationnelle serait précieuse pour un programme de sécurité. Il faut mettre sur pied des mécanismes permettant à tous les intéressés d'avoir plus facilement accès à ce genre de renseignements.

LA IMPORTANCIA DE LOS LITIGIOS JUDICIALES PARA LA INVESTIGACION SOBRE SEGURIDAD AERONAUTICA EN LOS EEUU

Esta nota trata de una fuente de información sobre accidentes de aviación que a veces se toma poco en cuenta. La investigación que se efectúa a raíz de litigios judiciales es a menudo mucho más amplia que la investigación inicial del gobierno, lo que a veces permite obtener importantes datos sobre los accidentes y que podrían ser de gran utilidad para un programa de seguridad. Es necesario encontrar una forma de facilitar el acceso a esta información.

РОЛЬ СУДЕБНОГО РАЗБИРАТЕЛЬСТВА В РАССЛЕДОВАНИИ БЕЗОПАСНОСТИ ПОЛЕТОВ В США

В настоящем документе рассматривается источник данных по расследованию авиационных происшествий, которым иногда пренебрегают или на который не обращают внимание. Судебное разбирательство расследования часто влечет за собой значительные изучения, которые выходят за пределы области начального правительственного расследования. Этот процесс иногда вскрывает важную информацию, относящуюся к происшествию, которая, если ее правильно использовать, будет неоценимой для программы безопасности. Существует требование по разработке системы, с помощью которой такую информацию можно было бы предоставлять для всех.

OBSERVATIONS ON SOME ASPECTS OF HELICOPTER SAFETY

An overview of the helicopter accident picture is presented based on statistical treatment of raw accident data obtained from both civilian and military sources. Current problem areas are identified from an analysis of accident type and accident cause data. The autorotation maneuver is identified as an accident contributer itself based upon a recent U.S. Army study. An explanation of the technical aspects of autorotations which contribute to an undesirable end result is offered.

OBSERVATIONS SUR LA SECURITE D'UTILISATION DES HELICOPTERES.

Généralités sur les accidents d'hélicoptères, d'après l'étude statistique de données brutes fournies par des utilisateurs civils et militaires. L'analyse de données sur le type et la cause des accidents met en évidence certains problèmes actuels. D'après une étude effectuée récemment par l'Armée des Etats-Unis, les évolutions en autorotation interviennent pour une grande part dans le taux des accidents d'hélicoptères. La note expose les caractéristiques techniques des manoeuvres en autorotation qui contribuent à déterminer des taux d'accident anormalement élevés.

Se presenta una visión general de los accidentes, a base de estadísticas civiles y militares. Se delimitan los problemas actuales, analizando los tipos de accidentes y sus causas. A base de un reciente estudio del ejército de EE UU se identifica la autorrotación como un factor que contribuye a los accidentes y se explican los aspectos técnicos de esta maniobra que pueden resultar inconvenientes.

ЗАМЕЧАНИЯ ПО НЕКОТОРЫМ АСПЕКТАМ БЕЗОПАСНОСТИ ПОЛЕТОВ ВЕРТОЛЕТОВ

Представляется обзор картины безопасности полетов, основанный на статистическом рассмотрении необработанных данных происшествий, полученных из гражданских и военных источников. Текущие проблемные районы определены на анализе данных типа и причины происшествий. Маневр авторотации определен как сам по себе содействующий происшествию, основываясь на недавних исследованиях, проведенных в армии США. Предлагается разъяснение технических аспектов авторотации, которые содействуют нежелательному конечному результату.

MANEUVRING STABILITY'S ROLE IN AIRCRAFT ACCIDENT CAUSATION

Basic aircraft maneuvering stability is reviewed. Maneuvering stability's role in aircraft accident causation is discussed. Past and current United States' certification requirements governing maneuvering flying qualities are reviewed. Specific utility/general aviation, fighter, and transport-type aircrafts' maneuvering stability levels are presented for examination. Guidelines for the consideration of maneuvering stability's role in accident causation are presented.

LA STABILITE DE MANOEUVRE COMME CAUSE D'ACCIDENT D'AVIATION.

Etude du rôle de la stabilité de manoeuvre comme cause d'accident d'aviation. Rappel des règlements américains actuels et anciens sur les qualités de vol au cours des manoeuvres. Etude des niveaux de stabilité de manoeuvre de certains appareils d'aviation générale, des chasseurs et des avions de transport. Précisions sur le rôle de la stabilité de manoeuvre comme cause d'accident.

PAPEL DE LA ESTABILIDAD DE MANIOBRA EN LOS ACCIDENTES DE AVIACION

Se examinan los aspectos fundamentales de la estabilidad de maniobra de las aeronaves y su papel en los accidentes. Se estudian los requisitos antiguos y actuales requisitos de certificación en lo que respecta a las maniobras de vuelo, impuestos en los Estados Unidos. A base de aviones de la aviación general, para usos especiales, aviones de guerra y transporte, se estudian problemas de maniobra. Se sientan principios para estudiar el papel de la estabilidad de maniobra en los accidentes.

РОЛЬ УСТОЙЧИВОСТИ ПРИ МАНЕВРЕ В ПРИЧИННОСТИ АВИАЦИОННЫХ ПРОИСШЕСТВИЙ

Рассматриваются основные принципы устойчивости воздушного судна при маневре. Обсуждается роль устойчивости при маневре в причинности авиационных происшествий. Пересматриваются прошлые и настоящие требования Соединенных Штатов по сертификации, распространяющиеся на летные качества при маневрах. Представляются для изучения конкретные уровни устойчивости при маневре воздушных судов коммерческого назначения/общего применения, истребителей и транспортных судов. Представляются основные принципы для рассмотрения роли устойчивости при маневре в причинности авиационных происшествий.

FLIGHT SAFETY THROUGH AN IMPROVED TRAINING AIRPLANE

Flight instruction is a basic key to aviation safety Yet at present there is no general aviation airplane designed for flight instruction. The aircraft used for virtually all civilian flight instruction are the lowest priced airplanes on the market Some of these airplanes are not approved for all training maneuvers, such as intentional spins. In fact, one such airplane — specifically advertised as a trainer — does not even offer dual controls as standard equipment.

Using the approach of analyzing the flight instruction mission and developing airplane characteristics to fit, a series of modifications to an existing airframe have been developed. These modifications include a revised instrument panel layout, additional instruments, and a variable cg ballast system

The training airplane will make it possible to simulate the effect of overextending the airplane's performance, such as high altitude takeoffs on a hot day, or operating out of the weight/cg envelope, as well as demonstrating the effects of systems malfunctions.

LA SECURITE AERIENNE ET L'AMELIORATION DES AVIONS D'ECOLAGE.

L'instruction en vol joue un rôle crucial dans la sécurité en aviation. Pourtant, aucun des appareils actuels de l'aviation générale n'est conçu à cette fin et l'on utilise les avions les moins coûteux, dont certains ne sont pas certifiés pour toutes les manoeuvres d'instruction, par exemple pour les exercices de vrille. L'un d'eux, présenté pourtant comme avion d'écolage, n'a même pas la double commande en équipement standard.

En analysant l'instruction en vol et les caractéristiques que doivent présenter les avions, l'auteur a déterminé une série de modifications pour un appareil existant (notamment un nouveau tableau de bord, des instruments additionnels et un dispositif permettant de faire varier le centrage).

L'appareil ainsi modifié permet de simuler les effets d'un dépassement des performances normales de l'avion (décollage à haute altitude par temps chaud ou dépassement des limites de poids et centrage par exemple) et de démontrer les conséquences d'une défectuosité de fonctionnement.

LA SEGURIDAD DEL VUELO Y EL MEJORAMIENTO DE LOS AVIONES DE ENTRENAMIENTO

La instrucción en vuelo es fundamental para la seguridad del vuelo, y sin embargo no existe actualmente ningún avión de la aviación general que se haya concebido especialmente para la instrucción. Prácticamente en todos los vuelos civiles de instrucción se emplean los aviones de menor precio. Algunos de ellos no están certificados para efectuar maniobras de instrucción, tales como tirabuzones. Aún más, un avión que en la publicidad se presenta como de instrucción ni siquiera cuenta con mandos dobles.

Se ha estudiado en qué consiste un vuelo de instrucción y las correspondientes características de la aeronave, para concebir las necesarias modificaciones de la célula, que afectan la presentación de los instrumentos en el tablero, y su número, previendo asimismo un sistema variable de determinación del centro de gravedad.

El avión de instrucción deberá poder simular situaciones en que se exige de la aeronave más de lo normal, por ejemplo, despegues a gran altitud en un día caluroso, o bien operaciones fuera de la envolvente de peso del centro de gravedad.

Летная подготовка является основным ключом к авиационной безопасности. Тем не менее в настоящее время еще нет самолета авиации общего применения, созданного для летной подготовки. Воздушные суда, используемые практически для всей летной подготовки в гражданской авиации, являются самолетами наиболее низкой стоимости на авиационном рынке. Некоторые из этих самолетов не одобрены для выполнения всех учебных маневров, таких как преднамеренный штопор. Фактически, один из таких самолетов, специально рекламированный как учебно-тренировочный, даже не предоставляет дублированного управления в качестве стандартного оборудования. Используя метод анализа задачи летной подготовки и разрабатывая соответствующие характеристики самолетов, была разработана серия модификаций к существующему планеру самолета. Эти модификации включают измененную компановку приборной доски, дополнительные инструменты и переменную систему баласта.

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COMMUNICATION/COORDINATION - THE KEY TOWARD IMPROVED CABIN SAFETY

Efforts are currently underway to establish an improved rapport between crewmembers of our nation's airlines and the Federal Aviation Administration in Washington, D.C. Particular attention is being focused on cabin safety, the flight attendant and the promotion of safety awareness throughout the aviation community. This is being achieved through the efforts of all elements of the system, of which we all are a part. A greater understanding of each other's responsibilities and a desire to work together to achieve an increased level of safety for all has added to the progress being seen. To illustrate the advanced thinking with respect to cabin safety, specific proposed rulemaking changes are currently under consideration to provide for a safer working environment and to substantially improve the safety and survivability for flight attendants, thereby insuring their vital leadership in any non-routine situation. This new communication/exchange are envisioned to significantly improve cabin safety and provide for a higher level of safety for our traveling public.

LES COMMUNICATIONS ET LA COORDINATION SONT LA CLE D'UNE AMELIORATION DE LA SECURITE A BORD.

La FAA des Etats-Unis s'efforce actuellement d'améliorer ses relations avec les membres d'équipage des compagnies sur les questions de sécurité à bord des avions et sur le rôle du personnel de cabine à cet égard. L'expérience a montré qu'un tel objectif exige le concours de tous. C'est pourquoi des projets de règlement visent à améliorer la sécurité des conditions de travail du personnel de cabine, afin que ce personnel puisse s'acquitter de ses responsabilités essentielles s'il se produit une situation anormale. Ses efforts devraient notablement améliorer la sécurité des passagers à bord des avions.

LA COMUNICACION Y LA COORDINACION, CLAVES DE LA SEGURIDAD EN LA CABINA

Se está tratando de mejorar las comunicaciones entre nuestras líneas aéreas y la Administración Federal de Aviación de Washington, DC. Se presta particular atención a la seguridad en la cabina, a los auxiliares de vuelo y a tratar de que la comunidad aeronáutica cobre mayor conciencia de la seguridad, a base del trabajo de todos sus elementos. Se dan ejemplos de nuevas normas propuestas en lo que se refiere a comunicaciones en la cabina, que irán en pro de la seguridad.

СВЯЗЬ/КООРДИНАЦИЯ ... КЛЮЧ К ПОВЫШЕННОЙ БЕЗОПАСНОСТИ САЛОНА

В настоящее время проводится работа по установлению лучшего взаимопонимания между членами экипажа наших национальных авиакомпаний и Федеральной авиационной администрации в Вашингтоне. Особое внимание сконцентрировано на безопасности салона и повышении сознания безопасности во всей авиационной индустрии. Более четкое понимание ответственности каждого и желание работать сообща для достижения повышенного уровня безопасности для всех является компонентом проводимой работы. Для иллюстрации прогрессивных людей в отношении безопасности салона в настоящее время рассматриваются конкретные, предложенные в качестве правил, изменения для обеспечения более безопасного рабочего окружения и значительного улучшения безопасности и возможности выживания для бортпроводников, тем самым обеспечивая их важную руководящую роль в любой необычной ситуации.

A STUDY OF RIGGING

Accidents arising from improper control rigging of aircraft prompted this study of rigging as a system which might benefit from standardization of methods. Regulations, manual instructions and accidents were studied and it was found that improvements in safety could be achieved by simplifying and standardizing regulations and instructions. It also is apparent that accidents must be investigated, not only with the objective of determination of cause, but to establish where tools, procedures, training or other factors having bearing beyond the particular aircraft and crew involved exhibit insufficient tolerance to human error in everday rigging practice.

LE REGLAGE DES COMMANDES.

A la suite d'accidents d'aviation dus au mauvais réglage des commandes, on a été amené à étudier comment une normalisation des méthodes pourrait améliorer cette opération considérée dans son ensemble. Il a été établi que la sécurité pourrait être améliorée par la simplification et la normalisation des règlements et des instructions. Il est évident qu'une enquête ne doit pas seulement avoir pour but d'établir la cause de l'accident, mais également de déterminer sur quel point l'outillage et les méthodes de réglage, ainsi que la formation du personnel et divers autres facteurs laissent trop de place aux erreurs de l'homme dans sa tâche quotidienne.

ESTUDIO DEL AJUSTE DE LOS MANDOS

Este estudio del ajuste de los mandos se emprendió en vista de los accidentes debidos a un ajuste inadecuado. Se pretende llegar a normalizar este procedimiento, para beneficio de la aviación. Se estudiaron los reglamentos y los manuales de instrucción, así como algunos accidentes, llegando a la conclusión de que iría en pro de la seguridad una simplificación y uniformalización de las reglas e instrucciones. Es también evidente que en la investigación de los accidentes no sólo debe determinarse la causa, sino también la posibilidad de que el uso de determinadas herramientas y procedimientos y el adiestramiento impartido al personal en lo que se refiere al ajuste de los mandos sean excesivamente susceptibles a la influencia del error humano.

ИССЛЕДОВАНИЕ МОНТАЖА

Происшествия, вытекающие из неправильного монтажа приборов управления воздушного судна, привели к этому исследованию монтажа как системы, которая может извлечь пользу из стандартизации методов. Были изучены правила, наставления и происшествия и пришли к выводу, что улучшения в области безопасности можно добиться путем упрощения и стандартизации правил и инструкций. Также очевидно, что происшествия следует рассматривать не только с целью определения причины, но и определения тех моментов, когда инструменты, процедуры, обучение или другие факторы, выходящие за пределы определенного воздушного судна и экипажа показывают недостаточные допуски по отношению к ошибкам, допущенным человеком в повседневной монтажной практике.

INTRODUCTION OF MINISTRY OF TRANSPORT'S AVIATION SAFETY BUREAU

The Aviation Safety Programs Division is charged with conducting informational and motivational programs for the aviation community. Our concern in Canada is to ensure that the raw data often produced by investigators and researchers is converted into safety material having a personal impact on the individual pilot or aircraft maintainer. This calls for employing the latest of communications technology to compete for people's attention. To add further impact to programs, the material is designed to be presented in person by a Regional Aviation Safety Officer.

PRESENTATION DU SERVICE DE SECURITE AERIENNE DU MINISTERE DES TRANSPORTS.

La Division des programmes de sécurité aérienne a pour rôle de réaliser des programmes qui visent à donner des informations et une motivation à ceux qui participent aux activités aéronautiques. Au Canada, nous voulons que les données brutes recueillies par les enquêteurs et les chercheurs se traduisent par des éléments d'information sur la sécurité, qui soient de nature à capter l'attention de chaque pilote ou de chaque mécanicien d'aviation. Il faut utiliser à cette fin les méthodes de communication les plus récentes. Pour rendre ces programmes encore plus efficaces, les éléments d'information sont présentés par un expert régional de la sécurité aérienne.

Presentación del Departamento de Seguridad Aeronáutica del Ministerio de Transporte

La Sección de Programas de Seguridad Aeronáutica está a cargo de programas de información y notificación para la comunidad aeronáutica. Nuestra meta es aprovechar en Canadá toda la información obtenida de las investigaciones para llegar al piloto y al personal de mantenimiento con elementos de seguridad. Con este fin, nos servimos de las más avanzadas técnicas de comunicaciones, y nuestros funcionarios regionales de seguridad aeronáutica presentan el material que elaboramos.

ПРЕДСТАВЛЕНИЕ БЮРО ПО АВИАЦИОННОЙ БЕЗОПАСНОСТИ МИНИСТЕРСТВА ТРАНСПОРТА

На управление по программам авиационной безопасности возложена задача осуществления информационных и мотивированных программ для авиационной общины. Нашей проблемой в Канаде является обеспечение того, чтобы необработанные данные, часто подготавливаемые расследователями и исследователями, переводились в материал по безопасности, имеющий личное воздействие на отдельного пилота или поддерживающее устройство воздушного судна. Это призывает использовать последнюю технологию связи, чтобы завоевать внимание людей. Чтобы добавить больше воздействия на программы, материал разработан для личного представления одним из сотрудников Регионального бюро по авиационной безопасности.

Failure Analysis and Its Safety Impact in Canada

A component fails resulting in a catastrophic sequence of events ending in an aircraft accident. Why did it fail? What was the mechanism? How can future occurrences be prevented? The Engineering Laboratory has engineering and technical specialists backed by up-to-date sophisticated technology designed to investigate such failures in depth and to result in subsequent safety proposals. With its specialist and equipment resources in the fields of metallurgical,aeronautical, performance,crash-worthiness,structures, avionics,systems and wreckage analysis,the Engineering Laboratory is a unique comprehensive facility for technical analysis and investigation. Examples of actual investigations will be described to illustrate the use of laboratory resources in resolving complex technical problems and how the laboratory interfaces with the investigation,research,and promotion elements of the safety process.

L'ANALYSE DES DEFAILLANCES ET LA SECURITE AERIENNE AU CANADA

par T.W. Heaslip

Lorsque la défaillance d'un élément mécanique entraîne un accident d'aviation, il faut déterminer la cause et le processus de cette défaillance et les méthodes préventives. Le Laboratoire technique est doté du personnel et du matériel moderne nécessaires pour mener des études approfondies en vue de présenter des propositions relatives à la sécurité. Les spécialistes et l'équipement dont il dispose dans les domaines de la métallurgie, de l'aéronautique, des performances, de la résistance à l'impact, des structures, de l'avionique, des circuits et de l'analyse des épaves lui permettent de procéder à des investigations et à des analyses techniques complètes. L'auteur donne des exemples d'activités du laboratoire en vue de la solution de problèmes techniques complexes et définit l'interface entre le Laboratoire et les enquêtes, la recherche et l'amélioration de la sécurité.

EL ANALISIS DE LAS FALLAS Y LA IMPORTANCIA QUE ASUME PARA LA SEGURIDAD EN CANADA

La falla de un componente desencadena una serie fatal de eventos que culminan en un accidente de aviación. ¿A qué se debió la falla? ¿Cuáles fueron sus etapas? ¿Cómo puede evitarse su repetición? El laboratorio de Ingeniería cuenta con técnicos e ingenieros que por medio de los procedimientos más perfeccionados, investigan meticulosamente estas fallas y formulan recomendaciones sobre seguridad. El laboratorio de ingeniería, es una singular institución de análisis e investigación que dispone de especialistas y equipo en las esferas metalúrgica, aeronáutica, desempeño de los materiales, resistencia al impacto, estructuras, aviónica y análisis de los restos de aeronaves. Se describen investigaciones que ilustran la forma en que se emplean los laboratorios para resolver complejos problemas técnicos, y la manera en que está relacionado el trabajo de los laboratorios con la investigación y el fomento de la seguridad.

Какой-то компонент отказывает в работе, приводя в результате к катастрофической последовательности событий, заканчивающихся авиационным происшествием. Почему он отказал? Инженерная лаборатория имеет инженерных и технических специалистов и снабжена сложной современной техникой, разработанной для расследования таких отказов в деталях и выработке последующих предложений по безопасности. Со своими специалистами и ресурсами оборудования в областях металлургии, авиационных характеристик, норм авиакатастроф, структур, авиационного электронного оборудования, анализа систем и обломков, инженерная лаборатория является уникальным всесторонним центром для технического анализа и расследования. Будут описаны примеры действительных расследований для иллюстрации использования лабораторных ресурсов в разрешении сложных технических проблем и того, как лаборатория связывает с расследованием исследования и основные элементы процесса безопасности.

AVIATION SAFETY PROGRAMS IN THE MINISTRY OF TRANSPORT

Aviation is a vital and dynamic industry in Canada. To provide all segments of the civil aeronautics system with accident prevention programs, conceived and developed by professional safety officers, a "systems safety management" concept has been put into practice within the Civil Aeronautics Directorate of the Ministry of Transport. This approach to safety is being broadened and refined to the extent that resources permit. The newly formed Aviation Safety Bureau, staffed by safety investigation and accident prevention specialists, acts as the catalyst of the systems safety management concept and plays a key role in a systematized safety education process.

PRESENTATION DE LA DIRECTION DE LA SECURITE AERIENNE DU MINISTERE DES TRANSPORTS.

L'aviation joue un rôle vital et dynamique au Canada. La Direction de l'Aviation civile du Ministère des Transports a mis en pratique le principe de gestion des systèmes pour que toutes les activités de l'aviation civile bénéficient des programmes de prévention. La méthode est perfectionnée et développée dans toute la mesure que permettent les ressources disponibles. La Direction de la Sécurité aérienne, créée récemment et formée d'enquêteurs et de spécialistes de la prévention des accidents, joue le rôle de catalyseur dans ces systèmes de gestion de la sécurité aérienne et remplit une fonction cruciale dans le programme systématique de promotion de la sécurité.

Presentación del Departamento de Seguridad Aeronáutica del Ministerio de Transporte

En Canadá la aviación es una industria vital y dinámica. La Dirección de Aviación Civil del Ministerio de Transporte está aplicando una organización de la seguridad de los sistemas, que proporciona a todos los sectores del sistema de aeronáutica civil, programas de prevención de accidentes, concebidos y elaborados por especialistas en seguridad. Se amplia y perfecciona esta organización en la medida en que lo permiten los recursos. El Departamento de Seguridad Aeronáutica, de reciente formación, está formado por especialistas en seguridad aeronáutica y prevención de accidentes, actúa como catalizador de la organización de la seguridad de los sistemas y desempeña un papel clave en la educación sistemática en materia de seguridad.

ПРЕДСТАВЛЕНИЕ БЮРО ПО АВИАЦИОННОЙ БЕЗОПАСНОСТИ МИНИСТЕРСТВА ТРАНСПОРТА

Авиация является жизненно важной и динамической индустрией Канады. Для того, чтобы облегчить все участки системы гражданской авиации программами по предотвращению происшествий, задуманными и разработанными профессиональными сотрудниками по безопасности полетов, в Директорате гражданской авиации Министерства транспорта введена идея "руководство системами безопасности". Этот подход к безопасности расширяется и усовершенствуется до такой степени, как позволяют источники. Недавно созданное Бюро по авиационной безопасности, укомплектованное специалистами по расследованию и предотвращению происшествий выступает как катализатор идеи руководства системами безопасности и играет ключевую роль в систематическом процессе изучения безопасности.

SAFETY RESEARCH WITHIN THE CANADIAN AVIATION SAFETY BUREAU

The Aviation Safety Research Division is responsible for identifying and defining aviation safety problems and hazards. The Division develops and supports research activity as required to devise solutions and develop aviation safety recommendations. Safety Investigation reports, particularly those containing safety proposals are a constant source of data. Other sources of data on hazards are: safety surveys, safety proposal from the aviation community, MOT and other government departments, other research agencies.

Activities of the Division will be described with reference to specific safety projects.

LES TRAVAUX DE RECHERCHE DE LA DIRECTION DE LA SECURITE AERIENNE DU CANADA.

La Division des recherches sur la sécurité aérienne a pour tâche d'identifier et de définir les problèmes que pose la sécurité aérienne. Les travaux de recherches qu'elle entreprend ou auxquels elle donne son appui visent à mettre au point des solutions et à élaborer des recommandations sur la sécurité aérienne. Les rapports d'enquête, notamment ceux qui contiennent des propositions relatives à la sécurité, constituent une source permanente de données. D'autres données proviennent d'études sur la sécurité, de propositions émanant des milieux aéronautiques, du Ministère des Transports et d'autres services officiels,ainsi que d'organismes de recherches.
L'auteur présente certains projets dans le domaine de la sécurité.

INVESTIGACION EN MATERIA DE SEGURIDAD EFECTUADAS POR EL DEPARTAMENTO CANADIENSE DE SEGURIDAD AERONAUTICA

Resumen de la nota que se presenta a la Sociedad de investigadores de Seguridad Aeronáutica en octubre de 1975.

La Sección de Investigaciones de seguridad Aeronáutica está a cargo de la determinación de los problemas de seguridad de la aviación, lleva a cabo y patrocina las investigaciones necesarias para idear soluciones y formular recomendaciones en esta esfera. Los informes sobre seguridad, y particularmente los que contienen recomendaciones son una inagotable fuente de datos. También se obtiene información de los estudios en materia de seguridad, de las propuestas al respecto presentadas por la comunidad aeronáutica, al Ministerio de Transporte y otros Departamentos del Gobierno, así como otros organismos que se dedican a la investigación.

Se presentan determinadas actividades de la Sección de Investigaciones.

Управление по исследованию авиационной безопасности несет ответственность за выяснение и определение проблем и опасности в области авиационной безопасности. Управление разрабатывает и поддерживает исследовательскую деятельность, требуемую для выработки решений и разработки рекомендаций по авиационной безопасности. Доклады о расследовании авиационной безопасности, особенно те, которые содержат предложения по безопасности,представляют собой постоянный источник данных. Другие источники данных по опасностям следующие: обзоры по безопасности, предложения по безопасности, поступающие от авиационной общины, министерства транспорта и других правительственных учреждений, других исследовательских агентств. Деятельность Управления будет описана со ссылкой на конкретные факторы по безопасности.

SAFETY IN THE AIR

Two aspects make up overall safety in the air. These are safety of the machine and safety in the machine's environment of operation. Designers have gone a long way with the former although none has yet showed us a crash proof aeroplane. Now there is a need to define areas and limitations of the human involvement in the machine's operations and also to define more accurately certain environmental effects. This paper discusses some problems related to human performance and the environment.

SECURITE AERIENNE

Le tableau d'ensemble de la sécurité aérienne présente deux volets : la sécurité du fonctionnement de la machine et la sécurité de l'environnement d'utilisation de cette machine. Dans le premier de ces volets, de grands progrès ont été accomplis, mais nous n'en sommes pas encore à l'avion à l'épreuve des accidents. Il faut maintenant définir les domaines et les limitations de l'intervention de l'homme dans le fonctionnement de la machine et définir aussi plus exactement certains effets dus à l'environnement. L'auteur examine divers problèmes liés aux performances humaines et à l'environnement.

SEGURIDAD EN EL AIRE

La seguridad en el aire tiene dos aspectos: el funcionamiento seguro de la maquinaria y la seguridad de su ambiente de operación. Se ha avanzado mucho en el primer aspecto, pero aun se está muy lejos del avión a prueba de accidentes. Es necesario ahora definir y delimitar la participación humana en el funcionamiento de la máquina y definir con mayor precisión determinados efectos ambientales. En esta nota se comentan algunos aspectos del desempeño humano y del ambiente.

БЕЗОПАСНОСТЬ В ВОЗДУХЕ

Два аспекта составляют общую безопасность в воздухе. Это – безопасность машины и безопасность в эксплуатационной окружающей среде машины. Конструкторы прошли длинный путь с первым из них, хотя никто еще не показал нам самолета, не поддающегося катастрофам. Сейчас существует необходимость определить районы и ограничения человеческого участия в эксплуатации машины и также более точно определить некоторые эффекты окружающей среды. В настоящем документе обсуждаются некоторые проблемы, касающиеся человеческих характеристик и окружающей среды.

Medical and Psychiatric Aspects of Accident Investigation

Biomedical factors account for 80-90% of the total 600 aircraft accidents each year. Mechanical failures as causative factors are 10-20%. Biomedical factors of fatalities include use of drugs and alcohol in order to cope with a possible stress, anxiety or frustration in the aircraft. The important role of personality factors in producing stress reactions requires that stress be defined in terms of transactions between individuals and situations,rather than of either one in isolation. When stress reactions are observed, it is assumed that these were brought about by stress conditions, and the accident investigator looks for them in order to understand the reaction that leads to the accident. In the field of fatal accident investigation where the causes of the event must be sought retrospectively the investigator usually assumes that the victim must have encountered severe stress to which the behavior represents a response. An individual's behavior is dependent upon the total effect of all the psychosocial variables that went into the making of this individual's life style.

LA MEDECINE ET LA PSYCHIATRIE DANS LE DOMAINE DES ACCIDENTS D'AVIATION.

Sur un total de 600 accidents d'aviation par an, 80 à 90% sont imputables à des causes d'ordre médical.Les défaillances mécaniques interviennent dans 10 à 20% des cas. Parmi les causes médicales d'accidents mortels figure l'utilisation de médicaments et d'alcool pour compenser d'éventuels cas de stress, d'anxiété ou de frustration. Mais la personnalité joue un rôle dans le comportement et chaque situation doit être évaluée en fonction de caractéristiques individuelles. En cas d'accident mortel, l'enquêteur admet généralement que la victime a été soumise à un stress important. Mais le comportement d'un individu soumis au stress dépend de l'ensemble des effets de tous les paramètres psychosociaux qui ont contribué à établir son mode de vie.

Aspectos médicos y siquiátricos de la investigación de accidentes

Los factores biomédicos son causa del 80-90% de los 600 accidentes anuales de aviación. Las fallas mecánicas son la causa de un 10-20% de dichos accidentes. Entre los factores biomédicos está el uso de drogas y alcohol para superar las tensiones y la ansiedad a bordo de la aeronave. Debido a la importancia de los factores personales en la forma en que se reacciona ante la tentensión, ésta debe determinarse por la relación entre el individuo y la situación, y no tomando aisladamente cada uno de estos factores. Al observarse reacciones de tensión, se supone que han sido producidas por condiciones determinadas que deben ser estudiadas por el investigador, para comprender la reacción que produjo el accidente. Cuando se trata de accidentes mortales, al buscar las causas, el investigador parte de la base que la víctima sufrió una grave tensión, y su conducta representa una respuesta a ella. La conducta de un individuo depende de todas las variables psicosociales que determinan su modo peculiar de vida.

Биомедицинские факторы являются причиной 80-90% общего количества 600 авиационных происшествий каждый год. Механические отказы, как причинные факторы, составляют I0-20%. Биомедицинские факторы смертельных случаев включают использование лекарств и алкоголя для того, чтобы справиться с возможным стрессом, беспокойством или расстройством на воздушном судне. Когда наблюдаются стрессовые реакции, предполагается, что они создаются условиями для стресса, и расследователь происшествия ищет их для того, чтобы понять реакцию, которая приводит к происшествию. В области расследования происшествий со смертельным исходом, где причины явления следует искать ретроспективным путем, расследователь обычно предполагает, что жертва должно быть столкнулась с тяжелым стрессом, ответом на который явилось ее поведение. Поведение личности зависит от общего эффекта всех психологических отклонений, которые составляют образ жизни этой личности.

POSSIBILITIES TO DETERMINATE WHETHER A LAMP OF AN AIRCRAFT WAS SWITCHED ON OR NOT AT THE TIME OF ACCIDENT.

Whether a broken lamp of an aircraft was switched on or not at the time of an accident can be determined on the basis of oxidation symptoms as well as the mode of fracture of tungsten filament wires.
Tests made show that such a result can also be obtained with light bulbs wich are not damaged externally. Besides the local mode of fracture of the tungsten filament wires, their overall plastic deformation is also taken into consideration. The tungsten filament wires distort only when illuminated at the time of the collision. The degree of deformation depends on the impact of the collision the lamp was exposed to as well as on the form and the strenght of the tungsten filament wires.

COMMENT DETERMINER SI UNE AMPOULE ETAIT OU NON ALLUMEE AU MOMENT DE L'ACCIDENT

L'examen d'une ampoule retrouvée brisée permet de déterminer si cette ampoule était ou non allumée au moment de l'accident d'après les traces d'oxydation du filament de tungstène et le mode de fracture de ce filament. On peut obtenir le même résultat si l'ampoule n'a pas été endommagée, d'après les déformations plastiques d'ensemble du filament. Les filaments de tungstène ne se déforment que si l'ampoule était allumée au moment de l'impact et cette déformation est fonction de la violence de l'impact, ainsi que de la forme et de la résistance du filament.

POSIBILIDAD DE DETERMINAR SI UNA BOMBILLA DEL AVION ESTABA ENCENDIDA EN EL MOMENTO DE UN ACCIDENTE

Estudiando el proceso de oxidación y la forma en que se ha quebrado el filamento de tungsteno, es posible determinar si una bombilla rota estaba encendida en el momento de un accidente.
Los ensayos demuestran que lo mismo puede hacerse cuando la envoltura de la bombilla no está rota. Además de la forma en que se han quebrado los filamentos de tungsteno, se tiene en cuenta su deformación. Los filamentos de tungsteno sólo se deforman cuando están encendidos en el momento de la colisión, y la deformación depende de la fuerza del impacto y la resistencia del filamento.

Была ли включена или нет разбитая фара воздушного судна во время происшествия можно установить на основе симптомов окисления, а также характера разрыва вольфрамовых нитей накала. Проведенные испытания показывают, что такой результат можно также получить с легкими лампочками, которые не получили наружных повреждений. Кроме того, местный характер разрыва вольфрамовых нитей накала, их общая пластическая деформация - все это также принимается во внимание. Вольфрамовые нити накала искривляются только тогда, когда во время столкновения они горят. Степень деформации зависит от удара столкновения, которому была подвержена фара, а также от формы и сопротивления вольфрамовых нитей накала.

TEMPORARY POWER DECREASE

At the example of the forced landing of a leight single engined aircraft in the Austrian Alps, the investigation methodology of the Accident Investigation Division of the Federal Ministry of Transport is shortly reviewed. Loss of power in certain flight attitudes was argued to be the reason for the discussed crash. Laboratory tests with the same engine and simulation of extreme "short of oil conditions" proved the hydrotappets to become inoperative before bearing failure occurred. The installed temperature and oil - pressure indicators did not monitor the dangerous situation. The measured loss of power turned out to be up to 20% of the nominal rated performance. So the pilot could not maintain the necessary cruising altitude to surmount the saddle of the Arlberg-mountain.

BAISSE TEMPORAIRE DE PUISSANCE

L'auteur rappelle l'atterrissage forcé d'un monomoteur léger dans les Alpes autrichiennes et expose brièvement les méthodes appliquées par la Division des enquêtes sur accident du Ministère autrichien des Transports. L'accident évoqué a été attribué à une baisse de puissance dans certaines assiettes de vol. Des essais en laboratoire sur un moteur de même type ont montré que les poussoirs hydrauliques de soupapes cessaient de fonctionner avant que le palier de vilebrequin soit endommagé. Les thermomètres et manomètres d'huile de l'avion n'avaient pas signalé cette anomalie. La baisse de puissance mesurée atteignait 20% par rapport aux performances nominales. Le pilote n'avait donc pas pu maintenir l'altitude de croisière voulue pour franchir l'Arlberg.

DISMINUCION TEMPORAL DE LA POTENCIA

Se examinan brevemente los métodos del Departamento de Investigación de Accidentes del Ministerio de Transporte. tomando como ejemplo el aterrizaje forzoso de un avión monomotor liviano en los Alpes Australianos. Se adujo que el accidente se había debido a la pérdida de potencia en determinadas altitudes de vuelo. Los ensayos de laboratorio con el mismo motor, simulando condiciones de escazes extrema de aceite, demostraron que el sistema hidráulico dejó de funcionar antes que fallaran los cojinetes. Los indicadores de temperatura y presión de aceite no advirtieron el peligro. Se midió una pérdida de potencia equivalente a un 20% del rendimiento nominal, por lo cual el piloto no pudo mantener la altitud necesaria para cruzar el Monte Arlberg.

ВРЕМЕННОЕ УМЕНЬШЕНИЕ МОЩНОСТИ

На примере вынужденной посадки легкого одномоторного воздушного судна в Австрийских Альпах вкратце рассматривается методика расследования, применяемая Отделом по расследованию происшествий Федерального министерства транспорта. Высказывалось предположение, что потеря мощности на определенных высотах полета является причиной рассматриваемой катастрофы. Лабораторные испытания с тем же двигателем и имитация крайней "недостаточности условий смазки" доказали, что толкатели гидроклапанов перестают работать прежде чем происходит отказ подшипника. Установленная температура и масляные манометры не контролировали опасную ситуацию. Измеренная потеря мощности оказалась до 20% от номинальных расчетных данных. Таким образом пилот не мог поддерживать необходимую крейсерскую высоту, чтобы преодолеть седловину горы Арлберг.

DETERMINATION OF THE PERSON PILOTING AN AIRCRAFT PRIOR TO ACCIDENT

Many times the accident investigators are confronted with the fact, that there are doubts with regard to the person who has piloted an aircraft at the time of accident. By exactly securing all traces in or on the aircraft and on the clothes of the persons on board it will be possible to pick out the person who has been piloting the aircraft. Hints to that circumstances could be obtained too by blood-traces, by the remnants of human tissue and hairs, textil-fibres, by the abrasion of synthetic products and of paint as well as by characteristicel defermations.
Besides that is to be mentioned a possibility (not yet enough considered) to make shure the piloting person. For this pupose the controllevers and their traces on gloves or shoes of the pilot must be taken into account and vice versa. Special physical-chemical methods are necessary to get a result.

COMMENT DETERMINER QUI ETAIT AUX COMANDES AU MOMENT DE L'ACCIDENT

Il est souvent difficile de déterminer qui était aux commandes au moment d'un accident. Pour lever le doute, il faut examiner avec soin tous les indices à l'intérieur de l'avion, sur l'avion et sur les vêtements des occupants. Des renseignements précieux peuvent être fournis par des traces de sang, des restes de tissus humains, des cheveux, des fibres textiles, des éraflures de produits synthétiques ou de peinture ou des déformations caractéristiques.

Enfin, l'examen des commandes et des traces qu'elles ont pu laisser sur les gants ou les chaussures du pilote peuvent fournir de précieuses indications à condition que l'on fasse appel à des méthodes physiques ou chimiques spéciales.

DETERMINACION DE LA PERSONA QUE PILOTABA EL AVION ANTES DE UN ACCIDENTE

A menudo es difícil para el investigador determinar quién pilotaba el avión antes del accidente. Si se conservan todas las huellas que pueden encontrarse en la aeronave y en la vestimenta de las personas a bordo, es posible identificar a la persona que pilotaba la aeronave. Entre estas huellas, están las trazas de sangre; los pigmentos de tejidos corporal o cabellos, fibras textiles, las huellas de abrasión de productos sintéticos y de la pintura, y las deformaciones características.
Además debe mencionarse una posibilidad de identificar a la persona, que aun no ha recibido suficiente atención. Se trata de detectar las huellas de los mandos en los guantes o zapatos del piloto y viceversa; para este fin, se emplean métodos físico-químicos.

Расследование авиационных происшествий много раз сталкивалось с фактом, что существуют сомнения относительно того лица, которое пилотировало воздушное судно во время происшествия. Посредством точного сохранения всех следов внутри и снаружи на воздушном судне и на одежде людей, находящихся на борту, можно будет определить лицо, которое пилотировало воздушное судно. Некоторые дополнения к этому обстоятельству могут быть получены с помощью следов крови, остатков человеческой ткани и волос, текстильных волокн, абразивностью синтетических продуктов и краски, а также деформационных характеристик. Кроме того, следует упомянуть еще одну возможность хотя еще и недостаточно рассмотренную, для того, чтобы быть уверенным, кто пилотировал воздушное судно. С этой целью должны быть приняты во внимание рычаги управления и их следы на перчатках и обуви пилота и наоборот. Для получения результатов необходимы специальные физико-химические методы.

SEARCH AND SALVAGE OF IMMERSED WRECKAGES

The first air accident in the world probably occurred when Icarus fell into the Aegean Sea but, although the legend tells us what happened to the airman's body, it gives no indication about his equipement which apparently would still lie under water.

More recently, the French Accident Investigation Department was involved in several search and salvage operations at sea.

A number of such operations were conducted successfully between 1950 and 1970. Four cases were selected to be described in this paper and comments are offered on their common aspects and pecularities, as well as on the experience that can be derived from each one of them.

RECHERCHE ET RECUPERATION D'EPAVES IMMERGEES

Le premier accident aérien remonte peut-être à la chute d'Icare en Mer Egée, et si l'on sait que son corps a été rejeté à la côte, la légende est muette sur le sort de son matériel apparemment toujours englouti sous les eaux.

Plus récemment, le Bureau "Enquêtes-Accidents" français a participé à un certain nombre d'opérations de recherches et de récupération d'épaves en mer.

Plusieurs opérations de ce genre ont été menées avec succès entre 1950 et 1970. Il a été choisi de présenter, ici, quatre de ces opérations, d'exposer leurs points communs comme leurs particularités, et de tenter d'en dégager quelques enseignements susceptibles d'intérêt.

BUSQUEDA Y RECUPERACION DE RESTOS SUMERGIDOS DE AERONAVE

Podría decirse que el primer accidente aéreo fue la caida de Icaro en el mar Egeo, y si bien se sabe que las aguas devolvieron su cuerpo a la costa, nada se sabe de su equipo, que sigue en el fondo del mar.

Desde hace cinco lustros el Departamento francés de investigación de accidentes ha participado en diversas operaciones de rescate de restos sumergidos en el mar.

La primera de estas operaciones que tiene verdadero interés fue el rescate de un hidroavión hexamotor Latecoère 631 frente al Cabo Ferret, en el Golfo de Gasconia, el 28 de marzo de 1951. La más reciente, que que también fue coronada por el éxito, se efectuó a comienzos de 1970

Presentamos 4 operaciones, señalando sus semejanzas y diferencias y las enseñanzas que nos pueden dar.

ПОИСК И СПАСЕНИЕ ЗАТОНУВШИХ ОСТАТКОВ ВОЗДУШНЫХ СУДОВ В КАТАСТРОФЕ

Первое авиационное происшествие в мире, вероятно, произошло, когда Икарус упал в Эгейское море, но хотя легенда рассказывает нам о том, что случилось с телом летчика, она не упоминает о его оборудовании, которое, несомненно, по-прежнему лежит под водой.

Совсем недавно французское управление по расследованию авиационных происшествий участвовало в нескольких операциях по поиску и спасению в море.

Целый ряд таких операций был успешно проведен в период между 1950 и 1970 годами. Четыре случая были выбраны для описания в настоящем документе и предлагаются комментарии по их общим аспектам и особенностям, а также по опыту, который может быть получен от каждого из них.

THE INVESTIGATION OF AN ARCTIC ACCIDENT

A Lockheed Electra aircraft was on a flight from Edmonton, Alberta to Rea Pt. Melville Is. when it struck the sea ice during the landing approach. Of the 34 people on board 2 of the 4 crew survived. Most of the aircraft wreckage sank to the bottom of the sea in about 100 ft. of water 1 mile from shore. The search and recovery required extensive use of divers and underwater video. The cockpit section was retrieved.

ENQUETE SUT UN ACCIDENT SURVENU DANS L'ARCTIQUE.

Allan J. Clark, Ministère des Transports du Canada.

Au cours d'un vol d'Edmonton (Alberta) à Rea Point (île Melville) un Lockheed Electra a percuté la banquise au cours de son approche. Sur les 34 occupants, dont 4 membres d'équipage, seuls deux de ces derniers ont survécu à l'accident. La majeure partie de l'épave a coulé par quelque 100 pieds de fond à environ 1 mille du rivage. Les opérations de recherches et de sauvetage ont fait largement appel à des plongeurs et à des caméras sous-marines. La section du poste de pilotage a été récupérée.

INVESTIGACION DE UN ACCIDENTE OCURRIDO EN EL ARTICO

Allan J. Clark, Ministerio de Transporte, Canadá

Un avión Lockheed Electra se encontraba en vuelo de Edmonton, Alberta a Rea Pt. Islas Melville, y se estrelló contra el hielo que cubría el mar al efectuar la aproximación al aterrizaje. Iban 34 personas a bordo, de las cuales 4 eran tripulantes. Sólo se salvaron dos tripulantes. Gran parte de los restos del avión se hundió en el mar, a unos 30 metros de profundidad y a 1 kilómetro y medio de la costa; para recuperarlos fue necesario emplear buzos y video de profundidad. Se recobró el puesto de pilotaje.

РАССЛЕДОВАНИЕ АВИАЦИОННОГО ПРОИСШЕСТВИЯ В АРКТИКЕ

Воздушное судно Локхид-Электра выполняло полет из Эдмонтона, Алберта, в Риа Мелвиль, когда оно во время захода на посадку разбилось о морской лед. Из 34 человек на борту выжило 2 человека из 4 человек экипажа. Большинство обломков воздушного судна утонуло на дне моря глубиной около 100 футов на расстоянии I мили от берега. Поиски и изучение их потребовали широкого применения водолазов и подводного телевидения. Удалось достать кабину экипажа.

ACCIDENT THEORY AND ACCIDENT INVESTIGATION

Problems with achievement of professional accident investigations are cited, and linked to the lack of underlying theory for analyzing, predicting or otherwise explaining the accident phenomenon. An accident theory is proposed that assumes an accident to be a process by which a homeostatic activity is transformed into a harmful outcome. Application of the theory by process charting is described. A procedure for developing accident process flow charts is presented; it includes display methods for the actors and actions (events) involved, testing of the events logic, the bridging of logic gaps due to missing evidence, identification of corrective measures, and development of "process templates" of accidents from investigations. Benefits from use of the theory and the charting procedures are described.

THEORIE DES ACCIDENTS ET ENQUETES SUR ACCIDENT

Ludwig Benner, Jr.

L'auteur attribue les difficultés de certaines enquêtes sur accident à l'absence de connaissances théoriques permettant d'analyser, de prévoir ou d'expliquer le phénomène de l'accident. Selon la théorie qu'il propose, l'accident est un processus par lequel le fait de compenser une perturbation apparente conduit à des conséquences préjudiciables. Il suggère l'établissement de graphiques de déroulement des accidents, qui seraient conçus pour représenter les acteurs et leurs interventions, évaluer la séquence logique des événements, remédier aux lacunes logiques, identifier les mesures correctives et établir des "schémas d'accident" à partir des résultats d'enquête.

La teoría de los accidentes y su investigación

Ludwing Benner, Jr.

Se mencionan los problemas que se presentan en el logro de una investigación verdaderamente profesional de los accidentes, señalando su vinculación con la falta de una teoría de análisis, predicción y explicación general del accidente. Se propone una teoría según la cual el accidente es un proceso mediante el cual una actividad homeostática se transforma de tal manera que lleva a un resultado perjudicial. Se describen organigramas de aplicación de la teoría, en los cuales pueden presentarse los actores y actos del proceso, poner a prueba la lógica del encadenamiento de sucesos, llenar los vacíos lógicos debidos a falta de pruebas, identificar las medidas correctivas y elaborar modelos de proceso en las investigaciones de accidentes. Se señalan las ventajas de la teoría y del empleo de organigramas.

Приводятся проблемы профессиональных расследований авиационных происшествий, они связываются с недостатком основной теории в анализе, предсказанием или иным образом разъяснения явления авиационного происшествия. Предлагается теория происшествий где допускается, что происшествие является процессом, посредством которого гомостатическая активность преобразуется во вредный результат. Дается описание применения теории посредством схематического процесса. Представлена процедура для развивающегося потока схем авиационных происшествий; она включает методы дисплея для действующих лиц и действий (событий), испытание логических явлений, связывание между собой логических пробелов в связи с недостатком очевидности, установление коррективных мер и разработку "шаблонных процессов" расследования авиационных происшествий. Дается описание преимуществ от использования этой теории и схематических процедур.

THE FLIGHT SIMULATOR - A TOOL FOR ACCIDENT INVESTIGATION

This paper briefly describes advancement in flight simulator technology, capabilities and limitations. The areas of basic flight safety research, recreation of accident sequences, and exploratory research are described with examples. The discussion and examples apply equally to military and civil aircraft accident investigators.

LE ROLE DES SIMULATEURS DE VOL DANS LES ENQUETES SUR ACCIDENT.

Exposé sommaire sur les progrès techniques des simulateurs de vol, sur les possibilités et sur les limitations de leur emploi. Des exemples précisent le rôle de cet équipement dans des recherches fondamentales sur la sécurité aérienne, dans la reconstitution du déroulement chronologique d'un accident et dans des études spéculatives. Les exemples étudiés sont valables pour les accidents d'aviation militaire comme pour les accidents d'aviation civile.

EL SIMULADOR DE VUELO: UN INSTRUMENTO DE LA INVESTIGACION DE ACCIDENTES

En esta nota se describen los progresos logrados en el empleo de los simuladores de vuelo para la investigación de accidentes, tanto en sus aspectos fundamentales como en la reproducción de accidentes ocurridos. Las observaciones y ejemplos se aplican tanto a la aiviación civil como a la militar

ЛЕТНЫЙ ТРЕНАЖЕР - ИНСТРУМЕНТ ДЛЯ РАССЛЕДОВАНИЯ ПРОИСШЕСТВИИ

В настоящем документе кратко излагается прогресс в технологии летного тренажера, возможности и ограничения. Даются описания с примерами районов основных исследований по безопасности полетов, воссоздания последовательности происшествий и исследовательских изучений. Дискуссия и примеры в равной степени применимы к расследователям военных и гражданских авиационных происшествий.

A WIND SHEAR ACCIDENT AS EVIDENCED BY INFORMATION FROM THE DIGITAL FLIGHT DATA RECORDER

An abrupt change in the direction or velocity of the horizontal wind component close to the ground can pose a threat to departing and approaching aircraft. In a recent accident investigated by NTSB, the captain of a wide-bodied aircraft was conducting an ILS approach in restricted visibility conditions. The aircraft struck an approach light stanchion and crashed on the airport. A digital flight data recorder provided heretofore unavailable information on 96 parameters of the flight. These data provided a means for accurately determining flight profile and the wind vectors during final approach. The evidence indicated that the aircraft descended through a significant low-altitude wind shear. The information was used to program an aircraft simulator. Pilots who participated in the tests agreed that immediate recognition of the wind shear effect and positive pilot action were required to prevent impact short of the runway threshold. In this accident, restricted visual cues hindered prompt recognition of the developing descent rate and accurate assessment of the pitch attitude change required to arrest the descent in time to prevent impact.

INDICES FOURNIS PAR UN ENREGISTREUR DE DONNEES DE VOL A LA SUITE D'UN ACCIDENT DÛ AU CISAILLEMENT DU VENT

Une variation brusque de la direction ou de la vitesse de la composante horizontale du vent à proximité du sol constitue un danger au départ ou à l'approche. Le NTSB a enquêté sur un accident survenu récemment à un avion gros porteur au cours d'une approche ILS par faible visibilité. L'avion avait percuté un support de feu d'approche et s'était écrasé sur l'aéroport. L'enregistreur digital de données de vol a permis de relever 96 paramètres grâce auxquels on a pu tracer avec précision le profil de vol et les vecteurs vent pendant l'approche finale. Ces indices ont montré que l'avion avait rencontré un fort cisaillement du vent à basse altitude. Ces conditions ont été reproduites sur un simulateur de vol et, d'après les pilotes qui ont participé à ces essais, il fallait identifier immédiatement l'effet de cisaillement du vent et intervenir sans tarder, ce que le pilote n'a pu faire au moment de l'accident à cause de la visibilité réduite.

EL REGISTRADOR DIGITAL DE DATOS DE VUELO REVELA UN ACCIDENTE PRODUCIDO POR LA GRADIENTE DEL VIENTO

Los vambios súbitos de la dirección y la velicidad de la componente horizontal del viento cerca de tierra pueden constituir un peligro para las aeronaves que parten o se aproximan. En un accidente estudiado hace poco por la NTSB, el capitán estaba efectuando una aproximación ILS en condiciones de visibilidad limitada. El avión chocó contra las luces de aproximación y se estrelló en el aeropuerto. El registrador digital de datos de vuelo entregó información sobre 96 parámetros de vuelo, que permitieron determinar exactamente el perfil del vuelo durante la aproximación final. Los datos indicaron que la aeronave descendió a través de una considerable gradiente del viento a baja altitud. Se empleo la información para programar un simulador de vuelo. Los pilotos que participaron en el ensayo se manifestaron de acuerdo en que era indispensable percibir de inmediato la gradiente y tomar las medidas adecuadas, para evitar estrellarse antes del umbral de la pista.

АВИАЦИОННОЕ ПРОИСШЕСТВИЕ, ВЫЗВАННОЕ ГРАДИЕНТОМ ВЕТРА, ЗАФИКСИРОВАННОЕ НА ОСНОВЕ ИНФОРМАЦИИ, ПОЛУЧЕННОИ С ПОМОЩЬЮ ЦИФРОВОГО САМОПИСЦА ПОЛЕТНЫХ ДАННЫХ

Резкое изменение направления или скорости горизонтального компонента ветра вблизи от земли может создать угрозу взлетающему или заходящему на посадку вааздушному судну. В недавнем происшествии, которое расследовало Т В, командир экипажа воздушного судна с широким фюзеляжем заходил на посадку по системе ИЛС в условиях ограниченной видимости. Воздушное судно ударилось о стойку огня захода на посадку и рухнуло на аэропорт. Цифровой самописец полетных данных предоставил не имевшуюся до этого информацию по 96 параметрам полета. Доказательства указали на то, что воздушное судно осуществляло снижение, имея значительный градиент ветра на низкой высоте. В этом происшествии ограниченная визуальная информация помешала быстро различить развивающуюся скорость снижения и положение по тангажу.

THE AIR TRAFFIC CONTROLLER IN
AIRCRAFT ACCIDENT INVESTIGATION AS:
A SOURCE OF INFORMATION
A FACTOR
AN INVESTIGATION PARTICIPANT

H.H. Henschler

Supervisor
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On Behalf of:

THE CANADIAN AIR TRAFFIC CONTROL ASSOCIATION AND
THE PROFESSIONAL AIR TRAFFIC CONTROLLERS ORGANIZATION (USA)

Air traffic Control, since its inception a little more than thirty years ago, like all other aviation-related fields and indeed most fields of human endeavour and science, has gone through a period of continuous evolutionary change and development.

Many factors have combined to help enhance and develop the ATC system. They were of an originally military nature such as radar and IFF or arose from the desire to transport people and cargo at a higher rate of speed or in greater numbers or tonnage.

The first major enhancement to the ATC system came about in the fifties when surveillance radar was made available to civil area control centres and terminal or approach control units. Before the introduction of radar and indeed still today in areas without radar coverage, air traffic was and is moved in accordance with rigid procedural separation standards. These standards, when applied correctly, provide safe separation between aircraft but result in "wasted" airspace when the numbers of aircraft which can safely be separated in a given area are assessed. Obviously, by virtue of "seeing aircraft" in the form of a radar return on the screen rather than having to visualize their relative positions, an air traffic controller can accept the responsibility of separating a greater number of aircraft at any given time in less airspace.

Radar, however, brought about another important change. For the first time ever the controller, now using radar, was made responsible to provide separation between aircraft and the terrain with the introduction of minimum radar vectoring altitudes which were below either the minimum enroute, or minimum safe altitudes displayed on the pilots' charts. Up to that point it was the pilot's sole responsibility to ensure that descent and climb in close proximity to the ground or water was conducted so as to avoid contact with terrain, except of course the right kind of terrain, the runway.

In addition, with the provision of terrain clearance, controllers were charged with providing another, potentially dangerous service. Radar provides a return on the screen from cumulus clouds and precipitation.

I said above "potentially dangerous". The reason for this is that because of certain necessary and desirable design restrictions air traffic control radar systems will not necessarily display all areas of cumulus activity or precipitation. As a result a controller may attempt to provide an aircraft with a steer, called a radar vector, around such areas and in reality vector the aircraft into cumulus activity not displayed on his screen.

A few years after the introduction of civil ATC radar systems the first commercial jet aircraft came on the market. This major step in aviation history doubled the speed of a portion of the commercial air traffic while the slower piston and turbo-prop equipped aircraft continued to be used.

This mixture of aircraft types and speeds did nothing to alleviate the air traffic controller's problems. It requires a great amount of predictive ability to make maximum safe use of a given airspace. While the number of large conventional transport aircraft is diminishing, relatively slow business and general aviation aircraft are being produced in increasing numbers and the problem of type and speed mix is still with us, albeit primarily in the terminal areas.

Many controllers who worked in the late fifties and early sixties will testify from personal experience to the overwhelming increase in traffic density. Of course, statistics are available which, without any personal involvement, show that the density of air traffic in North America has increased at least threefold with an even larger increase in the total number of passengers carried, both commercially and non-commercially.

In the middle of the nineteen sixties the concept of ground-based computerized air traffic control systems began to become reality. In the United States, the NAS (National Airways System) was developed, predominantly for "enroute" control. Later, ARTS (Automated Radar Terminal System) was added. In Canada the Joint Enroute Terminal System (JETS) is scheduled to go into operation, starting in Eastern Canada and progressively moving west, within the next two years.

These systems are generally based on the use of radar-derived information which is digitized and displayed on the screen together with a computer generated "data block". This data block, in addition to providing the aircraft identification, type and computed speed, will indicate the aircraft's "real" altitude. The altitude is derived by converting secondary radar pulses, which are carrying information from an airborne pressure altimeter, into digital form.

This process allows the controller to keep a check on the aircraft's real pressure altitude rather than relying on pilot-reported altitudes.

Again, responsibility has been shifted from the cockpit to the controller. The fact of terrain clearance can now more accurately be established. The occurrence of less than minimum vertical separation can be detected. Pilots are bypassed by a piece of hardware which reports directly to the ground facility. Controllers thus have available to them a continuously updated "real" altitude.

This new capability, together with the "traditional" radar display of range an azimuth, changes such a new ATC system into a "real-time" three-dimensional display.

We all know that, in addition to being able to transport a greater number of passengers per flight more comfortably, the fairly recently introduced wide-bodied jets and the development of "stretched" versions of first generation jet transports have brought us the problem of wake turbulence.

Wake turbulence, its prediction and detection, has itself been the subject of many papers, some of which have been presented at seminars of this Society.

So far, however, no practically proven way of detecting or predicting wake turbulence has been found. Until such time as it is, responsibility for providing a specified minimum standard of separation from the possible effects of wake turbulence created by one aircraft on other air traffic rests with the air traffic controller.

To assist him with this task, specific and increased minimum separation standards relating to those aircraft types which have been found to generate the greatest amounts of wake turbulence have been introduced, and as a matter of interest the standards have been substantially increased in the last few months.

These standards, like all ATC separation standards, only indicate the minimum separation required. If, in the controller's opinion, such minimum standard is not sufficient to ensure safety, he is obligated to increase the minimum separation.

While such permissive minimum standards are necessary they carry an inherent danger to the controller applying them.

The wake turbulence standards, in particular, can be cited as examples. Many variable and often unpredictable factors (such as surface wind shears, etc.) influence the formation, duration and direction of travel of aircraft-generated vortices.

The controller has to take all these variables into consideration when deciding on the separation he will use. Sometimes, as evidenced by aircraft accidents due to wake turbulence, his decision is a wrong one, almost always because of some factor or factors unknown to him when his decision was made.

We find ourselves at the start of a new era in aviation. The British-French built Concorde supersonic transport has commenced flight training to and at Gander, Nfld. This training is in preparation for scheduled service between Europe and North America across the crowded North Atlantic.

While during the supersonic enroute portion of the flight the SST's will be utilizing much higher, and mostly unused, altitudes than present traffic, during both the departure and arrival phase of their flights they will have to be integrated in the stream of other traffic.

We predict that the introduction of scheduled SST operations will add to the problems controllers are facing now. The operating characteristics of SST's do not allow for extended subsonic flight which may become necessary due to other traffic. The SST requires a steady and rapid climb to and descent from its cruising altitude. Any diversion from this profile could have an adverse effect on fuel consumption and schedule.

We have been told that, under normal circumstances, the scheduled introduction of SST's should pose no problems.

Air traffic controllers, under normal circumstances, have no problems. It is the everyday abnormal situation which makes this profession one of the most critical and which created the tension and stress and their resultant effect on the controller which is of real concern to us.

I am certain the above examples illustrate sufficiently the shift of responsibility from the flight deck to the air traffic controller. Recent accident investigations have led to NTSB and public pressure for the controller to accept even more responsibility in the areas of terrain clearance, wake turbulence, and go/no go decisions based on weather conditions.

In this new and ever-developing role the air traffic controller is more likely than ever to be suspected as the cause or contributor to, however peripherally, an aircraft accident. Therefore, air traffic controllers must assume a new role, namely that of a participant in the investigation of those aircraft accidents where there may be an ATC involvement.

Pilots have, through their Associations, traditionally "enjoyed" this right. As long as aircraft accidents could only be caused by pilot error, mechanical malfunctions, or weather, this may have been sufficient. But now a new dimension has gradually been added to the possible cause of accidents and air traffic controller participation in investigating aircraft accidents has become a practical necessity.

I will now outline three areas where we believe air traffic controllers, as specialized professionals, can be of immeasurable value when participating in aircraft accident investigations.

The Controller as a Source of Information

Air traffic control systems in North America, and indeed in most parts of the world, are now highly sophisticated entities which a non-controller cannot readily understand or even learn to understand given the restricted time frame which accident investigation boards operate under.

No longer is the only evidence available relating to air traffic control a transcript of, or the actual voice tape recording of, radio or telephone conversations, the flight progress strips which require manual updating or the testimony of air traffic controllers.

With the advent of computer-based air traffic control systems, computer-generated magnetic tapes are now available for a blow-by-blow replay, almost as soon as an accident occurs. In several cases recently where the aircraft flight data recordings have been damaged or destroyed these tapes have been used in their place to reconstruct the final portion of the flight.

Traffic co-ordination between sectors of the same air traffic control unit is accomplished mainly via recorded hot lines rather than controller-to-controller personal contact.

It has been suggested recently that area microphone systems be installed in air traffic control units. These systems as suggested would operate in a manner similar to the cockpit voice recorder systems now in use in commercial aircraft and would record conversations taking place between controllers in an air traffic control unit.

This suggestion originated from an investigative body hearing fragments of controller conversations in the background when listening to the radio and telephone recordings while investigating a recent aircraft accident.

While CATCA and PATCO both are opposed to the introduction of area recording systems on the grounds of infringement of the controllers' privacy, the suggestion of their introduction alone proves the value of the controller as a source of information.

However, regardless of whether or not we will ultimately be faced with area recording systems in air traffic control units, the existence already of computer-derived magnetic tapes and other related evidence requires that an expert in the field participate in the investigation of any aircraft accident where air traffic control may be involved.

Only the expert in the field, the professional air traffic controller, can interpret, translate and explain to the non-controller the intricacies of the system and the situation, control-, stress-, and traffic-wise, which existed at the time.

The Controller as a Factor in Aircraft Accidents

I have detailed in the foregoing parts of this paper the substantial and continued shift of responsibilities from pilot to controller. One has only to look at manned space travel, let alone unmanned space travel, to detect startling similarities.

In manned space travel, as witness the recent Appolo-Soyez mission, all manoeuvres are initiated and directed by the ground-based mission controllers. The task of the astronaut or cosmonaut in the actual manoeuvres of the craft is to add the finishing touches, much like a pilot executing a landing after an automatic approach to the runway.

This analogy, although some pilots may resent it, will become more and more accepted as funds are appropriated to develop advanced air traffic control systems. If these new systems in the future continue to make more information available to the controller, and give him a greater capability to take action, it appears likely that as in the past it will continue to be preferable to have one person with the whole picture make the necessary decisions and take the necessary action, rather than a large number of individuals acting independently with the resulting possibility of chaos.

Regardless of these future possibilities and the fact that to date airborne system development has sadly outstripped the capability of ground-based systems to keep pace, one has only to look at the past several years. A large number of aircraft accidents in those years have resulted in a large amount of time during Accident Investigations being devoted to the detailed reconstruction of ATC actions, and in some cases long and involved legal battles, with Air Traffic Controllers being sued for large sums. A few of the cases of which we are aware are detailed in what follows:

April 22, 1968	Vancouver B.C. Piper Aztec (Wake Turbulence Upset)
November 11, 1969	Wabush, Labrador. De Havilland 125 (Incorrect instrument approach)
July 6, 1970	Toronto, Ontario DC8 (Heavy landing)
January 9, 1971	Edison, New Jersey B707/C150 (Mid Air Collision)
May 30, 1972	Fort Worth, Texas DC9 (Wake Turbulence Upset)
December 8, 1972	Chicago, Illinois B737 (Stalled on approach)
December 29, 1972	Miami, Florida L1011 (Disconnected autopilot)
March 5, 1973	Nantes, France CV880/DC9 (Mid Air Collision)
July 31, 1973	Boston, Mass DC9 (Collision with sea wall)

Whether investigation of most of those accidents mentioned in the foregoing proved there was no real ATC involvement as a factor is immaterial. Where it was a factor there remains the question of possible misunderstandings or lack of system understanding on both the pilots' or controllers' part.

The Air Traffic Controller as an Investigation Participant

Both CATCA and PATCO, in their respective countries, have been granted by their respective aviation authorities the right to member or party status on aircraft accident fact-finding boards where air traffic control involvement may be indicated.

Both our associations are actively training selected members, in many cases elected association officals, in the science and techniques of aircraft accident investigation.

One of the problems our associations are faced with is that to the best of our knowledge no specialized courses in the science of aircraft accident investigation for air traffic controllers, as it relates to their profession, are available anywhere.

Given the increased involvement of air traffic controllers, their changed role in aviation and consequent contribution to the investigation of aircraft accidents, there is an urgent need to provide formalized training to air traffic controllers in the science and techniques of aircraft accident investigation.

In our opinion there is an obvious necessity for those universities and government agencies which already offer courses in aircraft accident investigation to develop courses tailored to the specific requirements of air traffic controllers participating in aircraft accident investigations. These courses should be aimed at a systematic procedure of gathering the facts available on the air traffic control aspects of the accident.

We call upon ICAO and the civil aviation regulatory and investigative bodies of all nations to prepare courses and offer training in the specific field of ATC in aircraft accident investigations and to encourage private institutions to do the same.

Controllers must have available to them the experience, the science and the techniques of investigating aircraft accidents, for we will be participating, one way or the other. We call upon you, the established Society of Air Safety Investigators, to render us all the assistance possible to fulfill our aim. To this end we, both CATCA and PATCO, are now or will become members of the Society in the hope that our participation will add to the already awesome body of knowledge and experience evident in it and that we may benefit from that knowledge and experience which you already possess.

Now we have arrived at a turning point. Your specialized profession, that of air safety investigators, has admitted into its ranks our specialized profession. In return both the Canadian Air Traffic Control Association and the Professional Air Traffic Controllers Organization pledge to do their utmost to make our new and changed relationship an enjoyable one, a close one, based on mutual respect and the knowledge that no one person can know or understand everything in all fields.

We are looking forward to your assistance and cooperation and a fruitful working relationship.

DISCREDITING ACCIDENT INVESTIGATION VIA THE WRITTEN ACCIDENT REPORT

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The primary objective of aircraft accident investigation is accident prevention. Accident investigators supply accident investigation data to agencies, authorities, and organizations that have regulatory authority and preventive responsibility. Accident prevention action is based on data in accident reports; logically then, accident prevention can be only as effective as the report is adequate. Unfortunately, the accident report often proves to be the weak link in the prevention chain. Technically qualified, dedicated investigators, by careless writing, discredit their investigations and impede accident prevention.

The following examples were taken from accident reports to illustrate how an accident investigation can be discredited by the written word.

1. The narrative section of a Preliminary (Accident/Incident) Resume Report, as received from a United States Government Agency, read:

> According to John Doe, Chief pilot for Ajax Aviation, Mr. Smith rented the Cessna for a pleasure flight to Airport Beta. He departed at approximately 1000 HR PST.
>
> FAA records show that the iarcraft landed at Airport Beta at approx. 1115 PST, parked in front of the tower, then departed at approx. 1245 PST.
>
> At approximately 1300 PST the aircraft was observed downwind at Airport Charley. Witnesses state that the aircraft cntinued the traffic pattern until on final approach the aircraft was observed to make several low altitude turns then decend into the groun approximately ¼ mile south east of Airport Charley. Both occupants received serious injuries. The aircraft was demolished.

Imagine yourself in court, as investigator in charge of this accident, trying to convince a judge that you are a qualified accident investigator even though you cannot spell <u>aircraft</u>, <u>descend</u>, <u>ground</u>, or <u>continued</u>. Numerous other errors also reflect on the quality of the investigation.

2. The aircraft continued in a right spin until it stalled and crashed.

If an aircraft is in a spin, it has already stalled. Perhaps the writer intended to state that the aircraft recovered from the spin, stalled, entered another spin, and crashed.

3. Following a normal ILS approach, landing, and roll-out, the aircraft overran the runway.

Is a normal ILS approach followed by an overrun? The writer implies that an overrun is standard operating procedure for normal situation. What constitutes normality?

4. The engine was examined at the accident site. The sparkplugs were removed and tested for the manufacturer's specified gap. The cylinder walls were examined with a boroscope.

The investigator knew which device he should use to inspect the cylinder walls, but his accident report indicated that he used a boroscope instead of a borescope; borescope is correct.

5. A hole approximately .125 in diameter was found in the number one hydraulic reservoir.

Accuracy is essential in aircraft accident investigation; but when something has been measured to one hundred and twenty-five thousandths of an inch, "approximately" should be omitted.

6. The assistance of the yaw dampener was lost when the hydraulic boost pumps were turned off.

A device that decreases, minimizes, or damps vibration is a damper and not a dampener. A dampener moistens or wets.

7. Severe stress and strain were apparent in the right wing spar.

Stress is the force per unit area and strain is the deformation per unit length; consequently, strain is either visible or apparent but stress is as difficult to see as magnetic force.

8. The aircraft was equipped with stationery landing gear.

This was a gross error in aircraft certification; paper landing gear has never been acceptable. Stationary landing gear is the correct word.

9. Aircraft, unlike most surface vehicles, are weight limited devices and lightning holes are engineered into their design.

Lightning may make holes in aircraft but the holes are usually not machined precisely enough for aeronautical engineering. The holes are lightening holes, not lightning holes.

10. Several passengers went to the rear galley after the "fasten seat belts" sign went off and they found the stewardess laying on the floor. Her leg appeared to be broken and two men picked her up and laid her in a rear seat.

It is unlikely that the stewardess was laying in the galley, especially with passengers on board and with the pain of a broken leg. Lying is correct; however, she was laid or placed in a rear seat.

11. Since poor cockpit discipline existed during the approach, the crew was unaware of their critical altitude and neglected to follow prescribed procedures.

Since is commonly misused as a synonym for because. Since indicates a time lapse: The crew was unaware of their critical altitude since passing the outer marker. Because of poor cockpit discipline during the approach, the crew was unaware of their critical altitude.

12. The pilot reported over the outer marker inbound at 0125Z but failed to report his altitude which is standard communications procedure.

Which is the standard communications procedure, to report or not to report? The writer undoubtedly knows the standard procedure, but is that procedure clear to the reader?

13. The pilot, who was type rated in the Boeing 747 and had over one thousand hours in the aircraft, was insulted when the investigator said, "Let's assume that you didn't touch down long, what do you think caused the overshoot?"

The pilot may have been justifiably offended because to assume means to pretend, or suppose. The pilot would probably have been more receptive if the word presume had been used. Presume means to take something for granted, or accept as true.

14. Two accident survivors were questioned in the hospital. One said that the stall warning horn was blowing continually after takeoff and during climb-out. The other witness was in agreement and described the warning horn as blowing continuously.

Continually or continuously, is there a difference in the meaning of the two words? Apparently the writer assumed that the words were synonymous because he wrote "the witnesses were in agreement." The investigator should have established whether the warning horn sound was intermittent or whether it was unbroken. The general concensus is that continually means recurring at intervals during a period of time and continuously means without interruption, unbroken, or constant. For example, the Earth revolves continuously around the Sun.

15. The aircraft impacted the concrete runway, bounced approximately fifty feet in the air, then stalled and crashed in a nose high attitude.

Impacted is a much more pretentious word than hit or struck, but impacted is not the correct word for describing this situation. A tooth or bullet can be impacted or buried, but an aircraft which strikes a concrete runway and bounces cannot.

16. According to the cockpit voice-recorder tape, the pilot asked the tower operator, "Tell me if my landing gear is down." The tower operator replied, "Roger." No further transmissions were made and a wheels-up landing occurred. The accident investigator indicated in his report that the tower operator failed to take the prudent warning action expected of a controller by not informing the pilot that the gear was up. The tower operator said in his statement that he did exactly as requested. Literally, the pilot asked to be told if the gear was down. Because the gear was not down, the controller did not inform the pilot.

The problem here is in the use of if instead of whether or not. If indicates a condition or choice. Literally, all the pilot requested was the good news that the landing gear was down and not the bad news that it was up. The landing gear was up, and consequently was not reported. The investigator was wrong in blaming the controller for doing precisely what he had been asked to do. The pilot was in error in assuming that "Roger" implied that the gear was down when actually "Roger" indicated that the controller would do as requested.

17. The Air Route Traffic Control Center tape indicated that the aircraft had been cleared for an approach and that the transmission had been acknowledged. It was apparent that the controller had been misunderstood because the aircraft entered a holding pattern.

How could the crew's misunderstanding have been apparent? Apparent means perceived by the senses. The correct word is evident that means proved or supported by the evidence that the aircraft entered a holding pattern.

18. A bird strike occurred at 2500 feet during climb-out. An emergency was declared and the flight returned to Boston. A large bird such as a gull or duck had been struck by the leading edge of the left wing. Part of the bird carcass was impinged in the hole in the wing.

If the bird carcass was imbedded or buried in the wing leading edge, it was not impinged. To impinge is to strike, hit, or contact rather than imbed or bury.

19. A microanalysis of the wing spar break was made at the accident site.

Microanalysis is defined as chemical analysis on a small or minute scale (milligrams or smaller) and requiring specialized, highly sensitive equipment. Such equipment is not usually available at accident sites. Perhaps the investigator merely examined the break with a magnifying glass; microanalysis sounded more technical and he reflected his visual observations in this way.

20. The aircraft flight crew was hospitalized after the accident. The attending physician approved questioning the captain, but disapproved questioning of the first officer who had a temperature.

Accident investigators who are not doctors should not express medical opinions in their accident reports. Any medical data included in the report should quote the doctor. The erroneous use of temperature instead of fever would be less likely. Although everyone has a temperature, not everyone has a fever.

21. The pilot was unfamiliar with the airport and landed on an adjacent expressway which paralleled the active runway. It is recommended that the airport management take immediate action to make the approach zone and runway lighting more distinct.

The pilot evidently mistook the expressway for the runway. The problem seems to be that of identification rather than visibility. If an object is distinct, it can be seen easily and there are no restrictions to visibility. A distinctive object is unique or different. The problem at this airport appears to be one of differentiating between the expressway and the runway. The investigator probably intended to recommend that the runway approach lighting be made more distinctive. Distinctive approach lighting would help pilots distinguish the runway from the expressway.

22. Air Traffic Control told the crew of the DC-3 that there was traffic at 12 o'clock, four miles. Evasive action was initiated and a midair collision occurred. When the DC-3 crew was interviewed, the captain said that the copilot was flying the

aircraft until seconds before the collision. The captain thought that a collision was imminent and took over the controls. Undoubtedly, the captain would have assumed command earlier if the copilot had not inferred that he had seen the other aircraft by turning right.

The copilot, by turning right, implied not inferred that he saw the other aircraft. The captain was the one who had inferred or had drawn the inference from the action of the copilot.

23. The aircraft wreckage was located five miles off shore at a depth of 500 feet. Attempts to salvage the wreckage were futile and an underwater camera proved to be most plausible for gathering data.

The underwater camera proved feasible not plausible. Something that is plausible is believable, acceptable or true. Anything that is feasible is capable of being done.

24. Eyewitnesses said that the aircraft bounced once or twice when landing, continued down the runway for approximately 500 feet and then veered to the right of the paved runway surface. The aircraft continued swerving right and stopped after turning approximately 240 degrees from the runway heading. The left main landing gear strut sheared off 150 feet from where the aircraft left the runway. There were no ditches, mounds, or obstructions in the area where the landing gear sheared.

Sheared is commonly misused as a synonym for broken, separated or parted, and is incorrectly used to specify a shear separation when there was no shearing action to cause the break. Shearing is the separating of a metal by forcing two opposing and slightly offsetting blades against the metal with sufficient force to cause separation. Shear has considerably more appeal to the average writer than break. In the former example, shear is incorrect. Incidentally, off is redundant; something sheared can be understood to be separated or divided.

25. Witnesses' attention was attracted by a loud roaring or screaming sound while the aircraft was in the overcast. The aircraft emerged from the overcast in a left wing low, 60 degree nosedown attitude and started to level off. At this time, an object either separated or fell from the aircraft. The object was later identified as the outboard six feet of the left wing. Failure had occurred in flight during pullout.

Here the problem is with the word failure. Did the wing fail to do what it was designed to do or was the separation induced by the pilot? In this situation the wing broke or separated; but did it fail? The careless use of words such as failure costs aircraft and component manufacturers millions of dollars annually. Accident report wording frequently places manufacturers on the defensive and forces them to convince the courts that the aircraft was not at fault even in accidents in which pilot error is evident.

26. The underlined words in the following examples are common accident report pitfalls:

a. Preventative versus preventive maintenance.

b. Implicit versus explicit instructions.

c. Leave versus let fly.

d. Presently versus currently qualified.

e. Liable versus likely to succeed.

f. Averse versus adverse weather.

g. Less versus fewer hours.

h. Stress riser versus stress raiser.

i. No admission versus no admittance.

j. Investigative capacity versus investigative ability.

k. Powerplant discrepancy versus powerplant malfunction.

l. A toxic poison versus a poison.

27. The following examples illustrate how humor adds to a presentation and detracts from an accident report:

a. The aircraft was serviced with 45 gallons of parathion, and 30 gallons of 100 octane fuel.

b. The pilot had been denied a medical certificate for alcohol addiction.

c. The pilot attempted to hand-prop the aircraft with the throttle too far open and not tied down.

d. The helicopter was loosing altitude after taking off from the roof of the building.

e. Witnesses observed the aircraft circling an open area surrounded by trees in a left turn.

f. The pilot was to depart and fly two surveyors and their equipment to a mountainous area that they were to survey at midnight.

This presentation has cited several examples in which writers have discredited their accident investigations by not following the rules of grammar, language usage, and spelling. We are technical people who write technical investigation reports about technical subjects. Let's do our best to be technical writers.

THE ROLE OF LITIGATION IN U.S. AIR SAFETY INVESTIGATION

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At the Washington meeting last year, considerable concern was expressed over the lack of coordination or exchange of information between various governmental agencies, organizations and individuals involved in the investigation of aircraft accidents. It was pointed out that there was no central information gathering facility or data bank from which existing information could be retrieved in the course of an accident investigation or accident prevention study. While the NTSB may have considerable information available for its use and various divisions of the FAA may have similarly indexed information available for its use, and while each military service may provide excellent facilities for its own investigators, there is, in fact, no central depository available to everyone. While this problem was discussed at length, few remedies were even suggested.

It is the purpose of this paper to draw attention to yet another source of aircraft accident investigative data which could be useful to all accident investigators. However, like the discussions at the Washington meeting, no readily apparent solution to this problem is suggested, but the source of such information is one which may not have been fully appreciated by most accident investigators.

Recognizing the magnitude of the job and the shortage of manpower and lack of funds, no criticism is intended of the investigations made by NTSB and FAA personnel of general aircraft accidents. However, the fact remains that if litigation, or even the possibility of litigation, exists from such an accident, in many instances extensive and expensive additional investigation is pursued by the interested parties involved. While this investigation may well be tainted with self interest, in an attempt to put the blame on somebody else, if equally pursued by all interests, the total results would be helpful in an objective approach to determine the various causes of the accident or in the gathering of information in an attempt to prevent other similar accidents.

Litigation investigation is usually conducted by experienced, trained specialists who are given the time and the resources to make an extensive investigation and dwell into matters beyond the practical realm of the initial governmental investigators. In fact, many litigation investigators are former government employees, well known and highly respected in the aviation community. It is not unusual for each party to a multi-party suit to spend ten to fifty thousand dollars, or more, in the course of such an investigation.

If the litigation progresses to that point, most, if not all, of these findings and opinions are made a matter of public record by the taking of oral depositions, the production of documents, reports and tests, and answers to written interrogatories. Access to this information would be invaluable to any safety program, and this substantial contribution should be available to, and taken advantage of, by all persons involved in aircraft accident prevention.

If this source is made known to the accident investigative community and its potential value is appreciated, then steps can be taken by those involved to devise a system whereby this information would be more readily available to all. Hopefully, this would include investigative data obtained by everyone involved in accident investigations, whereby some central depository would receive and disseminate this information to all participating parties.

It will not be the purpose of this talk to counter the ofttimes expressed attitude that litigation hinders investigation and is a deteriment to air safety. That ancient concept still expressed by a few could be the subject matter of another talk on another occasion. Time precludes the cominbation of both here, and it is felt that to accentuate the positive and to expose the accident investigator to this source of valuable information is of far greater importance than answering those who believe that immunity, privilege and other curtailments on the free exchange of information is the best course to follow in the interest of air safety.

While reiteration and expansion of the opinions previously expressed might be persuasive by use of the psychological advantages of repetition, it is felt that actual examples would be far more helpful and informative.

While returning his single engine aircraft from an annual inspection, a farmer in South Texas crashed at night near the approach end of the private strip near his home in what had all the earmarks of a spatial disorientation crash by a non-instrument rated pilot with no night flying experience. While this may well have been a cause, the investigation that followed, initiated by potential litigation, led to a major discovery in the interest of air safety.

After the NTSB investigator had left the scene and presumably concluded his investigation, a former director of the Bureau of Aviation Safety, now deceased, was asked to investigate this crash by the attorney representing the family of the deceased pilot. Since this aircraft had just received an annual inspection, the litigation investigator made a check-list of the various Airworthiness Directives then in effect and other areas which should have been covered in the annual inspection. At this time there was in effect an Airworthiness Directive concerning the flap actuator on certain aircraft built by the same manufacturer. The reoccurring experience of inadvertent flap actuation had led to the issuance of this Airworthiness Directive on the assumption that it was a maintenance problem requiring adequate lubrication. In order to check the compliance with this Airworthiness Directive, the litigation investigator requested the agent for the hull insurance carrier to have the flap actuator removed when the wreckage was carted away from the scene of the crash and stored for salvage.

By some means, it came to the attention of the NTSB investigator that his former boss had requested the removal and inspection of the flap actuator. For psychological reasons best understood by those who have worked in a bureaucracy, he immediately instructed the insurance company to send him the flap actuator instead of sending it to the litigation investigator. Upon receiving this flap actuator, it was forwarded to the Washington office of the NTSB, where it was tested and studied by the Bureau of Standards. These tests disclosed that this actuator would not withstand dynamic loading in a vibrational environment. This also led to the fact that this flap actuator had, in fact, never been designed or tested for use in aircraft, but had been manufactured solely for use in automobile seat adjustment. Following flight tests to determine the effect of inadvertent flap blow-up in the landing configuration, the FAA issued an Airworthiness Directive requiring the removal of this type flap actuator from practically every single engine aircraft currently in use by this manufacturer.

On another occasion, a light twin, during an air taxi flight, ascended through an overcast and into the side of a mountain in New Mexico, killing the pilot and six passengers on board. This wreckage was not readily accessible, being located in uninhabited, mountainous and heavily wooded terrain. The on-scene investigation by the NTSB revealed that all component parts of the aircraft were located in the wreckage area. There was no in flight fire or evidence of mechanical malfunction, and that the engines were apparently developing some power at impact. Since the pilot was some distance off his intended course and destination, not on an IFR flight plan, and had apparently descended through an overcast while in error as to his exact location, another obvious pilot error probable cause resulted. As is usually the case, no real attempt was made to explain why the pilot made this error.

As a result of potential litigation, litigation investigators, by use of a helicopter, made a thorough investigation of the wreckage at the accident site and removed the engines and component parts for further detailed study. This later investigation, with the help of additional experts, disclosed evidence that indicated the possibility that one of the engines of the aircraft was feathered at impact.

However, the most important facts disclosed at disassembly of the engines was that an internal failure of a piston skirt had in fact occurred prior to impact.

During the discovery that followed in subsequent litigation, it was established from the engine manufacturer's reports that a series of piston failures and difficulties which had been occurring in engines of this type was contributed to by off-square cylinders which had escaped quality control. These off-square cylinders were apparently substantial in number, as the manufacturer's reports reflected that they had been found on the production line of new engines, in factory remanufactured engines, as well as other engines in the field and in use. This fact had not been reported to the FAA, nor were users of this engine warned of this problem. No recall program had been initiated, nor was any attempt made to locate the cylinders, determine the number that were in use, or to take any steps to remove them from service, even though they were out of blueprint specifications and therefore not in compliance with the production certificate.

The only action taken by this manufacturer was to treat the symptom and retreat from a previous product improvement involving a long skirt piston, and revert back to the previous short skirt piston, which would minimize the effect of the off-square cylinder, even though it had previously been determined that otherwise the long skirt piston was an improvement over the short skirt piston.

While we might enter into heated debate over the question of whether this off-square cylinder was a cause of this crash, I doubt that anyone would suggest that this discovery might not be helpful in the interest of air safety. To my knowledge, this information, until the presentation of this paper, was known only to those intimately involved in this litigation.

Not all examples are limited to general aviation crashes. While the NTSB does make a detailed and usually exhaustive investigation of a major airline crash, the magnitude and ramifications of such a crash are not all within its financial or manpower resources. For instance, the governmental investigation of the Braniff Electra crash near Dawson, Texas, persuasively established that the crew had made an error in judgment in deviating around severe weather, had found themselves in a situation not to their liking, and had attempted to retreat from this position by execution of the well known 180^{o} turn, during which a structural failure of the right wing occurred. However, this investigation did not satisfactorily explain why this failure occurred. A read-out of the flight data recorder would indicate that the wing failure occurred at approximately 3.7 Gs when, in fact, the wing should have withheld up to 5.4 Gs under these circumstances. This investigation also disclosed a series of situations in which cracks formed in the wing panels of the Electra between inspection periods and progressed at an accelerated and unanticipated rate.

The five-week trial that subsequently occurred, involving Braniff, Lockheed and Alcoa, and pursued by the widow and children of the Braniff flight engineer, involved highly specialized metallurgical testimony concerning the heat treatment received by the upper No. 2 wing plank which had been installed on this aircraft during the modification program which resulted from two previous Electra crashes. This testimony involved the effect that minute variations during the heat treatment of this particular type aluminum would have on the formation of cracks, crack propagation, and the resultant weakening of the wing. While it is not suggested that the jury in this case, or any other case, should be the determinative fact-finding body in air safety decisions, it is suggested that this wealth of information might be useful to aircraft manufacturers, designers, maintenance personnel or others vitally concerned with air safety.

Time will not permit further examples. Those here discussed could be multiplied a hundred fold if the similar experiences of those involved in litigation could be collected.

Those experienced with litigation under our present tort system, whether they be plaintiff, defendant, insurance company representative, or manufacturer, will usually in confidential conversation candidly admit that litigation, or the threat of litigation, has had a substantial and positive effect on air safety. At a recent aviation symposium, general counsel for a major light aircraft manufacturer who is not known for his enthusiastic endorsement of product liability suits stated to the audience assembled that "our present tort system had done more for air safety than the FAA."

I hope that this talk will at least stimulate some thought toward a means by which this vast but yet untapped source of information can be more effectively utilized by those devoted to air safety and the prevention of accidents.

OBSERVATIONS ON SOME ASPECTS OF HELICOPTER SAFETY

by George H. Saunders

Summary: An overview of the helicopter accident picture is presented based on a statistical treatment of raw accident data obtained from both civilian and military sources. Current problem areas are identified from an analysis of accident type and accident cause data. The autorotation maneuver is identified as an accident contributor itself based upon a recent U.S. Army study. An explanation of the technical aspects of autorotations which contribute to an undesirable end result is offered.

Overview of Helicopter Accident Experience

The use of civilian helicopters in the general aviation communities of many parts of the world is rapidly growing. Using the technology base largely generated by increased military helicopter activity in the early stages of the Vietnam war, and by the current U.S. Army programs in attack, utility, and heavy-lift helicopters, manufacturers and now devoting a much higher percentage of their resources to meeting the needs of the civilian markets. The world-wide search for energy sources is creating the largest need for helicopters that the industry has ever witnessed. Figure 1 illustrates the growth in both the number of helicopters and the number of flying hours in the U.S. and Canada during the last six years. The average annual utilization of these helicopters is about 265 hours per year. The average annual growth rate is about 12%, over this period, with more recent growth rates being slightly higher. Helicopter flying hours represent approximately 4% of the total general aviation hours in the U.S. Figure 2 illustrates the percentage breakdown of users in the North American civilian helicopter community.

The growth in usage, and especially the growth in use in the more hostile environments associated with oil and mineral explorations, have resulted in more helicopter accidents. Fortunately, the development of the light turbine engine, advances in materials and designing for helicopter fatigue environments, and higher standards of safety awareness by the operators, has resulted in decreases in accident rates in most years. Figure 3 depicts the accident picture in terms of both number of accidents per 10,000 hours and average flight hours between accidents. The most recent few years show a leveling off to around 2.2 accidents per 10,000 hours, or roughly 4,550 hours between accidents. It should be noted that the majority of the civilian accident data presented here comes from raw data available from the National Transportation Safety Board, the Federal Aviation Administration, and the Helicopter Association of America. These organizations use the basic NTSB definition of an accident, as do most safety agencies world-wide. Since the definition of "substantial damage" specifically excludes damage sustained on the ground to rotor blades (main and tail rotors) many instances of helicopter rollovers which result in considerable repair or replacement cost for blades, but do not involve personal injury or other "substantial damage", do not become part of the accident base. Also, the charter of the NTSB does not require it to investigate accidents involving "public use" aircraft, although they may elect to do so in some cases. Since helicopters are used extensively by the U.S. Forest Service, law inforcement agencies, and other public agencies, the accident data base is incomplete in this respect. Further, the FAA <u>does</u> include public service aircraft in its determination of hours flown. Thus accident rate data which excludes public use aircraft accidents but includes them as the exposure side of the ratio, is clearly subject to some error. The H.A.A. is working actively with the NTSB and FAA to correct this situtation, not only to make the statistics more accurate but to provide the investigative services and talents of the NTSB to operators who are leasing their helicopters to public agencies.

A safety investigator who wishes to probe the details behind helicopter accident data should also be aware of the quality of the investigations which yield the data he is examining. The general subject of education and qualification for air safety investigators was the theme of the 1973 S.A.S.I. Forum held in Toronto. Some of the shortcomings in the quality of investigation discussed at that forum are especially applicable to helicopter accidents. While much of the investigative techniques developed for fixed-wing accidents may be successfully applied to helicopter accidents, there are a number of specialized aspects pertaining to the peculiar way in which a rotary-wing vehicle develops aerodynamic forces for both lift and control, that an investigator must grasp in order to do a competent job. By virtue of the high levels of rotational kinetic energy inherent in the main rotor, the degree and complexity of structural damage is always higher than the corresponding set of impact conditions for a fixed-wing aircraft of similar gross weight. Thus the reconstruction of the structural failure sequence requires a higher skill level. Inertial forces, notably the gyroscopic forces generated by motions of both main and tail rotors, are often the dominating forces in certain helicopter maneuvers. Their source, sense, and magnitude must be appreciated in reconstructing the sequence of events and motions prior to the impact. The fact is that the majority of helicopter accidents in the U.S. are investigated by individuals whose helicopter education and training are minimal. Specialized courses of instruction in helicopter peculiar aspects of accident investigation are needed.

Figure 4(a) and 4(b) allow a comparison of accident rates for different groups of users. Note that while the overall civilian helicopter accident rate in the U.S. is slightly higher than the corresponding fixed-wing rate, the military and the H.A.A. member users both operate with lower accident rates than general aviation fixed-wing operators. Thus the argument that helicopters are <u>inherently</u> more accident prone cannot be shown. The factors of pilot training, maintenance practice, operating environment and general safety awareness influence the final accident rate statistics, and one must use extreme caution in attributing observed differences in rates to one or more of these contributors, without additional data. Similar caution is recommended in comparing accident rates for different helicopter models (e.g. Figure 5).

Types and Causes of Helicopter Accidents

A breakdown of the "type" of helicopter accident (NTSB definition) for two successive years is given in Figure 6. About 40% are assigned to one of the "collision" type categories while another 30% or so are initiated by engine failures. The high percentage of collisions is inherent to the helicopter's role in low altitude, confined airspace activity, associated with sling load work, observation duties, and utility work in all manner of terran conditions. The lack of IFR capability for the majority of civilian helicopters, together with reduced VFR requirements for helicopters, encourage operation in poor visibility conditions close to the ground, inviting collisions with unseen or unavoidable obstacles. Unfortunately, the helicopter is somewhat unforgiving of such collisions, expecially when the main or tail rotors are involved. Relatively small mass imbalances in the high centrifugal force fields of such rotors may cause catastrophic vibratory structural loads. The widespread use of turbine engines in light helicopters, with their greater reliability, has reduced the number of accidents initiated by such a failure and has been a major factor in the overall reduction in the accident rate. About 30% of helicopter accidents are initiated by an engine failure. Some of these include misuse of the powerplant controls by the pilot, and fuel exhaustion.

Figure 7 provides the broad cause categories applied by the NTSB to the accidents of Figure 6. As in the fixed-wing experience, the pilot is identified as at least one of the causes in over 70% of the accidents. Note that in general more than one cause per accident is given and no attempt to rank cause factors is made. "Terrain" is given as a cause factor in over 30% of helicopter accidents. This includes the sub-classes of "rough/uneven", "wet/soft ground", "high obstruction" etc. This cause classification percentage is higher than fixed-wing statistics for at least two reasons: (1) helicopter missions are often defined such that prolonged periods of operation close to terrain totally unsuitable for landing is required, and (2) helicopter ground handing characteristics are traditionally poorer than fixed-wing aircraft, due in part to non-retractable skid-type landing gear and high vertical center-of-gravity to skid track ratios. Most helicopters are particularly sensitive to lateral motions at touchdown. A study of 71 U.S. Army utility helicopters revealed that in 60% of the cases the aircraft either impacted directly on its side or rolled on its side at least once during the crash sequence.

The air safety investigator interested in the information provided by accident statistics for preventive purposes can spend many hours analizing the mass of available data and the myriad of ways it can be presented. In doing so for helicopters it will become clear that many accidents (using the definition of personal injury or substantial damage) are not caused directly by the first event in the sequence, but by the last (it's not the fall that hurts but the sudden stop at the bottom). The link between the two for helicopters is the autorotation maneuver, and the "success" with which it is accomplished is often the difference between an incident and an accident. Looking behind the statistics now, let us examine some of the factors which can be identified as contributory to the success of an autorotation.

Autorotations and their Impact on Helicopter Accidents

To illustrate the magnitude of the problem the results of a recent U.S. Army study are helpful. For the purpose of this study the term "mishap" was used to include all helicopter accidents and incidents with some damage, attributable to the touchdown phase of an autorotation. Only non-combat related mishaps occuring in a 2½ year period between 1 July 1969 and 31 December 1971 were used. During this period 1195 mishaps occurred (709 emergency autorotations and 486 in practice) causing 82 fatalities, 606 injuries and $82 million in damage. It was found that 40% of all Army helicopter accidents during that period involved autorotation. A "success ratio" was defined for emergency autorotations as the ratio of no-damage autorotations to these resulting in damage requiring repair.

The overall "success ratio" for this period was found to be 1.12 to 1. In other words, roughly one emergency autorotation was "unsuccessful" for every successful one. The U.N. Navy's success ratio for the comparable period was 1.14, the USAF 8.00 and the U.S. Coast Guard 25.00. The obvious contributor to the higher ratios for the Air Force is the higher average mission altitudes (allowing for more time and area from which to select a suitable landing spot). The availability of suitable terrain to the Coast Guard, in the form of expanses of unobstructed water surface, helps explain their more favorable experience. A breakdown of both emergency autorotation rate and success ratio, by helicopter model, is given in Figure 8.

There are three readily definable portions to a helicopter's descent following loss of engine power (inadvertent of purposeful): entry, steady-state descent, flare and touchdown. The immediate and obvious effects of power loss are rotor RPM decay and out-of-trim rotational accelerations (notably left yaw). The most abrupt rotor RPM delay rates occur when collective pitch and consequent torque are the highest. Heavy weight, high density altitude, and either hovering or maximum speed, are the critical conditions. The rate at which a rotational system decays is directly proportional to the applied torque and inversely proportional to the moment of inertia. From the standpoint of minimizing rotor RPM delay (upon which both lift and control depend), the "high inertia rotor" is preferred. However, in terms of increasing RPM during the cyclic flare prior to touchdown, the opposite is true - a high inertia rotor here resists significant rates of RPM increase. Moreover, the high inertia rotor tends to lag collective input commands during the steady state portion of the descent (although the final RPM change achieved may be high). This characteristic can cause a tendency for the pilot to "chase the rotor speed" requiring extensive pilot effort in precise RPM control.

Figure 9 illustrates the magnitude of rotor RPM delay on one helicopter. Note that in the most severe case it takes only seconds (sometimes less than a second) for the delay to reach published minima, that is, the pilot must react very quickly in initiating a decrease in collective and/or cycle flare to prevent excessive RPM delay. The quickly developing yaw may induce uncontrolable rolling and pitching in some flight conditions if not arrested by the pilot in short order.

The time it takes to establish a true steady-state autorotative state (zero rotor torque, constant RPM, speed, rate of decent etc.) depends very much on flight condition and pilot technique. On all helicopters at least five to eight seconds are required to establish the condition. The decent angle and rate of descent are functions of configuration, airspeed, sideslip condition, and rotor RPM. Most helicopters have a minimum descent rate (corresponding to a particular airspeed) from 1400 to 2200 feet per minute. Maximum glide distance is achieved at higher speed (as it is in fixed-wing aircraft). Most single-rotor helicopters have a descent angle of about 17^{o} when flying at minimum descent rate, and an absolute minimum from 10 to 14^{o}. Thus the very best any helicopter can do is about 1 mile horizontally for every 1,000 feet of altitude during the steady-state portion of autorotation. This corresponds to a fixed-wing L/D ratio of about 6. Maximum L/D for fixed-wing aircraft are seldom that low, and may exceed

40 for high performance sailplanes. Thus the power-off glide performance of helicopters is better or worse than that of their fixed-wing counterparts only in terms of which characteristic is most desired-minimum rate of descent or maximum glide distance. The need of the helicopter to locate suitable terrain makes glide distance an important parameter.

The height-velocity diagram (dead man's curve) is an important piece of data on autorotation capability, usually available to the pilot in the operators manual. The purpose of an H-V diagram is to identify for the pilot the portions of the flight envelope from which a safe landing can be made after a sudden engine failure. Figure 10 illustrates the shape characteristics of an H-V diagram, which can usually be found in the operator's manual. Too often the manual conveys the following message along with the diagram:

> "This diagram is the result of flight test and indicates the combinations of airspeed and height about the ground which will allow the average pilot to successfully complete a landing after an engine failure."

The cannotation here is that if a satisfactory landing is not executed from "safe" areas, the pilot's performance is below average or substandard. Even more important, there is an implication that a really good pilot can probably accomplish a successful autorotation from well within the "avoid" area of the curve. Neither is necessarily true. The problem arises from the method of determining the curve itself.

The manufacturer's test pilot usually define the curve. They do so by approaching the expected boundary in careful steps. For example, the minimum height for high hover (point 1 in Figure 10) is usually found by initiating autorotation at zero airspeed and at heights well above the expected curve value. The test pilot experiments with technique and then slowly lowers the entry height in steps until he feels he has found the point below which the "average" pilot would not be successful. Among faults in this approach are the following:

1. It is in the manufacturer's best interests to have as small an "avoid" area as possible (from a business competition point of view), which may influence the test pilot's opinion in this rather subjective and fuzzy area.

2. The test pilot must assume a certain skill level as being that of the average pilot who will fly a helicopter not yet on the market. No "average" pilots are used in test flying.

3. Some specifications allow only a 1 sec pilot reaction time in demonstrating the H-V curve. Many average pilots, especially in machines lacking adequate visual, aural, and/or kinesthetic cues, will take much longer to diagnose the problem and to react.

4. The curve is demonstrated by simulating an actual failure (by retarding throttle) rather than shutting down the engine. Measurements have shown that there is a significant amount of engine output torque with normal engine rigging at the flight-idle position. This can produce a false sense of security in an individual faced with an actual emergency.

5. The curve is often determined, and demonstrated, from a straight and level steady state condition. Failures from climbs, descents, and turns are often not required.

6. Tests and demonstrations are usually conducted at one gross weight condition (often design mission weight) and at standard sea level conditions. Recent experiments have shown that curves so determined are on the unsafe side compared to higher weight and/or density altitude conditions.

To add to the problem, flight manuals usually contain little information on proper technique. The technique required to demonstrate a successful autorotation from the "knee" of the curve (point 2 in Figure 10) is vastly different from that at high speed, low altitude (point 5 of the figure). Most training programs emphasize autorotation practice from a "slot" position about 500 ft above terrain and at a moderate speed well within the "safe" area. In one experiment a group of instructors were asked to demonstrate touchdown autorotations from the "knee" of a published H-V diagram. All failed, requiring a powered recovery.

Based on these and other tests, the H-V diagrams of two Army helicopters have been drastically revised as shwon in Figure 11.

All these considerations have undobutedly contributed to the high rate of autorotation accidents. Suffice it to say that most helicopters have portions of their normal mission profiles within the published "avoid" areas. This is a known risk, which must be assumed by those responsible for defining procedures, and ultimately by the pilot.

Conclusion: Helicopter accident statistics, including type and cause factors, have revealed certain significant trends which differ from fixed-wing experience. These trends are attributable to the details of the helicopter's mission and operating environment and to the technical aspects of rotary wing configurations. The autorotation maneuver plays a unique role in helicopter accident causation. Air safety investigators involved in helicopter accident investigation require specialize training and experience to perform their duties competently.

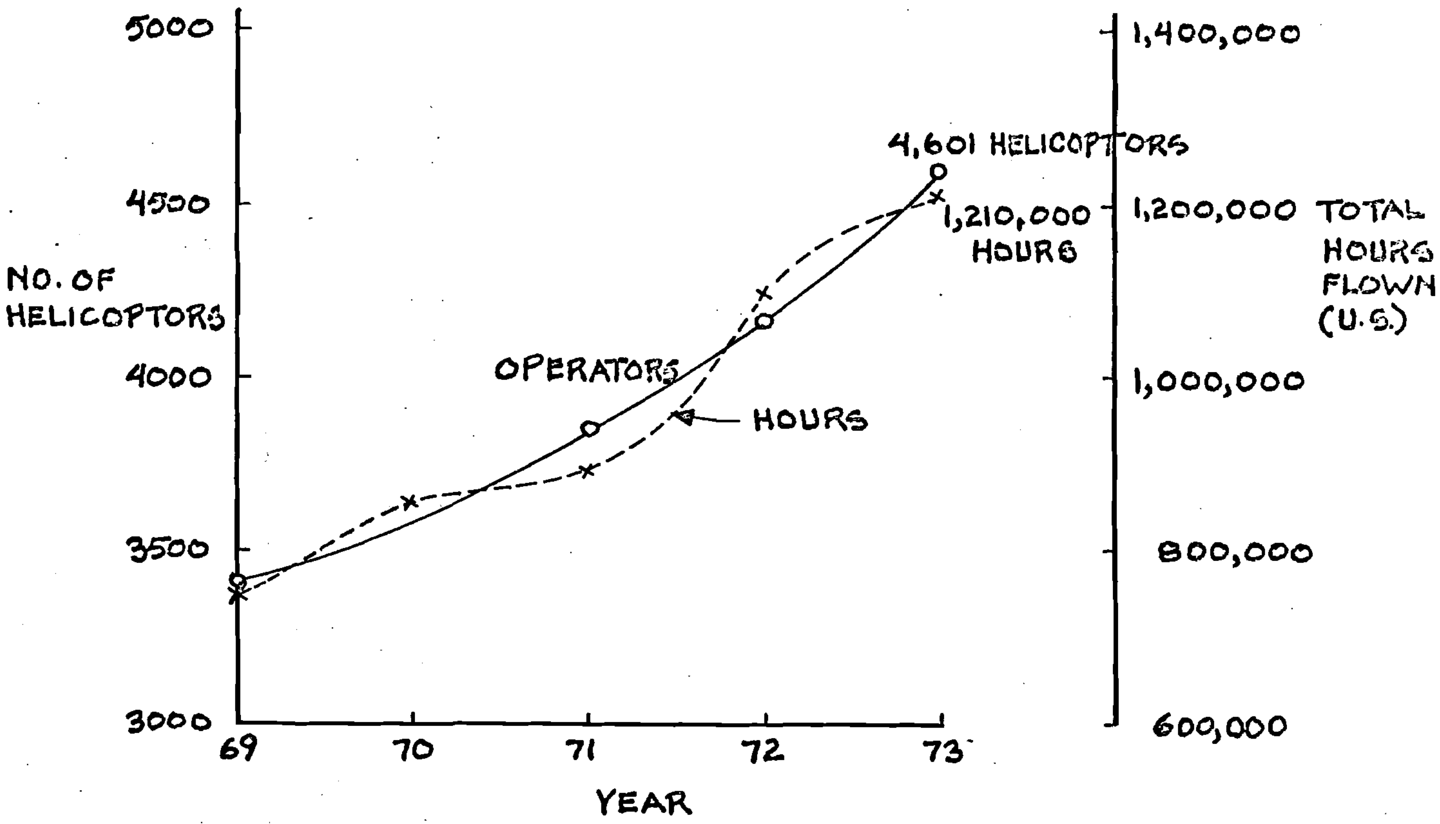


Figure 1: Helicopter Utilization in the United States and Canada (non-military).

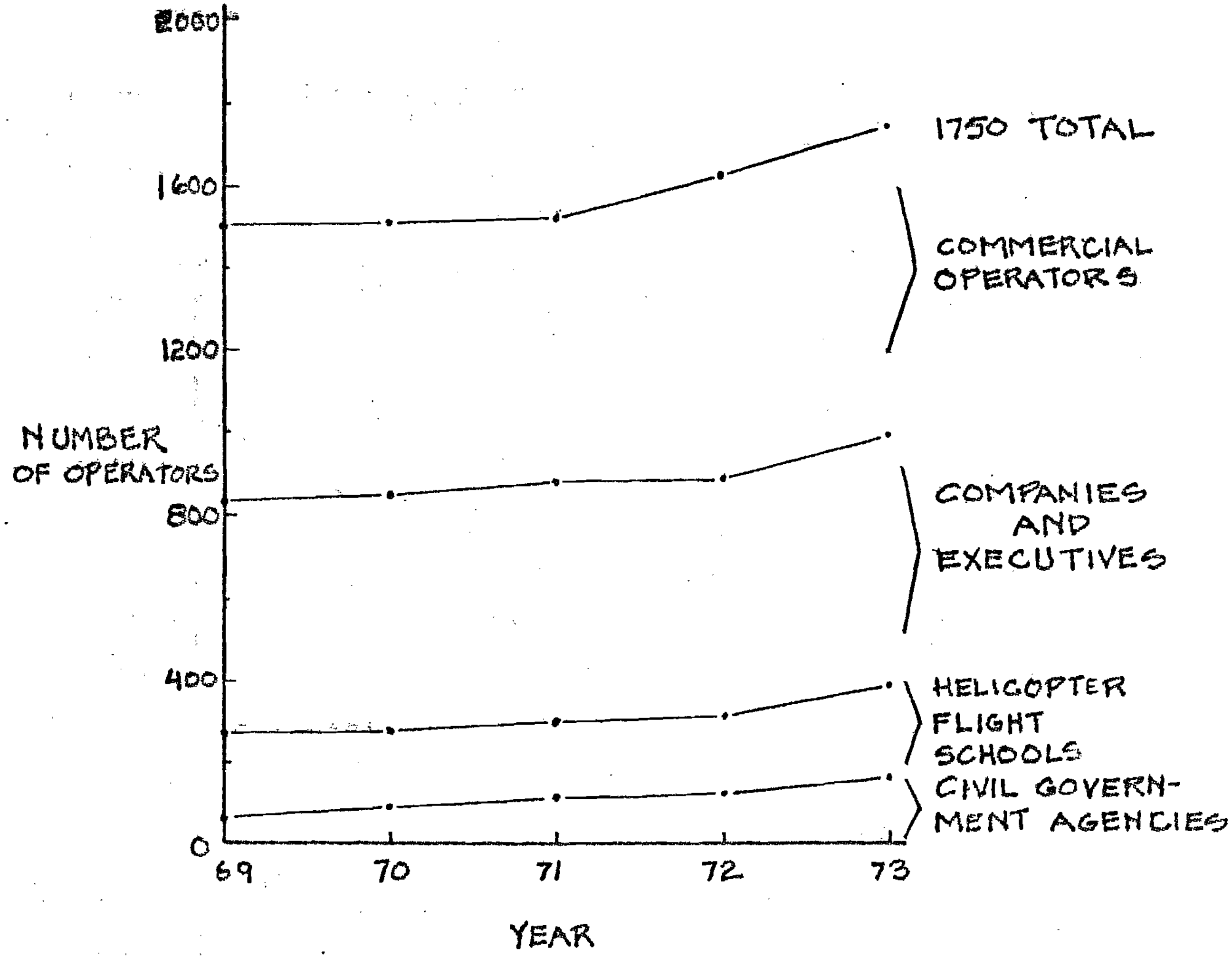


Figure 2: Helicopter Users in the United States and Canada (non-military).

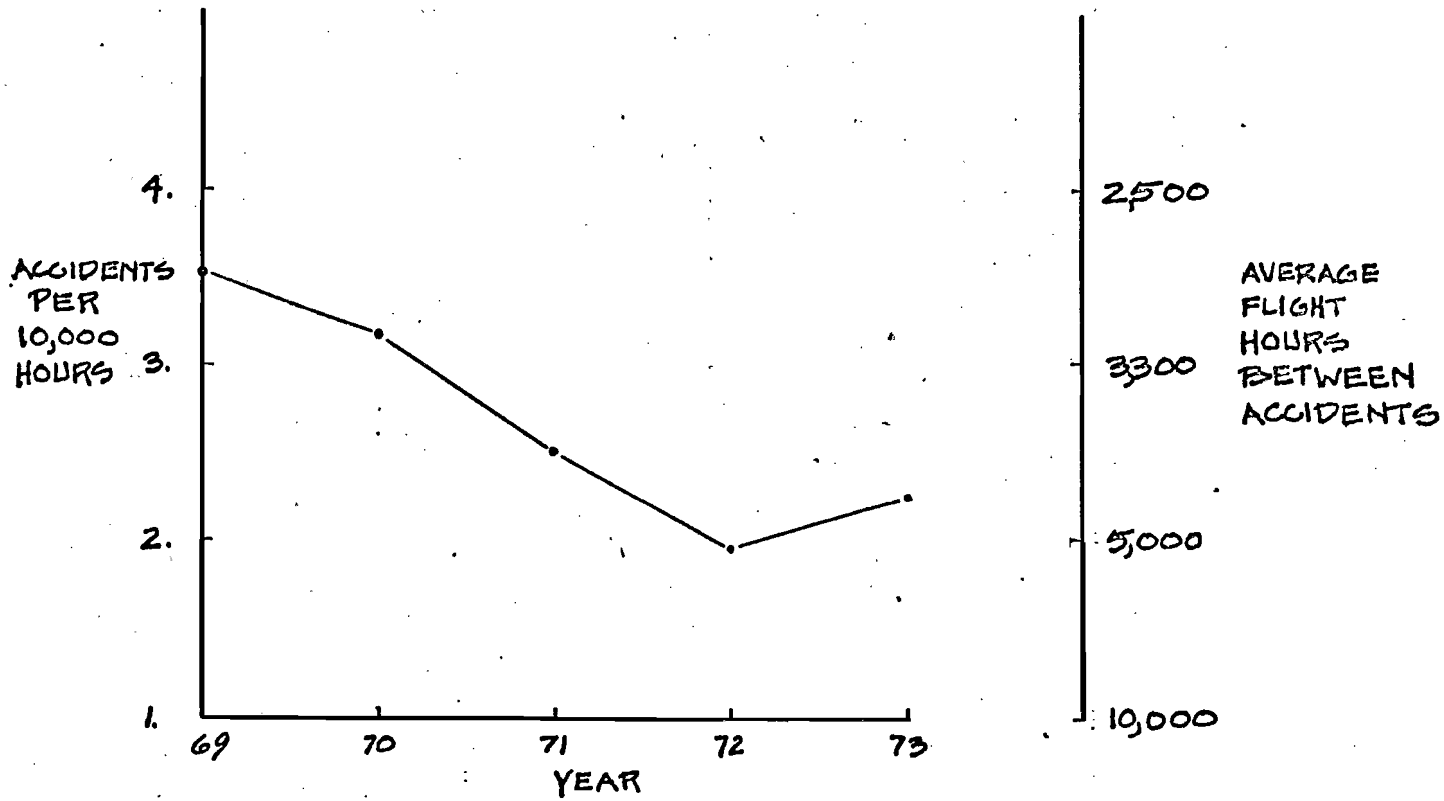
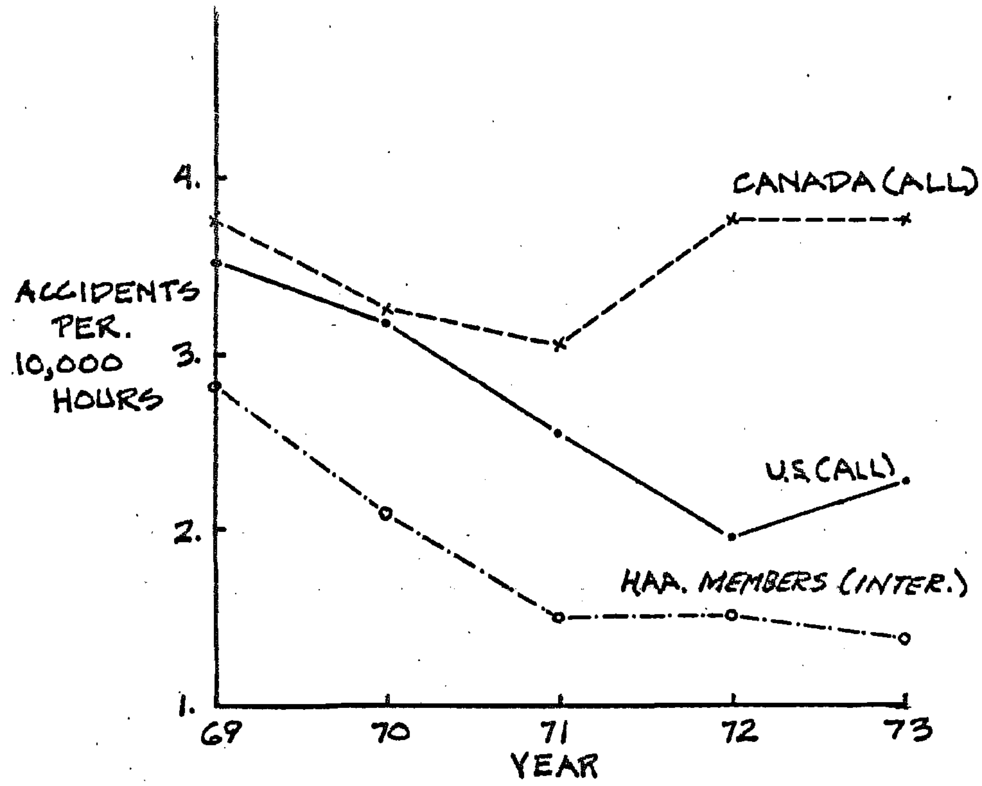


Figure 3: Helicopter Accident Rate in the United States (non-military).



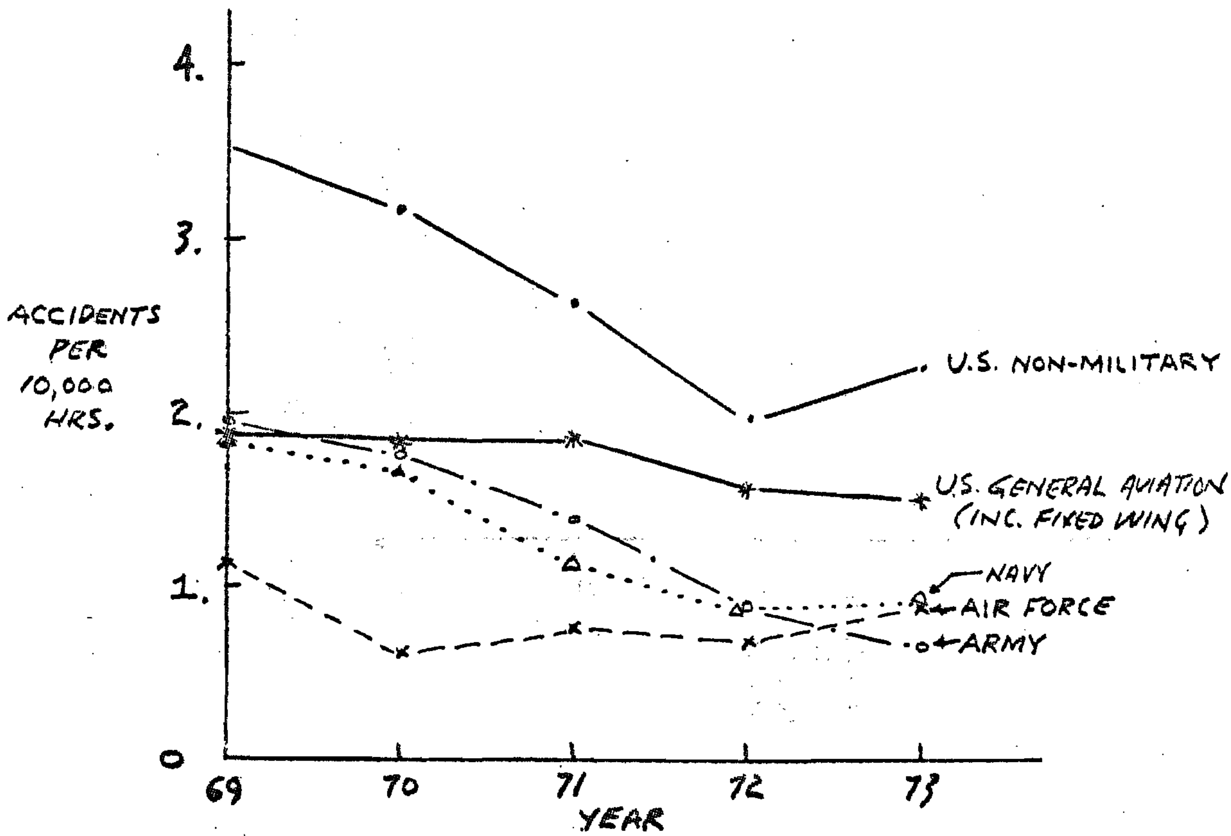


Figure 4: Comparison of Helicopter Accident Rates.

	MODEL	FLIGHT TIME (FAA)	NUMBER OF ACCIDENTS (NTSB)	ACCIDENT RATE PER 100,000 HRS.	TIME BETWEEN ACCIDENTS (HRS)
Aerospatiale	SA 318	14,342	4	27.9	3,586
	SA 316	5,180	0	0	∞
Bell	47 Series	354,530	91	25.7	3,896
	204/205	56,372	3	5.3	18,790
	206	211,065	10	4.7	21,106
	212	4,495	0	0	∞
Brantly	B2	5,758	4	69.5	1,440
	305	981	1	102.0	981
Enstrom	F28	12,433	5	40.2	2,487
Hiller	FH 1100	39,206	8	20.4	4,901
	UH 12	24,144	16	66.3	1,509
Hughes	269	107,522	54	50.2	1,991
	369	17,736	3	16.9	5,912
Sikorsky	S51	167	1	592.0	167
	S52	825	2	242.1	413
	S55	6,817	6	880.0	1,136
	S55T	220	0	0	∞
	S58	3,639	1	27.5	3,639
	S61	2,047	0	0	∞
	S62	10,636	0	0	∞
	S64	703	0	0	∞

Figure 5: Comparison of Helicopter Accident Rates for 1971 (U.S. Registered Helicopters Only).

TYPE OF ACCIDENTS	1971	1972
COLLISION, WIRES/POLES	10.2	13.9
COLLISION, TREES/CROPS	5.4	6.9
COLLISION, IN FLIGHT	1.9	0
COLLISION, OBJECT/BUILDING	7.3	6.5
COLLISION, GROUND/WATER, CONTROLLED	7.8	5.1
COLLISION, GROUND/WATER, UNCONTROLLED	10.7	6.9
HARD LANDING	11.1	9.3
ROLL OVER	1.9	6.0
NOSE OVER	.5	.5
ENGINE FAILURE/MALFUNCTION	31.2	27.4
TAIL/MAIN ROTOR FAILURE	4.3	5.5
MATERIAL FAILURE/MALFUNCTION	1.5	3.7
ROTOR ACCIDENT TO PERSON	1.5	3.2
GROUND/WATER, LOOP/SWERVE	1.0	.5
MISCELLANEOUS	3.4	4.6
	100.	100.

Figure 6: Percent of Accidents by Type (non-military U.S. Helicopters).

CAUSE/FACTOR	1971	1972
PILOT	67.9	73.1
OTHER PERSONNEL	14.6	15.3
TERRAIN	30.7	31.9
POWERPLANT	18.0	14.4
OTHER MECHANICAL	11.0	12.5
WEATHER	8.2	19.4
MISC./UNDETERMINED	20.5	10.1

* NOTE: MORE THAN ONE CAUSE FACTOR MAY BE INVOLVED IN EACH ACCIDENT. CONSEQUENTLY, THE PERCENTAGES TOTAL MORE THAN 100.

Figure 7: Percent of Accidents by Cause (non-military U.S. Helicopters).

AIRCRAFT	EMERGENCY AUTOROTATION RATE (PER 100,000 HRS)	SUCCESS RATIO
BELL AH-1	22.77	.51
BELL UH-1	12.21	1.07
BELL OH-58	14.88	1.75
HUGHES OH-6	24.41	.46
BELL T/OH-13	11.05	2.51
HUGHES TH-55	15.69	2.98
BOEING CH-47	2.52	.62
OVERALL: SINGLE ENG.	14.68	1.13
MULTI-ENG.	2.48	.55

Figure 8: Autorotation Experience by Make/Model.

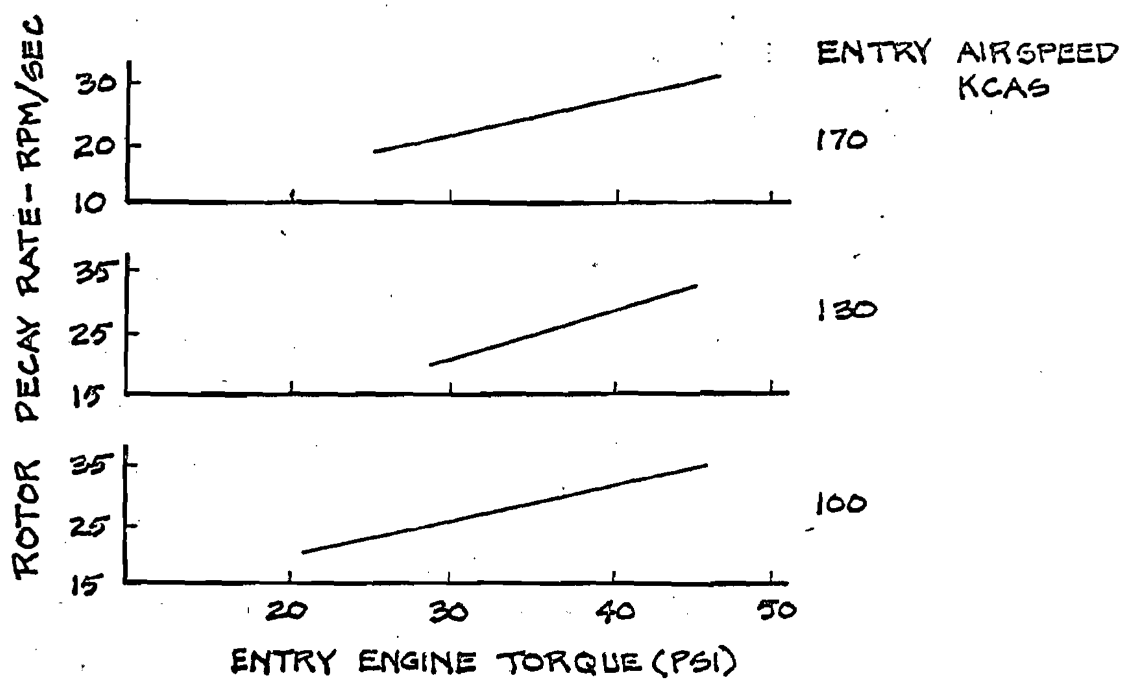


Figure 9: Rotor RPM Decay Following Engine Failure on an Attack Helicopter.

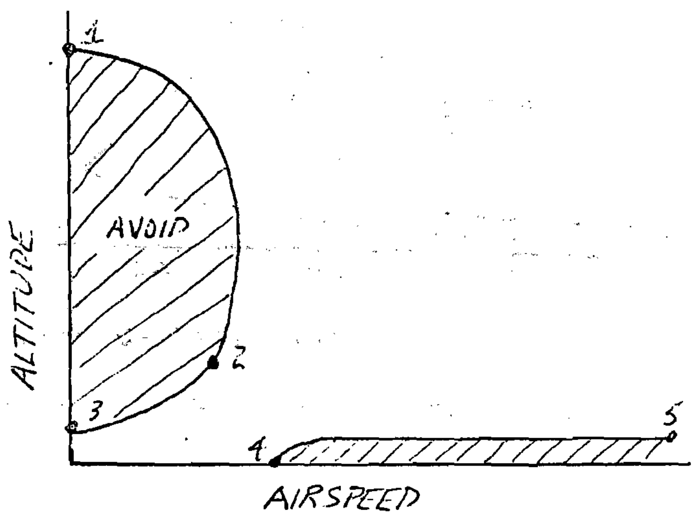


Figure 10: Height - Velocity Diagram (Dead-man's Curve).

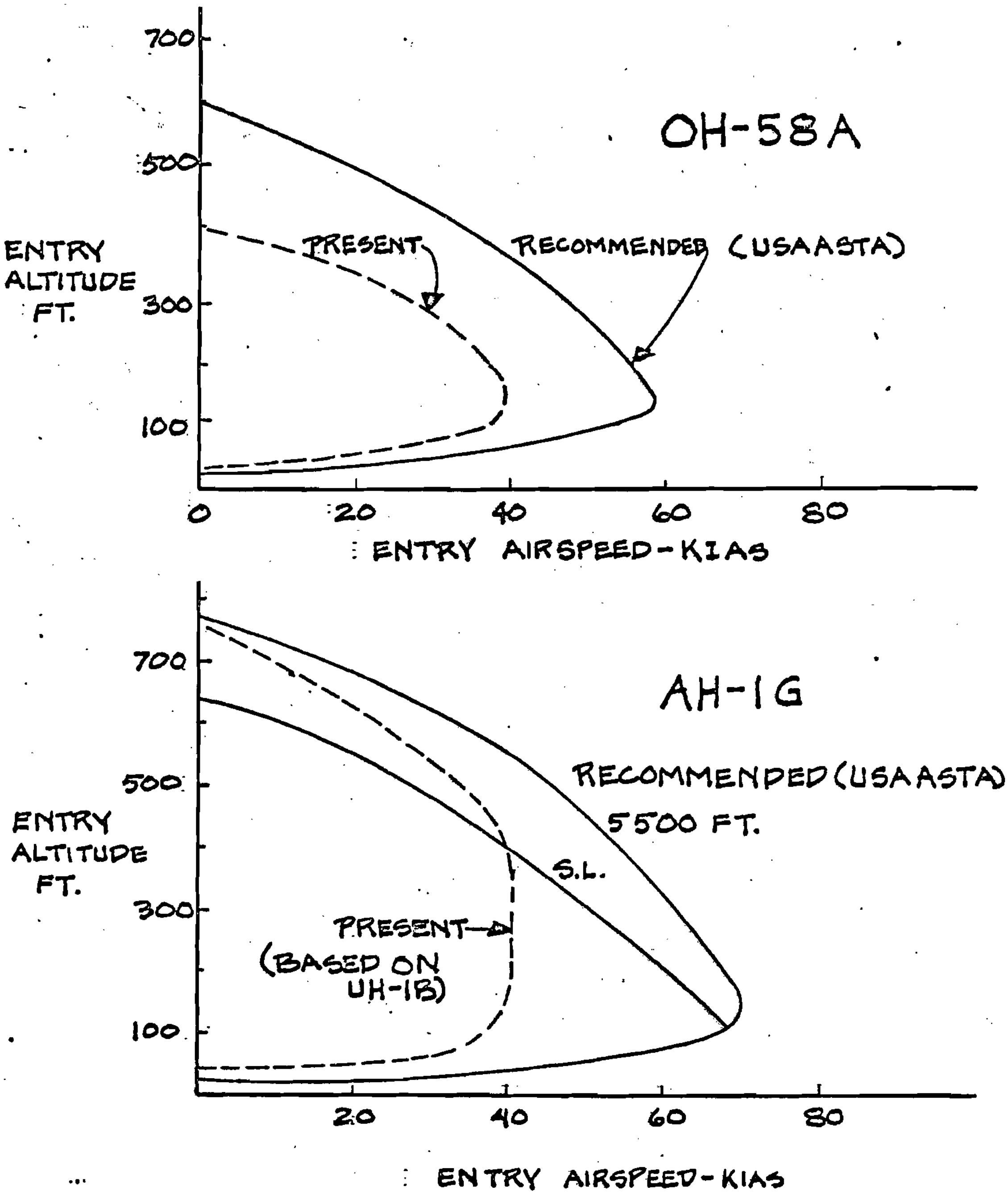


Figure 11: Recommended Changes to H-V Curves for OH-58A and AH-IG Helicopters (U.S. Army Data).

MANEUVERING STABILITY'S ROLE

IN AIRCRAFT ACCIDENT CAUSATION

by

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1.0 INTRODUCTION

As we look for ways to improve aircraft accident investigation methodology, we must realize that some improvement can come merely from a better understanding of present scientific principles. As a result of my teaching aircraft accident investigation methodology and recent aircraft accident investigations in which I have been involved, I realize that an incredible void exists in the literature for air safety investigators concerning the proper consideration and evaluation of maneuvering stability's role in accident causation analysis when an inflight overstress/failure of the aircraft's airframe occurs. In the National Transportation Safety Board's 1973-74 listing of aircraft accidents involving inflight airframe failures, it is shown that some 200 accidents of this type occurred in two years. While some of these accidents were induced by material defects such as fatigue, it is shown by the NTSB that more than sixty accidents occurred because the pilot exceeded the design stress limits of the aircraft. Air safety investigators cannot continue to be satisfied with a probable cause factor of this type. Aircraft accidents will continue to occur as long as this is the only approach taken in the investigation of this type of accident. In order to examine and illustrate the critical role that air safety investigators can and must play in the investigation and prevention of inflight overload induced accidents, consideration of an aircraft's maneuvering stability characteristics is required. Then, meaningful aircraft accident causation findings will result.

2.0 MANEUVERING STABILITY'S EFFECT ON SAFETY OF FLIGHT

The flying qualities of any airplane are defined as the stability and control characteristics which have an important bearing on the safety of flight and ease of flying an airplane in maneuvering as well as straight and level flight. The flying qualities of aircraft have been studied by the Federal Government through its various agencies and by the aircraft industry since 1939 to insure that the safest, best flying aircraft be produced. Numerous National Advisory Committee for Aeronautics reports document the efforts of the Government to establish appropriate safe flying qualities in aircraft manufactured for use during and after World War II. (References 1, 2, 3, 4). The results of this research established not only desirable levels of maneuvering stability for various types of airplanes, but also established that maneuvering stability was essential for safety of flight. The longitudinal maneuvering stability handling characteristics are best represented and evaluated by a plot of stick force (pull) versus load factor (g's) as shown in Figure 1. The maneuvering stability of any aircraft should always be positive and is represented by the slope of the stick force versus load factor plot. This slope is called the stick force gradient and must not only be positive in value (increasing pull force for increasing load factor) but must also be of the proper gradient or slope to insure a minimum level of safety while maneuvering any type of aircraft in flight. Catastrophic inflight failure or overstress of the aircraft's structure can result when an unsuspecting pilot attempts to maneuver an aircraft exhibiting a stick force gradient which is too low. For this reason the technical literature on maneuvering stability and aircraft flying qualities recognizes different levels of stick force gradients for different types of aircraft (See Figure 2).

A desirable stick force gradient for a sport and training-type general aviation aircraft is approximately 10 lbs. - 25 lbs. per "g". Light general aviation business transport aircraft require a slightly higher stick force gradient since increased safety rather than high maneuverability is desirable.

Fighter/aerobatic-type aircraft with their higher maneuvering requirements and higher load factor construction have the lowest stick force gradients. To utilize the maximum maneuvering capability of this type of aircraft while minimizing pilot fatigue, a stick force gradient of 3 lbs. - 10 lbs. per "g" is required.

Large transport-type aircraft utilize a very high stick force gradient on the order of 25 lbs. - 50 lbs. per "g". Most transport-type aircraft are limited by low maximum ultimate load factors on the order of 3.75 "g's". Load factors above this level would result in catastrophic failure or severe damage to the airframe structure. The low maneuvering requirements of transport aircraft's flight profiles allow such high stick force gradients to be satisfactory. Another requirement on the stick force gradient of any airplane and one that is often overlooked is that the aircraft's stick force gradient remain approximately linear throughout the airplane's flight envelope (See Figure 3). The technical literature stresses that the stick force gradient should never, under any condition, be allowed to have a slope of zero within an aircraft's flight envelope (See Figure 4). While the unacceptability of a zero stick force gradient within an aircraft's flight envelope is recognized as very hazardous to safety of flight, the seriousness of a negative stick force gradient or total stick force reversal anywhere within the aircraft's flight envelope is disastrous when it occurs. An airplane with a zero or negative stick force gradient is subject to extreme overstress or catastrophic failure of its airframe whenever it is maneuvered near the negative gradient portion of its stick force curve (See Figure 4). An airplane which experiences a total stick force reversal (See Figure 4) not only confronts the unsuspecting pilot with dangerous lightening but can disorient the pilot by forcing him to fly an airplane with reversed control inputs while operating near the limits of the aircraft's flight envelope. Of the two types of deficiencies, stick force gradient reversal and stick force reversal, it is stick force reversal which is intolerable as a maneuvering stability deficiency characteristic in an airplane. Various parameters within the control of the aircraft manufacturer and aircraft operator (pilot) affect the stick force gradient exhibited by any airplane.

In the design of an aircraft's flight controls and handling qualities, the aircraft's manufacturer can tailor the stick force characteristics of an airplane through various means and devices to achieve a desirable, safe level of maneuvering stability. Since the center of gravity location directly affects the stick force gradient as the center of gravity of the aircraft is moved rearward, the required stick force to pull the same load factor (g's) is lowered (See Figure 5). Replotting the data in Figure 5 yields a plot of stick force gradient versus center of gravity location usually expressed in percent of the mean aerodynamic chord of the wing (See Figure 6). While both Figures 5 and 6 convey the same basic information, Figure 6's format is ideal for examination of the stick force gradient over the certified center of gravity range. When the aircraft's center of gravity limits are placed on Figure 6, the values of the stick force gradient can very quickly be determined at the extreme center of gravity locations (See Figure 7). Since stick force gradient is a direct measure for evaluating an airplane's maneuvering stability level, the extreme limits of the certified center of gravity locations will establish the highest and lowest levels of maneuvering stability for a particular set of flight conditions. It is the violation of the flight manual's recommended limits on rearward center of gravity locations which can result in the aircraft being inadvertently overstressed when maneuvered in flight by the pilot.

3.0 UNITED STATES' CERTIFICATION REQUIREMENTS

As early as 1945, the United States stated aircraft certification requirements pertaining to aircraft maneuvering stability characteristics.

These can be found in Civil Air Regulation Number 3, Aircraft Flight Characteristics, Part 3.106, Controllability, which states, "It shall be possible to make a smooth transition from one flight condition to another, including turns and slips, without requiring an exceptional degree of skill, alertness, or strength on the part of the pilot and without danger of exceeding the limit load factor under all conditions of operation probable for the type..." aircraft. Civil Air Regulation Number 3 was replaced with Federal Air Regulation Parts 23 and 25, Airworthiness Standards. The requirements for maneuvering stability are found in the Flight Characteristics section under Part 23.143 and 25. 143, Controllability and Maneuverability. These regulations contain the same general approach to maneuvering stability requirements as is found in CAR Part 3.106.

With the adoption of Military Specification 8785, Flying Qualities of Piloted Airplanes, the U. S. Military synthesized years of research, flight testing, and available literature concerning essential flying qualities for various types of aircraft. MIL Standard 8785 requires stick force linearity as well as lower and upper limits on stick force gradients for various types of aircraft which are defined in Part 3.2.2.2.1, Control Forces in Maneuvering Flight.

When comparing the civil certification requirements with the military specifications concerning maneuvering stability requirements, it can be seen that the civil regulations do not specifically require stick force versus load factor data be supplied for certification evaluation.

4.0 EXAMPLES OF VARIOUS AIRCRAFTS' MANEUVERING STABILITY

To properly analyze the maneuvering stability of any aircraft, representative curve plots of the aircraft's stick force versus load factor are needed (See Figures 1 and 6). Figure 8 represents three aircraft types and levels of maneuvering stability. Aircraft A is a light general aviation twin engine aircraft which initially exhibits a dangerously low stick force gradient of approximately 2 lbs. per "g", then stick force gradient reversal occurs at approximately 2.3 "g's", and finally stick force reversal at approximately 2.75 "g's". It should be noted that this type of aircraft has experienced twenty-two cases of inflight overload/overstress damage or failure of its wing/wings (See Figure 9) (Reference 5). As a result of the issuance of an Airworthiness Directive, the aircraft has recently had its flight control system modified by a bobweight to increase the maneuvering stability levels of the aircraft.

Aircraft B is a current joint services fighter aircraft which exhibits an initially acceptable stick force gradient within the MIL standards and experiences stick force lightening at approximately 5 "g's". Beyond 5 "g's" stick force gradient reversal occurs for this configuration, speed, and altitude. While this aircraft's maneuvering characteristics lack total compliance with MIL 8785 specifications and are undesirable, catastrophic inflight airframe failures have been minimized by pilot training and a warning statement printed in the aircraft's flight manual which reads as follows:

"Nose rise can occur during high AOA maneuvering. This is characterized by a reduction or reversal of stick forces and can result in inadvertent increase in AOA and possible overstressing of the aircraft or loss of control."

Aircraft C is a large, four engine, turboprop, transport-type aircraft which exhibits a very high level of maneuvering stability on the order of 60 lbs. per "g". This high level of maneuvering stability insures a high margin of protection against inadvertently exceeding the low limit load factor of this aircraft of 3.0 "g's". This aircraft's stick force gradient results in a pilot pull force of approximately 180 lbs. on the control wheel to obtain the limit load factor. Since the maximum pilot pull force of which the pilot is physiologically capable is on the order of 75 lbs. of pull, a sizeable margin exists against pilot induced overstress of this type of aircraft.

5.0 GUIDELINES FOR DETERMINING MANEUVERING STABILITY'S ROLE IN ACCIDENT CAUSATION

In any inflight overstress failure aircraft accident, the air safety investigator must consider the aircraft's maneuvering stability levels and characteristics. It is tragic that an aircraft with undesirable maneuvering stability levels could and would be marketed in view of the literature available to aircraft designers and regulations requiring safe levels of maneuvering stability in aircraft. Some aircraft manufacturers have chosen to neglect or incorrectly assess the importance of attaining a proper level of maneuvering stability in their products. Consequently, an air safety investigator must have a systemic and educated approach to consider what in the past may have been dismissed as pilot error induced overload inflight failure of the airframe.

In the event that the aircraft stalls out before experiencing a catastrophic overload failure of its airframe, loss of control may result to an aircraft deficient in maneuvering stability. The investigator must realize that the accelerated stalling characteristics of an unstable maneuvering aircraft will be totally different from the airplane's normal one "g" stalling flight characteristics. A maneuvering unstable aircraft can thus result in the pilot experiencing a total loss of control in an accelerated maneuver which results in an uncontrolled pitch-up induced accelerated stall.

The following guidelines are offered to assist air safety investigators in their determination and assessment of an aircraft's maneuvering stability's role in an inflight airframe overload accident:

1. Obtain or generate a stick force versus load factor curve for all critical flight conditions and loadings.

2. Verify whether or not adequate data points were taken in flight test evaluation to represent the stick force versus load factor curves as drawn.

3. Compare the stick force versus load factor curves to other aircraft of similar type and function.

4. Evaluate the maximum load factor obtainable for the maximum possible pilot physiological pull force on the flight controls.

5. Consult a qualified graduate aeronautical engineer whose speciality and expertise is in aircraft stability, control, and flying qualities for the evaluation of the above factors.

6.0 CONCLUSIONS

An aircraft's maneuvering stability does have an important role in accident causation and prevention involving loss of control or inflight airframe overload accidents. While maneuvering stability's role in some of the examples given are shocking, the vast majority of aircraft today do exhibit exemplar levels of maneuvering stability. This is a result of many man hours of design and testing. Many companies take great pride in not only meeting airworthiness certification regulations but in marketing an aircraft which exhibits safe flying qualities. To blindly accept the fact that all aircraft possess a safe level of maneuvering stability on the basis of certification would be erroneous due to the system under which aircraft are certified in the United States. The air safety investigator must in his investigation consider and examine each aircraft's maneuvering stability characteristics for the reconstructed flight conditions involved in view of the guidelines offered in this paper. Only then can an objective assessment of the aircraft's maneuvering stability's role in accident causation be made.

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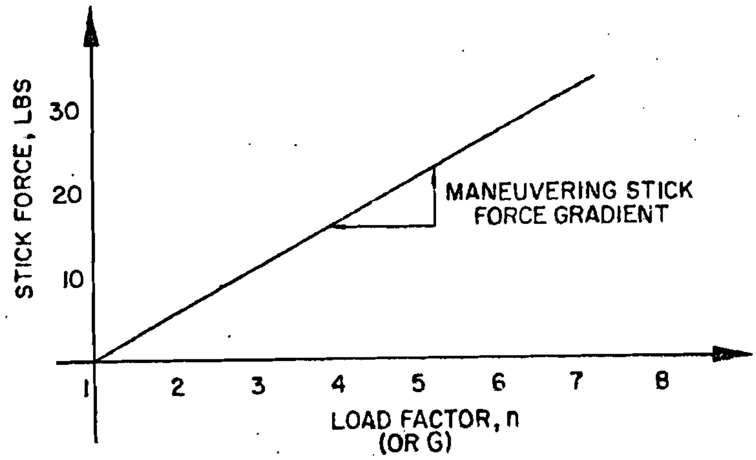

Figure 1

Stick Force Versus Load Factor

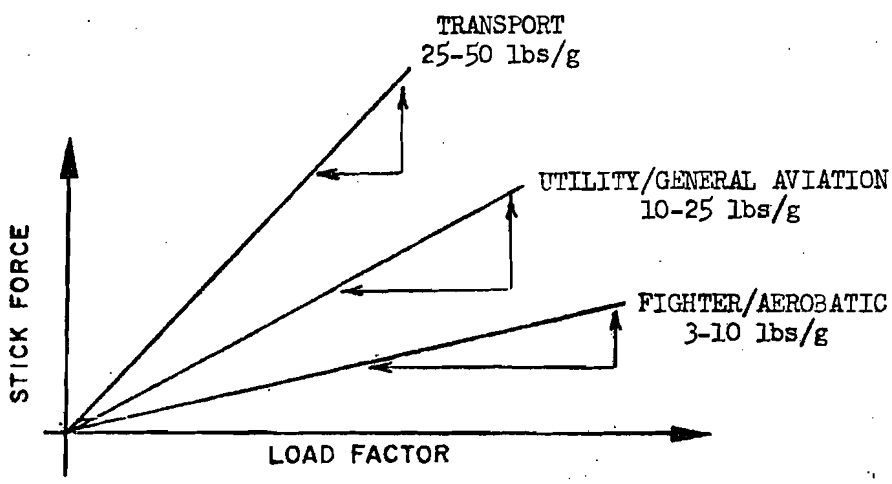

Figure 2

Maneuvering Stability Levels
for Various Type Aircraft

SAFE

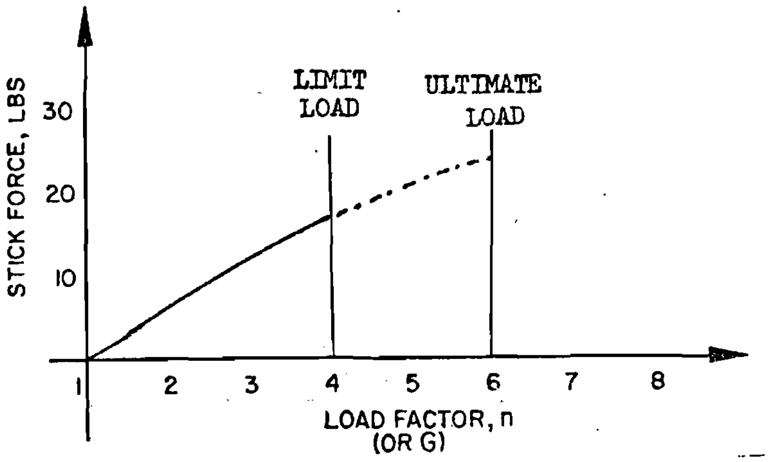

Figure 3

Safe Maneuvering Stability Characteristics

DANGEROUS

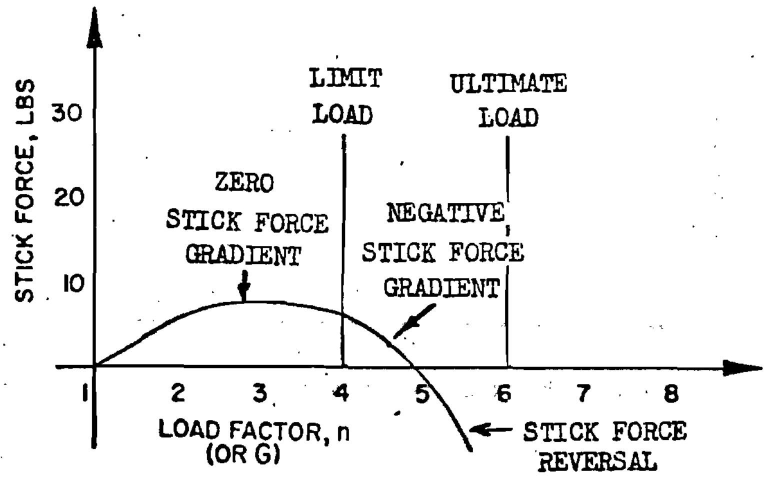

Figure 4

Dangerous Maneuvering Stability Characteristics

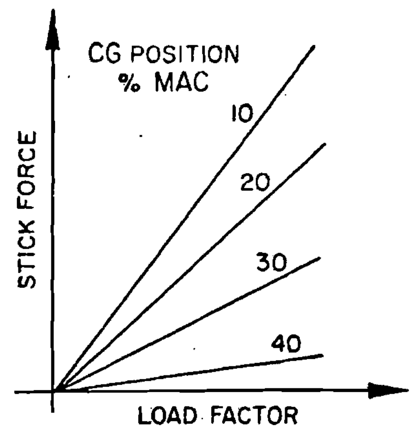

Figure 5

Center of Gravity's Effect on Maneuvering Stability

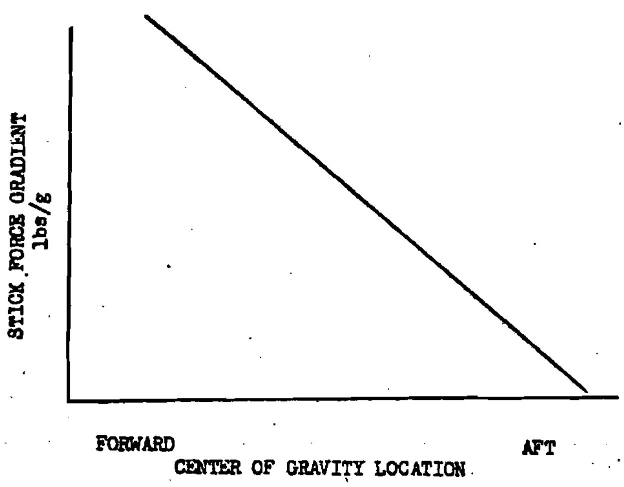

Figure 6

Stick Force Gradient Versus Center of Gravity Location

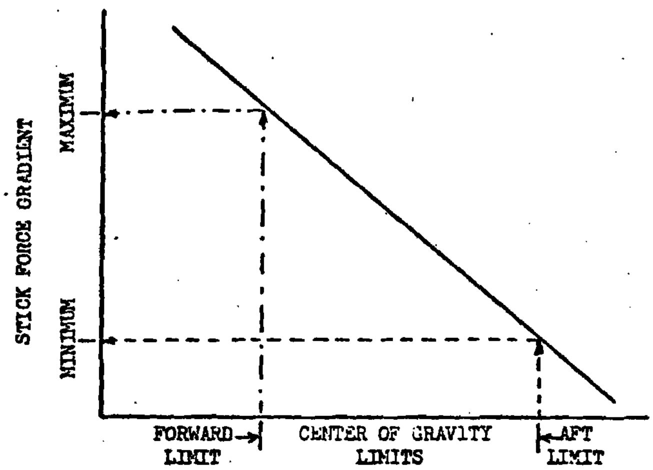

Figure 7

Center of Gravity's Effect on Maximum and Minimum Levels of Maneuvering Stability

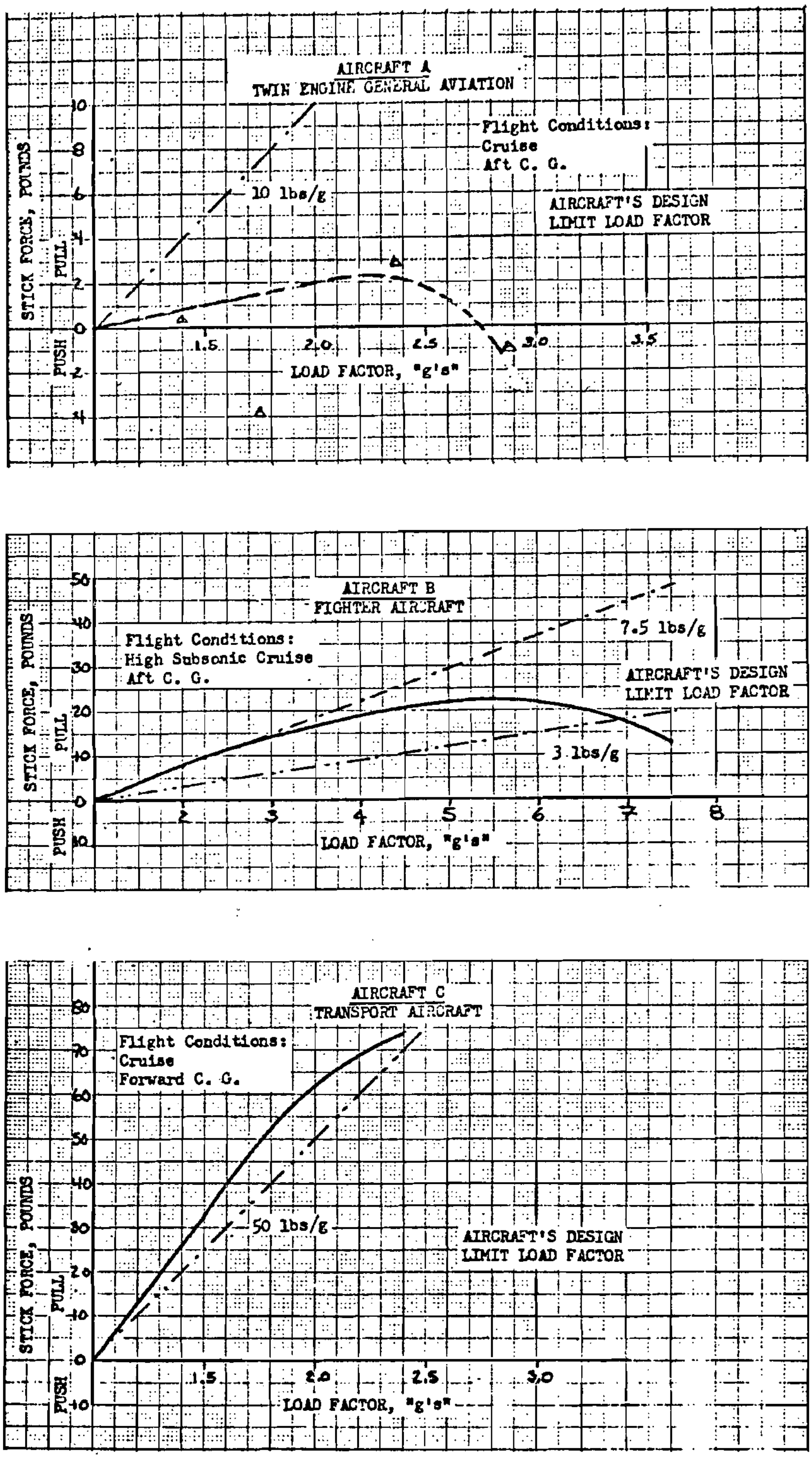

Figure 8

Three Aircrafts' Maneuvering Stability Curves

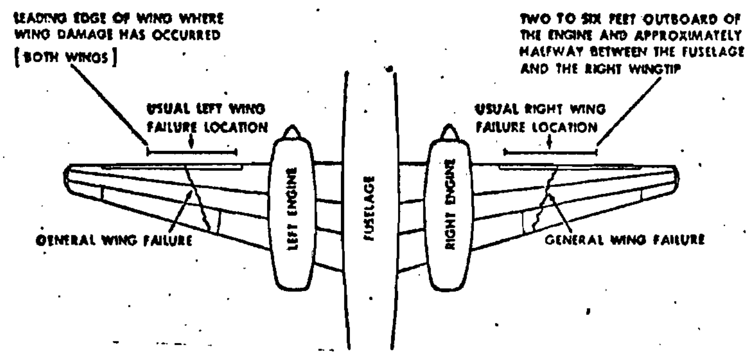

Figure 9

Illustration of Location of Damage or Failure to Aircraft Wings

FLIGHT SAFETY THROUGH AN IMPROVED TRAINING AIRPLANE

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At present there is no general aviation airplane specifically designed for flight instruction. The aircraft used for virtually all civilian flight instruction are the lowest priced, usually two-place airplanes on the market. Some of these airplanes are not approved for all training maneuvers, such as intentional spins. In fact, one airplane — advertised specifically as a trainer — does not even offer dual controls as standard equipment.

Based on flight instruction experience, we feel that the ideal training airplane should have definite characteristics. It should not be "easy to fly," but it should be forgiving a abuse It should be capable of demonstrating some of the common shortcomings found in the general aviation fleet. The airplane should be able to be spun safely.

Furthermore, the instructor should have a tool which he can use as a training aid. The training airplane should allow demonstration of aerodynamic basics -- facts that a novice (or even an experienced) pilot may find hard to believe. One of the most difficult concepts to convey is rudder/aileron coordination when instructing in an airplane with bungee interconnection.

The instrument panel of the training airplane should also be designed in light of using it as a training aid. The student's panel should be designed to show typical instrument deficiencies and failures. The primary flight instruments (those required by airworthiness) should be located in front of the instructor.

This is really nothing but a low cost, general aviation "inflight simulator." This concept was developed by Cornell Aeronautical Laboratory for research purposes and extended to training.(1) Briefly, the CAL airframe is based on an Allison-Convair 580. A research cockpit was added in front with a total fly-by-wire control system. The control system provides front cockpit "seat-of-the-pants" response identical with the airplane being simulated. NASA is using somewhat the same technique in their Terminal Configured Vehicle program; in this case the airframe is a Boeing 737 with the research cockpit located in the rear. A less ambitious program was advanced by Byrnes and Johnson (2) who reported on a pilot program to use a Lockheed Jetstar as a training simulator for larger jet transports This took advantage of the similiarity in handling between the Jetstar and the Boeing 727. although other airplanes were simulated as well. More recently, a single-engine military trainer has been modified to allow it to simulate twin engine airplanes, complete with simulated engine out handling problems.(3)

In the design of an airplane, some attention must be paid to the mission(s) to be flown It may seem unnecessary, but we feel that we should state that the typical mission of the trainer is the flight lesson. A typical flight lesson is approximately one hour in length, originates and terminates at the same airport, and is followed by an approximately 15 minute turn-around. This mission suggests several characteristics which make an airplane suitable for the training mission.

Range and cruising speed are of secondary importance. Mechanical reliability, on the other hand, is quite important. As a rule, takeoff and landing performance is not critical, but should be representative of the general aviation fleet.

The airplane itself should provide a platform from which a lesson can be taught. The noise level and visibility should be of paramount importance. The airplane systems should not require too much attention from the instructor. A fine line, however, must be drawn between challenging the student and allowing him and the instructor to concetrate on the lesson.

The airplane should also be a good simulator of those characteristics likely to be encountered by the student at later times. This means that the trainer should demonstrate "bad" features of other airplanes. It should be possible to simulate or demonstrate the effect of overextending the airplane's or pilot's performance (such as high altitude takeoffs on a hot day, or operating outside of the weight/cg envelope). Systems emergencies should be easily simulated -- without endangering student or instructor.

In line with the simulation characteristics, other additional features would make teaching easier. The airplane should allow separation of variables. Each axis should be able to be controlled without input to or from other axes. In addition, small second-order effects could be exagerated in other portions of the lessons. An example might be adverse yaw At one part of the training syllabus, complete elimination of adverse yaw would be in order; at another, adverse yaw should be exagerated.

Other items of the trainer's configuration have some effect, but the choice isn't clear: fixed vs. retractible gear, low vs. high wing, and two vs. four place. Fixed gear would appear to be the logical choice for a trainer, except that speed brakes might be an appropriate tool to demonstrate the effect of drag. Retractible gear would be a simple form of speed brakes. The low-wing/high-wing dichotomy is not at all clear. The only clear advantage might be tufting the upper surface of a low-wing airplane for flow visualization.(4)

Most existing trainers are two-place. A four-place trainer would allow students to ride and observe other students and thus accelerate their own learning.

SPECIFIC CHARACTERISTICS DESIRED IN A TRAINING AIRPLANE

Instruments and Systems

The instrument panel should not be simply the conventional arrangement. It should be laid out with the basic goal in mind — flight instruction. The student's panel should appear at first glance to be a conventional full panel. However it should have deviations where appropriate for the lesson

The student's static and pitot sources should be routed through a slector (controlled by the instructor) to one of several sources The different sources would show the effect of typical position errors found in the civil fleet. One source would be blocked to simulate icing.

The instructor should have a "trouble panel" with means to disable any of the student's instruments. Actual instrument failure is quite different from simply covering the gauge face with a card All required flight instruments should be duplicated on the instructor's panel without failure modes. The electrical system should be routed through the instructor's "trouble panel" with individual circuit breakers. Other systems should allow instructor induced failure modes.

The student's panel should include angle-of-attack and angle-of sideslip gauges.

Sufficent systems automation should be included to allow instructor and student to concentrate on the lesson. At the same time, this automation should not decrease overall reliability.

Performance

Aircraft performance is one of the least understood areas by general aviation pilots. The training airplane's performance should be carefully documented. The degree of documentation should be greater than that for existing airplanes for no other reason than to acquaint the student with the existence of more complete documentation. Data should be available for all possible takeoff and landing configurations, preferably in a variety of formats. With touch and go landings so popular, adequate touch and go performance data and procedures should be available to the instructor. It is left up to the instructor's judgment when to abandon the touch and go and convert to a full stop, but he has no data on which to base this decision.(5)

The effect of airplane configuration, of angle-of-attack and of-sideslip, and of power should be able to be shown. Lift and drag should be variables, i. e. spoilers and dive breaks would be desirable

While takeoff and landing performance is not critical, the performance levels should be high enough to allow simulated high altitude performance degradation demonstrations. Not only could poor high altitude performance be shown, but an actual demonstration of premature liftoff and resulting inability to climb out of ground effect. Possibly gross weight changes would be needed as well In any event, the airplane should have a large useful load capability to permit large gross weight variations.

Longitudinal Stability and Control

Since most airplanes can be easily loaded outside of the cg envelope, demonstration of cg shift is most important. The primary effect of a cg shift is decreased stability and stick forces as the cg moves aft. If the cg could be shifted during flight, these effects could be made quite clear. Using disposable ballast, the cg/weight could be changed from forward cg/maximum weight to aft cg/maximum weight to intermediate cg/reduced weight in flight. Such a variation could be a valuable teaching tool.

It would even be desirable to shift the cg aft of the neutral point to show the effect of an unstable airplane. Adequate safeguards, both equipment and procedures, must surround such a d monstration.

Some airplanes have bobweights or downsprings added to improve static longitudinal stability As Neal (6,7) points out, these can have a deleterious effect on the pilot's ability to control longitudinal oscillations. Undamped phugoid oscillations can make airspeed and flight path control very difficult. These are often the result of adding downsprings to compensate for an aft cg Demonstrations of these effects would probably only be useful to advanced students

Lateral-Directional Stability and Control

Low damping of the lateral-directional oscillation (Dutch roll) can create a very uncomfortable ride for the pilot and passenger. It can also present control problems, particularly during the landing. Dutch roll is often excited by adverse yaw. Most light general aviation airplanes have some adverse yaw from aileron deflection. Depending on the portion of the flight syllabus, either complete elimination of adverse yaw, or its exaggeration would be in order.

Most light airplanes have small amounts of spiral instability. This can have significant effects on the pilot's ability to fly the airplane while on instruments. This is the cause of the classic "graveyard spiral" accident.

All three of these effects would be worthwhile to demonstrate to students during their training It would probably be difficult to rig a device similiar to shifting ballast to demonstrate lateral-directional stability effects. In all likelihood, some form of negative stability augmentation would be needed, such as an autopilot working out of phase.

Stall-Spin Behavior

Every year, one of the leading causes of accidents is the stall/spin accident. Most light airplane pilots are happily ignorant of any but gentle stalls and any kind of spin. It could be very instructive to attempt to demonstrate spins at several different cg locations, and at various moments of inertia. Moments of inertia could be varied by having tip tanks full of liquid ballast. While this could be instructive, it would also be quite tricky. We will not consider spinning the training airplane beyond the normal "intentional spins permitted" envelope. Performing stalls at both forward and aft cg limits would be a valid training exercise, however.

Autopilot

In the preceeding subsections, we have touched on selected flight characteristics desired in a flight trainer To achieve them, it is likely that a suitable autopilot will be needed This autopilot will perform several functions: stability augmentation/deaugmentation, separation of variables, and demonstration of principles.

When actually equiping the airplane, there are two basic approaches to the control system: (1) equip each control axis with control surface servos into which the appropriate airplane responses are fed back; and (2) make simple modifications to a stanard autopilot. The first method produces a very high quality simulation, such as that needed for research. Method (2) is much simpler, more reliable, cheaper, and will involve a minimum of certification headaches. It does have the disadvantage of moving the pilot's controls, which can be annoying.

The autopilot approach would be needed for the demonstration of principles, also. Here we mean that the autopilot will be set up to fly the airplane at constant airspeed, at constant pitch attitude, etc. to demonstrate concretely to the student the effect of ehat he is trying to do. The autopilot is used to free the instructor to teach.

Make or Buy?

Given the requirements for a basic airframe, summarized in Table I, the choice is now, "Should we design a new airframe or modify an existing one?" While cost is not the overriding factor, it can not be ignored. Modification of a suitable existing design would be

TABLE I

BASIC AIRFRAME REQUIREMENTS

FOR A TRAINER

- o Two or four place
- o Good basic handling (it is easier to detune than to tune handling qualities.)
- o Safely spinnable
- o Single engine
- o Large useful load fraction
- o Simple systems
- o Reasonable performance

cheaper than a brand new design. With these requirements in mind, we can survey the market and see which light airplane comes closest to meeting the requirements. Suitable candidate airframes are the Grumman American Yankee, the Cessna 150 and 172, the Piper PA-22 and PA-28, the Beech Musketeer, and the Bellanca Champion.

We can reject the unspinnable Yankee on first examination. We shall further reject the Piper PA-22 as being non-representative of the general aviation fleet, in spite of its low potential cost and interesting flying qualities. To give a reasonable useful load fraction and some room for added systems and observers, we shall asso drop the two 2-place airplanes, the Cessna 150 and the Bellanca Champion. Of the remaining three, we shall make an arbitrary choice of the Piper PA-28, influenced in part by its relatively high useful load fraction and the availability of a retractible gear option for future growth.

The rest of this paper will outline proposed modifications to the flight instrument system and the design of a water ballast system to allow the cg to be varied in flight.

FLIGHT INSTRUMENT DISPLAY

Every airplane has a set of instruments whose purpose is to assist the pilot in flying the airplane. The instrument display provides the pilot with non-sensory data (e. g. orientation relative to magnetic north) or which he cannot sense accurately enough (e. g. alttude in visual flight conditions). According to Foxworth and Newman,(8,9) this data can be divided into three classes: Aerodynamic performance, Navigation in three dimensions, and Systems monitoring. Table II shows a list of flight instruments found in a typical light airplane together with any external sensors or power supplies.

What criteria do we have for the design of instrument displays and associated controls? Two criteria seem obvious: ease of use and tolerance of failures. First the display should be easy and natural to use correctly and difficult to use incorrectly. Specific design criteria can be found from a human factors text, such as McCormick.(10) Related items should be grouped together and have mutual compatibility. Angle-of-attack gauges

TABLE II

TYPICAL GENERAL AVIATION

FLIGHT INSTRUMENTS

Instrument	External Sensors	Power Supply	Failure Indicator
Airspeed	Pitot Tube Static Source	Electric Heat -	-
Altimeter	Static Source	-	-
Vertical Speed	Static Source	-	-
Turn and Bank	-	Electric	-
Attitude Gyro	-	Vacuum	Vacuum Gauge
Direction Gyro	-	Vacuum	Vacuum Gauge
Compass	-	-	-
Radio Navigation	Radio Signal	Electric	Warning Flag
Stall Warning	Angle-of-Attack	Electric	-
Oil Temperature	Thermistor	Electric	-
Oil Pressure	Probe	-	-
Cylinder Head Temperature	Thermocouple	-	-
Manifold Press	Probe	-	-
Fuel Quantity	Float Position	Electric	-
Fuel Pressure	Probe	-	-
Tachometer	Tach Drive	-	-

should move in the same sense as airspeed indicators as the airplane is manuevered. This means that angle-of-attack gauges should increase in a counter-clockwise sense. Critical instruments and controls should have a central location with less important items removed to a peripheral location. Critical in this sense is restricted to items operated or used in flight.(11) As an example, ignition switches should be removed from the critical areas and not placed next to fuel pump switches as is done on some airplanes.

The second criterion, failure tolerance, includes both easy recognition of failure and operability after failure Van Vlaenderen (12) developed a logical pattern for instruments to maximize the probability of error detection and at the same time provide for a flyable display even with a malfunction. Newman and Foxworth (9,13) have amplified these criteria for transport airplanes. However, very little has been done for light airplanes. Hasbrook represents the principal work to date.(14)

In addition to these criteria for all airplanes, trainers have others. The trainer display must be adaptive, must demonstrate principles, must be capable of simulating failures, and must be resistant to instruction-induced failures. An adaptive panel would allow the difficulty of use to vary with the student's progress. It is an accepted training technique (15,16) to start the student with a simple part-task and gradually increase the workload as his ability progresses. Flight instructors during early lessons assume much of the workload; navigation, systems monitoring, perhaps even flying the airplane about one or more axes. It follows that the panel should be designed for ease of use, but readily degraded to make it less easy to use. As much technology as possible should be included in the trainer's cockpit.

To demonstrate principles, specific instruments or variants may be required — angle-of-attack and of-sideslip, fully caging gyros, good demonstration of static and pitot error, to name a few System failures must be able to be produced with interuptable power supplies or sensors

Lastly, the interuptable power supply to the gyros and caging locks will be necessary to minimize wear and damage during spins or other extreme manuevers.

How well do today's general aviation aircraft fit these criteria? In our opinion, not very well at all. Most light airplane panels are not easy to use -- navigation displays spread all over the panel, identical switches located adjacent to each other, extremely hard to detect failure modes, to name a few. Even if panels comply with existing standards and recommended practices, they are still too hard to use correctly and do not lend themselves to easy failure detection.

We must minimize the effect of failures on the flyability of the airplane. Table III lists significant instrument failures common in general aviation airplanes. It is interesting to note that single failures can not normally disable both the rate gyro (turn and bank) and the attitude and direction gyros. This is typical practice for single engine airplanes. However, a recent incident did show that a single failure could disable both without any instrument showing an abnormal indication.(17) In the absence of instruments that will display failure modes prominently, we must redouble our efforts to train pilots to recognize erratic readings.

Additional hardware will be needed to supply accurate pitot and static pressures and angles-of-attack and of-sideslip. Reference 18 discusses some of the problems associated with accurate measurement of these quantities in flight. Additional, other representative pitot/static sources will be installed to give the student some idea of the range of position errors in the general aviation fleet. Figure 1 shows the block sketch of the display. (More detailed drawings are available from the authors.(19))

VARIABLE CENTER-OF-GRAVITY SYSTEM

Since it is relatively easy for any airplane to be loaded outside of its allowable weight and center-of-gravity (cg) envelope, and since the loading has definite effects on both handling qualities and the overall performance, a training airplane should demonstrate these effects of loading to the student.

While improper loading is cited relatively infrequently as a cause of aircraft accidents — it contributed to 18 fatal general aviation accidents in the US during 1969 (20)—

TABLE III

INSTRUMENT FAILURES

System	Specific Failure	Indications (in PA-28)	Problem	Typical Simulation[a]
Electrical system	Loss of alternator[b]	Ammeter reads zero	Rapid depletion of battery	-
	Component short	Popped breaker	Loss of component	Pull breaker
	Bus short	Popped generator breaker; possible fire	Loss of system, fire	-
Vacuum system	Loss of pump	Vacuum reads zero	Gyros drift down and spill	Cover with card
	Leak	Vacuum reads low	Gyros read erratically	Cover with card
Pitot tube	Plugged	Erratic reading	Erratic reading	Cover with card
	Leak	-	Incorrect reading	Cover with card
Static source	Plugged	-	Erratic airspeed, altimeter, vertical speed	Cover with card
	Leak	-	Slight error in airspeed and altimeter	-
Radios (ILS,VOR)	Loss of signal	Warning flag	No reading	Pull breaker
	Loss of power	Warning flag	No reading	Pull breaker
Radios (ADF)	Loss of signal	Needle hunting	No reading	Mis-tune radio
	Loss of power	-	No reading	Pull breaker
Gyros	Precession	-	Incorrect reading	Cover with card
	Loss of power	Vacuum reading	Slowly increasing precession	Cover with card
	Violent maneuver	Wildly erratic	Wildly erratic reading	Cover with card

(a) The simulation that is usually done in flight instruction.
(b) or loss of generator

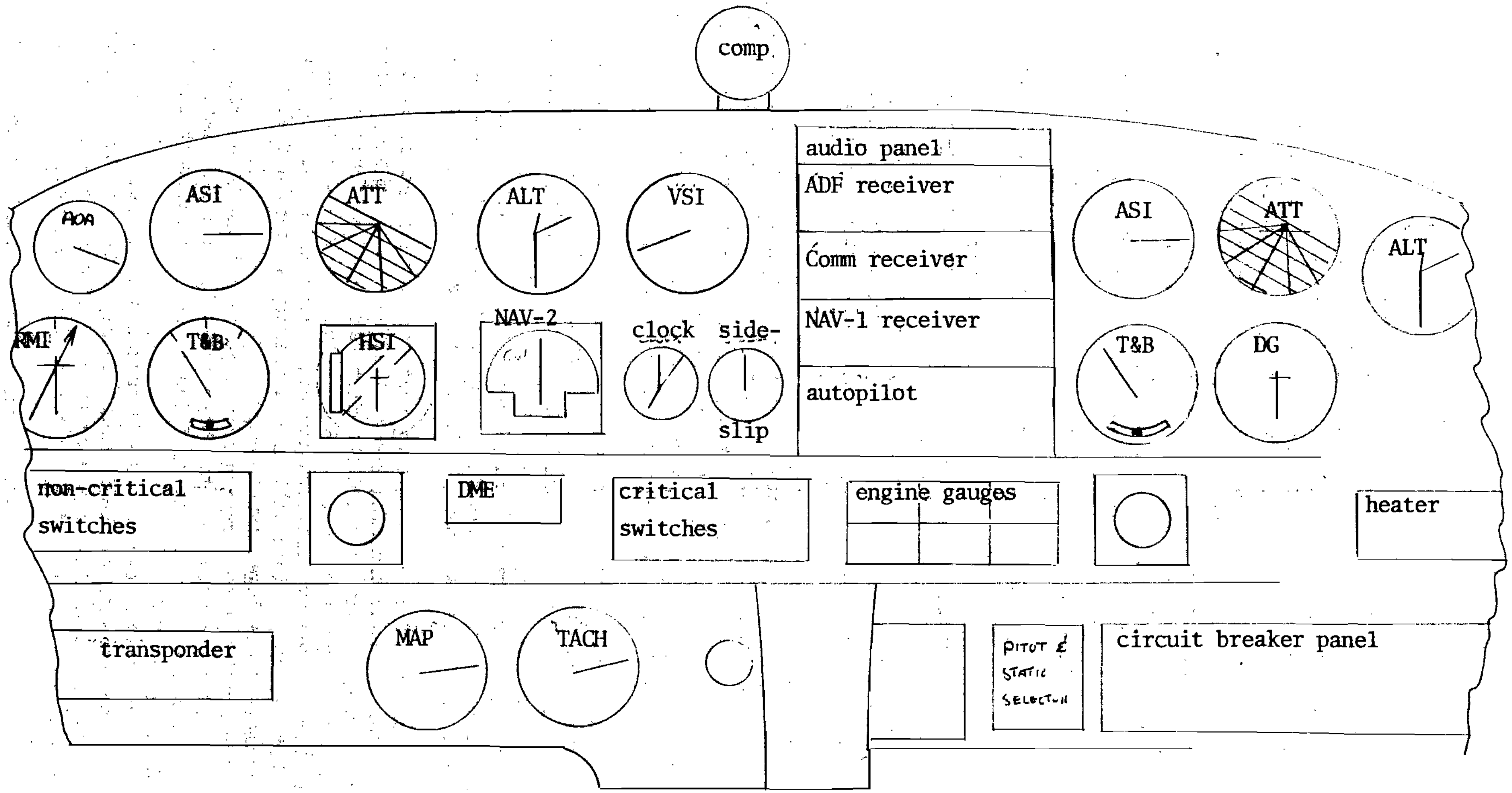

Figure 1

INSTRUMENT PANEL FOR TRAINER

it is probably more serious than these statistics would indicate. Improper loading would likely be cited as a causal factor only if the load were illegal. It would be difficult to assign improper loading as a factor if the load, while degrading the aircraft's flying qualities, was still within the legal limits. One cannot help but wonder if many stall/spin, high density altitude, or loss of control/instruments accidents were in part a result of reduced performance or reduced handling qualities. This would be especially true for inexperienced pilots. The CAB has cited at least one instance of a legal, but reduced stick force gradient as the cause of a loss of control in turbulence accident.(21)

It is interesting to note the pilot reaction to flying statically unstable airplanes, airplanes with the cg aft of the neutral point. While these airplanes are easy to over-control because of the very light stick forces, "...flying qualities for a visual manuevering task are good."(22) In contrast to the visual task, the instrument flying task is quite difficult Perhaps the most dangerous aspect of the reduced stick forces is not the light forces per se, but the change from what the pilot is used to.(23) This was brought out in the CAB report cited above.

Neal (6,7) discussed some of the dynamic problems resulting from attempting to artificially increase the static margin with downsprings or bobweights. Unfortunately these devices introduce new dynamics into the longitudinal response. Demonstration of all of these effects, however, is beyond the ability (and the scope) of the training airplane. These effects will be left to advanced research airplanes.

The Cornell TIFS airplane simulates the effects of loading with a fly-by-wire control system and programmed responses using an airborne computer.(1) This would be impractical for a light airplane to be used in flight instruction. Therefore we propose a moveable water ballast system.

The following ground rules were selected for the preliminary design: minimal changes to the basic airframe, simple pump and transfer system, redunancy against landing outside of Normal Category envelope, and no tanks or components shifted forward of firewall or into Subject to these constraints, the following arrangement was found to be satisfactory: 14.5 gal of water shifted between a tank at station 81.5 (under pilot seats) to a tank at station 228 (rear fuselage bulkhead); and 21.7 gal of water shifted between a tank at station 100 (rear seat hardpoints) to a tank in the baggage compartment. This provides 300 lb of disposable weight and a total moment change of 24540 in lb.

To keep the empty weight and moment within reasonable bounds, the battery was relocatted forward and the wheel fairings removed. Even with these changes, operation in the Utility Category restricts the load to two pilots and 1:20 fuel. (The basic PA-28 allows two pilots and 1:00 fuel in the Utility Category.)

Even with the most forward cg in the trainer, the forward loading limit cannot be reached with any disposable ballast. In the basic PA-28, there is no way to reach the forward cg limit. (A worst case: zero fuel and two 300 lb pilots has a cg location 3.8 in aft of the forward limit.)

Figure 2 shows the amount of variation in weight/cg that can be accomadated by the ballast system. This allows four separate training missions to be flown: Utility Category with two 190 lb pilots, Normal Category with two 170 lb pilots and optional observer, Normal Category weight and balance demonstration, and Restricted Category weight and balance demonstration. The Normal Category demonstration will restrict the aft cg travel to the certified limit for that category. This will give a primary student a feel for what can happen within the limits of the legal envelope.

For advanced students, the loading demonstration should go beyond the legal limit and include demonstration of cg aft of the neutral point. Unfortunately this information is not available, so it will be necessary to locate it by flight test. The aftmost limit shown in Figure 2 corresponds to 33 7% MAC.

It will be necessary to insure that water in the aft tank can be dumped. A failsafe dump design similiar to a flush toilet with two ball plugs and separate activating wires has been designed. The dumps are on each side in the event centrifugal force displaces the water to one side. Vents at the top will allow for discharge in unusual attitudes or in case of overfilling.

Since the demonstration of aft cg will be beyond certificated limits, a supplemental

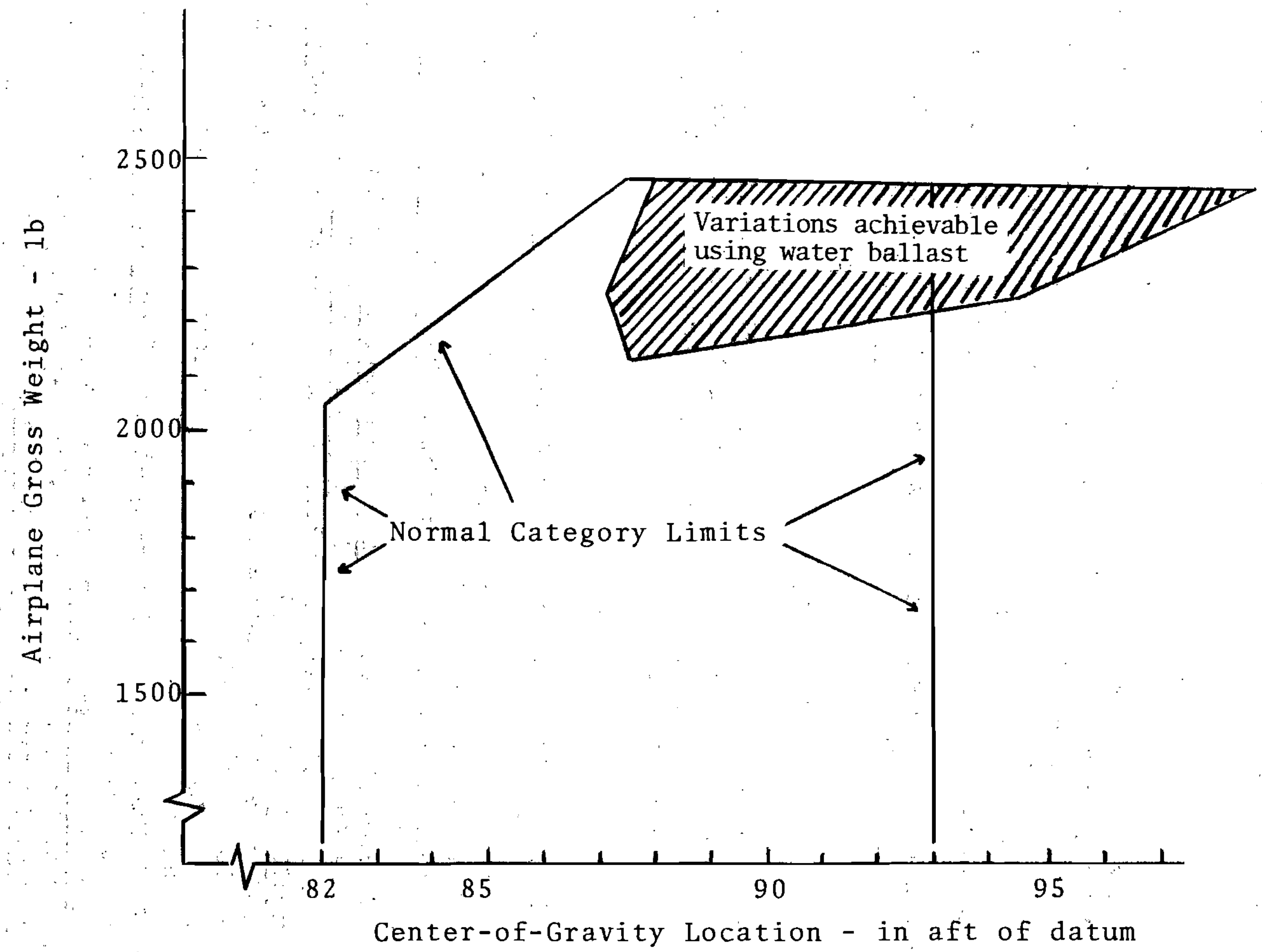

Figure 2

WEIGHT AND CG ENVELOPE FOR TRAINER
DURING LOADING DEMONSTRATION

type certificate will be needed to certify the airplane in the Restricted Category for the purposes of the demonstration. Requirements for a Restricted Category certificate require no unsafe conditions when used under the limitations prescribed. The following operational limitations are expected: takeoff and landing within Normal Category limits, Aft tank empty for takeoff and landing, Occupants restricted to dual student and approved instructor, Smooth air, Minimum air temperature of 35°F, Minimum altitude for demonstration to be determined from flight test, Allowable speed range to be determined from flight test, Flaps up, Inspect rear fuselage before further flight.

Flight test will verify the ability of the instructor to regain control if the airspeed limits are exceeded with the minimum altitude required to reflect the actual altitude lost.

SUMMARY

At this point, we have outlined modifications to an existing airframe to allow the flight instructor to do his job more easily. These modifications include changes to the instrument panel and a variable center-of-gravity system to demonstrate the effect of incorrect loading. We recognize that this is only a preliminary effort, but it is a necessary part of any instructional aircraft. Future work to develop an airplane to demonstrate the effect of both longitudinal and lateral loading on spin recovery would also be needed.

By necessity, this paper has skipped over many of the details. The original report goes into more detail and has drawings of the installations.(19) Copies are available from the authors.

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COMMUNICATION/COORDINATION . . . THE KEY TOWARD IMPROVED CABIN SAFETY

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Crewmember safety and well-being, in addition to passenger safety and survivability, cannot be over-emphasized and play a major role in the total aviation picture at this point in time and as it relates to the future of the aviation system in the United States. Without considerations of cabin safety, passenger safety and survivability, and the vital cockpit/cabin crewmember input, the aviation system is not complete, for these are integral parts of the system. We are all "users", users of the system we are all trying so desperately to improve and advance through safety efforts within the respective unions, airlines, civil and governmental organizations. The advancing "state-of-the-art" in aviation safety today can strengthen and aggrandize the United States aviation system and its recognition as a leader in this regard.

Efforts are currently underway to establish an improved rapport between field operations, specifically crewmembers representing our nation's air carriers, and the Federal Aviation Administration in Washington, D.C. It is encouraging, indeed, to see first-hand this changing scene, the realistic thinking, all of which will serve to enhance our progress in this area.

Particular attention is being focused on cabin safety, the flight attendant and the promotion of safety awareness throughout the aviation community. This is being achieved through the efforts of all elements of the system, of which we all are a part. A greater understanding of each other's responsibilities and a desire to work together to achieve an increased level of safety for all has added to the improvements being seen at this time.

This new approach to solving the problems inherent within everyday air carrier operations, especially as they relate to cabin crewmembers, has come about through efforts being focused initially on the local level, namely, with the Federal Aviation Administration's Air Carrier District Offices and their Principal Operations and Maintenance Inspectors assigned to the certificate holders. From that point, the communication has continued to the Regional Offices and Flight Standards Service in Washington, D.C.

Additionally, the establishment of a specific position devoted solely to cabin safety and flight attendants within the Air Carrier Division of Flight Standards Service has served to bridge the gap and provide the liaison so necessary in this element of the system. The Federal Aviation Administration's recognition of the requirement for this liaison, this continuous feedback, illustrates the concern and futuristic approach evident in our government today.

To further illustrate the advanced thinking with respect to cabin safety, and particularly cabin crewmembers, specific proposed rulemaking changes are currently under consideration to provide for a safer working environment and to significantly improve the safety and survivability for our nation's flight attendants, thereby insuring their vital leadership in any non-routine situation. These proposed rulemaking changes are a part of the First Biennial Airworthiness Review held in December 1974 and the forthcoming Operations Review.

The following discussion highlights some of the projects underway which relate to crewmember and passenger safety and survivability in air carrier operations:

Passenger Information/Education: A concentrated effort is being made to augment the amount and manner of presentation of safety information to the traveling public through the use of advanced concepts, such as audio-visual techniques. Some of the additional safety information to be provided will include not only the location but operation of emergency exits, use and operation of the oxygen system, emergency equipment, overwater provisions, etc. Additionally, efforts are being made to present the Federal Aviation Regulations applicable to the passenger in a manner to furnish the passenger with a better understanding of those regulations established for their safety, why they exist and should be complied with. Consideration is also being given to upgrading the safety information card -- an important element in the education of our traveling public. These efforts will assist in evacuation and survivability, in addition to greatly assisting cabin crewmembers in the performance of their duties and promoting a greater awareness of safety.

Flight Attendant Seating Installations: On 7 August 1975, a Notice of Proposed Rulemaking was issued to amend Part 39 of the Federal Aviation Regulations by adding an airworthiness directive applicable to specific transport category aircraft. To prevent injuries to flight attendants, to insure their ability to perform required duties under emergency conditions, and to insure occupant access to emergency exits, certain seats -- including side-facing installations -- are to be removed. Specific criteria are also set forth for any replacement seats to be approved by the Federal Aviation Administration Regions to include the following:

1. Be located near an approved floor level emergency exit;
2. Be equipped with a restraint system consisting of a combined safety belt and shoulder harness unit with a single-point release;
3. Have a means to secure each combined safety belt and shoulder harness, when not in use, to prevent interference with rapid egress in an emergency;
4. Be located to provide a view of the cabin area for which the flight attendant is individually responsible and to provide access to the communications system when seated;
5. Be forward-facing or rearward facing. In either case, the installation must have an energy absorbing rest that is designed to support the arms, shoulders, head and spine;
6. Be positioned to prevent interference with the use of passageways and exits; and
7. Be located to minimize the probability of its occupants suffering injury during any operation by being struck by items dislodged in a galley, or from a stowage compartment or serving cart. All items expected in these locations in service must be considered.

This action should significantly improve the safety and survivability for the cabin flight attendants, reduce injuries, and insure that their vital leadership will be available to the passengers under any non-routine occurrence.

Cabin Crewmember Training Programs: Significant proposals are included in the First Biennial Operations Review to commence in December 1975 relative to the subject of cabin crewmember training. The proposals pertain to initial, recurrent and transition training and include enhancement of curricula in the specific areas of emergency equipment, systems, evacuation and first aid. A prime factor considered in the proposals is "hands-on" training -- a concept to insure a thorough knowledge and understanding of the location and operation of the equipment and systems onboard the specific aircraft.

This frequent exposure and actual operation of exits/equipment, whether in initial, recurrent or transition training, should advance current training programs provided by the air carriers. This rulemaking change directly affects the safety and survivability of the traveling public. It will insure that each cabin crewmember recognizes responsibilities for the safety of passengers, and understands and is able to perform the duties required to furnish them maximum guidance and assistance in an emergency situation.

Flight Attendant Uniform Flammability: Current work on this subject includes a contract to develop a fire-protective overgarment to be used in-flight by the flight attendants in an effort to increase the time available and ability of the flight attendants to provide the vital leadership and assistance in an emergency evacuation involving post-crash fire, in addition to in-cabin occurrences. Also, current National

Bureau of Standards research and testing will define the burn testing parameters and degree of protection a fabric should provide. This data will allow for the development of uniform standards for the flight attendants, which is an ongoing effort.

Child Restraint Systems: A growing need for protection to infants and small children traveling aboard our air carrier aircraft provided the basis to initiate a project to develop criteria for approving future restraint systems and testing a prototype design. The Civil Aeromedical Institute (CAMI) was assigned this work. The forthcoming report of this effort will provide the basis for issuance of a Notice of Proposed Rulemaking on this subject. The current efforts in this area of concern will support a requirement for rulemaking change and insure protection to our small travelers.

Emergency Evacuation: Many elements related to evacuation in an emergency situation are currently under consideration for rulemaking change through proposals included in the First Biennial Airworthiness Review and forthcoming Operations Review. Specifically, emergency lighting requirements are proposed to be upgraded and intensified, in addition to the consideration of new lighting concepts. In 1974 an emergency evacuation demonstration, under simulated smoke conditions, was held for the purpose of examining the human factor aspects and of getting a first-hand look at both existing and new lighting concepts within an obscured atmosphere. Preliminary information provided some favorable results; however, it was concluded from demonstrations that more positive and controlled conditions must be developed for future testing (such testing is currently being planned).

Additionally, through proposed rulemaking change, slide/raft performance and reliability will be increased. Specific attention has been given to wide-bodied aircraft. Efforts in this area directly relate to survivability aspects of all aircraft occupants.

As discussed above, the augmentation of passenger information and education and the improvement of cabin crewmember training will serve to provide for successful evacuations, reduce injuries, and significantly increase the survivability rate for all occupants aboard our air carrier aircraft.

Through the work discussed above which encompasses a coordinated effort between all elements of the aviation community . . . the new communication underway . . . the vital exchange of knowledge and expertise to support change . . . definite advancements are envisioned to significantly improve cabin safety in the United States and ultimately provide for a higher level of safety for our traveling public.

A STUDY OF RIGGING

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A number of general aviation accidents has taken place as a result of improper assembly and adjustment of primary or secondary control systems. Although procedures used in rigging are peculiar to each aircraft model, some degree of standardization of methods would seem to offer means of reducing errors arising in the performance of these diverse procedures. This study was undertaken to examine the problem.

Examination of Government Documents

First the study of representative Federal Aviation Agency documents was made to determine what guidance is furnished manufacturers in their systems design and in preparation of manuals used by those doing the rigging. Then a manual for the training of mechanics was reviewed.

Airworthiness regulations (FAR Parts 23, 27 and 29) for fixed wing and rotary winged aircraft contain some requirements which should facilitate safe and proper rigging. Part 23 requires that when an adjustable stabilizer is used it must have stops limiting travel range to that allowing safe flight and landing. It also requires that trimming devices must continue to operate normally in the event of failure of an element of the primary controls. Further, each element in the flight control system must be so designed or marked to minimize the possibility of incorrect assembly. There must be reference marks for leveling the aircraft on the ground.

The helicopter airworthiness requirements (Parts 27 and 29) also require each control element to be designed or marked to avoid improper assembly. Stops are required both on the pilot's controls and on the main rotor blade hinges to limit movement.

The mechanic training manual reviewed was Advisory Circular 65-15, "Airframe & Powerplant Mechanics Airframe Handbook", Chapter 2, 'Assembly and Rigging'. This handbook turned out to be a surprise because it contained many errors, some simply a result of lack of knowledge or carelessness on the part of the author, but some of a nature that could lead to accidents. For example, to rig a trim tab the reader is informed, "The trim tab control is set to the neutral (no trim) position, and the surface tab is usually adjusted to streamline with the control surface". Then, if one examines a sketch labeled, "A - Trim Tab", it is seen to be a servo tab with an adjustable linkage. The consequence of following this instruction for a trim tab on a servo tab could be catastrophic. In the same sketch an antiservo tab is misidentified as a balance tab. In another paragraph it is stated, "A control surface that is statically balanced will also be dynamically balanced".

Examination of Example Aircraft Owner and Maintenance Manuals

Six examples of manuals have been chosen as being representative of current practice. They were selected from FAA Type-certificated general aviation types believed to cover the spectrum of usage. They included a foreign-built high-performance sailplane, an agricultural aircraft, two private owner airplanes and a light helicopter. The manufacturers' identities will not be disclosed, however they are all different and represent both small and large manufacturers. These manuals were examined to determine general rigging procedures laid down, type of tools and fixtures employed and principles and references utilized.

The foreign-built sailplane's flight and service manual is a translation of the manual approved by the country of origin. of the 31 pages of text in this manual, 19 are in the flight manual portion, five in maintenance and six in repair. The rigging instructions are concerned only with assembly of the aircraft. No control rigging procedures are given nor are tools or fixtures mentioned. The rigging of controls is covered in a three-view drawing giving the limits of control throws of ailerons and tail surfaces both in degrees and as offsets. The means of determining the reference zero for these throws is nowhere mentioned and the positioning of the cockpit controls is also omitted. The aircraft is also fitted with dive brakes and a tail parachute. No rigging instructions are contained for them.

The agricultural aircraft has a manual containing an illustrated parts list. Two and one-half pages of text are devoted to assembly and rigging of controls. Control deflections are given for all surfaces except for the trim tab. Ailerons are rigged with respect to the adjacent wing surface with control stick centered. The rudder, which has a full horn balance, is centered with the rudder pedals in neutral. Similar rigging instructions for the elevator with respect to stick position are, however, absent. There are no unusual features in this aircraft's control system and no special tools are prescribed.

The first private owner aircraft has a manual containing step-by-step rigging procedures for all controls. Ailerons are set to neutral using the flaps in the full up position as a reference. Travel then is checked using an inclinometer. The aircraft is equipped with an all-moving tailplane. Its neutral is by alignment of a rivet in the tail to a drilled hole in the fuselage. The neutral position of the control column is established by measurement in the cabin of its position with respect to the instrument panel. The inclinometer again is used to check travel of both the tail and the tab. The tab is neutralized with respect to the tailplane. The rudder is rigged by neutralizing using 2 x 4's clamped to the fin and blocking to obtain symmetry. A pointer is then fashioned from soft wire and throws of the trailing edge from the wire measured to assure proper travel. Thus this manual gives a level of detail much greater than the previous two aircraft manuals, using the airframe as the reference and one special tool, one makeshift fixture and an inclinometer for travel. Caution and warning notices appear regarding reversing of controls in assembly and on maximum tab travel.

The second private owner aircraft is similar in size to the first and also has an all-moving horizontal tail. It too has step-by-step rigging instructions. Both the horizontal tail and flaps are rigged with respect to the fuselage using a bubble protractor at the surface with the fuselage leveled. Again the ailerons are rigged by fairing to the flaps, but with the aileron bellcranks also neutralized using a special tool which employs the wing structure as the reference. Differential rigging of the flaps on this aircraft is permitted as a means of correcting for wing heaviness. Rudder rigging is accomplished with bars and "C clamps" to neutralize the rudder pedals, then centering the rudder over the stabilizer assembly by means of a rod inserted in the trailing edge of the rudder. Throws also are measured using the rod's displacement from the centerline. Stabilizer travel is checked using a leveling bar fabricated by the user, placed at a prescribed location, both spanwise and chordwise, on the stabilizer. A bubble protractor is then placed on the bar and neutral and throws set with reference to fuselage level. Control wheel neutral is determined in relation to the instrument panel. The tab is rigged by setting the actuator a prescribed amount from the stop, then connecting the tab with it while aligned to the stabilizer. Although the rigging of the tab is stated clearly to be done with the stabilizer in neutral, the tab is called simply a "trim mechanism" without attention being drawn to its antiservo function.

The helicopter is of the single main rotor - tail rotor configuration and is equipped with hydraulic power for the cyclic and collective controls. This aircraft has a system of rigging contrasting markedly with the other four. Neutral settings of all controls are established by means of rigging pins at the pilot and actuator ends of the control systems (except for the pedals). Proper orientation of intermediate rods and cranks is assured through a table permitting presetting of rod lengths. Adjustment of lower cyclic and collective controls in rigging to neutral is confined to one pushrod per system at the actuator input location. The swashplate and blades are rigged to neutral using the manufacturer's special tools. Travel of the controls is specified in terms of output of the respective actuators and is set by adjusting the control stops. Rigging of the main rotor is completed by optical tracking of blades with adjustments being made to incidence rods or blade tabs as necessary to bring the blade tips into track. The anti-torque rotor is rigged using a pin at the screwjack actuator. Tension of the pedal cables is set by measuring the length of tensioning springs. No requirement for pedal position is given, however full actuator output has to be possible using the pedals. Blade angles are set by means of index marks on blades and hub with final settings determined by tracking.

Accidents Caused by Improper Rigging

Two accident cases will be introduced as an example each of incorrect assembly and adjustment of controls.

Following a failure in an elevator tab trim control cable the pilot landed and summoned a mechanic. The mechanic could not repair the cable so placed the tab in a neutral position and cleared the aircraft for a short flight. The pilot took off, radioed that he was unable to withstand the control forces and plunged to earth with fatal results. The tab used for trimming in this case was also an antiservo tab, and the mechanic had neutralized it with the elevator hanging in the full down position, resulting in nose down trim when the elevator was in the flight position.

In 1971 an older aircraft, following maintenance, took off with the aileron cables crossed. The pilot crashed without serious injury, but with substantial damage to the aircraft. This aircraft was not certificated under FAR Part 23 and no requirement existed for marking or design of control elements in the Part under which the aircraft had been certificated.

Results and Conclusions

This brief study of rigging has permitted some observations which are believed generally valid and which could lead to improved safety experience in rigging practice.

Examination of Government and manufacturers' manuals has shown that little in the way of standardization in rigging procedures exists.

Manufacturers' manuals exhibited a great range in detail on procedures from complete absence to careful step-by-step instructions. As an example of serious omission, in the case of the sailplane, which has very flexible wings, rigging of the dive brakes must be done with the wings supported in the bowed-up flight position. Inasmuch as rigging of aircraft is usually done with it resting on the landing gear, the failure to give instructions practically insures that its dive brake system will be improperly rigged by the owner or maintenance personnel.

It would seem that, unless step-by-step procedures are provided to the mechanic, that there will exist many chances for error. Such procedures serve as a check list for even the experienced mechanic. Further, the stating of procedures in a manual constitutes a standardization which, through simplification with its reduction of number of operations, reduces overall probability of error, given any level of probability of error per operation. Incidentally, simplification and standardization are basic elements in cost control, so that rather than expecting such a step taken to increase safety to extract its cost, it should reduce operating costs as well as secure savings from accident reduction.

Part 23 has been noted to contain a requirement for limited travel of the stabilizer to that for safe flight and landing. It may be well to extend this requirement to all aerodynamic surfaces used for trim purposes. In the case of servo tabs, excessive deflections may result in changes in hinge moment characteristics of a dangerous nature.

Incorrect assembly of controls is a classical error and the FARs have required manufacturers to minimize the possibilities for such errors. On older aircraft color coding of control joints can help. Also, if the aircraft has a pair of cables connecting similarly to a control, the replacement during disassembly of all fastener elements in the cable side for one and in the control side for the other not only codes the assembly, but furnishes the mechanic with the old parts for comparison when replacement is desired. The selection of a bolt one size longer which might result in interference is less likely when the old bolt is in hand.

It is suggested that the FAA rewrite Chapter 2 of their Airframe Handbook.

Comparison of manuals indicated a wide variety of rigging methods. From the systems viewpoint some appeared much more dependable than others. Two settings for each control must be established, a reference setting or neutral and a range of movement.

Setting a control to neutral by first leveling the fuselage then the control with a bubble protractor requires correct performance of two steps and that the fuselage remain level throughout. Protractors such as the double vernier-scaled propeller protractors are very easily misread. If these instruments must be placed correctly, both spanwise and chordwise, on the control surface, then many chances for errors exist. Setting controls with respect to the airframe eliminates problems with leveling. Use of factory produced special tools would appear to reduce the chance for fabrication error of shop made tools, however, the employment of rigging pins, properly flagged, should offer a simple system with a minimum opportunity for human error.

The setting of one control in relation to another (e.g., ailerons with respect to flaps) seems fundamentally wrong, if not always dangerous, when there is the chance that a mistake in setting of the reference control could result in improper rigging of the other.

Ideally the travel of a control should be measured directly. This can be accomplished either using offset measurements from neutral or in extension of actuator arms when attached directly to the control.

In some cases, such as aileron systems with differential, it is important that intermediate levers be rigged in conjunction with the pilot's and surface controls. Failure to do so may make correct rigging impossible and may result in excessive loads in the control linkages.

The manuals examined erred on the side of too little rather than too much information, and the caution and warning notes sometimes were trite and not really helpful. One such caution note advised the mechanic to be sure the controls were rigged properly. To be helpful the note should be specific. Any teacher soon learns that students are likely to make certain types of errors and supervisors soon learn which jobs cause problems in the shop. It is suggested that tests be conducted by manufacturers on service jobs using their manual and that the performance be measured. Where certain tasks show a sizable number of errors the manual should either be rewritten to clarify instructions or helpful caution notes be inserted.

It is believed that accidents due to improper rigging can be virtually eliminated. Aircraft, tools, manuals, regulations, procedures and training can be improved to a point where the incidence of accidents involving rigging is not significant. One way to such a goal is to study accidents, not only to determine their causes, but to examine all related factors with the objective of increasing the tolerance to human error or eliminating the opportunity for such error. Study of accidents by government, manufacturing, service and training personnel should seek not only improvements to the aircraft system in question, but also to look for improvements generally applicable to the broad spectrum of aircraft. Where possible, simplification and standardization of rigging procedures should offer rewards in safety without economic penalty.

INTRODUCTION TO MINISTRY OF TRANSPORT'S AVIATION SAFETY BUREAU

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In Canada, during the latter part of the nineteen sixties, commercial and general aviation were growing at such a rapid rate that the Ministry's responsibility under the Aeronautics Act for the control and safety of civil aeronautics was being seriously tested. It became patently clear to those in authority that a reorganization of the Civil Aeronautics Directorate was needed to keep pace with this dynamic growth.

As a prelude to the reorganization an Aviation Safety Division was created in 1970 with the responsibility to identify safety problems, research such problems and finally disseminate resulting safety information to all segments of the aviation community as a means of preventing accidents.

This was an area that, prior to 1970, had been lacking in the safety process and it is little wonder that Canada's aircraft accident rate was reaching unacceptably high figures. In effect the missing link had prevented safety information, emanating from accident investigations and subsequent reports, from reaching the aviation community. Much of that vital information gathered dust on our file shelves.

A concept of Systems Safety Management became a fact of life within the Ministry with the establishment of the new Division. To amplify this point, I would like to refer you to the chart which is now being projected on the screen (See Figure 1). We have attempted to describe, diagramatically, the role of an aviation safety agency in relation to all other civil aeronautics systems. On the left side of the chart, major components of these systems are depicted - comprising from the top a Policy Body, Service/Regulatory Bodies, and finally the Aviation Community. On the right side of the chart, we show what is referred to as an aviation safety agency (in the Ministry's case, the Aviation Safety Bureau) which I will elaborate on in a few moments. I would ask you to look upon this diagram as a "total system"; perhaps it could be viewed as a wheel, with anticlockwise motion. Starting at a point in the wheel where we show Policy Body, you will note that this authority provides <u>direction</u> to Service/Regulatory Bodies which in turn provide <u>control</u> to the Aviation Community. Many factors, related to the flying activities performed within the Aviation Community, contribute to inevitable failures of various system(s) (i.e. man, machine, environment). These failures are revealed in terms of an aircraft accident, aircraft incident or aviation hazard. As a result of such occurrences or conditions, vital data is fed into the Aviation Safety Bureau through voluntary information and, of course, investigations. These data are then analysed within the Bureau and provide the ingredients for formulating safety advice and recommendations which, to complete the safety process, are fed back to the appropriate segment(s) of the civil aeronautics systems.

At this point, I would like to give you a brief look at the organizational structure of our Aviation Safety Bureau. Earlier this year, as part of the reorganization plan within the Civil Aeronautics Directorate, the separate Aviation Safety and Aircraft Accident Investigation Divisions were amalgamated to form the Aviation Safety Bureau. This Bureau has branch status within the Civil Aeronautics Directorate and, as a staff function, the Director is responsible to and reports to the Director General, Civil Aeronautics. The Bureau is comprised of four Divisions, as you can see on this chart (See Figure 2), in addition to which there is an Administrative support unit. I am pleased to say that there are, on this morning's program, representatives from each of the four Divisions who will describe to you their roles and activities. I will simply state that the Objective of the Bureau is "to provide accident prevention advice and safety recommendations to civil aeronautics systems". To meet this responsibility, we have been assigned three primary roles:

i) to investigate aircraft accidents and aircraft incidents (to determine the circumstances for the sole purpose of preventing aircraft accidents);

ii) to identify and research aviation safety problems and hazards; and

iii) to establish and conduct programs to promote aviation safety.

Before I conclude my brief remarks I would like to make one distinction with respect to our Aviation Safety Recommendations. The Aviation Safety Bureau makes every effort to encourage and solicit safety proposals from our field investigators, headquarters investigators (who analyse field reports) and from any other reliable source within the Bureau, the Civil Aeronautics Directorate, and the Aviation Community. A safety proposal is directed to the Bureau's Aviation Safety Research Division where it is carefully and critically analysed, together with other factors, data and trends. From this process the Division's safety experts determine the nature, scope and degree of remedial action(s) that their findings suggest be taken - one of the following actions is normally applied, although in certain circumstances any combination could be required to obtain the most desirable and effective results: safety consultation with appropriate parties, dissemination of safety information/advice, or issuance of a formal Aviation Safety Recommendation. I make this distinction, because it is our view that Aviation Safety Recommendations emanating from more than one source within the Civil Aeronautics Directorate, or indeed within the Ministry, could conceivably create confusion or add to a safety problem. Don Douglas, who heads the Division, will later describe to you two methods we use in processing such recommendations.

I hope I have set the scene for the speakers to come and that you have a general impression of how we are organized and conduct our business. Thank you very much for your kind attention.

ENGINEERING LABORATORY FAILURE ANALYSIS AND ITS SAFETY IMPACT IN CANADA

by T.W. Heaslip*

A component fails resulting in a catastrophic sequence of events ending in an aircraft accident. Why did it fail? What was the mechanism? How can future occurrences be prevented? In Canada the Engineering Laboratory of the Aviation Safety Bureau has evolved over the past ten years into a comprehensive, technologically up-to-date engineering facility with the capability of providing such answers.

LABORATORY FACILITY

The Engineering Laboratory is divided into four Sections - Materials, Aeronautics, Avionics and General. The Materials Failure Analysis Section has specialists in metallurgical engineering , mechanical engineering, and mechanical technology; the Aeronautics Section has an aeronautical engineer who is a specialist in structures, performance, and crash-worthiness analysis; the Avionics Section has an engineer who is a specialist in avionics, instruments and electrical analysis; while the General Investigation Section has aircraft maintenance engineers who specialize in systems, powerplants, non-metallic materials and wreckage analysis. The varied backgrounds of the lab staff in professional engineering, technology, and aircraft maintenance engineering allows a good mix of theoretical and practical knowledge of aircraft problems.

The equipment resources for technical analysis and investigation were selectively acquired within our financial resources to ensure as much as possible universality in their use, to allow reasonable turn-around time on projects, and to build facilities which are abreast of current technology in support of failure analyses. A comprehensive physical metallurgy laboratory has been developed which includes all of the basic materials preparation equipment. An advanced projection microscope has been acquired. The Engineering Laboratory has all the standard hardness testers, a universal tensile tester, macro-photography cameras and stereo-microscopes. An advanced scanning electron microscope with a 3-D viewer gives the Laboratory an unparalleled failure analysis capability. An x-ray energy spectrometer is connected into the electron microscope for the chemical analysis of materials. A full range of precision measurement equipment including a motorized digital comparator with a large table is available for dimensional analysis. Presently a sophisticated impact tester for ELT and crash-worthiness studies is being built. Video-tape equipment is available for recording crash scenes, component disassemblies, etc. A good basic machine shop has been established to carry out sectioning, building of jigs, modification of equipment, reconstruction of wreckage, simulation experiments, etc. Electronic test equipment and instrument analysis equipment round out the laboratory capability.

INVESTIGATION EXAMPLES

Examples of actual investigations carried out in the laboratory will now be described to illustrate the use of laboratory resources in resolving complex technical problems and to illustrate how the laboratory interfaces with the investigation, research, and promotion elements of the safety process.

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* T.W. Heaslip - Chief, Aviation Safety Engineering Laboratory,
Aviation Safety Bureau, Ministry of Transport,
Canada.

(A) JET ENGINE FAILURE

A Bell Jet Ranger crashed after suffering an engine failure. The Allison 250 C20 engine was suspected by the field investigators of having flamed out in flight as a result of a fuel problem. However, Engineering Laboratory examination during the engine tear-down determined that a mechanical failure had occurred. The spur adaptor gear shaft was found fractured but not typical of previously observed failures of similar parts. The forward splined end of the shaft had broken into three large pieces and numerous small pieces. Microscopic examination of the fracture faces revealed many fatigue areas.

The next stage of the investigation concentrated on discovering why the gear shaft had failed. The first possibility considered was that of misalignment of the compressor and turbine. The compressor adaptor coupling was removed from the impeller shaft. This coupling, the spur adaptor gear shaft, and the turbine-to-compressor coupling were all checked for symmetry on the optical comparator. No faults were found. The compressor and turbines were also checked and found to be running true.

Careful microscopic examination of the fracture portions of the spur adaptor gear shaft, the female splines of the compressor adaptor coupling and the sediment contained therein pointed to the possibility of inadequate lubrication of the spline area. The oil delivery tube, which is intended to direct a stream of oil to the spline, was removed. A simulation check of the flow through the tube indicated that the critical oil delivery hole was partially blocked.

The oil delivery tube assembly was radiographed by another government laboratory by taking a number of x-ray views of the part. The x-ray plates revealed clearly that the critical oil delivery hole, intended to direct a stream of oil onto the failed spline, did not correctly match up with the internal oil supply passage. As a result there was a severe restriction in the oil directed to the spline and it had finally failed because of the inadequate lubrication.

The laboratory investigation was assisted by participation of representatives of the engine manufacturer. They were able to ascertain that this particular assembly had been reworked and had unfortunately successfully passed through their quality control. Subsequently changes were made in their quality control procedures to ensure a similar problem could not escape detection again.

An item has been prepared for the Aviation Safety Letter as an illustration of how inadequate quality control inspection can have disastrous consequences.

(B) TWIN OTTER WATER BOMBER FLOAT FAILURES

Some Twin Otters on floats can be used as water bombers to fight forest fires. The floats are modified to pick up and carry a load of water while taxiing. They are equipped with drop doors on their lower surfaces which can be opened in the air to dump the water load on fires. The doors are then closed automatically by hydraulic jacks which extend to close and latch the doors, after which the jacks retract to a rest position.

There were several accidents and incidents to Twin Otter Water Bombers in which the doors came open unexpectedly when the aircraft was moving on the water. This usually caused violent yawing manoeuvers which were difficult to control and resulted in substantial damage to the aircraft. Malfunctions also occurred when passengers were being carried in these modified aircraft even when the water bombing system was not being used. The potential for fatal accidents was high.

The Aviation Safety Research Division initiated a project in the Engineering Laboratory requesting a study to determine the causes of the failure.

Table 1 containing comparative data from all Twin Otter Water Bomber accidents and incidents was made and the patterns were noted. The latest accident reports were reviewed in detail to determine if any weaknesses in design were revealed. All the technical reports available on the water bomber float of the Twin Otter were studied to check the correctness of load analysis, stress analysis, and structural tests.

Table 1 shows that: - the doors can be torn off when the airplane is planing after water pick-up even when the jacks have latched the doors and retracted, and the green lights indicating these conditions are on. See items 1, 2 and 7.

- numbers 3, 4, 5 and 6 showed no green lights for the doors which came open. For these cases the jack was extended and trying unsuccessfully to latch the doors. These jacks were found buckled.

- loss of rigging preload in the door closing mechanism could allow a door to open slightly and let the water in and force it open.

The engineering reports by the airplane manufacturer, the float manufacturer, and the water bomber modifications were reviewed and several discrepancies were found. There was a noticeable lack of load and stress analysis exhibited.

Problem areas were identified as:

- ineffective sealing of the doors
- improper rigging
- loss of rigging preloads due to weakness in design
- inadequate provision of a level of safety for the modified aircraft equal to the unmodified one when carrying passengers.

A safety proposal was made stating that the Engineering Laboratory report should be presented to design approval authorities to assist in improving the design to provide, when passengers are being carried, a level of safety as high as the unmodified float plane. Aviation Safety Research in liaison with Design Approval Engineering produced an Airworthiness Directive (see Figure 1) which restricts modified aircraft to water bombing operations and makes them no longer eligible for carrying passengers unless an approved modification is incorporated.

(C) FUEL QUANTITY INDICATION SYSTEM FAILURE

During a test flight, fuel starvation resulted in engine failure necessitating a forced landing during which a Mitsubishi MU-2F was substantially damaged. The pilot stated to the field investigators that although no physical check of fuel quantity was made, the fuel quantity indicator was indicating near full at take-off. Checks at the accident scene showed that there were only six gallons of fuel remaining in the main fuel tank and that the fuel quantity indicator continued to show that the tank was nearly full. After drawing the six gallons from the tank, the indicator still showed the tank to be approximately 3/4 full. The gauge test function was checked by the field investigator. This test function allows a check of the low fuel level warning circuit by causing the indicator needle to rotate to zero. As the needle passes the 20 gallon mark a microswitch in the gauge closes, illuminating the low fuel level warning light in the main annunciator panel. During the field check the low fuel level warning circuit functioned normally.

The fuel quantity indicator and the three tank sensor units were then removed from the aircraft and forwarded to the Engineering Laboratory for further examination.

The fuel quantity indicator gauge was bench tested. The indicator was wired as described in the maintenance manual with 115V 400Hz power supplied from a static inverter, an ohmmeter substituted for the light in the low fuel level warning circuit, a test switch and a variable condenser. As the variable condenser was adjusted to a series of different values, the fuel quantity gauge indication for each value was noted. A curve was then plotted showing the simulated transducer capacitance versus indicated fuel quantity. This curve proved to be linear and within 5% of the results specified in the maintenance procedure.

The tank units, three capacitor transducers, were then checked. The special electrical connectors were obtained and the three transducers wired in parallel. The transducers were then immersed in JP-4 to varying depths. Their capacitance while in the fuel was measured using a capacitance bridge with an oscilloscope to determine the null point. The values of transducer capacitance correlated very well with the fuel level suggesting that these units were serviceable. Therefore, the gremlin was elsewhere in the aircraft electrical system. This is typical of many laboratory projects where the investigation as often as not proved the examined components to be serviceable. However, a safety proposal in this case was submitted to the Aviation Safety Bureau's Research division for consideration. It was suggested that all models of Mitsubishi MU-2 turboprop aircraft earlier than the aircraft Serial No. 239 have their fuel quantity indicating systems modified to the same standard as that system in models later than those with No. 239.

The primary effect of this change is the improvement in the low fuel level warning system. In the older models, such as the aircraft involved in the accident, the low fuel level warning is dependant solely on the movement of the quantity indicator needle. That is, a low fuel level warning is based on the fuel quantity indication rather than an actual fuel level. The system used in the later models of this aircraft relies on a float switch in the fuel tank to sense a low fuel level, thereby making the low fuel warning independant of other components in the fuel quantity indicating system.

(D) MAIN ROTOR FITTING FAILURE

A Bell Jet Ranger was approaching to land in Labrador, with four on board, when it lost the main rotor assembly and subsequently crashed. The field investigator discovered that initially one main rotor blade had separated from the helicopter. It was found that the main rotor retention strap fitting had the appearance of being precracked. Therefore all the main rotor hub assembly parts were forwarded to the Engineering Laboratory for metallurgical analysis to determine the reason for fitting failure.

The fitting fractures were examined by stereo-microscope and were found to be premature discoloured fractures. Subsequently, an electron microscope examination of the fracture features revealed three zones. The initial zone was fatigue in nature developing into an intergranular hydrogen induced crack and the remaining portion was tensile overload. Hardness tests were performed and the fitting strength levels were determined to be within specification.

Two other similar accidents had occurred in the United States. Based on this experience, an Airworthiness Directive (A.D.) was proposed by the Laboratory recommending a decrease in the life of the fittings. An A.D. was promulgated calling for special inspections and that the fittings be replaced after 100 hours in service. This caused severe operational restrictions on Jet Ranger owners. The A.D. resulted in a rash of conflicting reports of discovered cracked fittings. Between the Aviation Safety Research Division and the Laboratory, it was decided to carry out a survey of fittings from all operators in Canada. The establishment of a pattern of failures was complicated by the fact that there were four different manufacturers of fittings. Thus a fairly large sample of fittings was required. It was found that primarily only the fittings of one manufacturer were cracking in Canada. The basic cause of the initial fatigue crack stemmed from a severe stress concentration produced by excessive hand filing along the edge of the ridge running between the fitting ears. The fatigue crack acted as a nucleating point for the hydrogen crack. It was concluded that hydrogen diffusing into the steel during the plating process had probably not been sufficiently driven out during the subsequent baking process in many fittings. Therefore, the problem had two root causes.

A metallurgical analysis of the microstructure disclosed no material abnormalities. The dimensional checks found the fittings conformed to specifications, including the hand filed ridge which had resulted in a severe stress concentration. An analysis of the manufacturer's fatigue tests was performed. From all the evidence it became apparent that the failures were basically due to inadequate design and inadequate heat treatment. The Engineering Laboratory recommended to Aviation Safety Research that a Safety Bulletin, Figure 2, be published to advise the aviation industry of the nature of the problem. A comprehensive A.D. was proposed and subsequently was promulgated requiring replacement with the new design fittings.

(E) BEECH C45H WING SPAR FAILURE

A Beech C45H aircraft was observed in flight to roll to the left and subsequently spin to the ground, crashing. Investigation by the field investigator disclosed that the left wing had folded in flight. Portions of the wing and spar assembly were forwarded to the Engineering Laboratory to determine if premature failure had occurred.

An apparent fatigue failure was found in the wing spar at the Laboratory. Electron microscopic examination confirmed the presence of a fatigue crack at the outboard end of the gusset plate welded to the upper surface of the elliptical tubular spar cap at wing station 81. Fatigue initiated at the toe of the weld and propagated through 80% of the tube area. Metallurgical and mechanical tests disclosed no abnormalities. The original radiographs, taken before the accident on the wing, were examined and a positive indication of a crack was found on one radiograph with a length of approximately 0.7 inches.

A number of similar catastrophic accidents, due to in-flight fracture of the lower front main spar cap at wing station 81, had occurred in the United States. These accidents resulted in Airworthiness Directives requiring various non-destructive testing (NDT) techniques to detect incipient failures. However, failures and accidents continued to occur until we had one in Canada. In each case, although NDT had been performed, examination of the radiographs after the accidents revealed crack indications.

The Laboratory investigation showed that the x-ray inspection of the critical wing area was nearly impossible to perform adequately. It was determined that a simpler and more reliable inspection technique was to do a relatively easy magnetic particle inspection (MPI) using a hand magnet. Therefore, a Safety Bulletin was proposed describing the problem and illustrating the MPI technique. The published Bulletin is shown in Figure 3.

It was also proposed that the wings be reinforced because of the inadequate fatigue life expectancy of the spars or more failures would likely occur. Subsequently an A.D., shown in Figure 4, was promulgated requiring that all Beech 18 wings over 1500 hours service time be modified with a reinforcing kit.

SUMMARY

This description of a laboratory facility for failure analysis and technical investigation gives a picture of what a country of Canada's relatively small population can do with limited resources. Such a facility allows in-depth investigations of technical failure trends and the resolution of technical failures before they develop into trends. Our ultimate objective is safety of flight and I believe that the Engineering Laboratory plays a significant role in the improvement of safety of flight in Canada.

TABLE 1 - COMPARISON OF ACCIDENTS AND INCIDENTS

No.	Date	Regis. (Model)	Oper. Cond.	Float Affect.	Door Cond.	Jack Cond.	A/C Motion	Float Leaks	Remarks
1	Sept.3 1969	YFT	Planning pre-T.O., post-water pick-up	Both	Both front torn off. Twisted hinges	Retracted	R.Yaw	Both leaked	Door latched - 2 green lights. Jacks retracted - 2 green lights. Play in front bell-cranks.
2	Oct.6 1969	WGE	Landing with cargo	Left twisted I/B	Left front torn off.	Retracted	L.Yaw	Left was leaking	Left float bulkhead damaged at main strut. Play in front bellcrank. System not armed.
3	July 4 1972	OPI (300)	Water pick-up 60 Kts.	Right moved aft.	Both R.H. opened. Hinge on rear bent.	Extended, bent, end broken.	R.Yaw		Drag strut pulled out. 2 R.H. green lights not on. Rear bellcrank broken.
4	July 11 1972	ZZM (200)	Water pick-up	Right rolled o/B	Both R.H. opened. Right hinge bent.	Extended, bent, end broken.	R.Yaw	Both leaked	Float rolled o/B 70°. Float structure failed at main strut o/B beam. (Elong.) Two green lights (R.H.) were not on.
5	June 6 1973	OPI (300)	After drop L.H. doors stayed open	Left	All doors open. No damage.	Clevis end broken off (before landing).	--	Left on T.O. substan.	No green lights on L.H.S. Emerg. handle used - all doors opened, handle jammed. Landed all doors open.
6	Aug. 3 1973	OPI (300)	Landing with passengers	Right at main strut o/B	Both R.H. doors torn off.	Extended bent, end stayed on.	R.Yaw	Right. Up to 2000 lb.	No green lights for R.H. Landed with R.H. doors partly open. Taper pin holes elongated.
7	July 10 1973	ZZM (200)	Water pick-up. Lifted off settled back.	Both substan.	L. front torn off. Latch engaged.	Retracted	L.Yaw	Both leaked.	Floats torn off. L.H. tie rod missing. Torque tube failed at taper pins.

Transport Canada Transports Canada

Air Air

N-AME-AO
No. 26/75
MAY 30, 1975

NOTICE TO AIRCRAFT MAINTENANCE ENGINEERS AND AIRCRAFT OWNERS

AIRWORTHINESS DIRECTIVE

CF-75-3 DE HAVILLAND

Applies to all De Havilland DHC-6 Model aircraft fitted with Canadian Aircraft Products Models 12000, 12000A or 12000B floats modified for water bombing operation in accordance with Field Aviation Company Limited Drawing Number 84193.

Compliance is required prior to next flight.

Because of the hazard introduced through the entry of unscheduled water into the water compartment of the CAP Model 12000, 12000A and 12000B floats, referred to above, all aircraft affected by this Airworthiness Directive are no longer eligible for the carriage of passengers.

The restriction imposed by this Airworthiness Directive may be alleviated by the incorporation of an acceptable modification approved by the Chief, Airworthiness, Ministry of Transport, for this purpose.

This Directive is effective June 15, 1975.

K.D.J. Owen
K.D.J. Owen,
Acting Chief, Airworthiness,
for Director General, Civil Aeronautics.

FIGURE - 1.

Bell 206 Main Rotor Retention Strap Fitting and Pin Failures

This summer, within a few weeks of each other, three Bell 206 helicopters were involved in catastrophic crashes - two in the USA and one in Canada - in which rotor blades separated from the aircraft. The sudden appearance of this problem led to an intensive and urgent investigation.

The first phase of the MOT response was the issuance of airworthiness directive CF72-5 dated 21 Aug 1972 calling for an interim procedure whereby fittings would be replaced at 100-hour cycles. Since the exact nature of the failures had not at that time been clearly established, several operators withdrew their Bell 206s from service. This fact gave additional sense of urgency to the investigation.

Fittings and pins from all over Canada were sent to the Aircraft Accident Investigation Division's laboratory at Ottawa for detailed metallurgical observation and analysis. From this, an understanding of the problem emerged. This bulletin has been prepared to describe in detail the problem; much misinformation and rumours are being spread undermining confidence in the aircraft.

The fitting failures in Canada have been identified as occurring exclusively to those bearing serial number prefix "MD" which were manufactured after 20 Sept 1971. These fittings had been hand-filed an excessive amount along the edge of the ridges running between the two "ears" of the fitting. The excessive filing caused a very small radius to occur at the intersection of several planes (photo 1), thereby producing high stress concentrations at four points in the fitting. Under loading, these stress concentrations produced cracks which propagated down through the fitting where the wall is thinnest. Fittings cracked in this manner have been found to have accumulated anywhere from 201 to 1190 hours TSN. The fatigue crack develops into intergranular cracking, the nature of which is believed to be either stress corrosion or more probably, hydrogen-induced cracking.

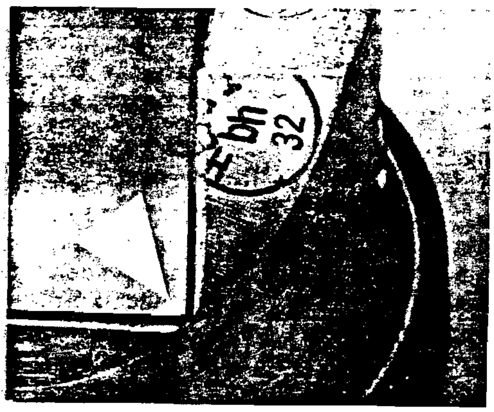

photo 1

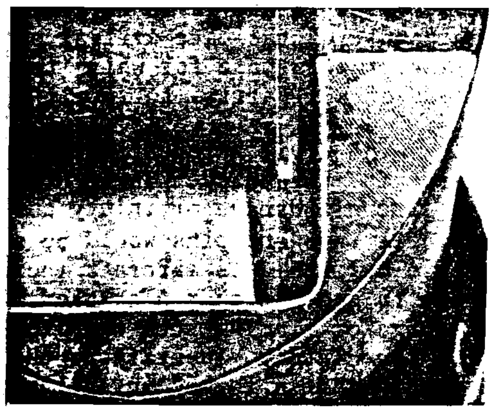

photo 2

Other fittings such as the "JI" series have correctly rounded corner radii (photo 2); to date none of these have been found by the MOT to be cracked. However, these fittings have proven susceptible to intergranular cracking but at a slower rate than the parts discussed above.

The pin failures investigated to date have been unrelated to the fitting failures except that a pin failure produces abnormally high stresses at the corners of the fitting. Six of the pin failures occurred to "MD" parts; all these failures were virtually identical. The cracking is intergranular and since there is no evidence of fatigue or corrosion it is probable that hydrogen cracking occurred.

FIGURE - 2.

continued.......2

Transport Canada Air
Transports Canada Air

AVIATION SAFETY bulletin

73/4

Wing Spar Failures - Beech C18S, C45G, C45H, D18S, E18S, G18S H18, TC45G, TC45H, 3N, 3NM, 3T and 3TM

A recent fatal accident involved the in-flight separation of a Beech C45H wing. The wing had failed at a fatigue crack in the lower spar boom at WS81. This Canadian accident was one of six known fatal accidents linked to similar wing failures of the Beech 18.

Regarding the crash in Canada, the required inspections had been performed but the crack was not detected; however, re-examination of the last x-ray radiograph in the area of failure revealed a crack 1.6 inches long. All six in-flight failures occurred in areas inspected in accordance with airworthiness directives; in one case, a crack had remained undetected throughout six x-ray inspections although <u>all</u> radiographs contained evidence of the crack.

An MOT survey representing responses from about two-thirds of Beech 18 owners shows that many operators have not complied with the requirements of FAA AD72-20-5 (N-AME-AO 37/73). Further, only about 60% of the x-rays were sent to the FAA as required. To add to the problem, the majority of the x-ray radiographs submitted were of poor quality, improperly identified, and in some cases portions had been cut away to assist the positioning of the x-ray plate. All this degraded the reliability of the x-ray inspection program. In spite of these problems, a significant 12% of the x-rays sent to the FAA revealed cracks previously undetected by Canadian technicians. This means a number of Canadian Beech 18 models that have not had their x-rays examined by the FAA may be flying with cracked spars.

An intensive MOT review of this urgent safety matter is underway. Alternatives being considered include the feasibility of wing reinforcement. In the meantime, you're urged to ensure that the required inspections are performed by qualified technicians and with the utmost thoroughness at the WS 81 area. It is obviously in the operator's interest to forward radiographs to the FAA and make sure that the analysis report is received.

Magnetic particle inspection has proven to be very effective, especially in detecting narrow cracks that the dye-penetrant technique may not find. For this test, you will need a moderately-powerful U-shaped magnet with at least 1 inch between poles. Thoroughly clean the area and place the magnet on the wing spar at the end of the gusset weld with the poles spanning the area of inspection (see photo). Apply fluorescent magnetic particle suspension fluid (Magnaglo 14M or equivalent) and using a hand mirror where necessary, reflect black light over the area.

FIGURE - 3 .

continued.......2

Transport Canada Air | Transports Canada Air

N-AME-AO
No. 56/74

November 8, 1974

NOTICE TO
AIRCRAFT MAINTENANCE ENGINEERS AND AIRCRAFT OWNERS

AIRWORTHINESS DIRECTIVE

CF-74-8 BEECH

Applies to all serial numbers of Beech Models C18S, C45G, C45H, D18S, E18S, G18S, TC45G, TC45H, 3N, 3NM, 3T, 3TM, AT-7, AT-7A, AT-7B, AT-7C, AT-11, C-45, C-45A, D18C, D18C-T, E18S-9700, JRB-1, JRB-2, JRB-3, JRB-4, JRB-6, RC-45J (SNB-5P), SNB-1, SNB-2, SNB-2C, TC45J(SNB-5), UC-45B, UC-45F and H-18 airplanes with Serial Numbers BA-730 and below, and to aircraft of the above models subsequently redesignated under a Supplemental Type Approval.

Compliance is required as indicated, unless already accomplished, for airplanes with 1,500 or more total hours time in service on the effective date of this A. D. or airplanes that subsequently accumulate 1,500 total hours time in service after that date.

To prevent inflight failures of the lower wing spar cap, accomplish the following:

(a) Incorporate one of the approved spar-strap modifications listed below:

   (i) Aerocon STA SA73-1

   (ii) Both Dee Howard STC's SA832SW and SA895SW

   (iii) Hamilton STC SA2000WE

   (iv) Other equivalent modifications specifically approved by the Chief Aeronautical Engineer, Ministry of Transport, Ottawa.

   M.O.T. Regional Offices should be contacted for information on modifications not specifically listed in this Directive.

(b) Inspect wing spar and spar-strap modification in accordance with Beech maintenance instructions and M.O.T. approved Supplemental instructions provided by the manufacturer of the modification kit installed, at intervals indicated in the applicable instructions.

continued 2

FIGURE - 4.

SAFETY RESEARCH WITHIN THE CANADIAN AVIATION SAFETY BUREAU

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CANADA.

Mr. Finley, our Director, has given you an overview of the Aviation Safety Bureau. Bill Howes and Terry Heaslip have described Aviation Safety Investigation and Safety Engineering. I will talk about aviation safety research as carried out within the Bureau. A number of specific projects will be used to illustrate our functions.

Bureau Management Guides and the organization chart for it place Aviation Safety Research in the middle, between Safety Investigation and Safety Programs (Promotion). This is done for a reason. Normal progression of safety work within the Bureau sees jobs progress from investigation and safety engineering into the research phase. Finally, after research, comes the safety promotion phase (Safety Programs) which John Richards will describe in the next session.

I must define "research", as we visualize it, since the word itself has on one or two occasions conveyed a false impression and over emphasis on the word "research". The nature of our work is such that all the emphasis should be on aviation safety. The Division consists of aviation safety officers. These men who have a broad background in aviation and they undertake projects to identify clearly and in detail the extent and nature of aviation safety problems. This, as you can see, is a form of applied research for the express purpose of enabling and facilitating the most effective accident prevention response possible. If, in this process, a need for basic research is identified, the assistance of other agencies is sought. Other agencies frequently used are National Research Council Laboratories, DND facilities, DNH&W medical officers, University Laboratories and other research facilities as appropriate not to mention the Safety Engineering Laboratory of the Bureau which we work with continuously.

Now to go on to a more detailed description of our research function as within the Bureau: Safety Proposals are frequently made by safety investigators and safety engineering staff. These proposals are forwarded to the Aviation Research Division for follow-up action. This follow-up action usually involves some of the following actions: collecting further data, co-ordinating with other agencies and other projects, liaising with specialists making safety recommendations (informal or formal) etc. When the project reaches a stage where a problem or problems have been clearly identified it is more obvious what further action is needed to prevent accidents. Quite often this further action consists of contacting persons who have an operational or regulatory responsibility to assist them in understanding the problem and then selecting the appropriate preventive action. This is our informal safety recommendation procedure and it has proven to be an effective way to resolve, reduce and eliminate identified hazards. In some cases the project officer will develop information for production of a safety bulletin. Safety Bulletins are dissemianted on a need-to-know basis. In some circumstances the safety bulletin is followed by an Airworthiness Directive, Information Circular, Amendment to Air Regulations, etc. Example of safety bulletins are available for your perusal. In some cases where accidents result from operational problems and are repetitive, the project officer co-ordinates information from the numerous accident files involved and prepares information to be used in safety brochures, audio-visual presentations or the aviation safety letter. An example of such a brochure "Flying the Alaska Highway" is also available for those who have an interest. John Richards will be discussing the safety letter and audio visual presentations and other safety promotion methods in more detail in the next session.

Aviation Safety Research project officers must maintain many contacts. Much of their time is spent consulting with outside agencies and the aviation community. They conduct safety surveys, monitor the circumstances of losses of separation and near collisions, participate in the Associate Committee on Bird Hazards to Aircraft and other Associate Committees of NRC. We are able to provide consulting service on request. This is done by conducting safety surveys, on a confidential basis, at the request of management. At the conclusion of a safety survey the manager who requested the survey is debriefed on a confidential and exclusive basis. In loss of separation cases we monitor the formal investigation as carried out by Air Traffic Services Standards Officers and conduct additional interviews and carry out further research as necessary to identify systems deficiencies. The interviews we carry out are done on a confidential basis or otherwise if requested by the person being interviewed.

Many of the projects which we have underway are described in a list which is available as a handout. Also available as a handouts are copies of our wake turbulence reporting form, our bird strike reporting form, the Canadian Service Difficulty reporting form, and safety bulletins. Our address and telephone number is listed on the project list and we are anxious to hear from any interested parties. Some of you undoubtedly will be able to contribute information to some of the projects and if we can help any of you who have related problems we would be glad to do so.

AVIATION SAFETY PROGRAMS IN THE MINISTRY OF TRANSPORT

J.T. Richards

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The past few years have seen some interesting changes in our approach to accident prevention. These changes range from re-thinking our basic philosophy (such as reappraising the function of the state in promoting safety), making major organizational changes, establishing new dialogues with the aviation community, experimenting with new techniques of communication, and, of course, developing plans for improving our programs in the future.

Today, I'd like to dwell on some of these aspects as it relates to the responsibilities assigned to us in the Aviation Safety Programs Division. (chart) As you can see, my Division participates in the safety process with Hal Fawcett and Don Douglas - making up the team whose challenging job is to reduce the unacceptably high loss of life and destruction of aircraft.

When I say "team" I don't wish to imply that the system relies on friendly cooperation alone. While this environment exists between the elements within the Bureau the fact that proposals reaching my Division are recorded and my response also inserted into our data file ensures that the time and effort spent on developing these internal safety proposals are not wasted through an oversight, loss, or deliberate disposal into file 13! Thus, we in Programs are accountable to make sure that the lessons taught by costly accident experience and investigation aren't lost. The fact that this relationship is on data file enables effective management monitoring.

I mentioned that some philosophical changes are occurring in our approach to aviation safety. Two profound changes have occurred:

there is a growing willingness on the part of government to protect its citizens, and

there is increasing evidence that safety is substantially a responsibility of the individual; which fact supplements the traditional approach of institutionalized safety of the previous decades - namely, regulations.

In the first instance, a recent Gallup poll in Canada established that Canadians accepted the proposition that the government was indeed entitled - and should accept the responsibility - to protect its citizens. This is probably an outgrowth of consumerism - a movement which, in this day of dwindling resource expectations, occupies everyone's mind and influences his spending habits. For it must be recognized that apart from the "motherhood" notion of safety as being an inherent good, an aircraft accident is essentially a needless resource waste to the country. (chart) This slide shows the extent of the impact to the various concerned parties of an aircraft accident - in this case, to a commercial aircraft. The chart is too complex to discuss in detail but each square represents an actual monitory loss - not to mention any human involvement. Someone has to pay for these losses, and that "someone" is ultimately you and I.

As to the second point, accident experience - particularly in general aviation and small commercial operations - proves that regulatory guidance is too often ignored. This point is important to us in safety because it steers us to an important conclusion: that the thrust of our aviation safety programs will very much be toward encouraging the establishment in Canada of safety groups large and small in the various organizations, both commercial and recreational. It is my conviction that these groups will provide the one essential element to the success of any safety program - motivation of the individual. After all, a person must first be motivated if he is to actively undertake his own safety program.

Let's look at this aspect of motivation for a moment because it substantially influences the way we, in Programs, work. (chart) In this chart I have taken liberties with the orthodox terminology for causal factors but it seems to me that the basic reasons for human failure - and here we're talking about 80% of accident causes - are attributable to these three problems: attitude, ignorance, and technique. Or put another way, (chart) "he knew better", "he didn't know", "he couldn't hack it". Come to think of it, that defines the person we must communicate with - for he is the one who'll crash sooner or later.

To find out why this potential customer of ours got that way, let's take this one step further by examining each of these in turn (chart of original 3) in an attempt to find the best techniques for safety promotion, remembering that the first two are intimate and judgemental. Attitude derives from a person's motivation to be a good pilot. This motivation, in turn, stems from his flying environment such as initial and recurrent training as well as the professional and informal environment of his company, club, or friends. The second point - and here, I'm using the term in its dictionary sense - could result from not only a lack of good training initially, but from an indifference, that is, lack of motivation toward upgrading his knowledge. The third point is the maintenance or upgrading of skill; again, we could implicate initial and continuing training as well as the priority the individual places on improving his skill level.

You'll note that as well as motivation I have identified training in each of these underlying human reasons for aircraft accidents; obviously, much remains to be done in this area. Nevertheless, training is available - admittedly for a price - a price in time and money that will be paid only by the well-motivated pilot. Training and motivation are therefore two basic challenges - to convey information and to motivate.

How to motivate for safety? Unless our programs not only inform but evoke an enthusiastic response toward a competent approach to flying they are not likely to succeed to any great degree. In what way does the foregoing influence our programs? Let's look at some of our efforts - and I would remind you that our Division is barely two years old. We publish (slide) the Aviation Safety Letter which is sent to all licensed pilots. This publication is informal and shuns bureaucratese since we hope to speak directly person-to-person. In other words, the items contain that important element of motivational encouragement as well as information. Investigational data is used to make the story interesting and provide authenticity but we avoid letting it interfere with the communications impact. Too long, have we assumed that sending raw investigational data to the aviation community will motivate people to be safe. It must also be remembered that our material must compete with the myriad appeals for individual attention in our home or flightroom.

To make the informational and guidance content more palatable, and hence consumable, we are expending a substantial portion of our resources to the creaton of slide/sound presentations. We recently presented the information needed to understand the role of the newly-introduced Emergency Locator Transmitter in dramatic terms. Here's a brief excerpt. (show excerpt) From the reaction of persons who have seen this program, we feel confident that it evoked an enthusiastic response. You'll note that in this case the presentation supplemented the traditional information circular which previously sufficed for conveying new information. Another example: earlier this year, we prepared a brief presentation to a technical seminar on recreational aircraft. By way of motivation we attempted to place a rather dry statistical review of homebuilt accidents in the context of the topical "consumerism" movement. (show excerpt) We have just released a slide/sound presentation "Flying This Winter" which we hope will motivate pilots to appreciate the hazards unique to the harsh winters of Canada. (show excerpts) Underway are similar audio-visual presentations on mountain flying, planning a takeoff, flying in weather, and so on.

This pamphlet (slide) "Flying the Alaska Highway" nicely exemplifies the interrelationship of our three Divisions. It began as a research project into aircraft accidents and evolved into guidance and cautionary material for pilots. Of course, the research was based to a major extent on investigative data - including the all-important photography.

I spoke at the opening of future plans. Our audio-visual presentations have been designed primarily as material for a Regional Aviation Safety Officer - a person who exists only in our planning documents at present. However, we expect to have at least one in each of the six Regions in Canada whose job will be to meet the public and promote the establishment of active safety programs aimed at encouraging good flying practices and attitudes in pilots. Primarily the motivational benefits of these programs, is that they create the climate for safe flying to be "the IN thing" - or conversely, the bringing into disrepute of unsafe attitudes and practices. As Chayter Mason has observed, pilots too often come under the influence of "the cult of masculinity" which, among other things, glorifies needless risk-taking.

To wrap up my comment, may I stress the fact that it is from air safety investigators' reports, findings, and recommendations that we in Programs derive our primary source of reference, guidance, and information. A specific investigation may contain the guidance and material we need or we may generalize by way of statistical analysis. Our homebuilt presentation was an example of using individual investigation reports as well as the overview provided by statistics. I hope that our activities have begun to satisfy the expectations of our investigators that we apply their efforts to prevent the recurrences which so often cause them to shake their heads in frustration and despair. In this respect it must be remembered that the (slide) filing cabinet drawer you see here represents not only human endeavour of a considerable magnitude, but the expenditure in this case, of $336,000. Committing these files to offical catacombs isn't too productive; I can assure you that our best efforts will be applied to making sure that the insights achieved so painstakingly are applied to the prevention of recurrences. No country can afford to content itself with just gathering facts and creating reports without protecting that investment preventing recurrences - and they're nearly all, recurrences.

What I've said today, I hope emphasizes that there is indeed room to extend the scope of investigations into achieving an understanding of the motivational problems I have discussed. The old pilot-oriented investigation of yesteryear is out. If investigations are to assist persons such as myself, the investigator must be continually aware of the ultimate end to which his endeavours will be applied. If the investigation report does not contain those vital elements needed for subsequent safety promotion programs - and here I'm speaking of useable insights into human behaviour such as are revealed by incisive questions which expose personality types and behavioural patterns, effective and message-carrying photography, and so on - the investigation may unfortunately possess the appearance of a professional job but its value for preventing a recurrence may be minimal.

My demands may be unsettling to some investigators who are prone to believe that the acquisition of facts is their sole function. Finding out what happened is only the first phase; we need to know why. If we are to effectively pursue the prevention of accidents, we in Programs must have the insights gained by investigators while finding out the "why?" so that, in turn, our pilot-audience will be motivated to prevent the accident that may well otherwise come his way.

SAFETY IN THE AIR

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INTRODUCTION

Two aspects make up overall safety in the air: safety of the machine and safety in the machine's environment of operation. Designers have gone a very long way with the former although none has yet showed us a crash proof aeroplane. The latter has far more unpredictable variables than we care to contend with. We therefore only try when we can to identify some and adopt preventive or corrective manoeuvres within the scope of the machine. Within the concept of safety though, we should be aware that such a state of affairs is unsatisfactory. The world has become much smaller with air transportation. Air machines have undergone various developmental stages so much so that it is difficult to imagine today the air machines of tomorrow. In all this advancement we still have the occasional crash that baffles both designers and investigators.

It would be interesting to hear what Rene Lorin, Frank Whittle or the Wright Brothers would have had to say about our modern aircraft, such men who pioneered the art during the early years of the flying machine. It is also amazing that their basic original concept is still being utilised; take for example the Jet Propulsion. Did these men consider safety, or better still, could it have been conceived that the safety aspect would have and still be reforming air machines to this extent? Personally I doubt that.

THE MACHINE AND THE MAN:

We are now in an era where air machines carry a varied collection of gadjets, mainly electronic, in an effort to minimise the human involvement in its operation, with firm hopes of improved safety. This truly is the only scientific and technological approach we know of these days. In our effort, we forget that these gadjets themselves are made up of basic components with operational criteria solely dependent upon prevailing conditions. Conditions not necessarily ideal for such components can turn out safe for the aircraft's operation, since it can merely be the result of variation of one or other of the environmental elements. Truly the high integrity of that whole equipment say for example a Computer can be so adversely affected that it would have been better were a pilot holding his controls, seeing things going wrong and trying to correct them.

It thus appears that:

(a) the human element cannot safely be divorced in-toto from the machine's operation;

(b) our emphasis on air safety could have been one-sided;

(c) the machine and its environment of operation cannot be explored in isolation.

Certain questions come readily to mind:

(i) Can we keep the pilot idle in the cockpit with assured safety?

(ii) How far can we rely on the electronic brain?

(iii) How much logic can we build into our automatic landing system?

If we can get the automatic landing system to take rational decisions, what happens to our pay-load factor? Because we would have built so much logic circuits into the system, that despite our progress in miniaturisation, the pay-load must have been affected. Even as it is now, many of the Airlines' Commercial Experts are not too happy about the limited pay-load imposed by the weight of these gadjets.

Another important fact which also reflects adversely on payload is the need for Fail Safe devices. As is usual, many of these units, if they should be reliable at all, must be duplicated.

What is the present position, and how can we now continue to improve safety? We have been putting so much emphasis on perfecting the machine to the extent that we forget that airline operation must be a money making concern. Fuel cost is presently a world-wide headache; fares must therefore be increased and have continued on the upward trend. It is obvious that the operators and the passenger feel these pinches most. Operators' profits are now very minimal; passengers too grumble with some of them reverting to cheaper but most incomparable forms of travel and Operators have consequently suspended services on many of the most unprofitable routes, and no one can blame either. Here, we are again preaching about safety or in effect telling the operator to install more and more equipment to make the craft safer. We are as it were asking them to utilise their minimal profits to install these equipment which will further diminish their pay-load capacity. This I dare say does not seem right.

Let us now view the problem from a different perspective or better still let us have a fundamental retrospect:

(i) Can the pilot function just that little bit more and still keep things within the safety envelope? That could be a possibility with design alterations not necessarily involving much expenditure, since such alterations would have been included in the original design concept.

(ii) Other subjects connected with the aircraft's operation can make life less arduous for the pilots and co-pilots and still preserve safety, e.g. Air Traffic Control feeding weather information can do so without direct speech contact with the pilots or co-pilots. This could be made up in some form of coding formats which can register as a display on the control panel in the cockpit. It is a known fact that our sense of speech demands more attention from the normal human being than some of the other senses; in fact it sometimes demands from related senses as well.

(iii) So far much has been designed into the machine. It is certain that without pay-load considerations, much more can still be done with the machine. But, why explore this in so much isolation from the environment? We can look more into phonomena like the weather, bad terrain detection, unseen elements with catastrophic effects on aircraft operation like Wake Turbulence, Vortices, Unique Tornadoes, (whirlwind) Fierce cross wind components etc. The first thing we should be concerned with is the identification of these elements. So far, researches have helped to identify some of them e.g. Wake Turbulence. But the devices so far are not in the finesse stage, nor have they been put into general use, and we cannot expect them to be cheap when they reach that stage. Once these phenomena are identified, the next problem is how to combat them. Here we have to remember that the machine has already got more than it can take by way of equipment. The first answer that comes to mind is avoidance. Yes, these areas can be avoided if the detection is early enough. What if for one reason or the other these areas cannot be avoided? Can a big blast of hot air for example create a different condition at that instant to say change the atmosphere, and so give a condition better ideal for the aircraft operation than the tornado, etc.? In any case, increased temperature at altitudes must have some effect which might make useful evasive manoeuvres. The important point is that such a jet blast must of course precede the aircraft.

We therefore see two areas worth looking into. (a) Capability of detecting adverse phonomena and (b) means of combating them. The large transport aircraft have good quantity of hot air in their exhaust systems presently. This may not readily produce the desired effect. How about Solar Radiation, a phonomena not yet investigated for application in general aviation? If any of these processes can improve one or other adverse environmental condition, designers can soon incorporate mechanism to direct a good volume of hot blasts or rays in front and or by the sides of the aircraft.

THE MACHINE AND THE ENVIRONMENT:

Admittedly the machine has developed through admirable stages. Unfortunately not enough seems to have been done to improve the environment. So far there are what we can proudly term elaborate Airborne, Navigational, Ground and Meteorological Aids. These we have also experienced are sometimes incapable to cope with the ever changing patterns of the environment. The interesting thought now is, can we sincerely support the view that our accidents today are purely the result of unpredictable weather, runway surface conditions, or the like? The answer is that we cannot. But the accident trend today, considering accidents which are not the result of sabotage or hijacking does seem to eliminate considerably the machine type failure. So with our aim of preventing aircraft accidents, we must turn to the other aspect, the environment.

Maybe we ought now to explore the environment in more detail and see whether some of their adverse conditions cannot be directly solved by elements already within the aircraft. A more detailed study of this could very well result in limited instrumentation than we now carry in the aircraft. The fundamental concepts connected with air machines and their propulsion are:

(1) Temperature

(2) Pressure

(3) Volume

(4) Velocity.

We know about pressure and temperature at altitudes. What we ought to look into is probably the effect of these four basic concepts on the weather elements. The machine at the moment possesses two of these basics in quantity from within, which I hope can be used in loco if required; they are temperature and velocity. These two can also affect pressure. What effects have these on prevailing weather? I am pretty sure they would have some effect, since weather itself is basically the effect of the first three elements on air.

Loosely, Temperature is hotness or coldness, two opposing ingredients we can now produce at will. Pressure is force and Newton had set us some bases of considering force. Wind is movement of air; air is a mixture of gases. Apart from Boyle, Charles and Gay Lussac's laws, there are other laws we know which govern the behaviour of gases. Agreeably, Volume is an element that can create much problem, since when one considers the flight path, Volume is limitless. But, if we can confine our thought of volume to just the atmosphere in the immediate surrounding of the aircraft in flight, we can imagine that increased temperature plus increased acceleration of the air particles $\frac{\text{Velocity}}{\text{Time}} \; \frac{L}{T^2}$ can certainly affect pressure. Since Pressure and Volume are two directly relative elements, the Volume, or to be more exact the Mass per Unit Volume $\frac{M}{V}$ (Density) must have correspondingly been affected; so that our basic $\frac{PV}{T} = K$ accordingly modified can apply. This is probably the only variation we required to improve some of these adverse environmental conditions. It seems to me therefore, that we may have ample data with which to explore certain of these problems, or better still, this safety aspect, once we can identify areas and define specific requirements. Can we not use these mutually for the benefit of safety? This is another area for research. Our aim ought to be to use the present potential of the machine to improve the environment if we can.

It will not be fair at this stage to proceed without mentioning our pride novelty the Supersonic Transport Aircraft (S.S.T.). Whether the SST is here to stay or not is anybody's guess. For progress sake alone, I earnestly hope they are here to stay. They share the same problems so far discussed, and more, for example, with our presently crowded Air Routes, ATC is tasked with integrating Supersonic Transport into Subsonic Network. This is by no means a simple problem in so far as air safety is concerned. Eurocontrol has undertaken extensive studies including simulation exercises, and certain criteria have so far been formulated for particular areas, where, in order to get for example, SST into the normal holding pattern, deceleration should be done between certain points. There are other areas where new routes will be set aside for SST and sectors defined for transonic acceleration, deceleration or subsonic cruise, plus two way watch being kept on aspects like profile separation and related sectoral coordination procedures. There is also Sonic Boom. There have been very brilliant papers on the subject. But in my view no one can give with any amount of certainty the entire effects of a Sonic Boom. So far we know it is something that depends on the locality, atmospheric condition, the altitude and the Mach Number of the aeroplane. Who knows, we may end up by using Sonic Booms to shield or shift one or other adverse environmental condition.

In the airfields, we have always tried to maintain ideal conditions for the aircraft's operation, although in some instances it has turned out most expensive indeed. If we can do this for all locality in the flight path, we would have solved these environmental difficulties quite considerably.

CONCLUSION:

It all now appears so simple. If we can correctly define areas and limitations of the human involvement in the machine's operation - meaning the functions of the Pilots, Co-pilots, Flight Engineers, Navigators, Air Traffic Controllers, Meteorologists, etc., and if we can solve the difficulties connected with the environment, then correlate and integrate such results into the design of the aircraft, the outcome will surely be improved safety in the air. It is also probable that such an aircraft could carry much less instrumentation, so making the airlines happier with better prospects of air travel no longer remaining a financial burden for many.

AN ATTACK ON HUMAN FACTORS AS PROBABLE CAUSE

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Taking a look at aviation worldwide, military and civilian alike, accident statistics for the last years show a general decrease in the rate per selected unit. This can be displayed very simply in a graph, figure 1:

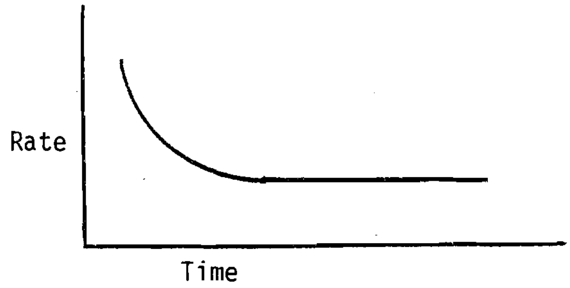

figure 1.

A vast majority of both military and civilian accident investigations end up with probable cause: "Human Factors." Mind you, this usually connotes human factors at the performance level only, and is rarely projected upwards to include the procedures and principles levels.

For some time, we have been desperately trying to make a dive underneath the almost stable accident rate. One recent method has been implementation of mandatory incident reporting systems, and in doing so hoping for more information on which to base loss-control programs. No question about it--as we know from our basic school of safety--there is a number of repetitious incidents/accidents and the causal factors by and large are divided into 85% Human Factors, with Material and Environmental Factors sharing the last 15%. The current conclusion seems to be that more information will result in better loss-control programs.

This is not so. There is a very weak link, and that is the human beings down at the performance level, who are vital for the system. The next culprits are the human beings analyzing incoming data and, more importantly, trying to translate this data into meaningful loss-control programs. Finally, the net result is meaningful to the individual only insofar as he voluntarily accepts and assimilates it. Bear in mind the barriers in communication where safety information is concerned.

It seems that mandatory incident reporting systems at various geographic locations and in different environments simultaneously became accepted as the magic to making a major breakthrough in getting better records. This is most likely a result of the fact that one area of the world, with a very low incident/accident record, utilizes a mandatory incident reporting system. I would like to postulate that a detailed study of the success will show different alternatives in the area of safety management.

We should, rather, concern ourselves in more detail with the underlying causes of the "Human Factors" listed on the placards of the past. The purpose of this paper, then, is 1) simply to uncover a corner of an area much too complex for one person to handle, 2) to stimulate your concern for deeper investigations of the human element, and

3) to suggest one way of developing a protocol for human investigation.

One way into this topic is a description of a day-to-day man/machine interface situation. There is an ever-changing demand for new and improved systems. These are not necessarily improvements toward a safer flight but toward a greater degree of mission accomplishment. We modify. To cite a few examples, there are the altitude alert systems, inertial navigational systems, and flight director/Ils coupling. Almost synonymous with these improvements are, at the best, selection of wrong altitudes, grave navigational errors, and non-stabilized approaches. At the worst, of course, we have an all-out accident investigation in progress.

Why this? Why is it that our highly qualified crews err, when we invest in these improvements aimed at eliminating the errors? I don't know all the answers, but what I do know is what happens when a company decides to improve its fleet.

What happens is that a management decision is followed by an implementation of the modification, with associated time before completion. At best a plan for aircrew training is augmented and away we go--a well-intentioned and safe program, if only it worked as intended.

Instead the aircrew training is implemented, usually by ground training complemented with flight training before the crew member is qualified. Right here we hit a weak area, the mismatch between ground-qualified crew, modified equipment, and availability of route-release-qualified instruction--all the while trying to fulfill the assigned mission. So what initially was a well-drafted plan ends up as a number of hypercritical cockpit combinations with a qualification level far less than desired. Yet the legal requirements have been met, giving the less dedicated investigator all he needs in order to label the incident or accident "Human Error."

He is less dedicated, not necessarily in relation to his personal attitude, but more frequently in having to work with organizational limitations such as facts not being made available regarding the whole system, or sometimes trite restrictions on manpower, once a "Human Error" label--superficial as it is--has been displayed.

But what about your next obvious "Human Error," where you do want to look for these underlying causes? What do you look for and where do you start? Is there really any other place to start than "year one"? With regard to aviation, wouldn't a start at any other point be patchwork?

It became obvious as far back as World War I that selection was necessary (in order to preserve the hardware!) and ever since, any entry into civilian and military flying has been through some kind of selection. It is not miswording that the term "some kind of selection" is used, because no system so far has been invented that will not reject some who would have succeeded if they had been accepted, and, inversely, not let some eventual failures slip through.

Selection is procedures for choosing, from a group of applicants, those individuals who will be best suited for some specified type of employment. Utilizing the word "ability" in its broadest sense, we can picture what a selection is, figure 2:

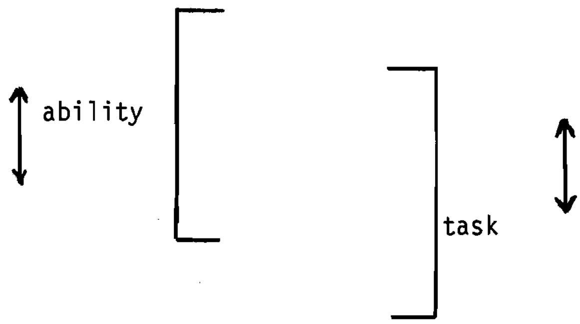

figure 2.

To select, we try to obtain the highest degree of match between ability and task. This matching process is exceedingly hampered by the fact that the "task" is ever-changing and thus cannot readily be defined. Who will challenge that the human element we need in the system of today is not the human element we needed in 1950--and yet the selection processes have changed little if at all over the past twenty-five years.

The fact that the task (or job description, if you like) is ever-changing calls for the closest feed-back to the selection group. This, however, is rarely if ever done. This feedback is particularly interesting in cases of initial and subsequent failures among the selected personnel. Up until two years ago such feed-back could not be documented; consequently, the total system encompasses a large amount of ability-task mismatches. It should be appreciated that the total system in this instance is not limited to the operators at the flight deck, but comprises air traffic controllers, dispatchers, management at foreman level, and the like.

To expect that a change in this area can be made in the span of a year or two is of course unrealistic. But accepting the facts institutes a process of correction to bring about a match between ability and task in the coming generation, and in doing so we can save others from having to talk in twenty years' time about the same weaknesses we are faced with today.

In the immediate future, that is, within the next five years, focus should be directed toward training, both initial and subsequent. To describe the total human aviation life cycle under one heading, "Training," is the most precise description, especially if we realize that training is development of a level of safety in our human element.

To be able to visualize the correlation between the aviation life cycle and the level of training/safety, let us examine this graph, figure 3:

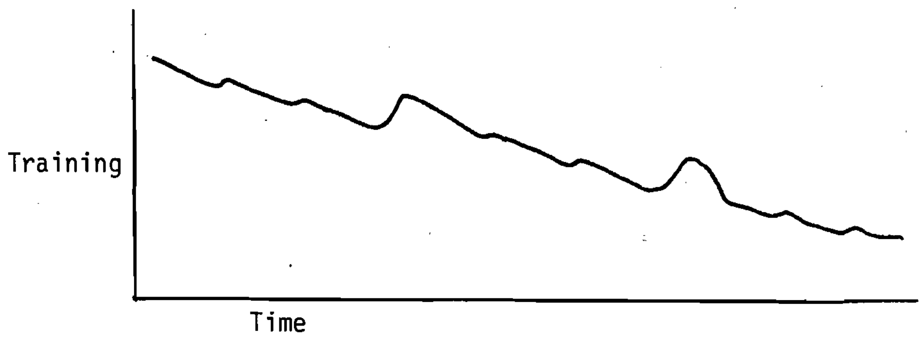

figure 3.

It can be observed, contrary to a common belief, that as the life-cycle progresses the level of training decreases. This is significant in order to understand the underlying cause for the number of incidents/accidents where the human being failed despite being what is generally described as well-qualified.

You will notice that the curve indicates an increase in the level of training at various points and of a varied magnitude, but then falls off and the initial level of training is never attained again. Reasons for the smaller increases would be recurrent proficiency training and performance for a supervisor; the larger increases would typically be due to conversion to other equipment in the fleet. Should one ask the question, What is the influence of experience? And will experience not counteract, and even at some point make up for, the decline in level of training?

To answer this it should be remembered that training imparts the ability to perform a given task--skill, if you like--whereas experience improves the accuracy, once the ability has been acquired. It is acknowledged that little, if anything, can substitute for the value of experience when it comes to assessment and judgment of situations which are not direct man/machine relationships.

Once again, to highlight this even further, the human being is faced with ever-changing variables on the part of the machine. That in turn aggravates the process of acquiring perfect or near-perfect ability. By-and-large, the industry has well-organized schooling programs for recurrent training and conversion, most of these directives being enforced by the regulatory authorities, of course. But there is a difference between organization and effectiveness, and the latter, unfortunately, is not automatically a consequence of the former. We shall examine just how it happens that what appears on the surface to be a well-organized program can turn out to be ineffective, to say the least.

We accept into the system, through a selection process with previously discussed faults, a human being with some arbitrarily accepted level of previous training. We then expect him/her to continue in the future as he/she performed in the past. This is especially important when we put the real label on this acceptance: "Goodwill." With goodwill towards what needs to be just one less-than-satisfying performance during initial training and transition, the remark in the records is "Satisfactory." And just one such nonfactual description of the performance in enough to trigger a sequence which roughly follows this pattern:

- --subsequent intructor(s) is hesitant to downgrade, due to neglect in doing so by the former instructor.
- --the training and transition program is passed with what only on the surface is satisfactory performance.
- --Release flights, even in the cases with poor performance, are passed. Why? Because, after all, the selection process and the school have no remarks, so any doubts must be just an isolated instance.

Thus the loop is completed and chances are that this state of operation continues until, hopefully, it is caught at a later, more stringent check; or until, as it often is, there is an unfortunate occurrence that gets labelled "Human Error." Would anyone care to comment on the presence of a high amount of "goodwill" and the risk of subjectivity when the human being has been in the system for, say, twenty years?

Specific attention should be directed towards the management tool, "Supervisors at the Foreman Level!" Are they supervising or are they filling out formulas? And if they perform only to ensure compliance with authorities' requirements for records showing "checks performed," why? Obviously in such a case the structure of the fleet supervision has to be scrutinized along the well-known parameters: selection, training, information, motivation, adjustment, feed-back. I will submit to you that an awful lot of human error down at the performance level in the past rightfully belongs very far upstream in the system.

Initially in this presentation we focused on the ever-changing system and, as a result, the need for an elevated human performance. We realized the problems of a fleetwise assurance of sufficient cognizance of the changes. Updating of questionnaires and the like is often as much as five to ten major modifications out of phase. Thus, in these systems designed to ensure a current knowledge, no specific attention is drawn to these new developments. Mind you, they are all being bought to ensure a higher degree of safety under a new required level of mission accomplishment. But lack of knowledge triggers insecurity, that in turn triggers non-familiarity. During task performance under tension (i.e., the difficult segments of the mission) the human being makes a trade-off and reverts to the known--pre-learned behavior that would, ironically, be appropriate to the situation the modification was designed for in the first place, in order to lessen the load.

Combine this load factor with what I should like to describe as the "subtle load," which is present for reasons outside the direct man-machine interrelationship. An example of this and its effects is a remark from ATC to the flight deck during an approach: "You are welcome to keep up the high speed." Here is an invitation to deviate from the standard procedures--the factors governing the extent to which the invitation is followed are several and need not be described on this occasion. The consequences are much more important. They might range from little or no influence, due to the presence of well-trained human beings and a "willing" machine, to disaster due to built-in instability when the pattern speeds for a stabilized approach are neglected. Yet the accident report in this case did not list the ATC as a cause factor. There is no doubt in my mind that a closer look at this type of accident will reveal similar "subtle loads," unnoticed despite the fact that they are right there in the read-out of the communication. They are unnoticed because they are underlying, and no protocol yet takes care of--offers no jurisdiction for--investigation and establishing of this type of cause factor.

Going back to figure 3, Training/Life Cycle, I should like to draw your attention to the social lifespan and its interaction with the human being's professional course. Professor Alken from the Naval Safety Center gave us a very interesting paper at our seminar in 1971 on stress versus social changes and the research being carried out toward establishing various levels of stress. Through a correlation we might find that at the time of an upswing in the training there is a drastically high level of accumulated personal stress in the social life. I should like to stress the word "accumulated" because through accumulation of stress the body chemistry undergoes a change and this influences the behavior pattern. If this condition of accumulated stress is not discovered, we may once again find ourselves with no solution to a completely irrational behavior on the professional side. As a consequence it is doubtful whether a listing of a week's, or up to a month's, personal events, as suggested by the ICAO manual, is enough.

The areas I have described here are 1) selection, 2) training, initial and subsequent, 3) service life of the human being, and 4) interaction of the social lifespan with these areas. To illustrate what I mean by "underlying causes," I have pointed out some of the weaknesses our present investigative procedures do not allow us to uncover.

In the current analysis-section of an accident report, technical and environmental factors are described in the most minute detail. They are relatively easy to determine, whereas the human investigation is increasingly more difficult.

True, we have excellent guidelines when it comes to determining direct man/machine relationships, intoxication, medical deficiencies, and even mental health, to a certain degree, at the time of the mishap. Here, as with clear metal fatigue failure, we deal with factual information. Our knowledge of the rest, the underlying causes, has so far been conjectural and consequently--correctly--never listed in the findings. Development of a protocol dealing with techniques for investigation of the human being in a total sense is a project for SASI to undertake. It is a project of vast dimensions; thus, I am afraid, waiting for a solution to come from ICAO, for example, or another authority, is wishful thinking.

The project could be the first of its kind, where SASI manifests its position--qualification, if you like--as the only true worldwide forum of professionals where major developments in investigative techniques originate. The results, of course, would be submitted to authorities and industry for approval, and made available to schools and in the professional literature.

Using our current organizational structure, this project could be given to one chapter (other projects, such as aspects of investigations involving supersonic transport, being assigned to other chapters). The yearly seminars can be partially restructured to incorporate progress reports from the chapters with subsequent submission for approval.

Fleet operation at a certain level of safety is a management decision. If managements are generally satisfied with the current situation, we do not need to worry--or do we? We have demonstrated over roughly the last ten years that we do not master investigation, with subsequent loss-control suggestions, to the point where we can penetrate below this stable level of safety. In reality this means that a request from management for a higher level of safety is beyond our current capacity. Rather frightening, isn't it?

Bjarne Prendal
September 1975

MEDICAL AND PSYCHIATRIC ASPECTS OF ACCIDENT INVESTIGATION

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At the 168th annual convention of the New York State Medical Society, Dr. Peter V. Siegel[1] who was at this time the Federal Air Surgeon, stated that biomedical factors are responsible for a significant number of more than 600 fatal aircraft accidents each year. Dr. Siegel also stated that the incidence of aircraft accidents resulting from mechanical failure is extremely low. The biomedical factors account for 80-90% of the total which leaves from 10-20% with mechanical failures as causative factors of the crash. As the investigations of the medical factors are in a high percentile of certainty, this area is comparatively well set and little is left with which to argue.

In the pursuance of accident investigations, the investigator would like to know, for example, if the pilot in command experienced a sudden incapacitation while in the cockpit, whether or not he had a myocardial infarct and died before the plane crashed or if the crash was the cause of death. This is an example of knowing "what" happened. In order to determine the actual events, the investigator attempts to obtain autopsies on whatever remains of the crew and as the investigator is interested in contributing factors, attempts are made to procure samples of blood, bile, urine, gastric contents, etc. in order to run extensive toxicological studies.

There exists a relationship with the Armed Forces Institute of Pathology that is very helpful to the investigator. The caliber of pathologist that is available to help with interpretations, suggestions and diagnosis is second to none. Investigators can depend upon their forensic pathologists to tell them if any disease state existed in the crew (if there are enough remains in condition to be studied) and ofttimes can help them formulate the relationship of this entity to the behavior of the pilot. This gives the investigator another leg upon "what" happened.

The samples of the body fluids go to the Federal Aviation Administration toxicology lab at the Civil Aeromedical Institute in Oklahoma City, Oklahoma. The investigator would like all of the samples to go there, but in 1973, for example, only 40% of the toxicological samples reached the CAMI labs. The remainder were run at other labs throughout the country and are studied with a satisfactory degree of competency in most of them. Obviously these computer readouts on the contents of the blood are most welcome and helpful in drawing conclusions in this field of accident investigation.

The drug possibilities that can be tested for run a wide spectrum. Considering alcohol as a drug and that this is an important causative factor (7-8%) of fatal accidents involving levels of alcohol higher than 0.05 mgs.%, readouts on ethyl alcohol, other volatile poisons such as methyl alcohol, isopropyl alcohol, chloralhydrate and other chlorinated hydrocarbons and toluene are obtained.

Other drugs can be divided into Acidic, this category containing the barbiturates, dilantin, Doriden, meprobamate, other sedatives and anticonvulsants; basic, this category would demonstrate the presence or absence of amphetamines and phenothiazines and the narcotics group embracing morphine, demerol and methadone.

Recently, a report was written by Dr. S. R. Mohler, Chief, Aeromedical Applications Division, Office of Aviation Medicine, on inhalant toxicity[2] This paper tells the investigator that detailed aeromedical studies were made of three survivable U.S. Transport accidents associated with fire during the 1961-65 period. These studies revealed that of the 105 fatalities 76 were the result of incapacitation prior to evacuation. The incapacitation was due to toxic substance inhalation, the inhalants generated by the post-crash fire.

Carbon monoxide from fuel fire is one source of inhalant toxicity. It also comes from burning cabin interior materials. More recent studies show that cyanide gas resulting from the heat effects on commonly used cabin interior materials such as exist, acrylonitrile-buta diene-styrene, modacrylics and wool, can reach incapacitating inhalation level in a minute or less. Also it has been shown that the toxic effects of carbon monoxide and cyanide are worse when the two substances are inhaled simultaneously as occurs during post-crash fires. With all the information available to investigators medically, it is believed that a good handle on the "what" happened is available. Mechanical failures can be determined by the highly specialized investigators available from the National Transportation Safety Board and Federal Aviation Administration. Not only are they able to tell the investigator what happened but when and how and what should be done to correct this.

Another look at the 80-90% of pilots who are frequently accused of displaying "poor judgment or pilot error" must be facilitated. "Why" did the pilot behave in such a manner that would indicate poor judgment or engage in erroneous perhaps inappropriate behavior.

It can also be said, for example, that the pilot's behavior was compromised by the excessive use of alcohol or other drugs. Knowing this, however, is only a small part of the battle for air safety. What must be discerned is the "why" the pilot resorted to alcohol or drugs or even other overt self-destructive behavior in order to cope with a threat or stress in the aircraft.

If the topic of stress were suddenly abandoned by scientists and eliminated from the technical literature, there would be huge holes left in the volumes of psychological research and writing. A great quantity of research is performed within the overlapping subjects of conflict, frustration, anxiety, defense, emotions (especially those of fear and anger) and disaster, to name some of the most important and obvious topics that fall under the rubric of stress. If we add psychopathology and psychosomatic disorders, because these are commonly assumed to be somehow a product of stress, the quantity increases greatly.

The reason for this voluminous activity is simply that stress, as a universal human phenomenon, results in intense and distressing experience and appears to be of tremendous influence in behavior. It is also of the utmost importance in the effectiveness of adaptation. In spite of the importance of stress, there is little coherence in the theory and research that emanates from books and journals dealing with it. Confusion often arises regarding terminology. For example, some writers employ the term "stress" where others use the terms "anxiety," frustration, conflict or defense to refer to exactly the same phenomena.

Not only is the terminology inconsistent and confused but the very definitions of the subject are contradictory. The distinction is only occasionally made between psychologically based stress reactions and those produced by noxious stimuli on bodily tissues. Thus it is stress when one's arm is plunged into icy water, and stress when a person is told damaging things about himself.

If the investigator tries to determine tolerances for stress, primarily at the lower limits, the investigator finds that what is mildly stressful for one individual may be highly stressful for another or anywhere on a severity scale depending upon the individual.

It soon becomes evident that stress cannot be defined exclusively by situations because the capacity of any situation to produce stress reactions in an individual does not provide adequate grounds for defining the situation associated with it as a stress, except for that individual or individuals like him. The important role of personality factors in producing stress reactions requires that stress be defined in terms of transactions between individuals and situations, rather than of either one in isolation.

The manner in which conceptions of the limits of stress are built up is to start from the obvious and unequivocal instances and extend the analysis to similar conditions which are, however, increasingly less severe or obvious. And because stress is thought of as a continuum, the lower border lines are most difficult to identify. The approach is also circular at first in that the stress stimulus is defined by the reaction, and the stress reaction is, in turn, defined by its relationship with the stress stimulus. When a stimulus condition is observed that has usually been defined as a stress, but if stress reactions are not observed a search for factors that would account for this discrepancy is made. Similarly, when stress reactions are observed it is assumed that these were brought about by stress conditions, and the investigator looks for them in order to understand the reaction. For example, in the field of fatal accident investigation where the causes of the event must be sought retrospectively, that is, by looking back and reconstructing the antecedent conditions the investigator usually assumes (and this is a bias) that the victim must have encountered severe stress to which the behavior represents a response. If he observes, however, similar life circumstances in a successful pilot, he then assumes or searches for additional factors which could explain the absence of stress reactions.

The word "stress" began to come into vogue in the United States during and following World War II. Psychiatrists, other physicians and psychologists had become active in the war effort. Their concern was with failure of adaptation in the military setting on the part of predominantly noncareer Army, Navy, and Air Force personnel. There was interest in the conditions under which men would fail to fire their weapons, show serious impairment of vital perceptual and motor skills, give thenselves up unnecessarily to the enemy or develop neurotic or even psychotic symptoms associated with combat or preparation for combat. It became clear that conditions of battle could result in marked psychological and physiological disorder, and these disorders were attributed to stress as well as to predisposing factors in the personality that resulted in vulnerability to stress.

There are three central issues in psychological stress. First there is the question: (1) What are the conditions and processes that determine when stress reactions will be produced and when will they not? For example, how does the individual differentiate between benign conditions and damaging conditions? Secondly, what happens when a stimulus is reacted to as stressful? For example, how does the individual cope with stress and what factors influence the choice of coping process? Thirdly, what are the patterns of reaction that define the presence of stress?

Since there are variations in reaction patterns in different individuals under different instances of stress, this issue turns us back to consideration of intervening processes and conditions. What accounts for these variations? How are the variations related to intervening processes? Any system must not only distinguish between the various discernable phenomena of psychological stress but must also postulate the processes intervening between the stress stimulus and stress response, and identify the factors that influence these processes. Psychological-stress analysis is distinguished from other types of stress analysis by the intervening variable of threat. Threat implies a state in which the individual anticipates a confrontation with a harmful condition of some sort. Stimuli resulting in threat or non-threat reactions are cues that signify to the individual some future condition, harmful, benign or beneficial.

Once a stimulus has been appraised as threatening, processes which function to reduce or eliminate the anticipated harm are set in motion. They are called coping processes.

The cognitive activity related to coping determines the form of the coping process, that is, the coping strategy adapted by the individual in attempting to master the danger.

This leads to the behavioral pattern displayed by the individual. It is known that stress produces stimuli that necessitate coping behavior. It then follows that it must be determined if the coping ability and coping processes of the airman are great enough to permit a satisfactory adaptation to the stress situation and if not why.

To understand this communication and to be of the same mind it becomes necessary to expound the meaning of the term psychological stress. Psychological stress is that force that attempts to destroy or threatens to destroy the individual's organization.

A question was asked several paragraphs ago after the statement was made concerning variations in reaction patterns in different individuals under different instances of stress. The question was, "What accounts for these variations?"

The trend of the results of basic research indicates that the investigator may be on the right track when he says that discriminant psychosocial variables account for the above questioned variations.

An individual's behavior is dependent upon the total effect of all the psychosocial variables that went into the making of this individual's life style. These psychosocial variables encompass all of the dynamics involved in the family constellation, the procreational family, the societal forces, the economic level, the educational level, the mental and physical level of health and on and on and on-. It has been found that each variable affects change and postdictally these factors become evident by utilizing a psychosocial reconstruction inventory[1]. Interviewer techniques with an unbiased approach often permit the investigator to know more about the victim than he ever knew about himself.

At this point in the behavioral response to a stressful event it becomes critical for the pilot to examine the forces leading to his victimhood. This may not be possible because most of these forces have been influencing his life style since birth and are largely functioning on an unconscious basis. The stress of comparatively constant change and his method of coping with this stress now become the operational platform upon which sudden change is added. The question arises as to how much stress is contained in the various events that are now happening. Also, the results of the necessary critical looks at these events are dependent upon whether the pilot has experienced the scenario before. It appears that it is the unusual event, the one that makes the greatest change in one's life style, especially undesirable change, that seems to be the most stressful.

Add to this stressful situation, a sudden change-undesirable change-plus some delusions of competence plus an overabundance of the Myth of Invulnerability[4] and the ingredients are present for an unsatisfactory adaptation to the stress loadings and self-destruction may inevitably occur.

After all the information and dynamics are sorted out and interrelated it is felt that the results of the investigation will help point up the basic probable cause of the pilot's behavior that led to his fatal event.

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The determination of the state of aircraft lights or surface craft lights at the time of accident (impact).

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The different vehicle lights (indicator lights,inside lights,headlamps, position lights) may show due to an impact characteristic variations which enable to determine if the light in question was shining at the time of impact.
All incandescent lamps are made out of a glass envelope which is either evacuated or filled with an inert gas (Helium,Argon,Nitrogen etc.) and within which a tungsten filament fastend to approviate electrodes is to be found.This tungsten filament becomes white hot by electric current. The temperature of the filament reaches a heat of about 2300 up to 2800°C. When at such temperatures the glass envelope breaks,the white hot tungsten filament will oxidize, by which process yellow to blue-green tungsten oxydes will be produced.The formation of tungsten oxyde results on any hot filament at temperatures over 1200°C.
If the temperature of the filament is lower than 1200°C (because for instance the electric current has broken down and the filament in consequence is already cooling down,in which case about 3 seconds must be calculated for cooling down from 2500°C to about 400°C) the formation of tungsten oxyde is not effected anymore while on the other hand only tempering colours are brought about.
When the lamp breaks small glass fragments of the glass envelope will fall into the filament and will be melted there if the temperature of the filament is high enough.The absence of such molten glass fragments is normally an evidence for the fact that the filament has been set under electric current only after breaking the envelope or that the filament had not been set under electric current at the time of the break.
New lamps show metallic clean tungsten filament wires upon which the drawing marks are clearly visible.
The mean life of a lamp is up to several hundred hours.
With approaching age the tungsten filament shows considerable recrystallisation,tungsten evaporates off the filament and will be condensed onto the inside of the glass envelope.The filament will look pale,the drawing marks are disappearing.At some time the filament will break or will be torn off at its weakest spot.
When the filament breaks in cold state,then typical features of a brittle breach will be visible.The fracture spot is sharp cornered and its surface coarse crystalline.
When breaking during operation time the fracture spot is showing smoothly shaped ends, in most cases a small pearl of molten tungsten metal is developing.Torne in consequence of a vigorous percussion during operation (impact) the filament will be thinned at the fracture spot.When torn in cold state,the filament will only show features of a brittle breach.
In cold state the filament is very brittle and not capable of deformation by impact.
While the determination of the operation state of a <u>broken lamp</u> is already known since a long time and is used in investigations,difficulties always arose again with regard to the investig-ation of lamps which remaind intact. The experience was known,that only hot filaments were capable of deformation, but quite a long time no reference criterions were at hand.

A test has been performed:Fastend into a metallic frame by which they were protected against breaking,a lighted lamp and a non- lighted lamp of the same type and model have been let fall down from defined altitudes. The impact resulted with maximum retardation (harshly) and refers in some way to the impact of a car frontally against a wall as well as to the impact of an aircraft against the ground.
It became evident,that it depends on the lamp type and on the configuration of the filament with regard to the direction of the impact or percussion, at what value of negative acceleration such a deformation will develop. Besides it depends on the intensity of light which the lamp is bound to produce.Lamps with small intensity (like for instance indicator lamps) and therefore drawing only a few watts or even parts thereoff,are equipped with very thin filaments,while on the other hand head lamps of high intensity of light are equipped with considerably much thicker filaments. This thicker filaments are less sensitive to impact than the filaments of weaker lamps.
The filaments of weaker lamps normally show deformations already at an impact from a speed of 15 mph while on the other hand head lamps or search lights with high intensity lamps in most cases only show such deformations at an impact from a speed of 40 - 60 mph.
It is characteristic to such deformations that the filament does not only get bent, but that on the front region of the filament,seen in direction of the impact,there will develop a clear reduction of the spiral distances of the filament which process may lead to the welding of single turns,while on the other hand, on the backward region of the filament the distance of the spiral is clearly increasing and this even to such an extent that the filament on that spot will tear off in consequence of sufficient reduction of diameter.
Among lamps,samples of which had been tested adequately,it will be even possible sometimes to determine the impact speed on behalf of the deformation of the filament.
For purpose of investig-ation it is necessary however to have at hand a number of lamps of the same production series as a calibration sample since already during manifacture deformations of filaments especially in the region where the filament andthe electrodes are connected may arise, a circumstance which may be observed at certain makers of lamps more often than at others.
Test showed that non-lighted filaments did not deforme at impacts and the only result of impact was the break of the filament whereby it may happen however that the filament is crumbling away in many small parts.(fragments).
For purpose of investigation of lamps a good microscope is absolutely necessary.A mere observation by naked eye or with the aid of a magnifying glass,especially in the investigation of lamps with very thin filaments, like for instance indicatorlamps,will by no means be sufficient.It must be warned against the attempt to test such lamps,before microsc.investigation, perhaps by switching on the electric circuit,because by this doing,on a lamp which has a fissure in the glass envelope the oxidation process would be initiated and thereby quite another trace figuration would arise as would be the case if such tests were abondoned for the first.The glass-envelope of small lamps shows normally finest metallic tungsten traces (slight brown colouring) spread over the entire glass envelope even if the spiral had not been deformed provided that the lamp was in operation at the time of impact.
It is evident therefore that normally as well as at damaged lamps and at non-damaged lamps too it can be determined after an accident (impact) if the lamps had been in operation at the time of accident or not.
The following pictures show such signs on lamps:

Fig.1 tungstenoxydes on the filament
Fig.2 and 3 tungstenoxydes and melted glas on the filament
Fig.4 recrystallisation of tungsten filament
Fig.5 and 6 filament broke during operation time
Fig.7 thinned End of a filament torne during operation time
Fig.8 drawing marks on a new filament and characteristic marks of a brittle breach
Fig.9 filament distorted by impact
Fig.10 and 12 filaments distorted by impact
Fig.11 maschine used for tests
Fig.13 - 24 tests with switched on lamps
Fig.13 Lamp (new)
Fig.14 impact with 30 mph
Fig.15 impact with 50 mph
Fig.16 new lamp
Fig.17 impact with 30 mph
Fig.18 impact with 50 mph
Fig.19 new lamp
Fig.20 impact with 12 mph
Fig.21 impact with 18 mph
Fig.22 impact with 25 mph
Fig.23 impact with 32 mph
Fig.24 impact with 50 mph

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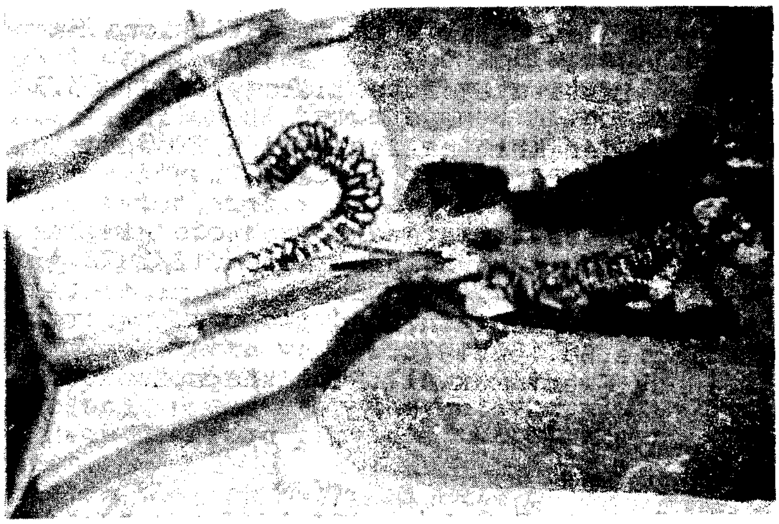

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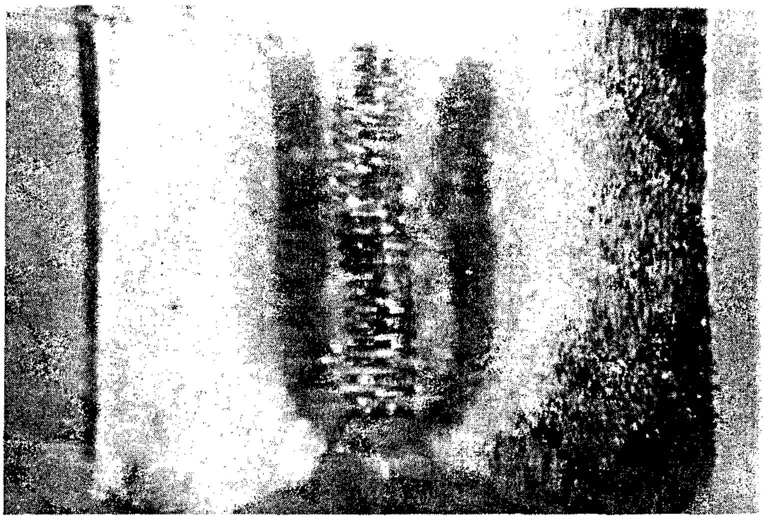

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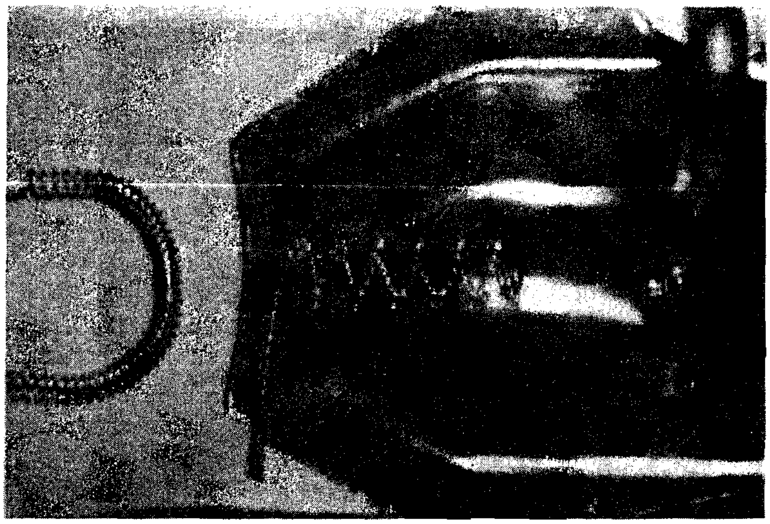

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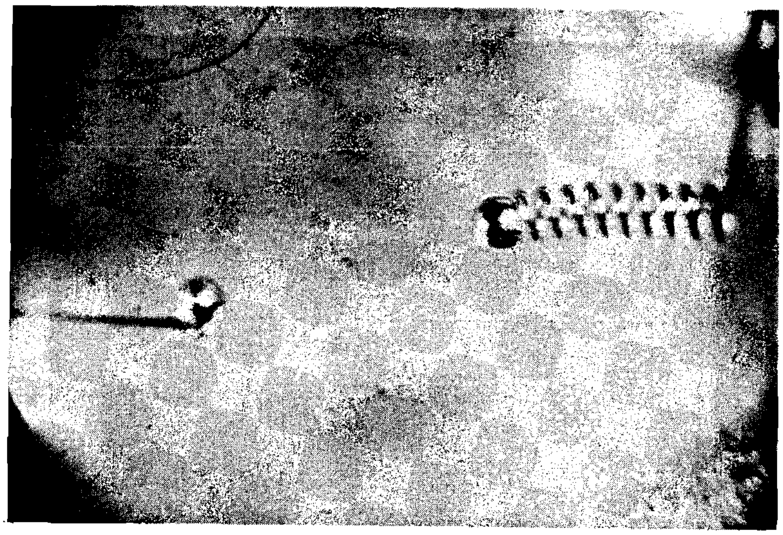

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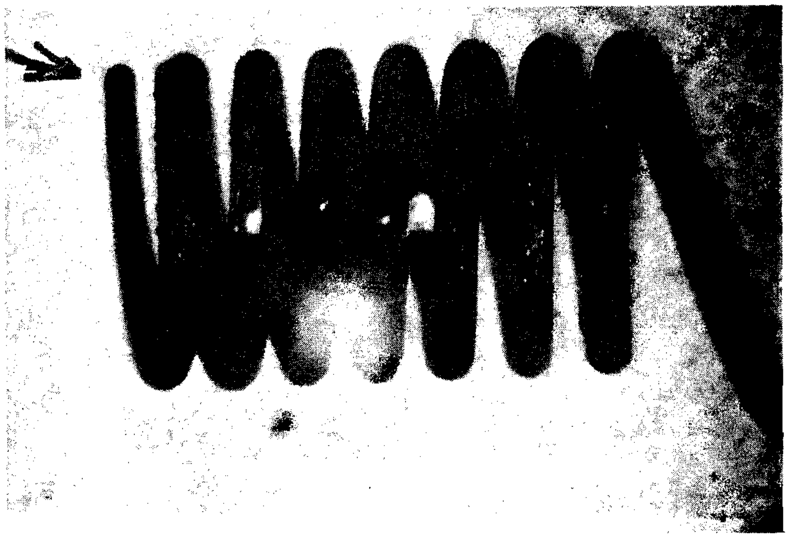

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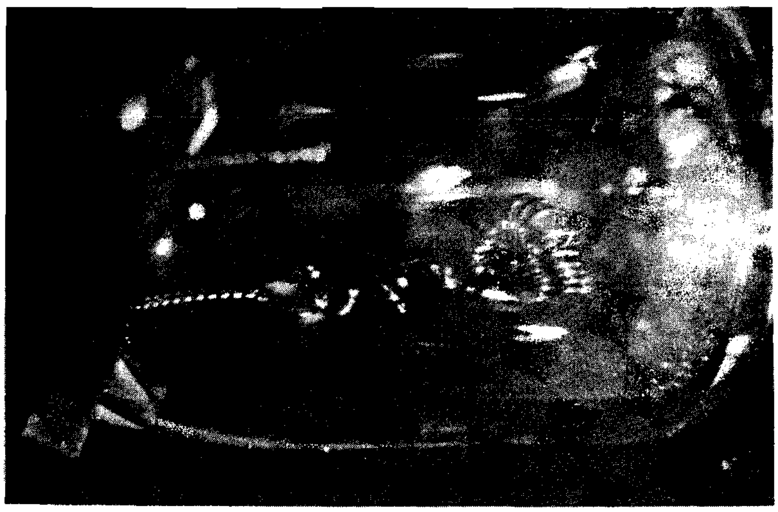

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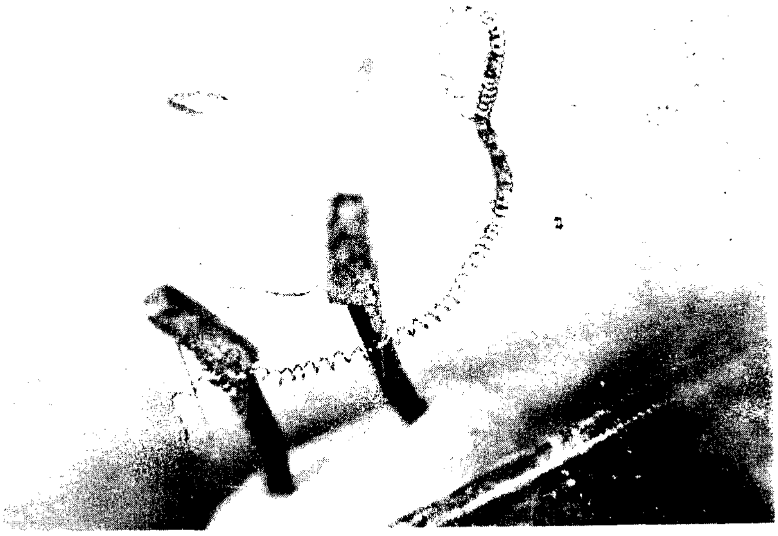

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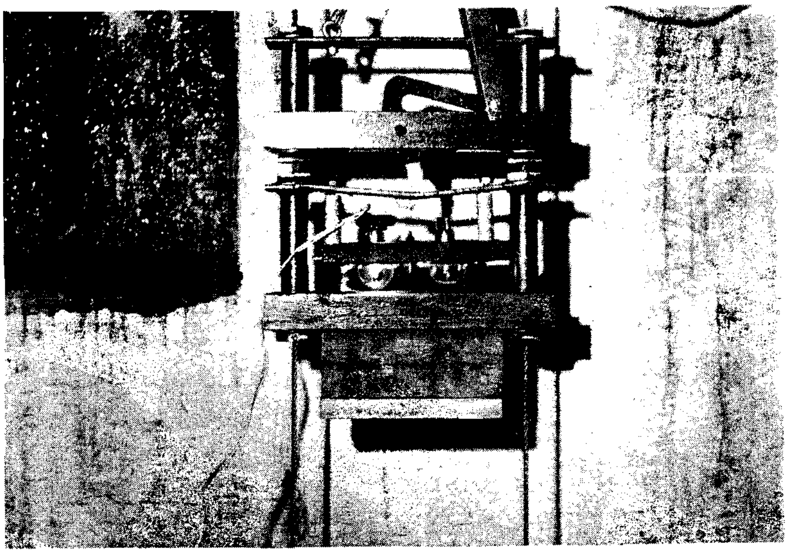

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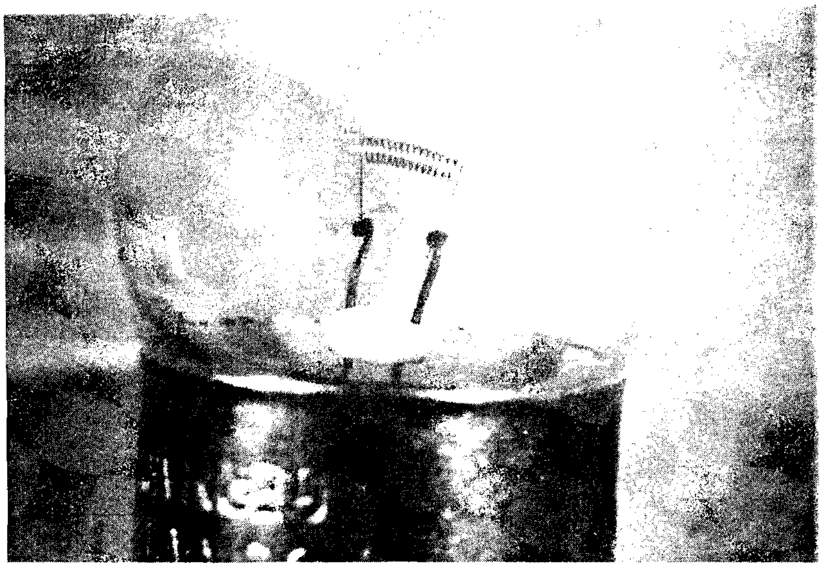

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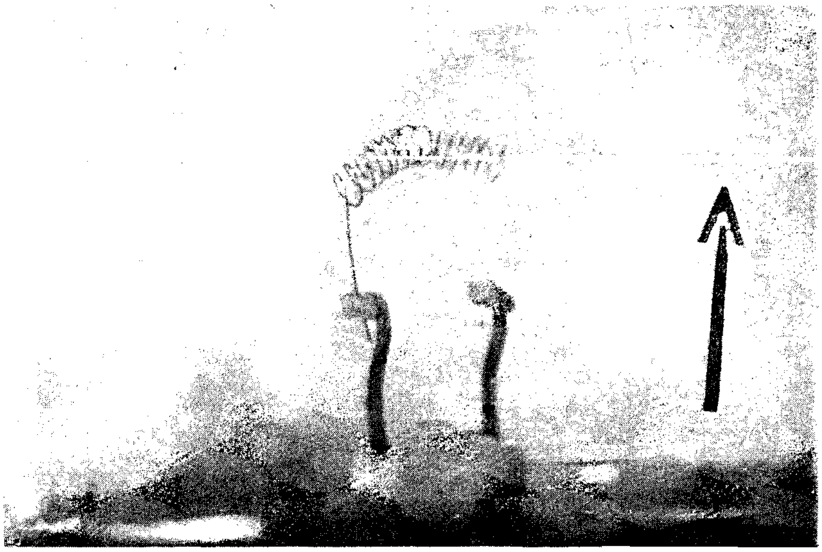

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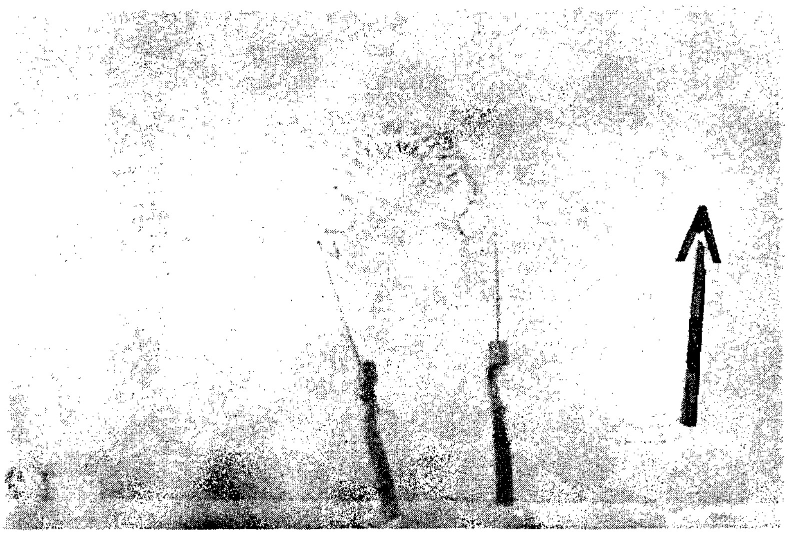

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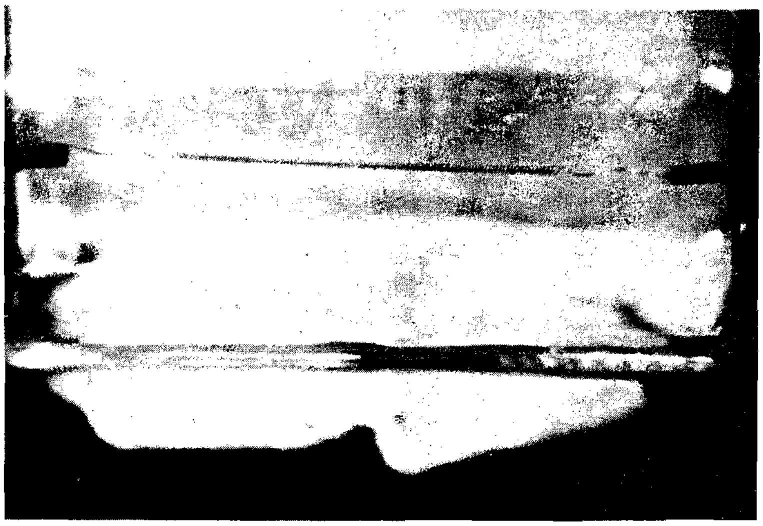
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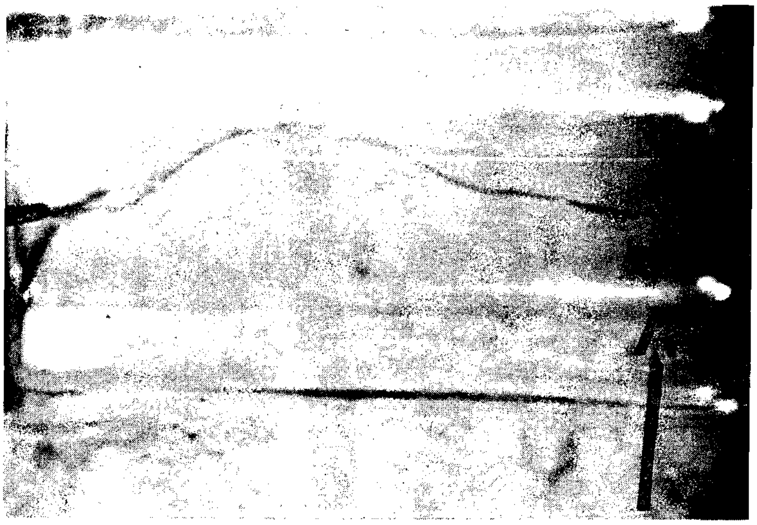
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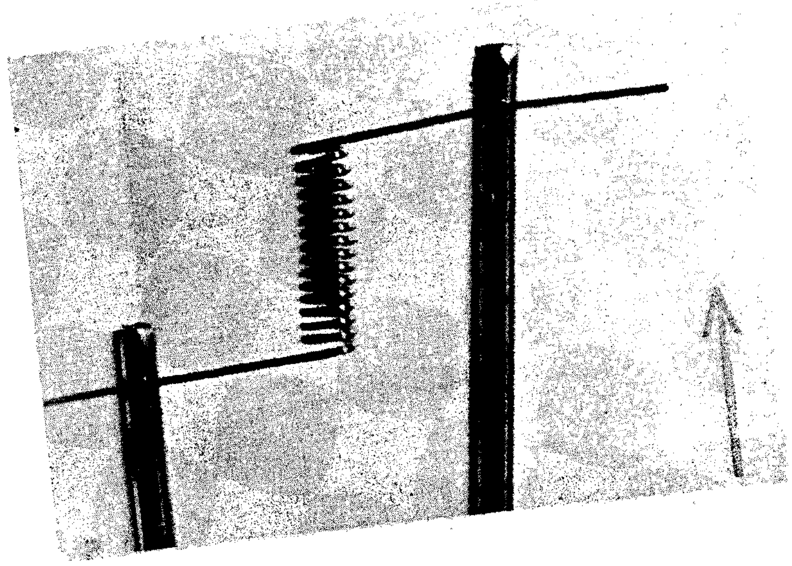

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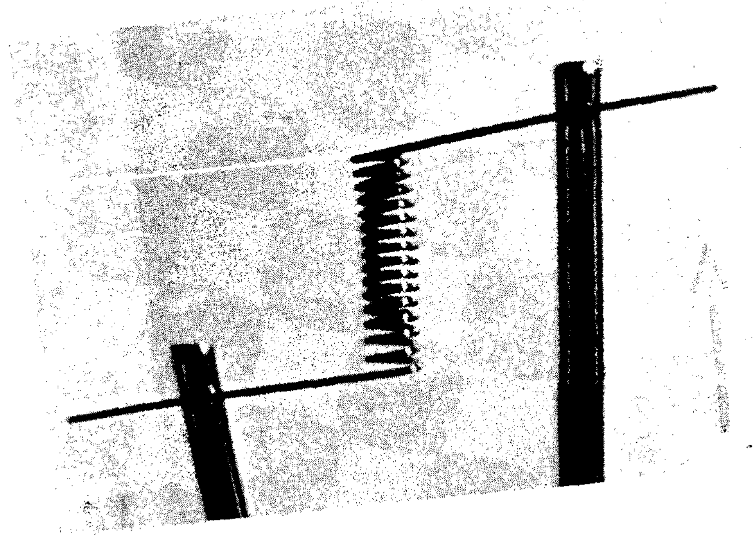

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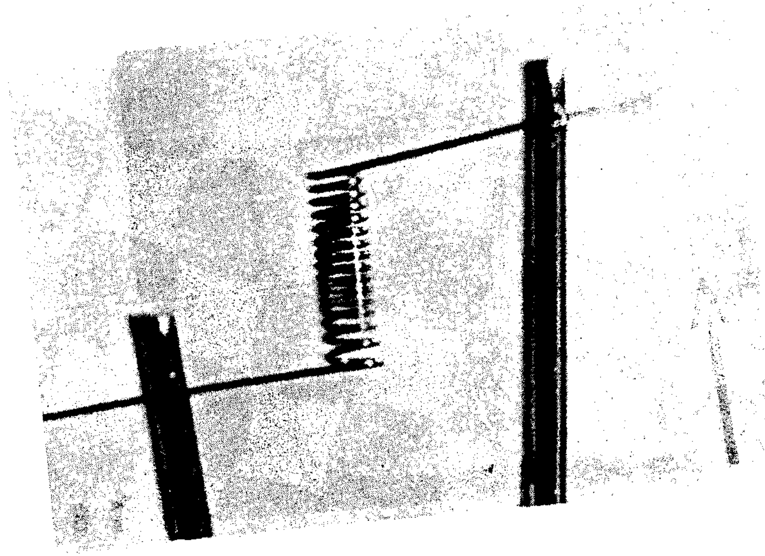

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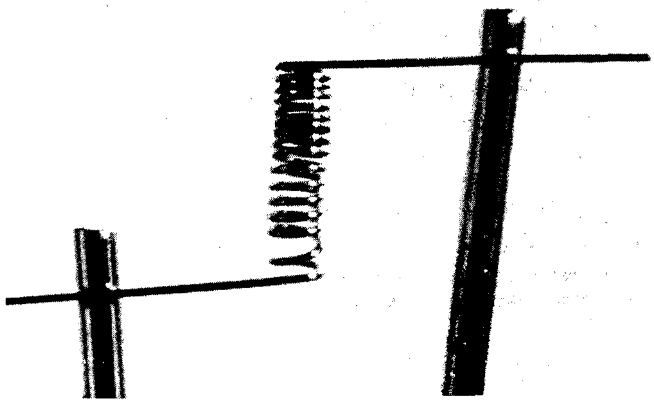

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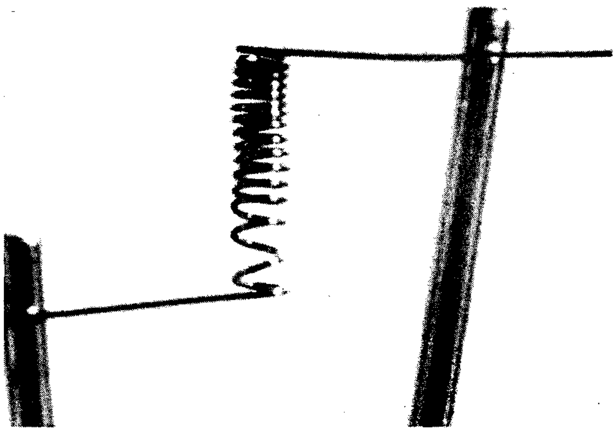

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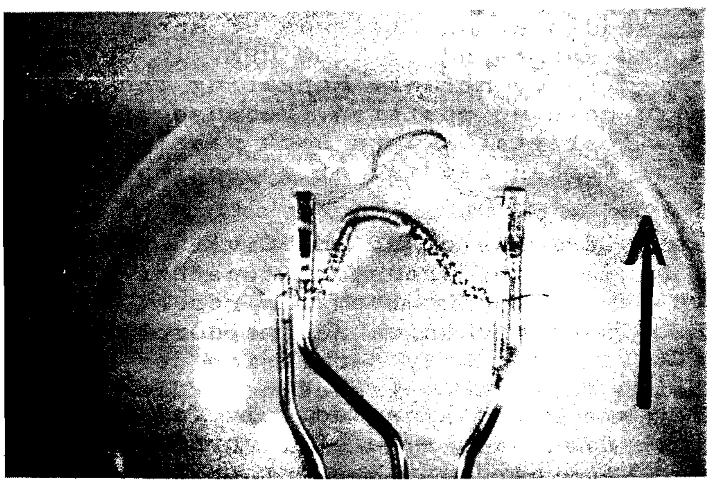

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TEMPORARY POWER DECREASED.

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1.0 SUMMARY

On the example of the forced landing of a leight single engined aircraft in the Austrian Alps, the investigation methodology of the Accident Investigation Division of the Federal Ministry of Transport is shortly reviewed. Loss of power in certain flight attitudes was argued to be the reason for the discussed crash. Laboratory tests with the same engine and simulation of "extreme short of oil conditions" proved the hydro-tappets to become inoperative before bearing failure occured. The installed temperature and oil-pressure indicators did not monitor the dangerous situation. The measured loss of power turned out to be up to 20% of the nominal rated performance. So the pilot could not maintain the necessary cruising altitude to surmount the saddle of the Arlberg-mountain.

2.0 INTRODUCTION

In 1971, September 27th, a Piper Cherokee crashed near the village Stuben in the Austrian Alps. A reconstruction of the flight according to hearings of the pilot and witnesses proved, that an evident loss of engine performance seemed to be the reason of this accident. During the climb to the Arlberg saddle at an altitude of approximately 1600 meters MSL the engine speed decreased to 2000 RPM. In descend attitude the engine operation seemed to be normal. Repeating the climb attitude, the engine failed again in nose up position. Because of the low height and the narrow valley of Klostertal a turn back was impossible and the pilot made an unsuccessful forced landing at approximately 1400 meters MSL.

An Accident Investigation Commission of the Civil Aviation Department of the Austrian Federal Ministry of Transport together with consultant experts had to deal with the following items: aircraft operations, aircraft engineering and flight mechanics and meteorology. Their report showed, that the aircraft had an oderly permission for operation. Maintenance and insp ection were accomplished according to manufacturers directions. The pilot was valid licenced. His flight experience and his experience on this discussed type of aircraft was sufficient. Although the flightpath of the aircraft was not optimal for operations in mountain regions. The weather conditions were not of predominant influence.

After all the investigation proved, that the discussed accident was provoked by the decrease of engine performance in climb attitude. Therefore the Institute for Aircraft Engineering of the Technical University of Vienna was charged with a systematic analysis of the engine behaviour at comparable flight conditions. As no comparable investigation is referred hitherto in literature, the results of this analysis seem to be of general interest.

3.0 OBJECTIVES OF THE INVESTIGATION PROGRAM

The kind of crash, the statements of passengers and witnesses showed that there was a temporary decrease of power and this decrease was the reason of the crash. Icing effects were not probable.

So primary it seems necessary to ask: Is it possible that piston engines will produce efficient changes of power output at different attitudes during normal aircraft operations. Which kind of troubles would be possible when an engine is operated with oil levels under the minimum mark. The log of oil refueling and the oil consumption of the engine in accordance with quantity of oil that was found in the engine after the crash, showed that the oil in the engine was not more than one quart.

The next question was: Will any sufficient change in the indications of the engine instruments inform the pilot of the reason of such a temporary power decrease, or will warn any other characteristic effects the pilot before or during decrease of power. This seems to be very interesting as the discussed type of aircraft is very common and a great number of this type is in use.

The above mentioned questions were the only important ones, as marks from throttle and carburater heating valve on the crashed engine seemed to be correct.

By using records and inspection forms similar to that in use for sceduled overhault an accurate history of the engine disassembly and inspection was preserved. The advantage of these check lists is, that important procedures cannot be missed.

4.0 BASIC RESULTS

The visual check of the engine assembly showed, that fire had taken place in the rear part of the engine compartment. The painting of the lateral and upper engine cowl was destroyed by heat. The deformation and fracture of the engine mount structure obviously was caused by the crash. The motorcase itself showed fire traces. The harness assembly was partly carbonized. The upper rubber bushing of the engine assembly was burned. The highest temperatures were assumed to be in the region of the rear cylinders. The carburator, the oil sump and the silencer showed specific deformations.

The scratches at the leading edge of the propeller tip together with a characteristic backward deformation of the outer part of the blades led to the conclusion, that the propeller rotated with low speed at the moment in the course of the impact, Both blades were bent around the crankcase.

The oil-sump andintake pipe assembly as well as all pipes and gaskets in the oil system were o.k. The oil system including oil cooler was tight even after the crash. No greater traces of oil could be found neither on the place of the crash nor on the engine mount.

Some screws of the propeller mount assembly were deformed, two of them were broken. The crankshaft could be turned without difficulties and no abnormal behaviour or noise was noticed. Summarising, there was no indication for a mechanical failure of the engine.

5.0 PARTICULAR TECHNICAL INVESTIGATIONS

The disassembly of the mechanical fuel pump did not show any mechanical defects. A functional test after reassembling the system gave positive results. The booster pump was completely destroyed by fire. The carburator, the complete fuel induction system and the primer system were o.k. The carburator air assembly was heavily deformed.

A spectrographic analasys of the deposits in the exhaust pipes and in the silencer unit was made. The deposits contained mainly lead, very small amounts of aluminiium, chronium and nickel, and traces of other metals. It is obvious, that these metallic components derive from the combustion process.

The oil sump, the accessory housing oil system components group, the oil filter and the oil pump were tight and mechanically in order. It was surprising that a rather small amount of motor oil was found in the engine. There was no more than one litre of oil in the sump and in the filters. Investigations at the place of the crash gave no proof for oil leakage in the course of the accident. A chemical analysis of the oil revealed it to be very similar to the motor oil ESSO 80E, which is a conventional aircraft engine oil.

The spark plugs, the surfaces of the pistons and the cylinder heads showed no indication of abnormal operation or carburator icing. Visual inspection of the cylinders and the crankcase did not show cracks or deformations. The bearings of the crankshaft and the reciprocating parts as well as the bearing inserts for main crankshaft bearings and connecting rod bearings showed normal wear of an engine with 122 service hours.

The intake and exhaust valves, the rockers and push rods were o.k. The camshaft showed expressed half-moon shaped pittings on the surface of the cam (Fig.1). The intakecams showed two of these pittings because of the two valves actuated. Hardness tests of the surfaces of the cams revealed a mean Rockwell-hardness of 58 HRC. This is a normal value.

Except the harness assembly, which showed firedamage, the ignition assembly worked correctly. The rest of the accessories was either damaged by the impact or in operative condition. It had no influence on the failure of the engine.

6.0 ANALYSIS OF THE FUNCTION OF THE HYDRO-TAPPETS

Summarising the results of chapter 5.0 reveal firstly surprising wear of the surfaces of the cams and secondly only one litre of motor oil in the whole engine. The half-moon shaped pittings on the cams indicate excessive tolerance in the valve train. The measured effective tolerances were in the maximum about 1,7 millimeters. This tolerance should be adjusted by the action of the hydro-tappets. Only malfunction of the hydro-tappets can cause the noticed excessive wear on the surfaces of the came.

The reason for the deficiency of oil can only be supposed. There was no hint that during the last 27 hours of flight more than 3 litres of motor oil have been refilled. With an average oil consumption of 0.3 litres per hour and an oil capacity of 7.6 litres the engine had a calculated oil deficiency of more than 5 litres at the beginning of the climb to the Arlberg. Because of the increased power requirement during climb the oil consumption will grow. Oil quantity in time of accident was not more than 1,5 litres. Experience with comparable engines shows no noticeable change of oil temperature and oil pressure indication, because the oil cooler is able to hold temperature when the amount of oil in the engine is less than 1,5 litres. According to the Manual the minimum safe oil quantity is 1,8 litres. A smaller oil quantity could be the reason of thermal troubles and furthermore of engine failure. In this case, especially in nose up attitude a considerable volume of air will be brought into the oil system. Experiences about the behaviour of the hydro-tappets with air bubbles in the oil were not available.

A theoretical investigation concerning the effective loss of flow during malfunction of the hydro-tappets is shown in Fig.2. The loss of power due to high tolerances in the valve train can be approximated by the diminuation of the flow integral of the intake valve. The flow integral can be approximated by the area under the valve excursion over the camshaft angle position. Introducing the designations N_o for the engine power with intact valve train, N for the engine power associated with the hydro-tappets inoperative, F_o for the area under the valve excursion with intact valve train and F_i for the sum of the respective areas for all cylinders with the hydro-tappets inoperative, yields the relation for a four cylinder engine.

$$N = N_o \frac{F_i}{4 \quad F_o}$$

Based on the measured output of N_o = 152 PS of the engine in discussion and using the informations of Fig.2 the expected output during operation with full travel in tolerance of valve train can be calculated as N = 126 PS. This is equal to a loss of power of 17.1%

Practical experiments should verify that the decrease of power could occur several times without troubles with the bearings.

7.0 ENGINE - CHECK ON THE TEST BED

To test power output of the original engine Lycoming O-320-E 2A a test bed type Hollman-NAV.COM. was used. Test should inform about following problems:

(1) verifying the loss of power of the engine with the hydro-tappets inoperative.

(2) how fast become the hydro-tappets inoperative in the case of air penetrated into the oil system ?

(3) what is the time of recovery of the hydro-tappets, when normal conditions are reestablished ?

(4) can engine work several periods at this mode without instantaneous damage of the bearings ?

The electronic registering device of the test bed is shown in Fig.4. The data: torque, revolutions per minute, oil-pressure, oil-temperature, cylinderhead-temperature, manifold pressure and time were automatically plotted.

Atest with the hydro-tappets operative resulted the normal maximum rated power output of the engine: 152 PS at 2700 RPM. This is conform to the indicated maximum rated power of 150 HP. A new test was made with the hydro-tappets inoperative. The measured maximum rated power at 2700 RPM was 132 PS. This yields an experimental loss of power of 13.2% with reference to the maximum power of 152 PS. It corresponds very well with the calculated data of chapter 6.0. With reassembled hydro-tappets and minimum oil quantity the tests were repeated. An additional device allowed exact quantity control of air penetration into the oil system. By opening or closing the air intake valve the condition of hydro-tappets operative or inoperative could be simulated. The expected variation of power output occurred. The change of the speed corresponds to the change of oil pressure indication. The time until a noticeable change of speed was some seconds. Recovery of power needs some seconds too after the air valve was closed. This proves that engines fitted with hydraulic tappets show a quick change in power output, proportional to tolerance of valve train caused by air bubbles in the oil system. Immediately after stopping airflow recovering occurrs. The same effect turned out several times at different speeds.

Disassembly of the engine after the experiments showed heavier impacts on the surfaces. This proves that too big tolerance of valve train was the reason for this damage.

8.0 CONCLUSION

Impacts on the cam surfaces of the engine and undamaged bearings were the reason for a detailed analasys of the behaviour of hydro-tappets under short of oil conditions. Theoretical analysis based on the flow integral of the intake valve and the measured tolerance of the valve train resulted in 17.1% drop of power output of the engine. 1.5 litres or less of oil in the sump could cause such a state of operation of the engine during climb attitude of the aircraft. Immediate damage of the bearings need not necessarily occur. Experimental simulation of these circumstances verified the above said results. Measured loss of power was approximately 13.2 %.

The reason of the crash of the Piper Cherokee was probably a too little quantity of oil. The reason of power decrease was penetration of air into the oil system during climb in nose up attitude. Therefore inefficiency of hydro-tappets occured. Nose down position normalized oil-flow and operation of hydro-tappets and engine. It seems that several cycles of power de- and increasing are possible without engine failure.

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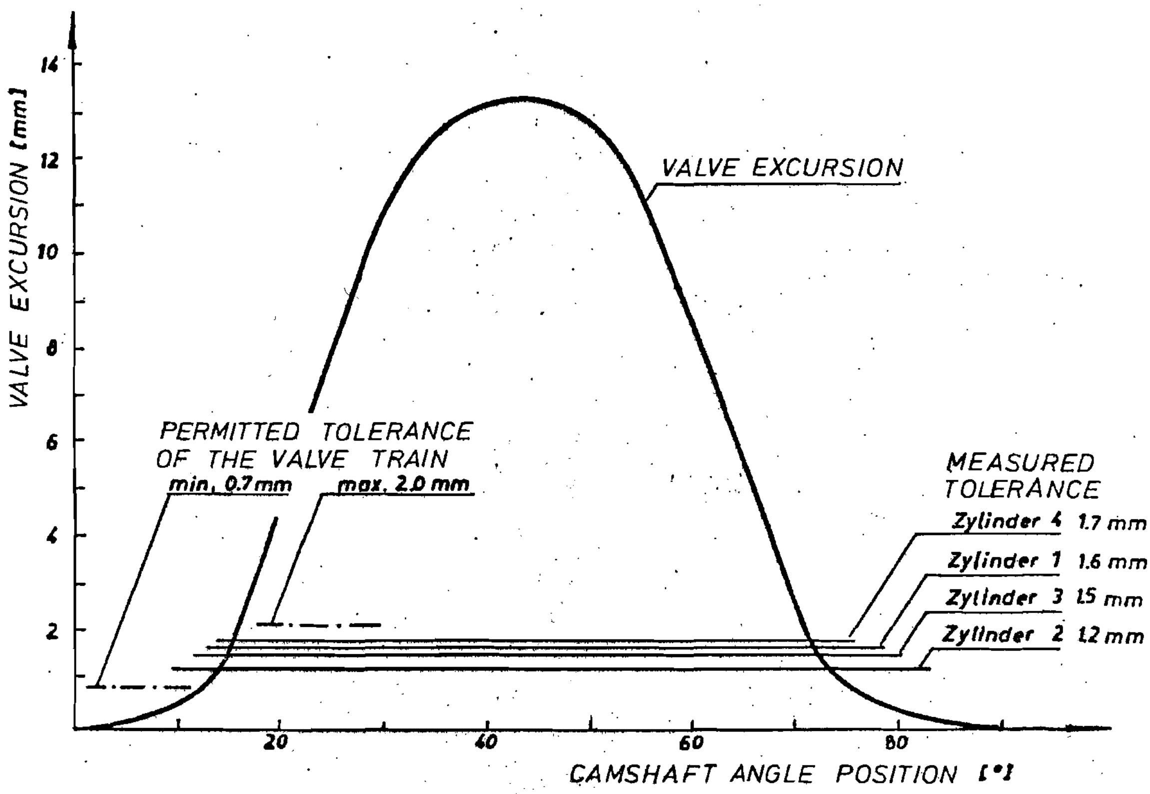

Fig.: 1 Valve excursion

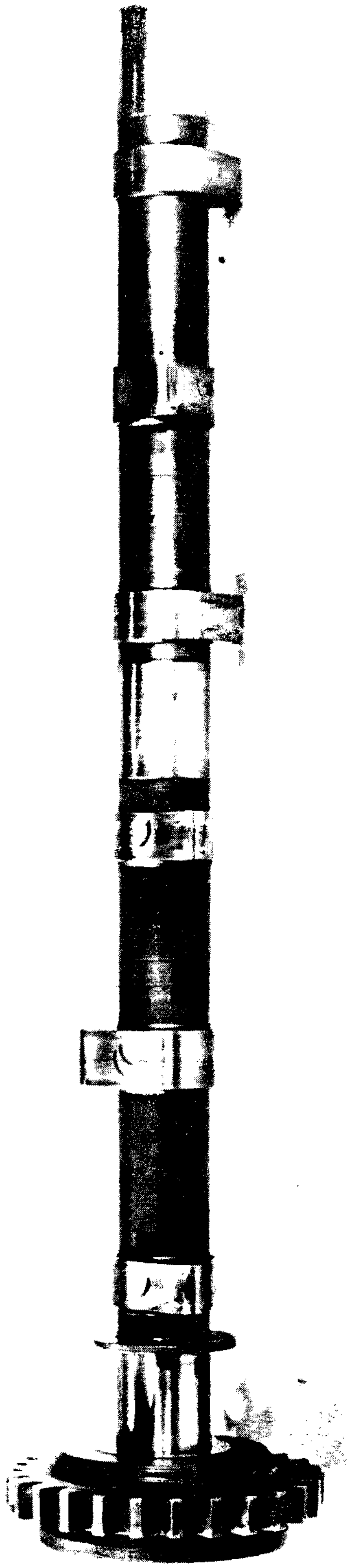

Fig.: 2 Camshaft with pittings

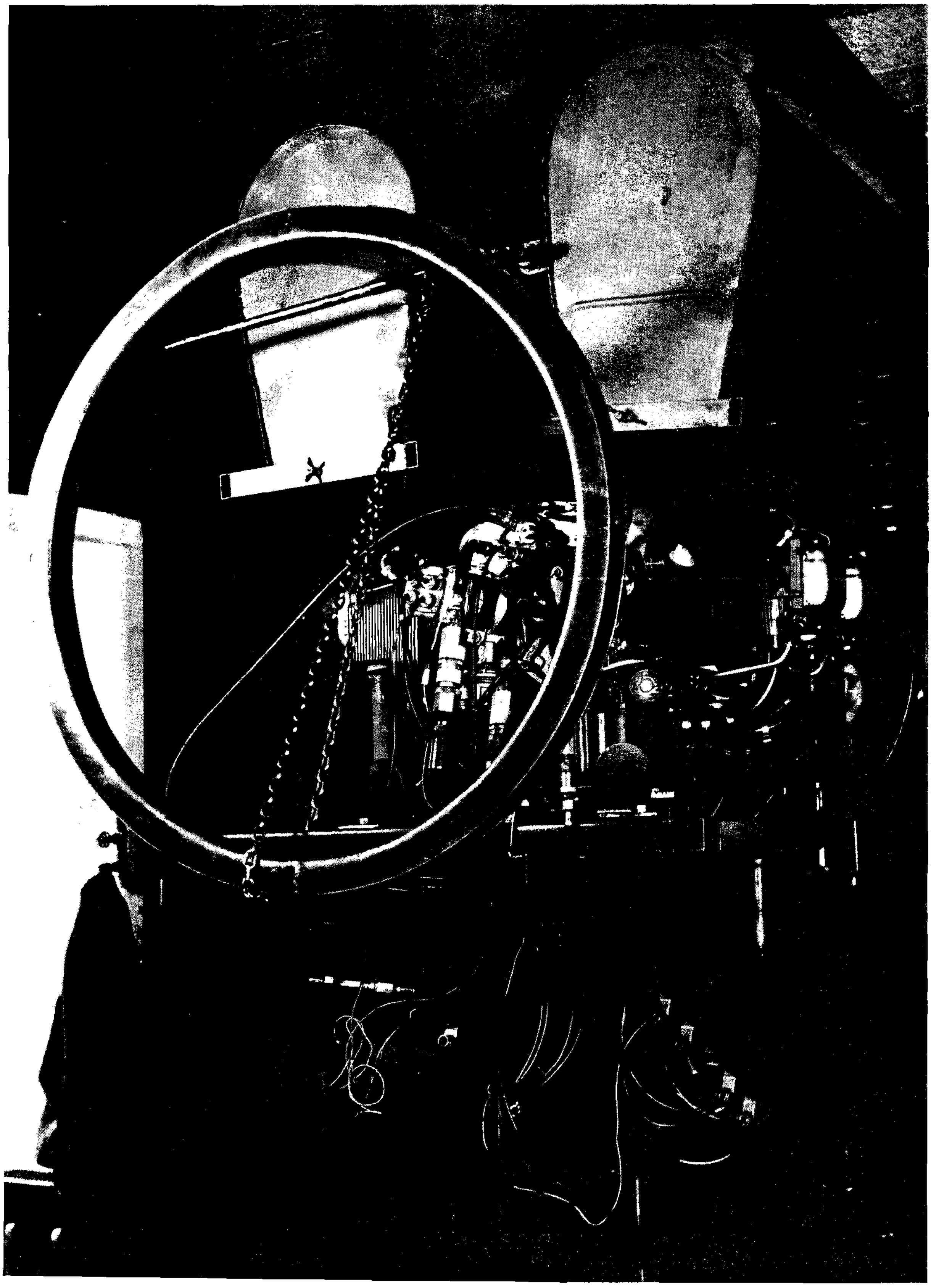

Fig.: 3 Engine Lycoming O-320-E2A mounted on the test bed
tvpe HOLLMANN - NAV.COM.

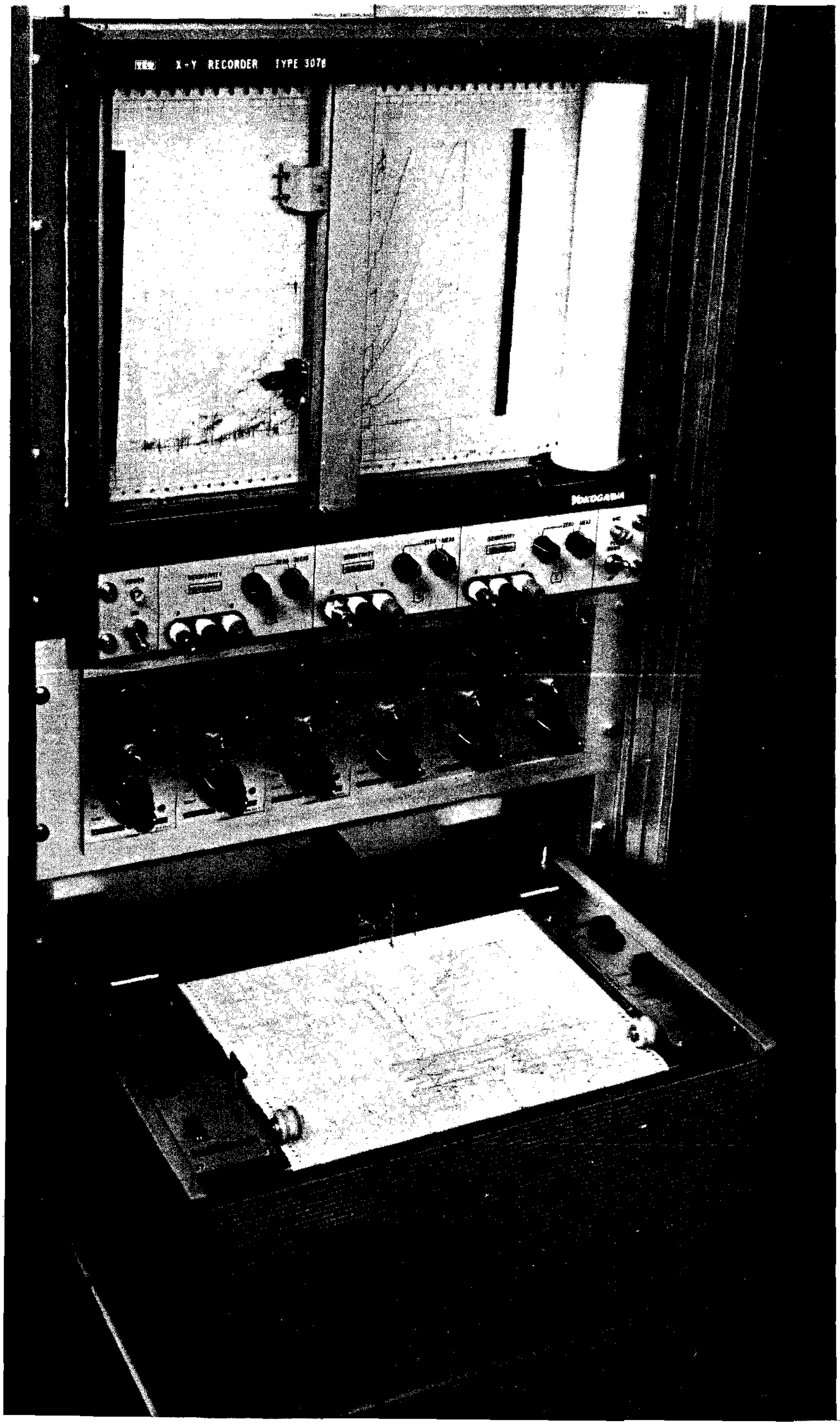

Fig.: 4 Electronic registering device of the test bed HOLLMANN - NAV.COM.

Determination of the person piloting an aircraft prior to accident

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There is often a dispute in investigation of aircraft accidents which person has been steering the aircraft at the time of accident.
It might happen that the occupants are thrown out of the aircraft and it is to be determined afterwards, who had been steering the aircraft respectively which person had occupied which seat in the plane. There is also the possibility that the occupants do not want or are not capable, due to injuries sustained, to remember. In many a case this problem arises if the surviving pilot takes his chance by pretending that not he himself had been piloting the aircraft but the dead occupant, to get away from criminal procedure. It also might be possible, that dependants to dead occupants in order to gain insurance advantages insist on a certain person for having piloted the aircraft.
By adequately securing the traces on the site of accident, on the aircraft and its remnants, on the clothes and the bodies of the occupants, it will in most cases be succesful to settle such arguments. Often the combined effords of forensic experts and experts on the field of flight medicine and the evaluation of the latter with regard to injuries of occupants in connect with characteristic injury marks (pedals, switches, instrument panel, windscreens etc., are required in order to clarify such a question beyond any doubt. Due to experiance it can be stated, that such circumstances can more easily be enlightend on such occupants, who already died at the site of accident and to whom no medical care had been applied. Due to transportation circumstances, to undressing (whereby very often the cloths are thrown away because intense bloodstains) likewise due to removal of traces out of wounds, it afterwards mostly will not be possible to determine the degree of injuries and to reconstruct the causes of these injuries.
At the investigation of the aircraft (or surface craft) might be found blood traces, tissue remnants and hairs. It is necessary to protect those traces against changes. Blood traces still in liquid state are to be secured in phiols. Liquid blood traces as well as tissue traces must be kept cool in oder to prevent them from decomposing. For the purpose of determining such blood vestiges and tissue particles serological and microscopical inverstigations will be necessarily reserved to the approviate forensic- medical laboratories. Dried up blood traces are best to be secured together with subsoil (cloth remnants etc) and to be kept in glass phiols too.
If there is no certainty wether there are blood traces in question, one might dab some "luminiol" or "bencidine" solution or an other peroxidase test onto a small spot of the trace whereby luminescence or a blue colour etc. will indicate blood. Otherwise no liquids should be brought in contact with blood because the blood could be decomposed. It is the task of the physician to secure adequate blood for comparaison tests. For the purpose of comparing hairs it will be necessary to secure hairs of the different parts of the head, as it is erroneous to anticipate that all the hairs of the head are equal. If one person has sustained an injury of the head and gets treatment in an hospital, in most cases all the hairs will be shaved. In consequence a succesful comparison is not practicable anymore if the hairs could not have been secured at time.

A further possibility consists in the preservation of textile fibres and their comparison with the clothes of the occupants. Special attention should be paid to safety belts in aircraft. At a chrash landing very easily a spreading of clothes-fibres on the safety belts will take place because the body of the person is pressed against the safety belt, while on the other hand pressure marks of the belt made upon the body or upon the clothes of the occupants might give informations.
Likewise abrasions of plastic or leather jackets etc. upon parts of the aircraft or vice versa abrasions of the aircraft paint, -plastics of the aircraftparts or of the instrument panel padding upon the clothes of the occupants could be found.
If for example the aircraft disposes of a white inside wall paint and such paint abrasions are to be found on the clothes of an aircraft occupant on his right body side, at an other occupant on his left body side, a clear conclusion is possible, where the person was sitting in the aircraft (surface craft).
Obviously still microscopic comparisons of the traces on the clothes with the aircraft paint will be necessary.
Such vestiges on the clothes can not allways be percieved by naked eye. Mostly the clothes must be inve-stigated under the microscope in order to find traces, since dust, blood and dirt may overlie such traces. Therefor it is necessary to secure as quickly as possible the clothes. Wet and humid clothes must not be packed. Such clothes must be dried up before, as otherwise putrefaction and mould formation could frustrate the investigation.
For the purpose of investigation of paint (varnish) traces spot - tests under the microscope are applied, whereby smallest varnish fragments are exposed to different reagents (sulphuric acid, nitric acid, trichloric-acetic-acid, acetone, chloroform, diphenylamine, brucine, etc.) and the changes of the paint are observed. Likewise the ashes of such paint flakes are examined. These simple reaktions already in most cases supply clear conclusions on the conformity or non-conformity of such varnish-traces.
Evidently in single cases infrared-spectroscopy, laser-microanalysis, x-ray-fluorescence- and diffractometry, mass-spectroscopy, etc. might give further informations.
There are still some further possiblities which not sufficient attention is paid to. Even at an aircraft crash or crash-landing inertial forces press the aircraft occupants against certain parts ot the body work within their seating positions. Persons whose feet are resting on pedals are especially pressed with their shoes against those pedals. Thereby abrasions of the pedals onto the shoes (shoe-soles) can be produced, on the other hand abrasions of the shoe soles onto the pedals might be caused too. Such marks are not produced by operating the aircraft normally or applying the brakes normally, whereby the maximum negative acceleration lies between 0,8 and 0,9 g. Only at pressure forces of several "g" such markes can be observed.
If such abrasion marks have been found it is not only possible to determine the person having steered (piloted) the craft (aircraft) but also to determine which pedals had been used.
This shall be demonstrated with the aid of two examples (however realting to surface vehicles). In both cases the survivor maintained that the dead person had been steering the vehicle wich had hit a tree (frontal hit with a speed abaut 65 mph).
At the examination of the vehicle (1) soil print marks of a rippled shoe sole had been detected on the clutch, on the brake pedal and on the throttle pedal. The dead had shoes with plain soles, the survivor such

with rippled soles. If the pedals had been operated by plane soles the soil traces would have been wipped away (Fig. 1 - 5). In the second case on the shoes of the survivor the traces shown in the following pictures had been determined (Fig. 7 and 8) On the sole of the right shoe blackish stripes had been found, on the heel of the right shoe round reddish print marks had been determined. On the left shoe no traces could be found. The pedals of the craft consisted of black rubber, the throttle pedal had a oblong striped design and a red heel protection with circular rills (Fig. 6). On the shoes of the dead no traces could be detected at all.
It could be ascertained that the survivor had steered the car and that it was him, who had resting his foot with his shoe on the throttle-pedal, which means that the survivor had bounced against the tree without showing any reaction. Besides that on the trowsers of the dead, that is on the outside of the right thigh, widespread greenish abrasions of plastic were found, that chemically coresponded with the plastic covering of the door panel of the right door. Therewith it could be made certain that the dead one was the driver's mate, who had been pressed against the right door at the impact.
Of course it is not allways possible that such clear prints can be found on the shoe soles or pedals like shown on the pictures. Often only minor transfer of material takes place whereupon such traces can only be made visible under the microscope and with a special illumination technique. The confiscation of the shoes and pedal coverings als well as clothes is therefor essential.
According to my opinion it is always necessary to investigate such traces with the aid of an approviate microscope, with application of spot-tests, infrared-spectroscopy, thin-layer-chromatography als well as gas-chromatography etc., if they are corresponding with regard to the material compounds.
Among pilots we may find traces of switches on the shoes as well as often on the handls (gloves) caused by switches or levers and especially by the steering wheel.
This short contribution will show the possibilities of determining the person piloting an aircraft or steering a surface craft and of determining the seat which had been taken by a person in the craft.

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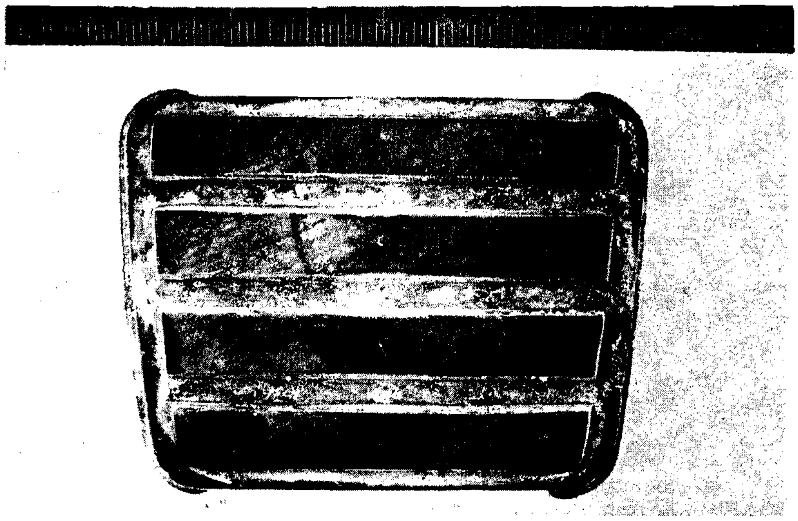

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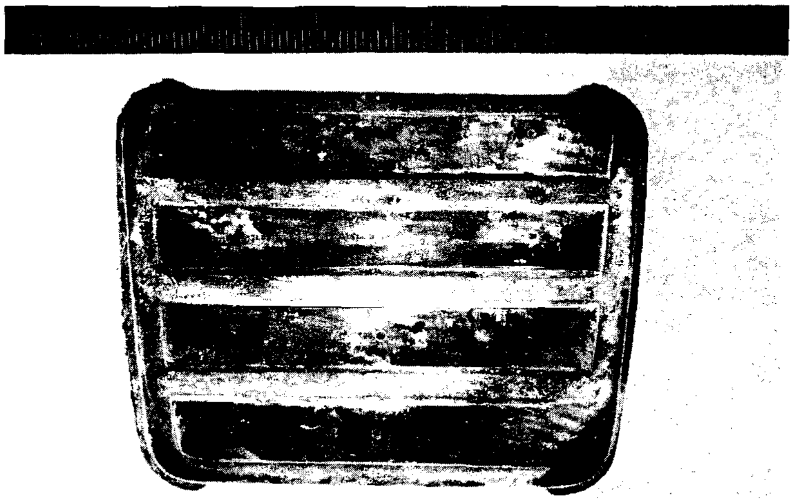

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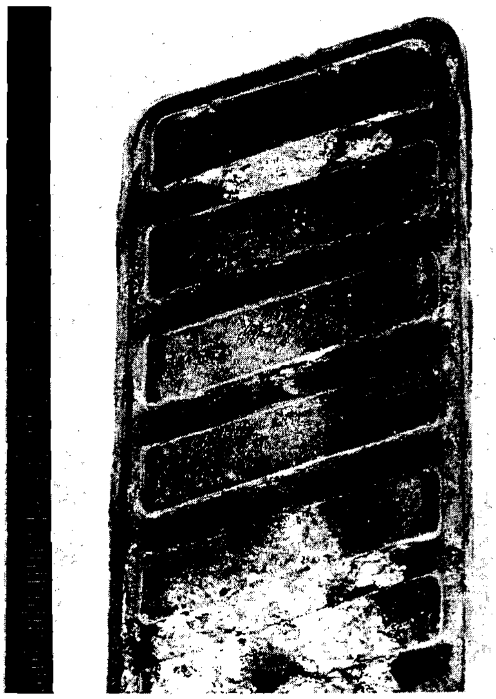

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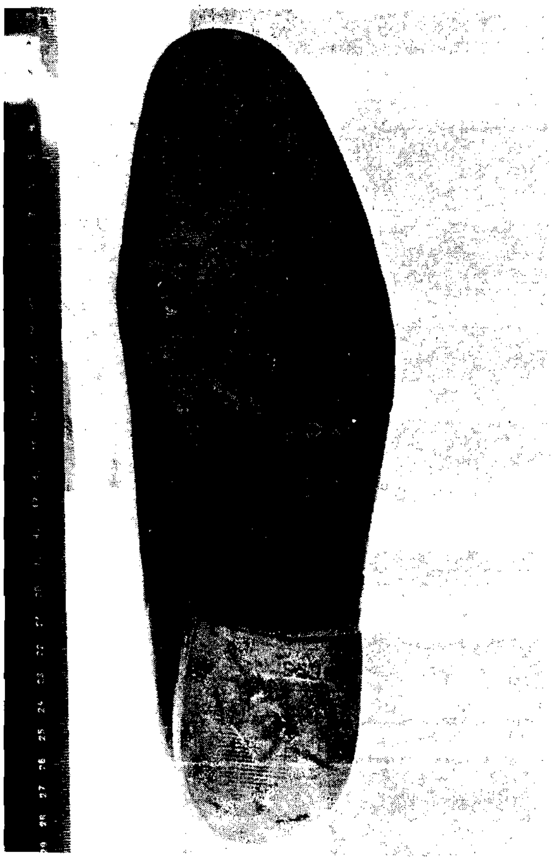

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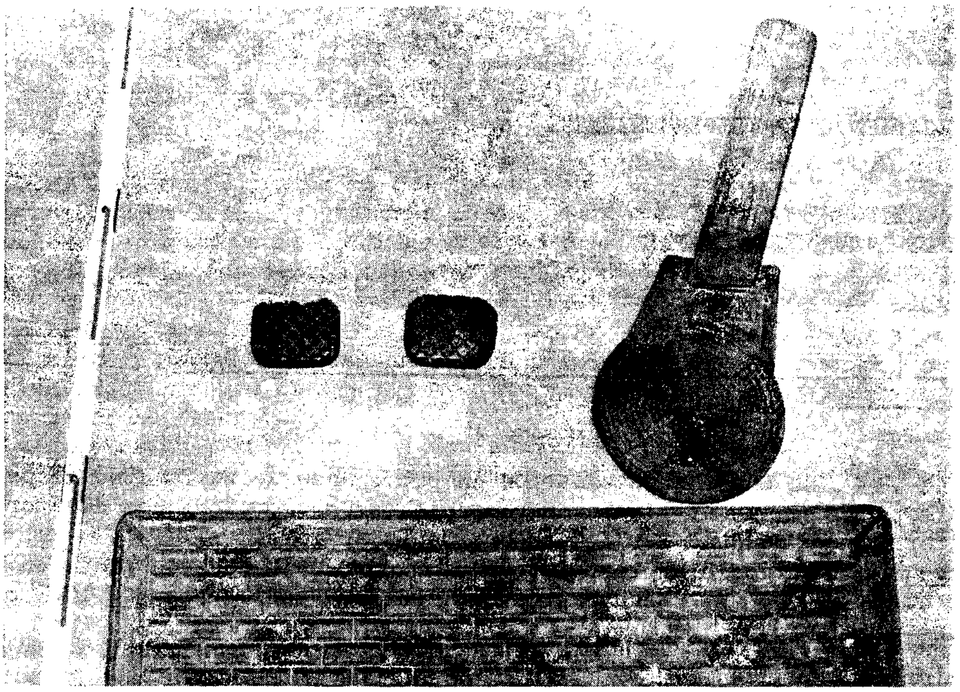

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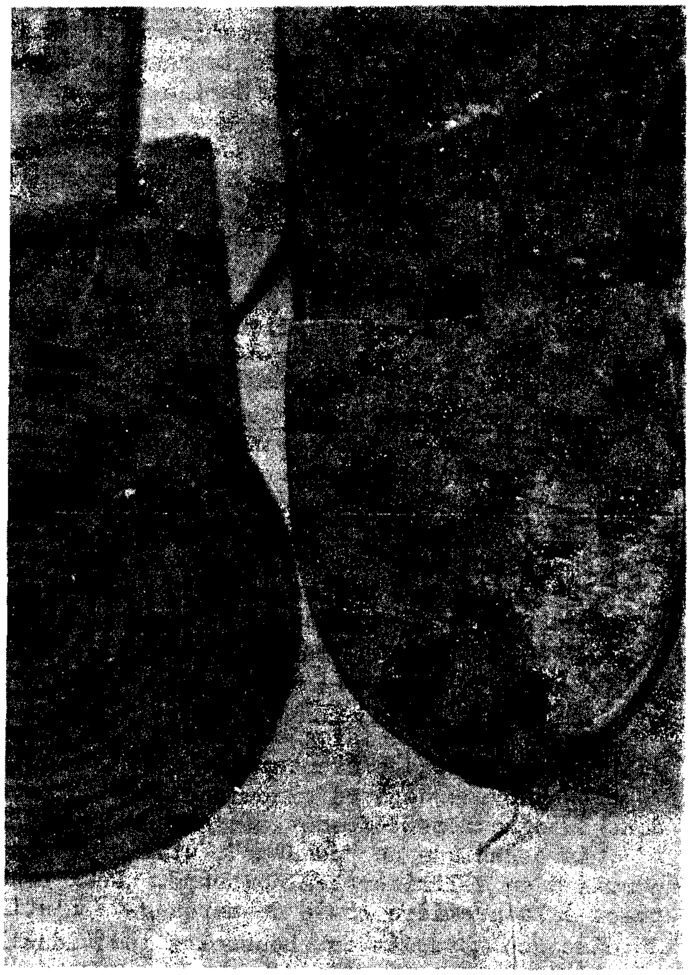

8

"RECHERCHE ET RÉCUPERATION D'ÉPAVES IMMERGÉES"

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CAS No 1: Épave d'un Lockheed 1049 G, immergé à 2 km5, au large de DAKAR, par 40 m de fond.

a/l'accident

Le lundi 29 août 1960, un Super Constellation en provenance de Paris avec 63 personnes à bord, doit effectuer, peu avant l'aube, par conditions météorologiques défavorables, une procédure "d'atterrissage manqué" sur l'aéroport de Dakar Yoff.

Après un passage à la verticale du terrain, l'avion disparaît dans un grain en direction de la mer et ne sera plus entendu après son annonce "vent arrière à 1000 pieds", moins de deux minutes plus tard.

b/ recherche de l'emplacement de l'épave

L'alerte, immédiatement déclenchée, permettait, moins d'une heure trente après l'interruption des communications, d'identifier des débris et des corps flottant à la surface en mer, à 2 à 3 km des côtes.

Par ailleurs, dès le début de la matinée, un témoin unique déclarait avoir vu, à l'heure probable de l'accident, deux éclats rouges, au large. Les enquêteurs pouvaient se replacer avec le témoin sur les lieux et dans les conditions de ses observations, d'où une direction compatible avec la zone de disparition présumée pouvait être déterminée.

Grâce au concours de la Marine Nationale qui détachait spécialement un navire porte-hélicoptère et des plongeurs, une prospection rapide des fonds de la zone probable permettait, dans le cours de la seconde journée, de repérer de gros débris et d'identifier avec certitude la position de l'épave.

Cette recherche rapide s'est effectuée selon la méthode dite du "pendeur": un homme grenouille "pend" très près du fond au bout d'un câble lesté remorqué par une vedette qui balaie la zone de prospection.

Dès l'identification, des bouées provisoires de marquage avaient été larguées et un hélicoptère survolait les lieux en permanence pour déceler d'éventuelles remontées d'huile, de carburant ou de nouveaux débris flottants.

c/ travaux de récupération des débris

L'étude des cartes marines, confirmée par les informations fournies par les plongeurs militaires et les navigateurs locaux, faisait ressortir la nature favorable des fonds peu accidentés et d'une profondeur sensiblement constante, variant de 35 à 40 m. Par contre, la visibilité restait généralement très médiocre et de nombreux requins, (considérés comme plus impressionnants qu'offensifs) croisaient en permanence dans ces eaux.

La profondeur, relativement faible, nécessitait cependant, pour tout travail un peu prolongé, des paliers dans la remontée des plongeurs afin d'éviter tout accident de décompression.

c.1. Cartographie au fond

Avant toute décision de remontée de l'épave, la connaissance de la répartition des débris sur le fond présentait un intérêt certain.

Les moyens déjà en place permettaient aux enquêteurs d'organiser cette cartographie dont le déroulement devait nécessiter plus d'une semaine.

La technique du "pendeur", utilisée systématiquement sur la zone repérée, avait permis d'en délimiter les contours. Deux bouées repères principales avaient été substituées à la première bouée de marquage. L'utilisation de cordeaux portant des indications de distance associés aux boussoles individuelles, permettait ensuite aux plongeurs de quadriller le fond, à partir de ces bouées.

Avant chaque descente et après chaque remontée, la coopération constante entre équipes de plongeurs et enquêteurs conduisait ainsi à la cartographie et l'identification de la plus grande partie des débris reposant sur le fond.

c. 2. Récupération

Il n'était pas envisagé de remonter la totalité de l'épave et le choix s'était porté essentiellement sur les quatre groupes motopropulseurs, les commandes et servocommandes, les trains et le cockpit.

Les moyens suivants devaient être utilisés:

- bâtiment poseur de câbles téléphoniques en raison de ses équipements propres à la remontée des débris importants,
- un petit thonier, disponible sur place, servant de base flottante aux enquêteurs et à quatre plongeurs professionnels.
  Ce thonier transportait également le matériel de plongée et un caisson de recompression.
- deux gros pneumatiques "zodiac" hors bord permettaient plus facilement le largage et la récupération des plongeurs.

Selon le cas, les éléments à récupérer seront soulevés par des sacs étanches gonflés avec les bouteilles des hommes grenouilles, puis hissés à bord des bâtiments ou directement saisis du fond de la mer après passage d'élingues par les plongeurs.

À noter que ces opérations, en raison de la profondeur, ont été lentes et délicates, le temps efficace de travail n'étant, selon les cas, que le tiers ou la moitié du temps total de plongée, compte tenu des paliers de décompression généralement nécessaires, ou des difficultés dues au manque de visibilité.

d/ résultats

Les opérations ont permis d'établir le plan de répartition des débris, significatif au moins en ce qui concerne les parties principales.

Environ le quart des débris comportant notamment les quatre moteurs et leurs hélices, les trains d'atterrissage, l'empennage, une partie de la voilure et une partie du pylône et du tableau de bord ont été récupérés.

Leur expertise a permis de déterminer la configuration de l'avion au moment de l'impact, son altitude, sa vitesse et le régime des moteurs.

CAS No 2: Épave d'un DH 125 immergé en Méditerranée à l'embouchure du Var par 130 m de fond

a/ l'accident

Le 5 juin 1966, au cours d'un meeting aérien, un DH 125 avec deux membres d'équipage technique décolle de Cannes vers Nice en début d'après-midi, afin de se présenter après des lâchers de parachutistes et des présentations d'hélicoptères.

À la fin du vol, des témoins ont noté derrière l'avion un phénomène qui ressemblait à des traînées de condensation, à peu près simultanément derrière les deux réacteurs, un incendie s'est manifesté, puis a gagné l'avion en remontant vers le bord de la voilure. Quand cette dernière a été atteinte, il y a eu un embrasement quasi général, et la boule de feu, avec une traînée incandescente, a continué à piquer vers l'eau où l'avion s'est englouti.

b/ recherche de l'emplacement de l'épave

L'accident s'est évidemment déroulé devant de très nombreux témoins, et outre des photos, la Commission d'enquête disposait d'un film en couleurs dont l'étude devait présenter un certain intérêt.

L'alerte a été déclenchée immédiatement, le personnel de sécurité ayant suivi le déroulement de l'accident et le message de la tour a été capté par l'ensemble des moyens de secours.

Moins de quatre minutes après l'impact, les embarcations de sauvetage et l'hélicoptère de la protection civile arrivaient sur place, récupéraient le corps du copilote et de nombreux débris légers. Une première reconnaissance en profondeur jusqu'à une profondeur de 40 m était effectuée par les plongeurs de l'aéroport et des sapeurs-pompiers, et la zone très probable du crash était balisée.

Une première étude des fonds marins indiquait que l'épave avait toute chance de reposer dans la partie sous-marine de l'embouchure d'un petit fleuve côtier, le Var. La profondeur se situait aux environs de 1 30 m sur un fond irrégulier, près d'un ravin de 300 m de profondeur. Le lit du fleuve étant assez boueux, la visibilité ne devait pas dépasser quelques mètres en raison d'un écoulement rapide et turbulent dans l'estuaire.

c/ récupération de l'épave

Les conditions probables ainsi définies conduisaient à faire appel aux moyens du Commandant COUSTEAU qui disposait à Nice de son bâtiment océanographique, le "Calypso" et d'un petit sous-marin autonome apte à prospecter les fonds.

Un accord entre les autorités françaises et les représentants du constructeur britannique permettait une répartition des frais; la plus grosse part était d'ailleurs réglée par les soins d'Hawker Siddeley dont un ingénieur devait participer à plusieurs descentes, à l'examen sur le fond d'un certain nombre de débris, ainsi qu'à la prise de films et photos de divers éléments de l'épave.

Différentes pièces pouvaient être remontées, mais il apparaissait que des parties importantes de l'épave avaient probablement été enterrées à la suite d'avalanches de boues provoquées par les fortes pluies survenues quelques dix jours après l'accident.

Dans ces conditions, le rôle des bâtiments Cousteau devait être complété par des travaux classiques par filet de drague qui permettaient d'obtenir des résultats assez importants.

L'ensemble de cette campagne a nécessité notamment douze jours de travaux de la Calypso et de la soucoupe SP 350 et deux périodes de huit jours du bâtiment "Le Lutin", s'étageant sur les mois de juin, juillet et début août 1966.

d/ résultats

Près de la moitié des éléments de l'épave du DH 125 a été récupérée et transportée par avion du C.E.V. de Brétigny à la base de Hatfield.

L'ensemble de ces débris avait souffert de la corrosion. Aucun indice d'incendie ou trace anormale de surchauffe n'était en évidence. Quatre ruptures importantes étaient notées, mais très probablement postérieures à l'impact.

Les examens et expertises ont, en effet, dû tenir compte:
- de l'impact à grande vitesse sur l'eau,
- de la descente dans la mer, sous pression croissante (environ 12 bars ou 170 p.s.i.),
- de l'impact sur le fond et des mouvements sous l'effet des courants,
- des opérations de relevage et des transports.

Une reconstitution de l'avion, à partir des éléments récupérés, a pu être effectuée à Hatfield et les résultats de nombreuses études et expérimentations ont été confrontés avec les constatations sur l'épave.

L'enquête a pu finalement mettre en évidence un dépassement des charges limites de calcul de la voilure provoquant une rupture à la hauteur de l'extrados près de l'emplanture d'où une importante quantité de kérosène s'est échappée, puis enflammée.

L'avion "décroché" sous facteur de charge élevé, n'a pu être repris par son pilote en raison de la faible marge d'altitude et de la détérioration de la structure.

CAS No 3: Épave d'une Caravelle III immergée à 22 NM dans le sud de l'aéroport de Nice, par plus de 2300 m de fond.

a/ l'accident

Le mercredi matin 11 septembre 1968, une Caravelle III avec 95 personnes à bord décolle d'Ajaccio à destination de Nice.

Après plus de 20 minutes de vol apparemment normales, alors que l'avion est en descente, l'équipage annonce "on a .... des ennuis ..." et demande une approche directe.

Immédiatement autorisé à continuer sa descente et à contacter Nice, le pilote indiquera encore à Marseille-Contrôle "on a... le feu à bord", puis entré en liaison avec Nice, confirmera l'incendie. Autorisé à faire une approche directe sans restriction, l'avion émettra son dernier message "... on va crasher si ça continue"; plus de deux minutes séparent la première annonce des ennuis de cette dernière communication.

Deux échos seront observés 30 et 40 secondes après les dernières paroles de l'équipage, à 25 NM dans le Sud-Sud est, puis à 22 NM dans le sud du radar de l'aéroport de Nice.

Des recherches par avions, hélicoptères, bâtiments et vedettes sont immédiatement déclenchées dans des conditions de visibilité médiocres.

b/ recherche de l'emplacement de l'épave

Au moment de la perte de contact radio avec Nice-approche, l'avion se trouvait à une distance de 22 à 25 milles nautiques dans le Sud de l'aérodrome de Nice. L'alerte fut immédiatement donnée et des recherches entreprises.

La mauvaise visibilité en mer et de fausses informations données par des "témoins" qui se trouvaient sur la côte entre Saint-Raphaël et Monaco, ne permirent le premier repérage de débris flottant sur la mer que deux heures après l'accident, par un Constellation SAR.

Le premier bateau ne pouvait arriver que 4 heures après l'accident et les débris avaient fortement dérivé sous l'action du vent et des courants de surface par rapport à leur position au moment de l'impact de l'avion.

L'ensemble de ces éléments était concentré dans une zone de petit diamètre, 300 m environ.

Les recherches à la surface furent poursuivies pendant plusieurs jours, alors que les épaves continuaient de dériver dans la direction du Sud-Ouest sous l'action des vents et des courants.

Leur extrême fragmentation laissait supposer que le choc à la surface de l'eau avait été extrêmement violent.

La zone d'incertitude s'étendait sur une surface considérable d'environ 30 milles carrés. Les fonds indiqués par l'institut océanographique de Monaco étaient de l'ordre de 2200/2300 m, constitués de vase dure, ils ne présentaient que peu de relief.

Une première campagne de chalutage commençait le 12 novembre à l'aide de deux navires câbliers, et avec l'assistance d'un navire hydrographe. Cette première campagne fut interrompue le 30 novembre, sans qu'aucun élément de l'épave recherchée ait pu être relevé.

L'expérimentation faite démontrait néanmoins l'efficacité de la méthode utilisée puisque de nombreux objets dragués par 2,000 à 2,600 m de fond étaient ramenés à la surface en dépit des mauvaises conditions météorologiques rencontrées.

L'étude des photos des spots radar, très délicate en raison de caractéristiques locales particulières, associée à divers essais en vol et recalibration, permettait début 1969 une meilleure définition de la zone de recherche.

c/ récupération de l'épave

Une campagne de dragage d'une durée de quinze jours, précédée d'une reconnaissance des fonds par une caméra sous-marine, (troïka "Cousteau") eut lieu en mars et avril 1969. Elle permettait de repêcher de nombreux débris de l'avion et de déterminer la position de l'épave.

Le mauvais temps et l'indisponibilité des bateaux se conjuguaient alors pour un nouvel arrêt des opérations au milieu d'avril 1969.

Deux plongées du bathyscaphe "Archimède" étaient effectuées les 1er et 22 mai 1969 sur les lieux signalés à la suite de la campagne de chalutage de mars-avril. Aucun débris provenant du F-BOHB n'est aperçu ni détecté.

Les travaux reprenaient en novembre et décembre 1969.

Les opérations de chalutage furent, au cours de cette dernière campagne, encore une fois gênées par le mauvais temps et par des difficultés de positionnement des navires très sérieuses.

La navigation avait été assurée par les seuls moyens de bord, à l'aide de bouées dont la position était déterminée par des mesures prises sur les amers et phares côtiers souvent peu visibles.

Malgré ces difficultés, la campagne de novembre décembre 1969 fut fructueuse puisque, pour la première fois, des éléments importants de l'avion, volets de voilure, partie de revêtement, fuselage et structure, équipement hydraulique, furent remontés. Les traits les plus réussis furent les derniers de la campagne. La disponibilité des navires câbliers et l'extrême fatigue des équipages qui avaient travaillé pendant un mois entier dans des conditions exceptionnellement dures ne permettaient malheureusement pas de poursuivre les opérations.

La Commission concluait à l'unanimité que seule une nouvelle campagne permettrait, mais sans certitude, de fournir l'explication de l'accident.

Primitivement prévue pour le mois de novembre 1970, cette opération fut reportée aux mois de mars et avril 1971. Elle fut précédée d'une nouvelle opération "Troïka", au cours de laquelle un certain nombre de photographies de débris au fond furent obtenues. Cette opération "Troïka" permit également d'obtenir un grand nombre de photographies de traces de chalut qui confirmaient la régularité de fonctionnement de l'engin utilisé et son efficacité: pratiquement aucun objet ne subsistait au fond sur les traits de chalutage.

Les principales difficultés rencontrées au cours des trois premières campagnes avaient été, d'une part, la détermination du point géographique des navires, d'autre part, le positionnement du chalut par rapport à ces navires.

La première difficulté tenait au moyen de navigation employé: localisation au radar sur une bouée dont la position ne pouvait être fixée avec une grande précision en raison de l'éloignement de la côte, souvent invisible, et de l'importance de son rayon d'évitage compte tenu de la profondeur du mouillage (2.300 m).

La seconde difficulté était inhérente aux dimensions du système: profondeur 2.300 m à 2.500 m, navires remorqueurs distants de 1.800 m environ longueur des câbles de remorque 4.000 à 5.000 m.

Au cours de la quatrième campagne, la navigation des bateaux remorqueurs était assurée à l'aide d'un système mobile Trident loué au service hydrographique de la marine nationale.

La localisation du chalut par rapport aux navires était obtenue grâce à un système acoustique original mis au point avec le concours de la compagnie Thomson-C.S.F. et constitué par un ensemble interrogateur-récepteur installé à bord de "l'Alsace" et un jeu de trois balises, une sur le chalut et deux sur "l'Ampère", l'une de ces dernières servant de relais aux réponses impulsionnelles de la balise du chalut.

Associé à un petit calculateur, ce système a parfaitement fonctionné et, dans les conditions de la dernière campagne, la position du chalut sur le fond était connue avec une précision de l'ordre de 30 m, inférieure à la largeur du chalut lui-même (56 m).

La dernière campagne commença le 25 mars 1971 pour s'achever le 13 avril.

Cette campagne fut, en outre, comme les précédentes, contrariées par de nombreux coups de vent qui obligèrent les navires à prendre la cape ou à s'abriter en rade de Cannes et rendirent extrêmement délicates certaines manoeuvres de relevage du chalut. Au total, le chalut ne fut filé que vingt fois.

Grâce aux perfectionnements apportés, ces vingt traits de chalut remontèrent cependant à peu près les trois quarts du total des débris repêchés.

d/ résultats

a) Au total dix à douze tonnes de débris provenant de toutes les parties de l'avion ont été repêchés au cours des quatre campagnes.

En raison de la grande profondeur d'immersion, ces éléments ne portaient aucune trace apparente d'oxydation ou d'altération quelconque à leur sortie de la mer.

Les débris recueillis au cours des deuxième et troisième campagnes ont fait l'objet d'un traitement de passivation destiné à arrêter la corrosion.

Pour la dernière campagne, un tel traitement s'avérait difficilement applicable en raison des dimensions de certains éléments.

L'évolution de la corrosion observée à fréquence rapprochée pendant plusieurs jours a permis de constater qu'après une première période de développement assez rapide, cette corrosion ne se développait plus que très lentement. Il faut noter qu'à partir d'une certaine profondeur, les pièces immergées ne subissent généralement que peu de réactions chimiques et peuvent demeurer intactes, au moins pendant quelques années.

Le traitement de passivation présentant le risque d'effacer des indices utiles pour la poursuite de l'enquête, il semble préférable de l'éviter dans le cas d'opérations de récupération analogues.

L'identification des débris a nécessité plus de 4.000 heures de travail.

À noter, enfin, que l'enregistreur de bord SFIM A 261 (photographique) a été récupéré, mais inexploitable en raison du séjour prolongé de la pellicule dans l'eau de mer.

b) Tous les débris jugés intéressants pour l'enquête ont été disposés sur un tracé au sol représentant, en vraie grandeur, un fuselage de Caravelle.

Il est apparu que la seule partie de l'avion qui avait subi l'incendie était la partie arrière de la cabine. Sa reconstitution partielle sur un gabarit permit de localiser avec certitude le foyer de l'incendie dans la toilette droite et de faire apparaître, toutefois, que le feu avait trouvé un étroit chemin de propagation au plafond de l'avion le long de la garniture des luminaires facilement conmbustible.

Pour expliquer la catastrophe, la Commission retenait, en définitive, deux hypothèses:

- soit une panique des passagers, refluant vers l'avant et envahissant le cockpit jusqu'à rendre tout mouvement efficace impossible pour les pilotes,
- soit la suffocation de l'équipage au cas où les masques n'auraient pas été employés assez tôt ou n'auraient pas assuré une protection suffisante.

CAS No 4: Épave d'un Boeing 707, immergé à 4 à 5 km au large de l'aéroport de CARACAS-LA GUAIRE par environ 100 m de fond.

a/ l'accident

Le mercredi 3 décembre 1969, de nuit, un Boeing 707, à destination de Paris via La Guadeloupe, avec 62 personnes à bord dont deux équipages, un en fonction, l'autre en mise en place, décolle en piste 08, face à la baie.

Une minute après le roulement au décollage, l'avion s'annonce et reçoit l'autorisation de monter au niveau 90 sur le radial 085. Quatre secondes après la fin de cette communication, l'équipage d'un Avro, face à l'aérodrome en descente vers la branche vent arrière, annonce qu'il survole la zone de crash d'un avion venant de percuter la mer.

Le décollage du Boeing s'est effectué phares allumés et au cours de son vol, dont la durée est de l'ordre de la minute, il semble que l'avion ne soit pas monté à une hauteur supérieure à 1000 pieds et ait viré à gauche très peu de temps avant l'impact.

L'équipage de l'Avro déclare que le crash s'est produit sur la droite de sa trajectoire à faible distance, et que la différence d'altitude entre les deux avions devrait être de 700 à 800 pieds.

Il faut encore rappeler que le décollage s'est effectué sur la mer avec le littoral montagneux éclairé sur la droite et que le virage sur la gauche s'est effectué de nuit, sans lune, vers une zone totalement noire.

b/ recherche de l'emplacement de l'épave

L'étude des témoignages des sauveteurs, l'audition des témoins, les reconnaissances effectuées en bateau et hélicoptère, la localisation par le radar de l'Avro à la verticale de l'impact, situaient le lieu de l'accident à l'intérieur des eaux territoriales vénézueliennes, dans une zone d'un mille carré, dont le centre se trouve à 2, 5 NM dans le 065 du radar.

Une importante tache de kérosène remontant du fond était repérée, dans la journée du lendemain, sensiblement à cette position.

De nombreux débris flottants étaient récupérés, mais la récupération de l'épave s'avérait nécessaire.

Avec l'accord des Autorités vénézueliennes, les représentants français prenaient contact avec différentes sociétés spécialisées et, finalement, la compagnie OCEANS SYSTEMS procédait, à partir du lundi 15 décembre, à une première recherche SONAR.

En dépit de quelques pannes du remorqueur local, les travaux préliminaires permettaient, dès le lendemain soir, de conclure à la nature favorable des fonds (sablonneux, en pente douce, peu de rochers), et de repérer les emplacements d'une barge coulée ainsi que l'épave d'un F.86 Sabre englouti depuis 3 ou 4 ans.

Entre temps des renseignements avaient annoncé la présence d'épaves du Boeing le long des lagunes, à 180 km à l'est de la zone d'impact. Les enquêteurs français et vénézueliens survolaient la région en avion et hélicoptère et récupéraient effectivement des débris légers; les représentants d'une seconde société de plongée, la COMEX, étaient chargés de prospecter les côtes, et pendant plus de quinze jours, retrouvaient un grand nombre de coussins, nid d'abeilles, débris de sièges, d'aménagement cabines, ...Il est à noter que la plupart des spécialistes interrogés avaient estimé fort peu probable l'existence de courants susceptibles de transporter des épaves de la Guaira vers ce secteur.

Les travaux en cours permettaient enfin, le 19 décembre, d'identifier et d'enregistrer au SONAR une large traînée d'échos (par 100 m de profondeur et sur environ 500 m axés Nord-Est/Sud-Ouest, très probablement les débris très fragmentés de l'avion.

c/ travaux de repêchage des débris

La nature des fonds repérés et les informations marines permettaient d'envisager l'utilisation de filets de chalutage.

Par ailleurs, la mauvaise visibilité rencontrée n'autorisait que difficilement l'emploi de plongeurs autonomes et l'utilisation d'une cloche de plongées, prévue, n'a pu être effectuée dans des conditions satisfaisantes.

Enfin, l'emplacement des débris ayant été bien repéré et les points remarquables de la côte étant visibles en permanence, la précision de la navigation par segments capables était excellents, des moyens radioélectriques n'étaient donc plus nécessaires.

Dans ces conditions, la location d'un chalutier de moyen tonnage et de ses marins, ainsi que l'emploi d'un fort chalut de pêche permettaient aux enquêteurs de réaliser en six semaines, une récupération de l'ordre de 50% de l'épave.

De nombreux corps étaient également remontés en surface et permettaient, pour certains d'entre eux, des identifications complémentaires.

d/ résultats

La non utilisation de la caméra de télévision sous-marine, les difficultés rencontrées par les plongeurs autonomes ou la cloche de plongées, n'ont pas permis d'établir une cartographie des débris au fond, non plus qu'un examen, même sommaire, avant leur remontée.

L'enregistrement SONAR a pu cependant fournir, outre la position des débris, un aspect général de l'orientation de l'ensemble et de la grande fragmentation.

Les récupérations d'objets flottants ou rejetés à la côte, soit sur les lieux de l'accident, soit à près de 200 km à l'est, ont permis d'examiner un très grand nombre de coussins ou d'éléments de sièges, ainsi que de l'aménagement intérieur. Les coussins ont pu ainsi être radiographiés et n'ont mis en évidence aucun indice suspect.

Des éléments de toutes les sections de l'avion, représentant près de 50% du total, ont pu être sortis de l'eau et inspectés. Une reconstitution partielle du fuselage et des ailes, ainsi que l'examen des débris de train et des éléments des réacteurs, ont pu être effectués mettant en évidence les conditions d'impact de l'appareil.

Divers éléments de carlingue ont été, avec l'accord des Autorités vénézueliennes, transportés à Paris et ont pu faire l'objet d'examens spéciaux.

À noter, enfin, que l'enregistreur de bord n'a pu être récupéré.

CONCLUSIONS

L'expérience acquise au cours des travaux précédemment exposés conduit à quelques réflexions susceptibles d'être utiles à de futures opérations:

- Repérage de l'emplacement des épaves -

L'emplacement exact des débris n'a pas toujours été facilement déterminé. Or, il est bien évident qu'il conditionne la suite des travaux. Il est capital que, dès le début des opérations de sauvetage, un enquêteur, en liaison directe et étroite avec les autorités responsables, soit exclusivement chargé de suivre, voire coordonner, toutes les informations disponibles et fasse assurer le marquage des zones probables:

- Les témoignages (déclarations, photos ou films), les comptes rendus des avions, hélicoptères et bateaux, les renseignements fournis par les sauveteurs et les plongeurs, l'écoute et la transcription des communications, l'étude des films radar (éventuellement complétés par des survols calibrés), doivent être exploités dans les meilleurs délais.

- Une fois repéré, l'emplacement probable doit être, non seulement porté sur les cartes, mais le mouillage de bouées doit être systématiquement effectué.

- Dès que possible, la confirmation matérielle de l'existence de l'épave doit être obtenue à l'aide des moyens appropriés (plongeurs ou soucoupes plongeantes, photographie ou télévision sous-marine, sonar, ...).

- Étude des conditions de l'environnement sous-marin -

La connaissance des fonds (nature, obstacles, déclivité, profondeur), des courants, de la luminosité probable et de la faune ou flore dangereuses éventuelles, s'est révélée indispensable à la décision et à la conduite des travaux. Les cartes hydrographiques, la consultation des spécialistes de la marine de guerre ou de commerce, les renseignements fournis par les professionnels de la pêche ou les navigateurs locaux, les sondages, les prélèvements d'échantillons, les photos ou la télévision sous-marine, sont les sources utiles d'information, bien que des surprises ne soient pas à exclure.

De tels renseignements sont essentiels préalablement à toute décision et au choix des moyens.

- Cartographie de l'épave sur le fond -

Dans la mesure du possible et avant les opérations de repêchage, une telle cartographie doit être tentée. Outre les renseignements, utiles aux investigations, qu'elle apporte sur la répartition des débris, elle peut guider le choix ou l'ordre des éléments à remonter, selon leur intérêt probable pour l'enquête ou leur facilité de récupération.

- Mise en oeuvre des moyens de récupération des débris -

Il est probable que chaque épave immergée constitue un cas d'espèce: sur le plan de la nature des fonds et de la profondeur d'abord, sur celui des parties en présence (selon qu'il s'agit d'un accident mettant en jeu un ou plusieurs états, selon l'intérêt qu'il présente pour le constructeur, l'exploitant ...) et naturellement sur le plan des moyens utilisables (en fonction de leur disponibilité locale et des crédits pouvant y être consacrés).

La décision, puis la mise en oeuvre des opérations, résulteront bien évidemment de l'ensemble des données dépendant de ces trois plans, confrontées à la forme même de l'accident.

La nature des fonds rencontrés dans les quatre opérations présentées a conduit à diverses solutions:

- par fonds assez faibles, l'utilisation de plongeurs et soucoupes a permis des résultats intéressants,
- par fonds du même ordre et par très grands fonds favorables, le chalutage s'est révélé un outil extrêmement efficient: s'il n'est pas souhaitable de l'employer pour la recherche avant d'avoir épuisé les autres moyens, il permet cependant un balayage des zones actuellement quasi inaccessibles par d'autres méthodes; de plus, il s'est révélé d'une efficacité et d'un intérêt certains sur le plan économique.

- Aspects financiers -

Il est difficile d'évaluer de façon précise le coût des opérations présentées. Les sommes engagées comportent de nombreux chapitres s'interpénétrant:

- Traitements normaux des enquêteurs, autres personnels d'État civils ou militaires, agents des compagnies ou des constructeurs,
- Salaires particuliers des plongeurs spécialisés, marins ou employés des entreprises privées,
- Achats, locations ou prêts de matériels divers de plongée, de chalutage, de levage, de transport, de localisation radioélectrique de films ou télévision.
- Affrètements ou prêts de bateaux de différents tonnages, dotation des aéroports, Marine Nationale, Direction des Câbles et Communication, pêcheurs professionnels ou entreprises spécialisées.

Si l'on fait abstraction des frais fixes, quel que soit le nombre des accidents et de certains prêts gracieux, il semblerait que l'on puisse évaluer la journée de repêchage dans une enveloppe moyenne de 2.000 à 10.000 dollars US.

En tout état de cause, il est à noter que pour les cas considérés, ces frais ont été partagés entre l'État ou les États intéressés, les compagnies, les constructeurs, selon des critères propres à chacun des accidents.

- Délais d'exécution -

Les durées des opérations qui s'étagent, selon les cas, de quelques deux mois à près de trois ans, mettent en évidence, non seulement l'ampleur des problèmes techniques, mais surtout les difficultés considérables de coordiantion d'un grand nombre d'éléments, tels que, par exemple, l'état de disponibilité des navires et les conditions météorologiques. Trop souvent des prévisions apparemment fondées ont été démenties par les faits et les travaux ont dû être modifiés ou totalement interrompus.

De telles entreprises sont sujettes, peut-être plus que beaucoup d'autres, à de nombreux contretemps, et il est nécessaire que les responsables d'opérations futures prennent très sérieusement ces facteurs en considération.

- Intérêt des opérations de repêchage -

La question doit être posée de savoir si les résultats obtenus sont à la mesure des sommes, souvent énormes, dépensées et si les enseignements tirés ont été productifs en matière de sécurité.

Avant toute chose, la chute en mer d'un aéronef pose le pénible problème de la disparition de beaucoup de ses occupants: tout doit être tenté pour retrouver leurs corps et faire droit aux soucis légitimes de leurs familles.

Sur le seul plan technique, la récupération des débris d'un aéronef immergé a essentiellement pour but de permettre à l'enquête de pouvoir se dérouler dans les mêmes conditions que celles d'un accident où l'épave repose sur le sol.

Le succès complet des opérations de sauvetage signifiera donc simplement la reprise du cours classique de l'enquête avec les meilleures chances pour tenter d'aboutir à des résultats satisfaisants.

- la cartographie des débris, lorsqu'elle a lieu, est très difficile à réaliser, elle reste souvent inexacte ou incomplète,

- la préservation des indices souffre de nombreux problèmes: détériorations dues aux différences de pression ou aux déplacements par de forts courants, corrosions, dommages provoqués lors de l'arrimage, la remontée ou les manipulations pendant le transport,...,

En particulier, les enregistreurs de bord risquent souvent de se révéler inexploitables après des séjours de trop longue durée dans l'eau de mer.

- les examens et expertises n'en seront pas facilités: ils sont évidemment limités aux seules pièces récupérées, et donc souvent incomplets, voire trompeurs. Par ailleurs, les analyses chimiques pourront être gravement faussées (et de façon difficilement décelable) lors de séjours prolongés des débris dans des zones diversement contaminées, soit sur le fond de la mer, soit dans les cales ou entrepôts lors des transbordements inévitables.

- enfin, la durée des travaux, outre le retard apporté à l'enquête proprement dite, est un facteur défavorable supplémentaire. De longs séjours sous-marins peuvent conduire à la disparition de certains indices, interdire l'expertise d'un matériel ou rendre inexploitable un enregistreur retrouvé trop tardivement.

Dès le départ, l'enquêteur doit donc faire preuve d'un optimisme extrêmement mesuré quant à la somme et la qualité des informations que peuvent lui apporter de telles opérations. Il doit également être convaincu qu'il lui appartient de s'y associer très étroitement et d'en connaître les moindres détails s'il veut ensuite pouvoir travailler avec tout l'esprit critique indispensable.

Les résultats obtenus lors des quatre cas précédemment cités montrent cependant, en dépit de leurs imperfections, un bilan positif pour une meilleure connaissance des faits et, par conséquent, pour l'amélioration de la sécurité.

INVESTIGATION OF AN ARCTIC ACCIDENT   A.J. CLARKE   MOT CANADA

Flight 416, a Lockheed Electra, landed at Edmonton International Airport on 29 October 1974 at 1835 hours MST after a flight from Calgary. After landing, the aircraft was prepared for the continuing flight north to Rea Point on Melville Island in the high Arctic. The load consisted of 20,000 lbs. of freight and 30 passengers.

Weather for the enroute flight was checked at Edmonton by the aircraft captain. An IFR flight plan was filed with ATS to Rea Point via direct Fort Smith, direct Contwoyto Lake, direct Byron Bay, direct Rea Point at an initial cruising altitude of 18,000 feet; the estimated time enroute was 4 hours 12 minutes. Pedder Point, NWT, was filed as the alternate.

The aircraft departed Edmonton at 2004 MST 29 October 1974 and proceeded via the flight planned route. At Fort Smith the aircraft was cleared to 21,000 feet and eventually to FL 250 passing Contwoyto Lake. CF-PAB reported over Byron Bay at 2304 MST with an estimated time of arrival Rea Point at 0016 MST.

At approximately 65 nautical miles from Rea Point, descent was commenced for a straight in approach to runway 33. At 0015 MST the crew reported to Rea Point that they were 6 miles and at 1500 feet on final approach. Rea Point acknowledged the transmission and passed the 2400 MST weather as thin obscured 1 mile in blowing snow, temperature - 11°F, wind 312 degrees true at 30 gusting to 38, altimeter 29.91.

At 0020 MST the radio operator realized that the aircraft was 4 minutes overdue and also became aware of deteriorating weather conditions, indefinate ceiling, sky obscured, visibility less than 1/8 of a mile. This observed weather was transmitted to flight 416. However, there is no record of the crew acknowledging the transmission. A search aircraft located the wreakage 2.5 miles south of the approach end of runway 33.

Early on the morning of October 30, we were notified in Ottawa of the disaster and alerted our stand-by team. However, in this case we realized we were faced with a probability that we would require an under-water search and recovery capability. Our past experience in Canada was in the search and recovery of smaller aircraft and not under the ice. As a result of meeting Bob Kutzleb at a SASI conference some years previously, I knew his background and experience in under-water aircraft search and recovery could be useful. A phone call resulted in Bob joining the team. At this stage we were not sure how much wreckage remained on the ice surface and to what extent the water recovery capability would be required.

Because of the remoteness of the accident site in the high Arctic, we flew on a regular Canadian Forces flight to Resolute Bay and chartered a DC-3 for the 300 mile flight, northwest to Rea Point. Three of our Regional Investigators had arrived the previous day and a preliminary examination of the scene had been completed with the recovery of bodies under way by the R.C.M.P. assisted by our Chairman of the Human Factors Group.

When we visited the scene, it was obvious that most of the aircraft was on the ocean floor of Byam Channel and considerable resources for underwater search and recovery would be required. However, because of the thin new sea ice, we would be restricted in the kind of recovery equipment that could be used.

To allow us to make decisions as to the extent of the diving operation that would be required, we initially used an under-water camera suspended through holes in the ice to the sea bottom. The camera was rotated by turning the cable and the pitch or vertical adjustment was made by a rope attached to the camera. All focusing was done by the camera operator on the surface. The video recordings allowed us to review the material at the end of each day as well as providing a permanent record. Very shortly after we started to use the under-water camera, we negotiated a contract with Can-Dive Services

Limited of Vancouver, to supply us with a diving group and support equipment. Panarctic Oils Ltd., the company involved, using their other Lockheed Electra Aircraft, flew a crew of six divers and 13,000 pounds of equipment from Vancouver to Rea Point.

By the time the divers arrived, we had many hours of scanning with a suspended video camera which allowed us to establish search and recovery priorities.

From a humanitarian point of view, it was necessary to recover as many bodies as possible before continuing with the routine investigative requirements. However, as we had been able to determine that the rear section of the fuselage was comparatively undamaged and the main passenger door was open, providing easy access, we planned an initial dive for recorder recovery. As the recorders were situated under a false floor in the rear of the passenger compartment, this dive would establish whether or not any of the missing bodies still remained in the fuselage. For this initial dive, two divers were used on the bottom with the other normal stand-by on the surface. It was possible to thoroughly brief the divers with photographs and diagrams of the recorders as well as utilizing our video coverage so that they would know precisely what they would encounter.

Prior to this first dive and during the time the under-water camera was suspended from the surface, a sonobuoy was dropped near the main passenger entrance door to facilitate the location in the event that a storm broke up the ice surface. Our appreciation of our precarious position and the sense of urgency with the vicissitudes of the Arctic weather was always present. Without warning, a sudden loud crack produced a lead in the ice which extended as far as one could see with the thought that the ice on which we were standing would become an ice flow. With this growing concern, a small aluminum boat was put on the ice which provided more reassurance than actual safety.

The first descent to the rear portion of the fuselage by the two divers, in more than a hundred feet of water, revealed all the passenger seats had been ejected forward out of the compartment. This allowed easy access to the rear of the cabin where the false floor had been disrupted exposing the cockpit and data recorder boxes. The boxes were easily removed, tied to a line and brought to the surface. When we dismantled the cockpit voice recorder and washed it with fresh water we found the tape had been broken by what later was determined to be an improper splice. We suspected and it was later established, that no voice communication of this flight had been recorded. While the data recorder looked to have been functioning normally from our initial cursory examination, I was advised a few days later after our initial laboratory examination that little useful information could be expected. Although we always initiate our field investigations on the basis that information will not be available from flight recorders lack of information from the flight recorders increased our sense of urgency.

Within a few days when amazingly all the bodies were recovered, including the Captain from his seat in the separated cockpit section, we were able to use all our diving resources to continue our search, examination and survey of the under-water wreckage. The next step was to have the divers hand hold the video camera and examine the wreckage in response to our directions from the surface. There was initial concern on the part of the Diving Master as to the possible reduction of his direct control over the divers and the investigator's lack of appreciation of the operation and even the terminology. However, thorough briefings and well planned dives overcame this problem as well as insured maximum utilization of the limited bottom time available. Every effort was made to keep within the no decompression stop bottom time of twenty-five minutes. The water temperature being near 0^{o} centigrade made decompression stops uncomfortable or even hazardous.

The use of the diver held video camera allowed the investigator to examine pieces of wreckage in great detail. However, it was difficult to get an over-all perspective of wreckage from the limit imposed by the illumination from the camera light. The under-water visability was excellent as illustrated by the fact that it was possible to see the camera light illuminating the fuselage from a hole 100 feet above on the surface. Another difficulty was the surveying or plotting of pieces of wreckage identified on the sea-bottom. The method used allowed an adequate survey as well as the orientation of each diver. Our surface survey line extending approximately through the centre of the surface wreckage trail had stakes at fifty foot intervals. At these positions, near the area of abundance of bottom wreckage holes were drilled in the ice and flood lamps pointed downward. The divers were able to advise us at what light and distance either side of the centre line, they were when examining a particular piece of wreckage. Using the surface plot we would direct the diver in a regular search pattern. After procedures were established, the remainder of the wreckage survey and examination was routine.

While the diving operation was under way, some of our investigators interviewed the First Officer and Flight Engineer in hospital in Edmonton. Their testimony as well as the result of examining the single engine and other wreckage on the surface, suggested that an aircraft malfunction was not directly involved. As with many accidents, the indications were that we were confronted with a detailed examination of the man-machine interface. At this stage there was little doubt that we would have to attempt to recover the instrumentation and perhaps the whole cockpit.

The cockpit section was about 850 feet closer to the shore and in about 60 feet of water. which would give a no decompression bottom time of one hour which would be limited by the low temperature. The amount of time to train divers to remove instrument and radio panels was prohibitive. As the cockpit area was located on the sea bottom directly underneath almost 20,000 pounds of cargo, that was frozen to the under-surface of the ice, it was necessary to move the cockpit before work could start in safety. By attaching a cable through a hole in the ice, a skidozer (a small tracked vehicle), was able to move the cockpit section approximately 100 feet from its original position. Most of the aircraft documentation was recovered from the cockpit area and a detailed video examination of all instrument and radio panels was completed. Utilizing the talent and facilities of the Panarctic Oil camp and personnel an "A" frame consisting of 35 foot pieces of drill-rod was erected on the ice over the cockpit. Timber platforms were used as pads for the "A" frame and cables were anchored in the ice for support. It was necessary to cut the hole in the ice as far away from the pads as possible to maintain the strength in the twelve inch thick new ice. A hole approximately 25 feet in diameter was cut in a day and a half using chain saws, hand saws and ice augers. Of great help was the skidozer that was used to pull large blocks of ice out of thehole. The work was hazardous due to the water covered ice near the hole and the blowing snow that would cover both water and ice. The cable was carefully attached to the cockpit to avoid further damage. The other end was attached to a 12 volt powered winch on the back of one skidozer and with the other skidozer attached to provide greater friction. On the third attempt, the cockpit section was raised. A line was attached to the lifting cable and by manpower the cockpit was centred in the ice hole during the lift. Once the cockpit was recovered, the examination was routine.

While the many arctic fox and occasional wolf added a welcome diversion, the presence of polar bears did little to enhance the appeal of the work on the ice.

The clothing we used that we found to be satisfactory, were down-filled coverall type skidoo suits. When not involved with physical effort, we would also wear a parka. The head gear varied with toques or hats but of course always covered by the skidoo and/or parka hood. Face covering of some kind was essential to prevent frost bite. In my case I included a pair of ski goggles that were very helpful. On our hands we wore very warm mitts with gauntlets, but you frequently had your hands out of them handling cameras or other pieces of equipment. Most of us found that the best foot-wear considering both warmth and convenience were skidoo boots. These have hard rubber soles, nylon uppers and a thick felt inner boot.

Without the facilities available at the permanent Panarctic camp, a substantial airlift operation would have been required. This would probably have entailed the building of an ice or land airstrip with the inherent time and hazard problems. Since this accident, we have met with other Canadian Government Departments and Agencies to plan for what we all hope will never happen, another major air disaster in the Arctic remote from any facility or habitation.

ACCIDENT THEORY AND ACCIDENT INVESTIGATION

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(The views expressed are those of the author and not necessarily those of the U.S. National Transportation Safety Board.)

Preface

This paper has diverse origins. The need for a theory reflects difficulties experienced by the author during the investigation and reporting of accidents involving all modes of transportation. The discussion of accident theory and charting methods is an extension of ideas presented in a paper titled "Accident Investigation: Multilinear Events Sequencing Methods"[1] recently republished in the Fall, 1975 SASI FORUM. The application of the theory and methods described has produced promising results.

Accident Theory: Why Bother?

Members of The Society of Air Safety Investigators consider themselves to be members of a profession. Let us examine that assumption for a moment. A profession has been defined as

> "a calling requiring specialized knowledge and often long and intensive preparation, including instruction in skills and methods as well as in the scientific, historical or scholarly principles underlying such skills and methods, maintaining by force of organization or concerted opinion high standards of achievement and conduct, and committing its members to continued study and to a kind of work which has as its prime purpose the rendering of a public service."[2]

Note the emphasis on scientific, historical or scholarly principles. Note also the purpose of the calling. Let us focus today on the principles first, then the purpose. We'll save the other points for a future meeting.

If you are a practicing professional, what are these scientific, historical or scholarly principles underlying the accident investigation methods you practice? One of the most frequent things you investigate are aircraft accidents. Yet if someone were to poll a random sample of your membership to determine what an accident is--in greater detail than the ICAO definition--widespread differences in individual perceptions of the accident phenomenon would become evident. If one were to ask when an accident begins and ends, and what the criteria are for establishing the beginning and the end of an accident, the range of view would increase. If you need further evidence of the lack of underlying principles in the field of accident investigation, try to apply scientific rigor to the investigator's jargon--words like human or pilot error, accident proneness, near miss, hazard, etc. Each example is a symptom of the lack of a sound theoretical basis of accident investigation.

By theoretical basis I mean that theory guides or shapes your investigative activities. Reflect on what a theory is:

> "systematically organized knowledge applicable in a wide variety of circumstances; especially, a system of assumptions, accepted principles, and rules of procedure devised to analyze, predict, or otherwise explain the nature or behavior of a specified set of phenomena."[3]

The most persuasive argument for developing an accident theory for SASI members is that assumptions, principles and rules of procedure are nowhere systematically organized, and that generally accepted rules of procedure for analyzing, predicting or explaining the accident phenomenon are not available to the accident investigator. The ICAO manual contains procedures for organizing the investigation, its coordination and the reporting of investigative findings. But the contents do not address the underlying scientific principles, nor reflect scientific method. Knowledge of these principles is assumed to be the province of the investigators. Each investigator has specialized knowledge and technique which he brings to an investigation. In a large accident, where investigative groups are formed, the coordination of these individual skills compensates to some extent for the absence of professional principles and theories, because interactions among the group members generate hypotheses that are subject to vigorous debate. However, the principles governing the scope and development of the hypothesis are not well organized or documented. Accident investigation methods for establishing their validity are even less rigorous, and almost totally undocumented, in most modes of transportation. In small accident investigations, conducted by one investigator, even this compensating mechanism is absent.

The result is that the investigative effort is often inefficient, and may be incomplete, or may leave unresolved significant points of controversy. Furthermore, it usually does not provide scientifically rigorous contributions to the body of data from which future assumptions, principles or rules of procedure can be discovered and practiced by others in the profession.

To elaborate on this latter point, each accident can be viewed as an unscheduled and largely uninstrumented scientific experiment performed to test a hypothesis (or theory.) In this context, the experiment and all the costs of performing it--the injuries, damage, anguish, monetary loss, delays, disruptions--are wasted if the investigator has no hypothesis or theory to evaluate.

As an investigator, how do you establish the scope of your investigation? How far back in time must you delve--an hour, a day, a year, two years, five? What rules of procedure or what principles establish the beginning or end of the accident? How is one assured of enough facts in an investigation, and how are the facts to be reported distinguished from the facts that are not reported? What rules or principles govern these decisions?

Still other problems attributable to the lack of theory could be cited, including research difficulties, training deficiencies, inequitable litigation, popular misconceptions about the nature of accidents and others, but this would be redundant. The point is that if we are to be professional investigators of accidents, we need to organize the principles on which our work is based in a professional manner.

What Theories Exist Now?

Some rules and principles do exist now for the accident investigator. However, they are fragmented, occasionally contradictory, often privately communicated, usually not scientifically tested, and sometimes wholly without merit. Their systematic organization has not yet been achieved. When this organization is accomplished, the contradictions and fallacious assumptions will become evident, and gaps can be remedied.

A brief review of some of the most influential historical assumptions, principles and rules discloses the present state of accident theory.

The statistical work of Greenwood and Woods in 1919[4] and Newbold[5] suggested the "accident proneness" concept. Their work still influences some accident investigation, particularly in the police accident investigation field with its focus on license revocation or suspension proceedings which reflect this concept. Investigators still look for data in accidents that will support the idea that "conditions" such as attitudes, attentiveness and so forth "cause" accidents. This statistical work focused on static conditions and set the pattern for untold man years of research into "unsafe conditions" as causes of accidents. In aviation, Ames contributed much to perpetuation of this view.[6]

In 1936, Heinrich[7] suggested the "domino" theory of accidents. His idea was that accidents are a sequence of events in a predetermined proceed/follow relationship, like a row of falling dominos. This view changed the thrust of investigations toward the events involved, rather than the conditions. It represented a redirection of the search for understanding of the accident phenomenon on the basis of a "chain-of-events" that had occurred.

An accident "reconstruction" approach emerged not long thereafter[8,9] which was refined extensively in the highway accident investigation field by Baker. The reconstruction focused on identification of the linear chain of events theory of the accident phenomenon.

About 1960, work at Bell Laboratories in missile system safety produced another breakthrough in the field.[10] This was the "fault tree analysis" method, generally credited to H. A. Watson.[11] This is a method for arraying events in a flow chart with a proceed/follow logic pattern. It provided an objective for the analytical effort in the sense of management by objectives, and it provided a procedure by which informed speculations about accident events sequences were organized in a visible, easily criticised and readily understood display. This work introduced a "branched events chains" concept of accidents through use of the "and/or" logic gates.

About the same time, air safety investigators contributed another milestone in the accident investigation field. The Civil Aeronautics Board published the first chart on which were plotted the flight data recorder (FDR) data.[12] This chart was the first display of the parallel events along a time scale, showing what can be viewed as a "multilinear events sequence" on which the findings were partially based. It appears to be the first to use the time=0 term, about which more will be said shortly. It also is the predecessor of the "multilinear events sequence theory" for the accident phenomenon.

In the latter 1960's, a medical doctor changed accident investigation approaches significantly with his insistence on an etiologic basis for looking at accident trauma.[13] Haddon also introduced a matrix of accident phases and components of the accident events sequence. This work was influenced by DeHaven's research in 1942, but it was Haddon who brought about the directions in accident research which now largely dominate the highway accident field at the Federal level.

Attempts by Surry[14] and others to organize these and other related concepts into a general accident model are indicated in the SASI Forum article. The concept of homeostasis is an essential theory for the understanding of accidents. The term is generally applied in medicine to a state of physiological equilibrium produced by a balance of functions and chemical composition in an organism. I propose this concept be extended to "activities," in the sense that an operational equilibrium is produced by a balancing of interrelated functions and capabilities in response to varying influences arising as the activity progresses toward its intended outcome.

The principal conclusion suggested is that an accident is not a single event, but rather an accident is the transformation process by which a homeostatic activity is interrupted with accompanying unintentional harm. The critical point is that an accident is a process involving interacting elements and certain necessary or sufficient conditions.

The objective of an accident investigation should be to isolate this process and prepare a description of the entire process by which the activity was transformed.

Expansion of some of the elements of my earlier accident process chart may be helpful. Maintenance of homeostasis during an activity requires a continuing series of adaptive responses to perturbations which arise as the activity progresses. To achieve the intended outcome, these perturbations must be accomodated without injury to any of the "actors" and without discontinuing the activity. For example, an aircraft crew makes many adaptive responses to external and internal influencing events during the course of a flight from one point to another, to maintain a stable flight activity within prescribed operational bounds. This is accomplished through a process of detecting the perturbation or indications of its presence or occurrence; of predicting the significance of the data detected; of identifying the adaptive action choices that would maintain homeostasis; of selecting the best adaptive action; of implementing the action selected; of monitoring the effects of the action implemented; and of deciding whether or not the adaptive response countered the perturbation sufficiently to maintain homeostasis without further adaptive response. Each step is an element of an accident process chart if the adaptive response is unsuccessful. Any breakdown in the adaptive process described can be used to identify the beginning (t_0) of the transformation from homeostasis into the accident being investigated.

This approach differs from the "last clear chance" doctrine in law, from the key event approach of Baker[15] and the "critical event" approach of Perchonok,[16] in that they characterize different events in a linear events sequence.

The last event in the process must be the last injurious event directly linked to one or more of the pre-existing actors in the activity. The problem of secondary harm can be treated by considering the impinged activity in the accident sequence.[17]

The product of the process charting effort could take two forms. First, a detailed chart with all the actions by all the actors who acted in the specific accident would be generated, for all immediate users in need of a complete technical description of the accident. The second output could be an abbreviated, more generalized model, such as is found in an NTSB surface accident report[18] or in the hazardous materials field.[19] Criteria for entries on such a general process chart would depend on its use; reference 19 describes possible use for development of countermeasure strategies.

Applications of Accident Theory.

The accident process flow chart preparation seems most nearly available in air carrier investigations. The FDR charts, now routinely plotted, are often correlated with the cockpit voice recorder (CVR) data in a linear form[20] which could readily be converted to a multilinear events chart. Actions of others such as air traffic controllers, as indicated by the ATC tapes, could be added. Any gaps in the events sequence discovered by the application of the proceed/follow logic tests for any of the actors could be bridged by the use of logic tree analysis methods. On a linear scale, the same technique can be used in light aircraft accidents.

To provide an indication of the work effort involved, the following procedural steps are presented; they reflect the approximate order to be followed to produce the detailed chart.

1. Determine, in gross terms, the apparent events sequence that describes what happened, and sketch it in events chart form.

2. From this gross description, delineate the actors (animate and inanimate) whose actions probably were involved in the accident process, i.e., the pilot, an aircraft component, the controller, wind currents, passengers, etc.

3. Using the general process model described above, tentatively assign t_0 to the point in the flight when the perturbation which transformed homeostasis occurred.

4. In a vertical column ahead of t_0 list on a large chart each actor so the actions of each actor can be listed chronologically across the chart according to the time the action occurred (approximately, if necessary.)

5. Begin to record the "actions" of each actor for which supportable evidentary data is developed. Add to these entries as new evidence is developed. Note that the search for evidence is guided by the gaps which become visible in the action sequence and the general process model.

6. Test each event pair entered on the chart against its temporal and spatial proceed/follow logic, both vertically for its relationship with actions of other actors and horizontally for its relationship to prior or subsequent actions (chronology) by that actor. This is the key method of validating assumed events or time/space relationships.

7. Where evidence of missing actions, suggested by the logic tests in step 6, can not be located, for whatever reason, construct a logic tree to identify possible predecessor events or actions, using the event or action to the right of the gap as the "top" event for the tree.[21] It is likely that evidence of one or more of the hypothesized events placed on the tree can be found to identify a "critical path." Alternatively, the use of simulators has helped to discover missing actions, or establish informed judgments about the comparative likelihood of alternative critical paths through the logic tree.

8. Insert the most likely events sequence for each actor and then test the vertical chronological or spatial relationships. Repeat the cycle if logic errors appear.

9. Compare the refined multilinear events sequence logic chart against the general accident process model, and verify t_0 and t_{end}. Note that the cascading events or actions as harm cascades, either in series or parallel, may become very complex. These events usually progress naturally according to physical laws. The value of detailing this phase of the process may or may not warrant the level of detail if catastrophes are analyzed and the injury mode is repeated frequently.

10. Prepare a refined process chart of the entire accident.

11. Depending on the purpose of the investigation, a companion chart on which the path of correctible events flows is shown, and to which the necessary and sufficient conditions for the events to occur are added, can be prepared. This procedure provides an approach for identifying corrective actions which might be taken to reduce future risk.

Rules to govern the description and coding of the process charts have not yet been developed. Codes denoting precise events sequence pairs or sets or patterns seem to be feasible. The development of libraries of accident "process patterns" by professional investigators also seems feasible.

Such descriptions of accidents should help to dispel semantic difficulties in the accident investigation and safety field. For example, if the time required to adapt to a perturbation is less than the time it takes for the human organism to process the data and go through the physical motions of implementing the action selected, how should this be described? As human error, or human perception, diagnostic, or muscular limitations? A narrative is not very informative compared to a process chart which displays these relationships.

Expectations of an Accident Theory.

What can the application of this theory and the related charting procedures do for the professional accident investigator? Since both the theory and methods are essentially untested, prediction of the effects of their use is highly speculative. However, based on the author's experience, the following expectations appear reasonable.

1. The efficiency of accident investigations will be significantly enhanced. This will be accomplished by reducing the quantity of data needed to explain the accident, and by introducing "objectives" toward which the investigator is able to narrow his search for facts. No longer need the investigator "get all the facts" and then come home for the analysis, hopeful that he has all the data he needs.

2. It appears that "templates" of accident processes could be developed so each accident does not constitute a mystery for the investigator.[22] Accumulation of accident data in chart form would make available a "library" of accident processes for numerous purposes such as training, design, safety regulations, etc.

3. Development and adoption of systematically organized assumptions, principles and procedures by accident investigators would elevate their activities to professional status, if other considerations of a profession were met.

4. The availability of process charts would probably have a profound effect on safety research, and probably would permit the development of risk analyses based on the resultant data base and process research.

5. The visualization of the processes would be likely to change the public's concept of the nature of accidents, and changes in liability and tort concepts would be likely to follow as the nature of accidents is clarified.

What Can You Do?

Now, let us consider the purpose of a profession--the rendering of a public service. If you concur with the contention that the accident investigation field would benefit by the development of accident theory and systematically organized rules of procedure, then you can make some specific contributions.

One approach is to take the theory and procedures advanced in this paper, apply them in your work, and help to correct or refine them. Make an effort to identify--and chart--the t_0 and the perturbing, adaptive, stressing, injurious, cascading and subsiding events in the accident.

Secondly, review past accidents that you have investigated, as time permits, and identify these same events sequences in these accidents. Chart them, too. In other words, help to build the data base to support the process theory and methods.

Third, share the results of your experience, through the SASI FORUM or perhaps, through SASI, establish a mechanism for the exchange of professional criticism of these process "templates." This assumes you are not inhibited from such exchanges by your work or position. If you are so inhibited, start to try to change the constraints. Suppresion of such exchanges seems contrary to one's professional interests.

Lastly, if the theories which have been suggested are unsatisfactory to you, propose your alternatives for testing by your fellow SASI members. In my view, air safety investigators are in a unique position to exercise leadership in this effort, because of the FDR, CVR and other records of actions by most of the actors involved in accidents. If you have the will, yours can become an outstanding contribution in the safety field.

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THE FLIGHT SIMULATOR--A TOOL FOR ACCIDENT INVESTIGATION

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INTRODUCTION

The development of flight simulators has progressed steadily for the past 40 years. From the early instrument or "link trainers" of the World War II era to the present motion capable visual simulators, development has closely followed improvements in aircraft design. Todays simulators, however, utilize space age computer technology to an even greater extent than most aircraft. Major advances in flight simulation technology might be summarized as follows:

Instrument trainers	1937-1945
Crew trainers	1949-1955
Analog application	1960-1965
Motion simulation	1960-Present
Miniaturized circuit technology	1968-Present
Visual presentations	1969-Present

Flight simulators are available today for virtually every aircraft with a commercial or military application. Almost every flight and ground condition can be simulated: from engine start, through maximum performance, emergency conditions, landing, taxi-in and shut down.

The driving force behind flight simulator development has been two fold: First the obvious economic benefit. Flight simulator training time is estimated to cost only one tenth to one twentieth as much as aircraft training time. Secondly, the flight simulator allows practice and development of emergency procedures which pose unacceptably high risk factors in the actual aircraft. Such things as ditching, multiple engine failures, and severe flight control malfunctions fall into this category.

An ancillary benefit of the flight simulator is its use in accident investigation and flight safety research. An example of recognition of this value the USAF's Military Airlift Command regulation entitled: "Management of Class I Trainer Program" lists the purpose of their flight simulators in this order:

1. Provide initial training in normal and emergency procedures to aircrews transitioning to MAC-committed aircraft.
2. Increase aircrew proficiency in all normal and emergency procedures that can be reproduced realistically in the flight simulator. Place particular emphasis on emergency procedures which cannot be accomplished safely in the aircraft.
3. Minimize expenditure of aircraft flying hours necessary to qualify and upgrade aircrews.
4. Conduct research into conditions which contribute to aircraft accidents or hazards.
5. Conduct flights to accomplish evaluation and refresher requirements.

WHAT FLIGHT SIMULATORS CANNOT DO

Before discussing how a flight simulator can be used as an investigative tool it is essential to understand some limitations that are inherent to a simulator:

The flight simulator is not an aircraft; it is a complex computer that portrays programed information on a cockpit display. It can only portray programed conditions. For example if spin characteristics and spin recovery techniques have not been programed; then the simulator cannot duplicate them. Simulator manufacturers and programers are only as good as the data they are given. Obviously, it becomes incumbent on aircraft manufacturers and test organizations to promptly provide simulator programers accurate test data, Engineering evaluations, modification information and accurate performance data.

The second limitation is the human factor. In spite of the realism offered by simulators, aircrews basically know they won't be killed in a simulator crash. They know there will always be a second chance and if a situation gets out of hand the simulator can be stopped and the problem evaluated. These are luxuries not always available in an aircraft. Additionally, there are some almost unexplainable factors that seem to account for aircrews performing better (or worse) in the actual aircraft than in a simulator. Some of the later actual examples will show this. Limitations of the motion systems and visual display systems occasionally confuse pilots during some maneuvers. Severe yaw like that encountered in a hard over rudder condition or dutch roll can only be simulated by a sideward bump, a drifting heading indication and the inclinometer ball displaced to the side of its race. A hard over condition would be unmistakeable in the actual aircraft. Visual simulators that do not have side window displays and therefore deprive pilots of peripheral visual cues often result in hard landings that would not occur in the aircraft. Pilots cannot distinguish between a decrease in airspeed and a leveling off condition without lateral references.

WHAT FLIGHT SIMULATORS CAN DO

For simplicity, capabilities can be grouped into three broad categories: basic flight safety research, re-creation of accident sequences and exploratory research. This arbitrary grouping seems to classify the different applications an investigator might require of a flight simulator. The remainder of this paper discusses actual experiences of using flight simulators in these three types of applications. Because of the wide variety of simulators in use and the broad differences in capabilities, no rules or suggestions that would have universal application are offered. Close coordination between the investigator and the flight simulator operators is necessary to gain optimum benefit in any application.

BASIC FLIGHT SAFETY RESEARCH

Working under the premise that the goal of investigation is prevention; then research that leads to accident prevention is one of the aims of every investigator. Basic to this is the question: why do accidents happen?--as well as, how accidents happen? A series of accidents and serious incidents occured where conflicting cockpit indications confused pilots to the point of making wrong decisions. These accidents created concern about pilots apparent lack of proper evaluation of all information prior to making an irreversable decision.

A two engine jet transport had two main electrical buses each powered by its respective engine driven generator. A bus tie circuit was provided so that, in the event of generator failure, either generator could power both buses. This bus tie circuit was in turn protected by a bus tie relay so that a shorted bus would not result in failure of both buses. Following a touch-and-go practice landing, after applying take-off power and reaching decision speed, the right engine disintegrated due to a turbine failure. Almost immediately following the initial failure the generator power cables were shorted causing the bus tie relay to open. This caused several instruments for the right side of the aircraft to fail in the operating range. Next, the student pilot, in the left seat, slightly retarded both power levers. Most probably the instructor pilot noted the slight spin down of all of the left engine instruments while some right engine instruments remained at the high settings, and incorrectly assumed that the left engine had failed. He pulled the fire control handle for the good left engine when the aircraft was less than 100 feet above the ground. All three occupants perished in the crash.

As pointed out earlier this was one of several fatal and near fatal pilot errors that led to a research project to determine, "Why?". Investigators were asked to examine training, flight manuals, aircraft instrument presentations, and aircrew techniques. Although, specific examples were available from accident files, a broader base of data was required if force wide conclusions were to be drawn. Flight simulators offered the best source of this data.

One area of concern was the classic engine failure on take off. To evaluate this condition one hundred crews undergoing refresher simulator training were given a series of four emergencies at decision speed. Their reactions were then recorded and compared. The crews were random, previously scheduled C-141 aircrews, from five different bases using similar flight simulator programs. The emergency conditions were as shown in Table I.

The results of this study were rather interesting. In the first instance 92 pilots made the correct response while 8 pulled the fire control handle, discharged the fire agent and called for the "Fire on Takeoff Checklist" for number one engine. It was concluded that the flashing master fire light and flashing light in the fire control handle created a greater sense of urgency than a steady light, and, in a stressful moment the more serious condition was presumed. A dimmer, steady amber light for overheat and a brighter flashing red light for fire would be a more logical warning.

On day two all pilots correctly analyzed the problem, however, there was some discussion whether a precautionary engine shut down versus an

TABLE I

DAY	CONDITION	INDICATED BY	PROPER CORRECTIVE ACTION
1	Number one engine overheat	1-Flashing master fire warning light 2-Flashing light in number one fire control handle 3-High exhaust gas temperature	1-Retard number one throttle
2	Number four engine failure	1-Loud bang 2-Spin down of number four engine instruments 3-Increase in number four engine vibration indicator (EVI) 4-Yaw to right 5-Low oil pressure/temperature on number four engine 6-Low fuel pressure light for number four engine	1-Pull number four engine fire control handle 2-Call for number four "Engine Failure On Takeoff Checklist"
3	Number three engine fire	1-Steady master fire warning light 2-Steady light in number three engine fire control handle 3-Audible fire warning signal	1-Pull number three engine fire control handle 2-Discharge extinguishing agent for number three engine 3-If fire continues select alternate and discharge alternate extinguishing agent 4-Call for number three "Engine Fire On Takeoff Checklist"

TABLE I (Cont.)

DAY	CONDITION	INDICATED BY	PROPER CORRECTIVE ACTION
4	Number two engine disentegration with turbine blade inpingement into wing resulting in fuel leaks and shorting of number one engine fire warning circuit. (Note 1: Occurrence at 110 kts with two engine minimum control airspeed of 142 kts. Runway 08 Honolulu IAP requiring right turn out for terrain avoidance.) (Note 2: This or similar occurrence had been reported three times during operational life of the C-141 aircraft, in all three cases the aircrew successfully coped with the emergency.)	1-Series of loud bangs or explosions 2-Spin down of number two engine instruments 3-Off scale vibration indications on number two engine 4-Slight left yaw 5-Low oil quantity light on, number two engine 6-Zero oil pressure, number two engine 7-Low fuel pressure light number two engine 8-Master fire warning light on steady 9-Steady light in number one engine fire control handle 10-Audible fire warning signal	Not specified in handbook but a pilot would be expected to maintain aircraft control, evaluate the situation and take proper corrective action: Desired action would be: 1-A visual scan of number two engine. If pilot calls for scan, scanner confirms failure of number two engine and that number one engine looks OK. 2-Accelerate to two engine minimum control airspeed. 3-Pull fire control handle on number two engine. 4-Call for number two "Engine Failure on Takeoff Checklist" 5-Test and monitor number one engine for fire/failure

(Note 3: Military Airlift Command procedures specify that if decision speed is below rotate speed the copilot will call "GO" at decision speed and "ROTATE" at rotate speed. For this test, decision speed was always calculated to be below rotate speed and the emergency condition was started on the copilots command "GO". In two cases the copilot failed to state "GO" and only called "ROTATE" at rotate speed. In three cases the pilot incorrectly aborted the takeoff after decision speed. These five cases were not included in the study. Additionally, there were three instances where a crew substitution was made on one or more of the four days, these crews were also excluded from the study.

engine failure shut down was appropriate. This is immaterial and was a fault of the programing.

On day three all pilots correctly evaluated the condition and took the proper corrective action. The audible warning undoubtedly assisted in correct definition of the condition. The success on this day reenforced the conclusions regarding the engine overheat condition on the first day problem.

On day four the results were startling and are as follows:

Correct action or acceptable variation	Incorrectly pulled number one fire control handle below two engine Vmca (crashed)	Failed to control aircraft and flew into ground (crashed)	Did not correct emergency but successfully flew aircraft
36	44	14	6

Total surviving 42 (includes those who did nothing but fly the aircraft)

Total crashed 58

Needless to say, this study prompted several immediate changes in hardware, training programs, aircrew procedures and evaluations.

RE-CREATION OF ACCIDENT SEQUENCES

Re-creation of accidents through use of a flight simulator can yield a good deal of data to either prove or disprove theories. Factors such as aircraft performance, time relationships and track over the ground are some of the things that can be placed in proper and singular perspective for careful evaluation.

Known data inputs contribute greatly to the accuracy of this technique. The investigator, technical flight simulator personnel and flight crew, together, should carefully review all known facts about the flight. Suspected conditions should be cautiously screened as objectives to be proven or disproven during the simulated flight. Some system of observing and recording conditions during the simulated flight should be agreed upon. Data sources that can provide known facts include such things as: known cockpit switch positions and instrument readings, known meteorological conditions, flight data recorder information, aircraft integrated data (AID) recorder information, air traffic control recorded voice information and more recently the recorded computer data from the NAS stage A and ARTS III systems within the U.S.. Sources that can provide suspected data inputs include such things as: witness statements, aircraft maintenance records and interviews with other crew members.

Once the data have been assembled the accident aircraft flight profile can be flown to recreate the accident conditions. The value of a flight simulator for this is greater accuracy, the ability to repeat or"freeze" any conditions for detailed study, and the ability to record all conditions, both photographically and electronically.

This type of investigation has frequently exonerated aircrews who were unjustly charged with responsibility for the accident. Certainly we can gain valuable data on such things as wake turbulance and wind shear limitations and pilot capabilities through use of a flight simulator.

During a night touch and go landing practice a C-141 became airborne prematurely. Both pilots applied forward pressure to the yoke, however the aircraft continued to rotate to approximately 40 degrees of pitch. The third pilot, occupying the flight examiners seat, called "Runaway pitch trim, depressurize number two hydraulic system". The engineer did this then went forward to assist the instructor pilot in applying forward yoke pressure. As the airspeed bled off past 80 knots the instructor pilot rolled into a 70 degree bank to avoid a stall. He attempted to keep the aircraft in a corkscrewing climbing turn to maintain control. Both pilots had depressed their pitch trim disconnect buttons but didn't dare take a hand off the yoke to manually retrim the aircraft. The non-flying pilot correctly analyzed the situation, re-engaged the electrical trim and trimmed the aircraft back to a controllable attitude. The flight data recorder indicated 920 degrees of turn and a climb of 8,500 feet in one minute and fifty seconds.

(Note: With the flaps beyond the approach position, 12 degrees of nose up pitch trim is available. Full elevator deflection can only counteract four degrees of pitch trim. Additionally, through the artificial feel system, 57 pounds of forward pressure on the yoke yields maximum elevator deflection.)

Since the runaway condition occured during the ground roll the crew had no pitch up warning until almost full trim was applied. This almost uncontrollable condition, with a full twelve degrees of horizontal stabilizer deflection, dictated a full and formal investigation.

The investigators were charged with first determining and correcting the cause of the malfunction and secondly verifying the published emergency procedures.

By design, the pitch trim system is fail safe; that is, a single failure must not cause system failure. With this in mind investigators started an exhaustive evaluation of all components. After two weeks not a single failed component or out-of-adjustment condition was found. At least two malfunctions would be required to cause a runaway condition. The hydraulic, electrical and mechanical investigation sub-groups issued a statement, that in their opinion, the most probable cause of the mishap was a pilot inadvertantly holding the pitch trim thumb switches on the yoke during the ground roll. The operations group was furious and the investigative effort started to break down.

An exhaustive flight simulator program was developed to simulate all conceivable failure combinations to verify the thoroughness of the investigation and to point out any overlooked area. This program, together with the aircraft findings, eliminated approximately 70 percent of the possible cause factors. The manual hydraulic pitch trim system and the hydraulic portion of the electro-hydraulic system were ruled out. The electric portion of the electro-hydraulic system and the pure electric system were to be investigated further. A simultaneous double electrical control input fault was a prime suspect.

The cause was finally attributed to a misrouted wire bundle which was chafing on a bolt and grounding the copilot's trim switch. This, in combination with a metal drill chip in an autopilot cannon plug, allowed a hydraulic solenoid to become powered. In both cases electrical contact was only made during airframe vibration, such as experienced during a high speed taxi or take off run. This condition always resulted in a nose up runaway pitch trim condition.

The second charge of the investigators was verification of published emergency procedures. Ten crews who were only vaguely familiar with the occurrence were given the emergency in the flight simulator. It is significant that all crashed. The problem was clearly one of rapid identification of the runaway condition. An improved pitch trim indicating system resulted. Next, based on data obtained in the earlier simulator investigation, three wiring changes were made in the disconnect circuit. Use of the manual hydraulic pitch trim handle was found to be more effective than system depressurization in overcoming a hydraulic runaway. A procedural change resulted. Lastly, wide publication of the incident and the flight simulator experience have produced a more knowledgeable aircrew force that can cope with the problem almost 100 percent of the time.

EXPLORATORY RESEARCH

The area of exploratory research is unique and somewhat questionable. It involves taking known performance parameters and then projecting the curves into areas where no data is available. This type of research is desireable for conditions which are so rare that no actual data are available or conditions which appear to be too dangerous to duplicate in flight tests. Turbulence involving extremely high horizontal gust velocities or shear forces is a good example. Pilot capabilities as well as aircraft performance can be evaluated.

Earlier this year a C-5 made a high speed crash landing near Saigon. The aircraft had experienced a massive structural failure of the aft cargo loading door complex. Secondary damage severed all empennage flight control cables, hydraulic lines and electrical bundles. The horizontal stabilizer pitch control surfaces were fixed at the 257 knot, zero trim, position. The pilot had aileron control but pitch attitude could only be controlled by power and bank. When the pitch attitude got too high the pilot could bank and let the nose drop below the horizon. When the pitch angle got too low he could only level the wings and apply power. Within 250 to 270 knots the aircraft was fairly stable. After returning to the airport vicinity the landing gear was lowered at ten thousand feet. A gradual descending turn to final approach was started. About half way through the turn the nose started to drop so the pilot rolled the wings level and applied power. Realizing that only airspeed could arrest the descent he continued with the engines set at maximum power until the aircraft began to level. A few feet off the ground the pilot realized this may be the best approach he could make and idled the engines. At this point the aircraft was almost perfectly level. Both aft main landing gear made a two inch cut in a rice paddy dike and the next contact was three hundred and fifty yards later. Airspeed was two hundred and sixty knots.

Following this accident, persons, at the very highest level, speculated that some combination of secondary flight controls could have been used to control the aircraft and reduce the trimmed airspeed to provide a slower and more controlled touch down. Ramifications of such speculations are obvious. Intense national interest required that all possibilities be quickly and thoroughly evaluated and the speculation either proved or disproved. Prudence dictated that another 50 million dollar aircraft should not be used for such dangerous experimentation as simultaneously deactivating all rudder, elevator, pitch trim and auto stabilization systems. The flight simulator was the ideal tool.

To accomplish the tests highly qualified flight crews were selected and thoroughly briefed on the accident and the test parameters. In four hour shifts, they worked the flight simulator for sixty-eight continuous hours, experimenting and recording various combinations of power, landing gear, flaps, slats, spoilers, thrust reversers and lift distribution control system configurations. They succeeded only in verifying that the accident pilot used the only possible technique to control the aircraft. Additionally, no flight simulator crew was able to approximate a level touch down attitude at ground level, as the accident pilot did, irregardless of proximity to a runway.

For his superior airmanship, skill, courage and dedication to his passengers during a severe inflight emergency and crash landing the pilot was awarded his nations second highest medal, The Air Force Cross. Unquestionably, the flight simulator aided in laying to rest any speculation about the correctness of the pilot's actions.

CONCLUSION:

The complexities of modern aircraft require continuing development of proven investigative techniques. The use of the flight simulator as an investigative tool is proving effective in promoting aviation safety. Basic flight safety research, recreation of accident sequences and exploratory research are three areas where the flight simulator can be utilized.

The flight simulator offers a safe vehicle to evaluate and record many man, machine and environment interfaces. Investigators should possess a working knowledge of the capabilities and limitations of flight simulators and how they can be used to further aviation safety through investigation.

A WIND SHEAR ACCIDENT AS EVIDENCED BY INFORMATION FROM THE DIGITAL FLIGHT DATA RECORDER

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I. INTRODUCTION

Wind shear is recognized as a problem in some accidents involving departing and approaching aircraft. Such occurrences have been difficult to prove, however. The information recorded by a digital flight data recorder (DFDR) installed in a wide-bodied aircraft recently involved in such an accident has provided investigators with data substantiating the fact that a descent through a significant low-altitude wind shear caused the aircraft to impact short of the runway.

The DFDR contained information on 96 parameters. This is an unusually large amount of recorded information compared with that required by U. S. Federal Aviation Regulations (FAR's); it proved a boon to investigators. Much was learned about the circumstances of this accident and about the insidiousness of the wind-shear phenomenon in general.

The Air Line Pilots Association in a letter to NTSB Chairman John H. Reed 1/ stated, "We believe the Board has conducted a most commendable investigation. Through the use of the sophisticated flight recorder information, this is the first time wind shear has been proven to have a primary factor /sic/ in the causation of an accident. While we suspect that several other accidents in the past have been caused by wind shear, the older flight recorders simply did not have the capability to make this determination. As a result of this investigation, we are confident that the Board will exert more emphasis on the subject of wind shear to prevent future accidents."

Because the National Transportation Safety Board is currently investigating another wind-shear related accident in which over 100 persons lost their lives, the authors believe that the wind-shear phenomenon is of major interest to pilots, investigators, and all other safety-conscious people.

II. THE PHENOMENON

A. An Analogy

Wind shear, a term which has become quite familiar in connection with the cause of some recent aircraft accidents, is simply an abrupt change in the direction or velocity of the relative wind flowing across the aerodynamic surfaces of the aircraft. While a change in the relative wind vector is effected by the pilot each time that he makes thrust or pitch attitude changes, in the case of wind shear the change is effected by a change in the environment through which the aircraft is flying. The passage of an aircraft through a frontal system wherein the adjoining air masses are moving in different directions is probably the most classical type of wind shear encounter; however, the combination of vertical currents and variable horizontal flow in the vicinity of isolated thunderstorms can also present rapid change to the aircraft's relative wind.

How does the rapid change in relative wind affect the aircraft during flight? The effect of vertical currents is reasonably apparent; neglecting an analysis of longitudinal stability, a vertical wind will have a nearly direct effect on the vertical velocity of the aircraft. The effect of an abrupt change in the horizontal or headwind component is a bit less obvious. A good analogy to illustrate this condition is given by J. A. Tannenbaum 2/, a staff reporter of the Wall Street Journal. He compares the flight of the airplane with the movement of a man running from the front to the back of a moving train, where the train is analogous to the wind. So long as the train moves at a constant velocity, the man has no trouble running at an even pace. If, however, the train brakes suddenly, similar to a decreasing headwind, the man finds himself decelerating backwards. Conversely, if the train starts to increase speed, the man will be thrust forward. As soon as the brakes are released or acceleration stops, the man must exert what energy is necessary to reestablish his original pace. Note that there is no reference to the man's speed relative to the ground, although, it is obvious that this also changes as the train changes speed.

Applying this analogy to the aircraft, if the headwind component suddenly increases (the train picking up speed), the airplane will be thrust forward relative to the wind, i.e.

its indicated airspeed will rise. Assuming that the pitch attitude remains constant, the rise in airspeed will cause an increase in the total lift being developed, thereby producing an incremental positive vertical velocity. If the headwind component suddenly decreases, the indicated airspeed will drop and, consequently, lift will be reduced causing a negative vertical velocity increment.

As in the train analogy, when the wind velocity stabilizes at a new fixed value, the aircraft must accelerate (or decelerate) to its original indicated airspeed. If the wind-shear encounter occurs while the aircraft is at higher altitudes and operating in the cruise range, the pilot, depending upon the severity of the shear, may not make any power changes, but effect only minor attitude changes to maintain his assigned altitude The thrust-drag imbalance imposed by the airspeed change will itself produce the positive or negative energy necessary for the aircraft to regain its original indicated airspeed, albeit at a newly established ground speed.

If, however, the transition from one airmass to another takes a significant period of time, the pilot may detect the apparent acceleration of the aircraft, or more precisely, the acceleration of the wind relative to the aircraft, and act to prevent the indicated airspeed change by coordinated thrust and pitch-attitude corrections. The pilot will, in effect, attempt to reduce the relative acceleration of the wind to zero by creating an offsetting thrust-drag increment. Then, when the actual wind velocity stabilizes, the aircraft will have thrust-drag imbalance which will cause it to begin deviating from the airspeed which the pilot is trying to maintain. As a result, the pilot must, upon exiting the shear, make a second thrust correction opposite to the correction made upon entering the shear.

B. Hazards

What are the hazards involved in a wind shear encounter? First, the changes in relative wind direction and velocity often occur as the aircraft changes altitude because of the characteristic frontal slope at the junction of two airmasses. The changes in wind near the ground may be even more severe than those at higher altitudes because of the effect of terrain friction on the flow of air. Second, an aircraft flying in a takeoff climb or approach descent environment is often operating with very little speed margin, in a high drag configuration, and, in the case of some airplanes, with little excess power available for both acceleration and climb. In takeoff and approach situations, a sudden decrease in the relative wind across an airfoil, as caused by a wind-shear encounter, can have a significant effect on lift and can produce high vertical velocities. It is obvious that, at low altitudes, the pilot must act promptly and correctly to maintain flying speed and, at the same time, to prevent descent into terrain.

Perhaps the greatest hazard of a low-altitude wind shear is that it is not anticipated; the onset may go unnoticed. The decreasing airspeed and increasing sink rate may develop into a nonrecoverable situation before the pilot reacts. There may even be a tendency for the pilot to raise the nose and stall the aircraft in a futile attempt to prevent impact with the ground.

The situation created when a pilot is attempting to maintain a given approach speed and position on a precision glidepath and localizer course can be even more complicated. Consider, for example, an aircraft conducting a precision approach which is initiated with a high tailwind component and shears at low altitude to a light headwind. During the early phase of such an approach, the higher-than-normal ground speed produced by the stable tail-wind component requires that a higher-than-normal descent rate be maintained to match the desired descent profile. Thrust is, therefore, less than that used in the more common no-wind or headwind approach. As the descent continues, the onset of shear is evident by a rapid decrease in the tailwind component; this is the same as an increase in headwind. The effect is an increase in indicated airspeed, with a corresponding increase in lift which causes the aircraft to rise above the glideslope. The pilot is likely to respond by reducing thrust and readjusting pitch attitude to increase descent rate and reduce, or at least prevent further increase in, the indicated airspeed. As the aircraft reintercepts the glideslope and decelerates to the desired approach speed, the pilot must add thrust to prevent the "high and fast" condition from developing into a "low and slow" situation. As the tailwind component continues to diminish or becomes an increasing headwind, the thrust must be continually readjusted to stay on the glideslope. Ideally, the thrust at any instant is that required to match the deceleration of the aircraft to the rate of change of the along-track wind component, while maintaining a descent rate compatible to the instantaneous ground speed and the glideslope angle. Theoretically, this requires a continual increase in thrust. When the aircraft completes its descent through the shear, i.e. when the along-track wind component becomes constant, a rapid increase in thrust is needed to prevent a decrease in indicated airspeed and development of a high sink rate below glideslope.

The hazard in this type of approach is the continual need for more thrust after the initial thrust reduction. The final thrust level will be greater than that required before shear entry as a result of the decrease in ground speed. In addition to the thrust and pitch-attitude corrections, the pilot may be confronted with lateral control and runway alignment problems caused by a changing crosswind component. The ability of the pilot to limit deviations from the glideslope and localizer is thus dependent upon his recognition of such deviations and his responses with the proper control inputs. The thrust/acceleration schedule of the engines and the dynamic responses of the aircraft are also important factors.

When a shear persists to low altitude, the total response of the system becomes critical.

C. "Failure to Maintain Flying Speed"

While the NTSB and most others in the aviation safety business have long recognized the role of the wind-shear hazard in accident causation, there have undoubtedly been many general aviation accidents (and probably some air carrier accidents) in which a wind shear encounter occurred and was overlooked in the causal determination process. The reason is obvious; it leaves no tangible evidence that it existed and the effects are difficult to analyze.

Consider, for example, a general aviation aircraft takeoff which terminates when the aircraft stalls and impacts the ground. The accident investigator arrives on the scene, probably an uncontrolled airport, 12 to 18 hours after the accident. The weather is good with calm winds when he arrives. Although the recent passage of a front, or the presence of severe thundershowers, is not likely to go unnoticed, wind aloft information may not be available. Ground witnesses are unaware of the wind changes that occurred between the surface and 500 feet. Even the pilot--if he is still alive--is probably puzzled by the apparent degradation of airplane performance that occurred during the climbout.

The cause of the accident is specified as "failure to maintain flying speed." The investigator has no evidence upon which to base any other conclusion.

D. Wind Shear and Flight Data Recorders

In the case of an air carrier accident, the investigator has better tools. More comprehensive meteorological information, which allows an accurate reconstruction of the weather, is likely to be available if the accident occurs in the vicinity of a busy airport.

The flight data recorder provides potentially useful information, even if only the four basic U. S. parameters (altitude, airspeed, heading, and vertical acceleration) versus time are obtained. If, for example, a rapid change in airspeed is noted simultaneously with a change in vertical velocity, and if the direction or magnitude of these changes is analyzed to be inconsistent with the theoretical performance of the aircraft, the possibilities that the aircraft passed through a wind-shear condition should be considered. Such changes might not be obvious, however, and can be masked by pilot control inputs, thrust, or configuration changes. Even if wind shear is suspected, analysis of the severity of the situation is difficult with no additional information.

Certainly one advantage of the digital flight data recorder 3/ now installed on the wide-bodied aircraft is the additional capability to record parameters not heretofore monitored. U. S. Federal Aviation Regulations require that, in addition to the four basic parameters, pilot control inputs (three axes) or control surface positions be recorded, as well as pitch and roll angles, and thrust. Other parameters are also required; see Appendix A. The advantage of having the additional parameters is that pilot inputs can be separated from the effects of the wind shear on the aircraft.

The investigator now has the capability to accurately reconstruct the accident situation.

III. THE ACCIDENT

The full value of the additional parameters recorded by the DFDR was made evident during the investigation of the accident which involved an Iberia Air Lines DC-10 at the Boston Logan International Airport in December, 1973. 4/

A. Accident Summary

The aircraft was making an Instrument Landing System (ILS) approach to runway 33 when it struck an approach light stanchion about 500 feet short of the runway threshold. The initial impact caused damage to major parts of the aircraft structure, but it remained airborne until impact with the runway surface. The airplane broke in two upon impact. Fortunately, the 14 crewmembers and all 153 passengers survived the accident and evacuated the aircraft successfully. The weather in the airport area was characterized by low ceilings, rain, and fog with visibilities ranging from 3/4 mile to 2 miles.

According to the flightcrew, the approach was conducted using the autopilot coupler with the autothrottle system controlling thrust until the aircraft descended below 200 feet. The approach lights were to the right of the aircraft when acquired visually by the crew at about 200 feet. The captain was attempting to align the aircraft with the runway when the crew recognized that they were sinking below a safe descent path. They reacted to the situation by applying thrust and pitch corrections but failed to stop the descent in sufficient time to prevent impact.

The meteorological data obtained after the accident disclosed that the winds aloft in the Boston vicinity, recorded at altitudes above 1,000 feet, were generally from the south at approximately 40 knots. The surface wind measured at Logan was from a westerly direction at 9 knots. These winds would have produced a tailwind component at altitude, and a nearly zero, or slow headwind, component upon landing. Hence, a wind shear was suspected as having had a causal role in the accident.

B. The DFDR

The aircraft was equipped with a recording system that included a Teledyne flight data acquisition unit and a Sundstrand DFDR. This system monitored all U. S. required parameters, plus many others. Among these were radio altimeters, localizer and glideslope deviation, middle and outer marker passage, landing gear lever position, autopilot mode, and fuel flow. The full list of the 96 parameters recorded as a function of time is given in Appendix B.

The magnetic tape from the recorder was processed to retrieve the data. A printout of pertinent portions of the tape in engineering units was generated. The information proved invaluable in determining the probable cause of the accident.

These data indicated that, as the aircraft neared the outer marker, it was configured for landing with the gear down and flaps extended to 50°. The aircraft was established on the glideslope and localizer centerlines when it passed the outer marker. The radio and pressure altimeter altitudes corresponded, within recording tolerances, to the published glideslope crossing altitude of 1,457 feet m.s.l. The aircraft's magnetic heading was 318°, or 11° left of the published localizer heading. The computed (indicated) airspeed was 148 knots.

After passing the outer marker, the aircraft remained on the localizer and glideslope centerlines for 62 seconds while descending to 500 feet m.s.l. During this period of time, the rate of descent averaged 911 feet per minute (f.p.m.).

As the descent continued below 500 feet m.s.l., a gradually increasing deviation to the left of the localizer centerline began. At the same time, the aircraft rose slightly above the glideslope, the airspeed increased 4 to 6 knots, and both the pitch attitude and thrust decreased. The recorded values for longitudinal acceleration were negative.

The aircraft passed the middle marker left of the localizer course about 110 feet. The glideslope deviation indicated that the aircraft was about 3 feet below the glideslope. The pitch attitude, airspeed, and heading were 0.9° a.n.u., 153 knots, and 329°, respectively. The thrust settings were about 56 percent N1.

The autopilot command mode was disengaged within 3 seconds after the aircraft passed the middle marker. Thrust settings at that time were 54 percent N1, approximately, on engines Nos. 1 and 3 and 48.5 percent on engine No. 2. A trailing-edge-down elevator pulse was recorded coincidentially with autopilot disengagement. The aircraft's pitch attitude was 0°. Within 3 seconds after autopilot disengagement, an aircraft nose-up pitch change began; 3 seconds later the thrust settings began to increase.

Nine seconds after the autopilot was disconnected, the pitch attitude was 5.4° a.n.u., and the thrust was increasing through 77 percent N1. At that time, step increases in both the vertical and longitudinal acceleration traces were recorded. During that 9-second period, the aircraft's rate of descent averaged 1,060 f.p.m. The discrete signal which indicates that the landing gear are extended was interrupted 12 seconds after the autopilot was disconnected. This interruption was attributed to impact with the runway surface.

3. Wind Calculations

The data recorded on the DFDR were analyzed using various methods to determine the wind acting upon the aircraft during the final approach.

The first method consisted of comparing a no-wind plot of aircraft position with a plot of its apparent position relative to the runway. The no-wind position was derived from altitude, airspeed, and heading data. The apparent position relative to the runway was derived from altitude, glideslope deviation, and localizer deviation data. The distance of the aircraft at a particular DFDR time was determined by aligning the aircraft position with the position along the glideslope at which glideslope elevation plus or minus the recorded glideslope deviation equalled the aircraft's recorded altitude. The position was offset laterally from the localizer centerline by the distance calculated from the recorded localizer deviation.

The no-wind plot was correlated to the apparent position plot by fixing the aircraft over the outer marker at the DFDR time that outer marker passage was recorded. The wind was then computed by measuring the distance between the position of the aircraft on the no-wind plot and the actual position at uniform time intervals during the descent.

The Douglas Company employed a second method of calculating the winds. This method consisted of analyzing the theoretical performance of the DC-10 aircraft and the flightpath of the accident aircraft as described by the recorded airspeed, altitude, heading, and body acceleration data. The pilot's control inputs, aircraft attitude, thrust, and configuration were determined from the DFDR and compared to instantaneous values of vertical, longitudinal and lateral acceleration. The differences between theoretical body accelerations and those evident on the flight recorder were attributed to external forces acting on the aircraft, which were in turn equated to changes in wind velocity. Using this method, vertical wind components were also determined, but were considered insignificant and were subsequently neglected.

NASA used a simpler variation of this method, comparing the derivative of indicated airspeed with the measured longitudinal acceleration to determine a time history of the acceleration of the along-track wind component.

Because of their interest in wind-shear phenomena, and their expertise, the meteorological staff of Northwest Airlines were participants in the investigation. Northwest Airlines conducted a study of available meteorological data which included the temperature gradient that existed at the time of the accident. The wind velocities and the altitude band of the shear condition were estimated from these data.

Significantly, the winds which were determined by each party, working independently, were in close agreement. The winds calculated for segments of the approach were smoothed and interpolated to produce the following:

Altitude (feet m.s.l.)	Wind Direction (°True)	Wind Velocity (Kts.)
Surface	300	8
100	295	8
200	245	12
300	210	15
400	190	20
500	185	24
600	182	28
700	180	30
800	178	31
900	176	32
1,000	176	35

4. Simulator Tests

Tests were conducted in a McDonnell Douglas DC-10 simulator equipped with a Redifon Electronics, Inc., Visualator System. The simulator was programmed to reproduce the aircraft characteristics, approach, and environmental conditions that existed at the time of the accident. The objectives of the simulator tests were to: (1) further evaluate the data obtained from the accident aircraft's DFDR, (2) observe the performance of the

DC-10-30 autopilot/approach coupler, and (3) examine the dynamic situation that confronted the flightcrew of Flight 933 during the transition from automatic to manual flight.

The simulator was programmed for the Logan International Airport runway 33L ILS approach, i.e. a 3° glideslope having a runway intercept 750 feet from the threshold and an inbound localizer course of 330° magnetic. Instrumentation provided a continuous record of those data parameters which could be directly compared with the data recorded on the accident aircraft DFDR. The visual system was used to reproduce a daylight 4,000 - foot runway visual range condition.

A total of 58 simulated approaches were flown during the test period; 49 of these were flown by qualified DC-10 captains. A total of 48 simulated approaches were conducted with autopilot in ILS mode and autothrottle in the speed mode to an altitude of 200 ft. or below. All of these approaches were initiated with the aircraft established on the localizer centerline outside of the outer marker at an altitude of 1,500 feet approximately. An IAS of 145 knots was selected on the autothrottle system speed command. During most approaches, the pilot was instructed to disengage the autopilot after passing through 200 feet and induce specific actions, either separate or simultaneous pitch attitude and thrust changes.

The instrumentation data were examined following the intial test approaches to determine similarity with data recorded by the DFDR during the accident approach. It was evident that minor changes in the programmed winds aloft data caused variations in the recorded pitch attitude, airspeed, and thrust traces during that portion of the approach flown on autopilot. The winds were modified where necessary to cause the simulator data to exhibit characteristics more consistent with those evident for the accident approach.

With the wind entered into the simulation, the average rate of descent from the outer marker to an altitude of 400 feet was 840 f.p.m. The rate of descent decreased to 780 f.p.m. as the aircraft neared 200 feet. When the autopilot was disengaged at 200 feet, the existing pitch attitude and thrust conditions, if not altered, produced an increase in the rate of descent to 1,170 f.p.m. within 7 seconds. If a substantial pitch attitude increase was not initiated within 6 seconds after disengagement, the aircraft descended to runway elevation, prior to reaching the threshold, in approximately 9 seconds. The pilots were unable to recover from the higher descent rate by adding thrust alone. When left engaged after passing 200 feet, the autopilot made pitch and thrust corrections that resulted in a no-flare wheel contact with the runway 130 feet from the threshold.

Each of the DC-10 qualified pilots conducted two or three approaches wherein the transition from automatic flight control and instrument references to manual flight control and visual references was made between 180 and 160 feet above the runway elevation. All were successful in landing on the runway; however, on several approaches, the wheel clearance above an imaginary approach light 250 feet from the threshold was 10 feet or less. On most of the approaches, the pilots applied elevator control inputs within 4 seconds after autopilot disengagement to increase the aircraft's pitch attitude to about 6° a.n.u., within 10 seconds. All of the pilots had observed the initial tests and were aware of the action required to prevent a high rate of descent from developing following autopilot disengagement.

The pilots generally agreed that the runway picture observed from 200 feet was neither alarming nor compelling with regard to the initiation of a missed approach procedure. Several pilots acknowledged the subtle nature of the increased rate of descent that followed autopilot disengagement. Also, they commented on the difficulty in judging the pitch attitude and descent profile from the visual cues available with the programmed, 4,000-foot runway visual range.

E. Probable Cause

The National Transportation Safety Board determined that the probable cause of this accident was that the captain did not recognize, and may have been unable to recognize, an increased rate of descent in time to arrest it before the aircraft struck the approach light piers. The increased rate of descent was induced by an encounter with a low-altitude wind shear at a critical point in the landing approach where he was transitioning from automatic flight control under instrument flight conditions to manual flight control with visual references. The captain's ability to detect and arrest the increased rate of descent was adversely affected by a lack of information as to the existence of the wind shear and the marginal visual cues available. The minimal DC-10 wheel clearance above the approach lights and the runway threshold afforded by the ILS glideslope made the response time critical and, under the circumstances, produced a situation wherein a pilot's ability to make a safe landing was greatly diminished.

IV. SUMMARY--RECOMMENDATIONS

As a direct result of the information obtained from the flight data recorder, the National Transportation Safety Board was able to determine, with a high degree of confidence, the wind-shear environment which the aircraft encountered during the approach. This determination made it possible to simulate the situation and demonstrate the extent to which wind shear and low visibility affected the ability of the flightcrew to complete a safe approach and landing.

The Safety Board made several recommendations 5/ to the Federal Aviation Administration following this investigation. Among these were actions designed to reduce the time required for a pilot to react correctly to a wind-shear encounter:

1. Issue an Advisory Circular which describes the wind shear phenomenon, highlights the necessity for prompt pilot recognition and proper piloting techniques to prevent short or long landings, and emphasizes the need to be constantly aware of the aircraft's rate of descent, attitude and thrust during approaches using autopilot/autothrottle systems.
2. Modify initial and recurrent pilot training programs and tests to include a demonstration of the applicant's knowledge of wind shear and its effect on an aircraft's flight profile, and of proper piloting techniques necessary to counter such effects.
3. Develop a system whereby wind shear information developed from meteorological measurements or pilot reports will be provided to the pilots of arriving and departing aircraft.

V. REFERENCES

1. Letter to Hon. John H. Reed, Chairman, NTSB, from John J. O'Donnell, President, ALPA, Sept. 30, 1974, NTSB Notation No. 1354.
2. J. A. Tannenbaum, "Deadly Wind Changes Are Now Being Linked With Aircraft Crashes," Wall Street Journal, Vol. CLXXXVI, No. 15, July 22, 1975, front page.
3. C. A. Roberts, "The Flight Data Recorder and the NTSB's New Data Reduction Station," SASI 1974 5th International Seminar Proceedings, Wash., D.C.
4. Aircraft Accident Report, Iberia Lineas Aereas de Espana (Iberian Airlines) McDonnell Douglas DC-10-30, EC CBN, Logan International Airport, Boston, Mass., Dec. 17, 1973, Report No. NTSB AAR-74-14.
5. NTSB Safety Recommendations A-74-77 through 83, October 3, 1974.

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	-3g 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	±.05g 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.

APPENDIX A

Information	Range	Accuracy, minimum (recorder and readout)	Recording interval, maximum (seconds)
Pitch Trim Position	Full range	$\pm 1^\circ$ or $\pm 5\%$ whichever is greater	2.
Control Column or Pitch Control Surface Position	Full range	$\pm 2^\circ$	1.
Control Wheel or Lateral Control Surface Position	Full range	$\pm 2^\circ$	1.
Rudder Pedal or Yaw Control Surface Position	Full range	$\pm 2^\circ$	0.5.
Thrust of Each Engine	Full range forward	$\pm 2\%$	4.
Position of Each Thrust Reverser	Stowed and Full Reverse		4.
Trailing Edge Flap or Cockpit Flap Control Position	Full range (or each discrete position)	$\pm 3^\circ$	2.
Leading Edge Flap or Cockpit Flap Control Position	Each discrete position		2.
Angle of Attack (If recorded directly)	-20° to $+40^\circ$	± 1	0.5

APPENDIX B

SUMMARY OF DFDR DATA

PARAMETER	SOURCE	TYPE SIGNAL	RANGE	SAMPLING RATE (Seconds)
1. Radio Altimeter - Coarse	Radio Altimeter RT's	High Level DC	-20 to 2,500 Feet	1 Per
2. Radio Altimeter - Fine	Radio Altimeter RT's	Low Level DC	-20 to 230 Feet	1 Per 2
3. Pressure Altitude	Air Data Computer No. 2	Digital	-1,000 to 50,000 Feet	1 Per
4. Computed Airspeed	Air Data Computer No. 2	Digital	30 to 450 Knots	1 Per
5. Mach Number	Air Data Computer No. 2	Digital	0.2 to 1.0 Mach	1 Per 2
6. Max. Allowable Airspeed	Air Data Computer No. 2	Digital	175 to 450 Knots	1 Per 2
7. Total Air Temperature	Air Data Computer No. 2	Digital	-99° to +50°C	1 Per 2
8. Pitch Attitude	Inertial Nav. System	Synchro	-85° (Down) to +85°	1 Per
9. Roll Attitude	Inertial Nav. System	Synchro	-180° (L) to +180°	1 Per
10. Magnetic Heading	Compass System	Synchro	0° to 360°	1 Per
11. Glideslope Deviation 1	ILS Receiver	Very Low Level DC	-2 to + 2 Dots	1 Per
12. Glideslope Deviation 2	ILS Receiver	Very Low Level DC	+ = Fly Down CMD	1 Per
13. Localizer Deviation 1	ILS Receiver	Very Low Level DC	-2 to + 2 Dots	1 Per
14. Localizer Deviation 2	ILS Receiver	Very Low Level DC	+ = Fly Right CMD	1 Per
15. GMT (Hours: Minutes)	Flight Engr. Clock	Digital	24 Hour Clock	1 Per 4
16. Vertical Acceleration	Accelerometer	Low Level DC	-3G to +6G	4 Per
17. Lateral Acceleration	Accelerometer	Low Level DC	-1G to 1G	4 Per
18. Longitudinal Acceleration	Accelerometer	Low Level DC	-1G to 1G	2 Per
19. Elevator Pos'n - L. Inbd.	Elev. Actuator Assembly	AC Ratio No. 2	-16.5° (Down) to +27°	1 Per
20. Elevator Pos'n - R. Outbd.	Elev. Actuator Assembly	AC Ratio No. 2	-16.5° (Down) to +27°	1 Per
21. Rudder Pos'n - Upper	Rud. Actuator Assembly	AC Ratio No. 2	-23° (L) to +23° (R)	2 Per
22. Rudder Pos'n - Lower	Rud. Actuator Assembly	AC Ratio No. 2	-23° (L) to +23° (R)	1 Per
23. Aileron LH. Inbd.	Ail. Actuator Assembly	AC Ratio No. 2	-20.2° to +20.2°	1 Per
24. Aileron RH. Outbd.	Ail. Actuator Assembly	AC Ratio No. 2	-20° to +20°	1 Per
25. Spoiler Pos'n, No. 3 R.	Spoiler Pos'n Transmitter	Synchro	0° (Retract) to 60°	1 Per
26. Spoiler Pos'n, No. 5 L	Spoiler Pos'n Transmitter	Synchro	(Full Extend)	1 Per
27. Flap - RH. Inbd., No. 3	R. Inbd. Transmitter	Synchro	0° to 50°	1 Per 2
28. Horiz. Stabilizer (Pitch Trim)	Horizontal Stab. Sensor	Synchro	-15° (Nose Up) to +5°	1 Per 2
29. Thrust (N1), Engine 1	N1 Indicator	Low Level DC	0% to 125%	1 Per 4
30. Thrust (N1), Engine 2	N1 Indicator	Low Level DC	100% =	1 Per 4
31. Thrust (N1), Engine 3	N1 Indicator	Low Level DC	3432.5 RPM	1 Per 4
32. Core Speed (N2), Engine 1	N2 Tachometer	Tachometer	0% to 120%	1 Per 4
33. Core Speed (N2), Engine 2	N2 Tachometer	Tachometer	100% =	1 Per 4
34. Core Speed (N2), Engine 3	N2 Tachometer	Tachometer	9827 RPM	1 Per 4
35. Power Lever Angle, Engine 1	Pots Installed in Pedestal	Pots	Idle 0°	1 Per 4
36. Power Lever Angle, Engine 2	Pots Installed in Pedestal	Pots	Full Forward +68°	1 Per 4
37. Power Lever Angle, Engine 3	Pots Installed in Pedestal	Pots	Full Reverse -57°	1 Per 4

SUMMARY OF DFDR DATA

PARAMETER	SOURCE	TYPE SIGNAL	RANGE	SAMPLING RATE (Seconds)
38. Exhaust Gas Temp., Engine 1	Engine EGT Indicator	Tachometer	0° to 1,000°C	1 Per 4
39. Exhaust Gas Temp., Engine 2	Engine EGT Indicator	Tachometer	0° to 1,000°C	1 Per 4
40. Exhaust Gas Temp., Engine 3	Engine EGT Indicator	Tachometer	0° to 1,000°C	1 Per 4
41. Fuel Flow, Engine 1	Fuel Flow Electronics	DC Ratio 1	0 to 21,876 PPH	1 Per 4
42. Fuel Flow, Engine 2	Fuel Flow Electronics	DC Ratio 1	0 to 21,876 PPH	1 Per 4
43. Fuel Flow, Engine 3	Fuel Flow Electronics	DC Ratio 1	0 to 21,876 PPH	1 Per 4
44. Oil Quantity, Engine 1	Oil Quantity Indicator	Low Level DC	0 to 22 Quarts	1 Per 2
45. Oil Quantity, Engine 2	Oil Quantity Indicator	Low Level DC	0 to 22 Quarts	1 Per 4
46. Oil Quantity, Engine 3	Oil Quantity Indicator	Low Level DC	0 to 22 Quarts	1 Per 4
47. Fan Vibration, Engine 1	EVM Signal Conditioner	Pot	0-100% (100% = 5 IPS)	1 Per 2
48. Fan Vibration, Engine 2	EVM Signal Conditioner	Pot	0-100% (100% = 5 IPS)	1 Per 2
49. Fan Vibration, Engine 3	EVM Signal Conditioner	Pot	0-100% (100% = 5 IPS)	1 Per 2
50. Turbine Vibration, Engine 1	EVM Signal Conditioner	Pot	0-100% (100% = 5 IPS)	1 Per 2
51. Turbine Vibration, Engine 2	EVM Signal Conditioner	Pot	0-100% (100% = 5 IPS)	1 Per 2
52. Turbine Vibration, Engine 3	EVM Signal Conditioner	Pot	0-100% (100% = 5 IPS)	1 Per 2
53. Turbine Inlet Pressure, 1	EPR Unit	Low Level DC	0 to 90 PSIA	2 Per
54. Turbine Inlet Pressure, 2	EPR Unit	Low Level DC	0 to 90 PSIA	1 Per
55. Turbine Inlet Pressure, 3	EPR Unit	Low Level DC	0 to 90 PSIA	2 Per
56. Engine Inlet Pressure	EPR Unit	Low Level DC	0 to 20 PSIA	1 Per
57. Squat Switch	Ground Sensing Relay	Discrete	0 Ground, 1 Airborne	1 Per
58. VHF Keying, Transmitter 1	VHF Transceivers	Discrete	0 Not Keyed	1 Per
59. VHF Keying, Transmitter 2	VHF Transceivers	Discrete	0 Not Keyed	1 Per
60. VHF Keying, Transmitter 3	VHF Transceivers	Discrete	0 Not Keyed	1 Per
61. HF Keying, Transmitter 1	HF Interlock Relay	Discrete	0 Not Keyed	1 Per
62. HF Keying, Transmitter 2	HF Interlock Relay	Discrete	0 Not Keyed	1 Per

PARAMETER	SOURCE	TYPE SIGNAL	Retract	Transit	T/O	LND	SAMPLING RATE (Seconds)
63. Slat L/4A (No. 1)	Proximity Electronics Unit	Discrete	0	0	1	1	1 Per
64. Slat L/4B (No. 2)	Proximity Electronics Unit	Discrete	1	0	0	1	1 Per
65. Slat L/2A (No. 3)	Proximity Electronics Unit	Discrete	0	0	1	1	1 Per
66. Slat L/2B (No. 4)	Proximity Electronics Unit	Discrete	1	0	0	1	1 Per
67. Slat R/4A (No. 5)	Proximity Electronics Unit	Discrete	0	0	1	1	1 Per
68. Slat R/4B (No. 6)	Proximity Electronics Unit	Discrete	1	0	0	1	1 Per

PARAMETER	SOURCE	TYPE SIGNAL	RANGE	SAMPLING RATE (Seconds)
69. Thrust Reverser Unlock 1	Thrust Reverser Switch	Discrete	0 Transit, 1 Stowed	1 Per 4
70. Thrust Reverser Unlock 2	Thrust Reverser Switch	Discrete	0 Transit, 1 or	1 Per 4
71. Thrust Reverser Unlock 3	Thrust Reverser Switch	Discrete	0 Transit, 1 Deployed	1 Per 4
72. Thrust Reverser Deployed 1	Thrust Reverser Switch	Discrete	0 Deployed, 1 Stowed	1 Per 4
73. Thrust Reverser Deployed 2	Thrust Reverser Switch	Discrete	0 Deployed, 1 or in	1 Per 4
74. Thrust Reverser Deployed 3	Thrust Reverser Switch	Discrete	0 Deployed, 1 Transit	1 Per 4

APPENDIX B

SUMMARY OF DFDR DATA

PARAMETER	SOURCE	TYPE SIGNAL	RANGE	SAMPLING RATE (Seconds)
75. Outer Marker	Marker Beacon Receiver	Discrete	1 > 2.5V.AC, 0 < 1.5V.AC	1 Per
76. Middle Marker	Marker Beacon Receiver	Discrete	1 > 2V.AC, 0 < 1.5V.AC	1 Per
77. Landing Gear Lever Down	Proximity Electronics Unit	Discrete	0 Up, 1 Down	1 Per 2
78. Landing Gear Lever Up	Proximity Electronics Unit	Discrete	1 Up, 0 Down	1 Per 2
79. Autopilot No. 1 CWS	Switch on A/P Controller	Discrete	0 Off, 1 Engaged	1 Per
80. Autopilot No. 1 CMD	Switch on A/P Controller	Discrete	0 Off, 1 Engaged	1 Per
81. Autopilot No. 2 CWS	Switch on A/P Controller	Discrete	0 Off, 1 Engaged	1 Per
82. Autopilot No. 2 CMD	Switch on A/P Controller	Discrete	0 Off, 1 Engaged	1 Per
83. Anti-ice Eng. 1 (Inlet Valve)	Anti-ice Valve	Discrete	0 Open, 1 Closed	1 Per 2
84. Anti-ice Eng. 2 (Inlet Valve)	Anti-ice Valve	Discrete	0 Open, 1 Closed	1 Per 2
85. Anti-ice Eng. 3 (Inlet Valve)	Anti-ice Valve	Discrete	0 Open, 1 Closed	1 Per 2
86. Event Marker	Flight Data Entry Panel	Discrete	1 Mark	1 Per
87. Pack Mode Select 1	Mode Select Switch	Discrete	1 Off	1 Per 4
88. Pack Mode Select 2	Mode Select Switch	Discrete	1 Off	1 Per 4
89. Pack Mode Select 3	Mode Select Switch	Discrete	1 Off	1 Per 4
90. Start Valve 1	Start Valve Light Low	Discrete	0 Open, 1 Closed	1 Per
91. Start Valve 2	Start Valve Light Low	Discrete	0 Open, 1 Closed	1 Per
92. Start Valve 3	Start Valve Light Low	Discrete	0 Open, 1 Closed	1 Per
93. Isolation Valve Switch 1-2	Isolation Valve Switch	Discrete	0 Open, 1 Closed	1 Per 4
94. Isolation Valve Switch 1-3	Isolation Valve Switch	Discrete	0 Open, 1 Closed	1 Per 4
95. APU Isolation Valve	APU Isolation Valve Switch	Discrete	0 Open, 1 Closed	1 Per 4
96. Wing Anti-ice Valve	Wing Anti-ice Valves	Discrete	0 Closed. 1 Open	1 Per 4

CANADIAN CIVIL AVIATION SAFETY INVESTIGATION PROCEDURES

W. M. Howes

The history of Aviation Safety Investigations in Canada does back a long time. Let me take you back 55 years to the year 1920, when we had a series of accidents indicative of some problems of the times.

> Vancouver, B.C. August 18th, 1920. "The pilot, whilst making a test flight for his commercial air-pilots certificate, made one alighting and took off again. At a height of about 1,000 feet the machine appeared to be out of control and at the same time the pilot fell out. The machine then glided slowly on her back and crashed into the water. The Court of Enquiry considered that a possible cause was the fact that the pilot's scarf, which was later found in a badly torn condition, had jammed the pulleys between the passenger seats which carried the elevator control wires."

> Lake Onatchiway, Quebec, August 18, 1920. "The machine got out of control at a height of 1,000 feet shortly after takeoff, due to the chain having come off the sprocket of the incidence gear wheel. The pilot lost control while trying to replace the chain in it's sprocket."

> Shawville, Quebec, September 22nd, 1920. "The pilot lost control of the machine at about 1500 feet. The machine went into a spinning dive and crashed. The opinion of the Court of Enquiry was that the accident was caused by the control column being jammed during flight."

I like to think that life was fairly simple in those days, but perhaps it was not. If such a series of accidents had occurred today, it would give our system a real work-out. In 1920, there were 9 accidents reported and investigated by "Courts of Inquiry". Today in 1975, we maintain an Aviation Safety Investigation and accident prevention organization that investigates 750 accidents per year plus a considerable number of incidents. We maintain six investigation centres across the country, and a Headquarters in Ottawa concerned with functional control, investigation standards training, analysis, research and the generation of safety proposals. This central office also provides a nucleus of specialists whose concern is the investigation of major accidents. In all, there are approximately 50 field investigators on staff.

Our investigators all have an extensive aviation background in operational, technical or engineering fields and participate in a continuing education program to update and maintain their skills. Fully 10% of our operating budget is dedicated to the training program. A new investigator, after a period of field indoctrination, is sent to an ICAO recommended course, either to the University of Southern California or to the Institute of Aviation Safety, the Royal Institute of Technology, Stockholm, Sweden. In addition, all our investigators attend a course in Crash Survival, at Arizona State University. We also have our own facilities and personnel for specialized investigation training including witness interviewing techniques. This training makes extensive use of closed circuit television and role playing, with magnetically recorded video tapes.

Our investigations are supported by a central technical laboratory with very modern facilities and, on request by the facilities of the National Research Council. Aeromedical specialists of the Department of Health and Welfare work closely with our investigators in every region and attend all fatal accidents. In addition to physiological studies, which include autopsies on all crew-members and lactate measurements, they also supply us with their professional views on human factors aspects of accidents and maintain a sophisticated computer program dedicated to accident prevention and research from the aeromedical point of view.

General Aviation Accidents

General aviation accidents are investigated by teams from our field offices. Investigators have government aircraft available when needed and have authority to charter commercial aircraft to reach remote areas. Investigation and reporting procedures are standardized to a high degree aided by an annual conference to discuss problems and new techniques. Our most northerly accident investigation was at Ice Island T-3, three hundred miles from the North Pole. We also participate in investigations in other countries under the terms of the I.C.A.O. agreement, and have done investigations for other countries, particularly French speaking countries of Africa.

Major Accidents

Accidents designated as major are handled by specialists from Ottawa and from the regional offices. As is done in other countries, a group system is used which allows flexibility and the incorporation of expertise from other organizations. We have a pre-arranged "Planned Investigation Program" (PIP) which is an adaptation of the PERT critical path organization approach coupled with a comprehensive check list for each group and for the investigator-in-charge. These lists are in the form of a booklet and have a great steadying effect during the first few hectic days of a major investigation.

Participation in an Investigation

The participation by persons other than our investigators is permissable only when those persons have a clearly contributory role. This provision is necessary to preserve the objectivity of an investigation and to protect the rights of individuals involved in the accident. The investigator-in-charge has full authority to control participation, to define the scope of the assigned job and to ensure a clear understanding that participation is conditional on strict adherence to the terms of reference.

In practice, the airline involved usually designates specialists, and we obtain assistance from the manufacturers or from wherever necessary to handle a particular problem.

We invariably ask the Canadian Air Line Pilots Association to provide one or more pilots qualified on the type of aircraft involved and the Association has always responded willingly. Our experience has been that these experts and their organizations have always behaved in a thoroughly objective and professional manner. Participants are free to pass essential safety information back to their parent organizations but are expected to avoid making public statements.

Provincial and local authorities have statutory and other responsibilities and their work is permitted to the greatest extent possible consistent with the requirements of the investigation. Advance arrangements are made to minimize conflicts of jurisdiction.

We recognize the legitimate interest of other persons such as concerned citizens, damage claimants, representatives of trade or employee organizations, legal counsels, etc. Unfortunately we cannot accommodate these persons during the investigation but we assure them that factual information will be released as soon as possible and remind them that full control of participation ensures an efficient and objective investigation and early accident prevention results. In special circumstances observer status may be granted through our Headquarters, but the field investigators do not have this authority.

Release of Information

Essential safety information is transmitted to the appropriate organizations without delay. Each major investigation has a public affairs officer assigned to it whose duty is to provide correct factual information to the press and other interested parties during the course of the investigation. We do not release witness statements, records, documents, transcripts of electronic or mechanical recordings or any other evidence which might infringe the rights of an individual. It is our policy to make copies of most material for purposes of the investigation, and return the originals to the owners.

We are particularly anxious to protect information from cock-pit voice recorders and flight data recorders from improper use. The assignment of blame of liability plays no part in our work. In the case of a public inquiry however, the judicial authority can decide how to dispose of evidence.

We are aware that our policy differs from that of some other countries that have full disclosure of information. Things may change in Canada but basically we feel the view that the rights of the individual to privacy and the need for unobstructed aviation safety action are paramount will prevail. We recognize the need and right of individuals and organizations to factual information. We release such material as soon as the urgency of the investigation permits.

Public reports are issued on all aircraft accidents. Most reports are in the form of a brief synopsis. Selected reports are published in more detail. These are accidents involving fatalities, air carriers, technical failures, special safety interest, wide public interest, or on special request from our regional offices. We follow I.C.A.O. procedures for reporting on major accidents.

Electronic Data Processing and Analysis

This organization has used electronic data processing for factual accident information since 1 January 1970. We use a federal government IBM 360 computer. We have strengthened our library of data by incorporating the total experience of the U.S.A., Australia and New Zealand going back to 1965. This produces the recorded experience of approximately 45,000 accidents. In addition we are now storing aeromedical information and crashworthiness information.

Two years ago we added data from a new development SPAN, a procedure intended to achieve a complete analysis of each accident and to store the resultant "judgmental" data for research and accident prevention purposes. This approach takes the view that the pilot is also a victim of the accident and that the various aviation systems involved performed imperfectly to create a set of circumstances that were too much for him to overcome.

"SPAN" SYSTEMS PERFORMANCE ANALYSIS NETWORK

"SPAN" is a computer related analysis technique intended to accommodate either "accidents" or "incidents" and to provide the most direct route between investigation and prevention. With this system combined with the present factual data being stored in our computer, practically all of the information provided by investigators in the field is put to use - rather than just part of it. "SPAN" is an investigation tool, an accident prevention research tool, and a management information system.

The essence of "information" - as opposed to data is that information is data that has been evaluated for a particular purpose. Our purpose is accident prevention.

The "SPAN" approach recognizes that the responsibility of the Minister of Transport is for the safe and orderly development of aviation in Canada. This responsibility is administered through the Ministry, which in turn has developed a number of systems to achieve the aim. The overall authority is clearly defined in the Aeronautics Act and other legislation. The systems to which reference has been made are supported in regulations or standards.

Each system has its reflection in the air carriers in what is, in effect, delegated responsibility. Each system also has its feedback devices. The input to a system is at the Ministry of Transport; and output is visible in the safety of aviation services offered by the carrier.

Seven basic systems have been identified:

(1) Personnel competency

(2) Airworthiness engineering

(3) Air Traffic Control

(4) Aviation Safety Management

(5) Air Navigation Services (Airports/Weather/Telecom)

(6) Regulations

(7) Air Carrier Certification

Each of these systems is reviewed with respect to a particular occurrence as to its performance in the following:

- Standards
- Communication of Standards
- Compliance with Standards
- Monitoring
- Feedback of Information
- Enforcement

The performance of individuals, carriers, and the MOT is examined in great detail as specified in a "code book" and then entered in a computer file. This information is de-identified and is not intended for release to the public. It will be available for safety and accident investigation/prevention research purposes.

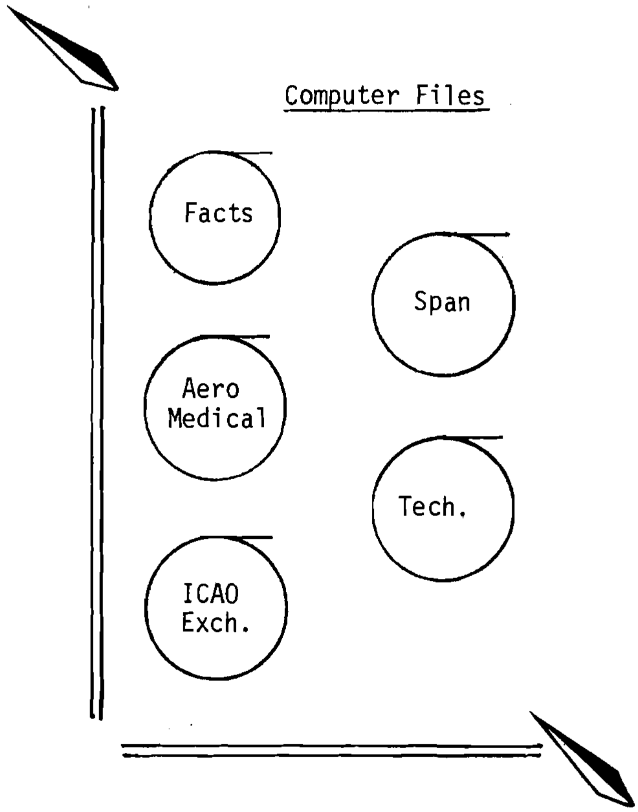
All accident and incident reports received from the Regions are now analysed by the "SPAN" technique. A copy of each analysis sheet is mailed back to the original investigator. No comments are required unless there is disagreement with the analysis. Entries are made into the computer file every three months. Errors can easily be corrected before entry, and if considered serious, can be corrected after entry into the computer. "Software" has been developed for routine studies and for plain language printouts.

This systems approach to analysis and storage of the operational aspects of accidents and incidents is, as far as we know, not used by other countries. A more detailed explanation of the "SPAN" process and information about the "code book" and the procedure for gaining access to information stored in the computer is available.

<u>Research Capability</u>

This variety of recorded data and judgmental information gives us great research capability as the following diagram illustrates.

RESEARCH CAPABILITY



"Software" has been developed and routine print-outs are provided to each regional office and to other divisions of our civil aeronautics system. A complete computer record is kept of all preventive proposals and subsequent action. We have also found it possible to use the computer as an aid to investigation of accidents and incidents. For example, it will provide a record of factors involved in similar previous occurrences which makes a "check-list" for an investigation.

To sum up, the Safety Investigations Division of the Bureau of Aviation Safety, Ministry of Transport is attempting to contribute to the development of air transportation through intelligent application of modern investigative and research techniques.