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Call for Papers

The 1983 ISASI International Seminar of the International Society of Air Safety Investigators will be held at the Chicago Marriott Hotel in Chicago, Illinois
October 11-14, 1983

The theme of the seminar will be:

"The Air Safety Investigator:
Meeting the Future Challenge of
Aerospace Technology"

(Presentations on other topics will be considered)

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

Jack J. Eggspuehler
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Abstracts must be received by April 30, 1983.
Final Papers will be required by August 15, 1983.

The Jerome F. Lederer Award

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

Any ISASI member may submit a nomination for this award. It must be sent to the Chairman of the Board of Award not later than 15 May 1983, and must include a statement describing why the nominee should be considered. This statement should be sufficiently descriptive to justify the selection but no more than one typewritten page in length.

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

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

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THE JEROME F. LEDERER AWARD

1982

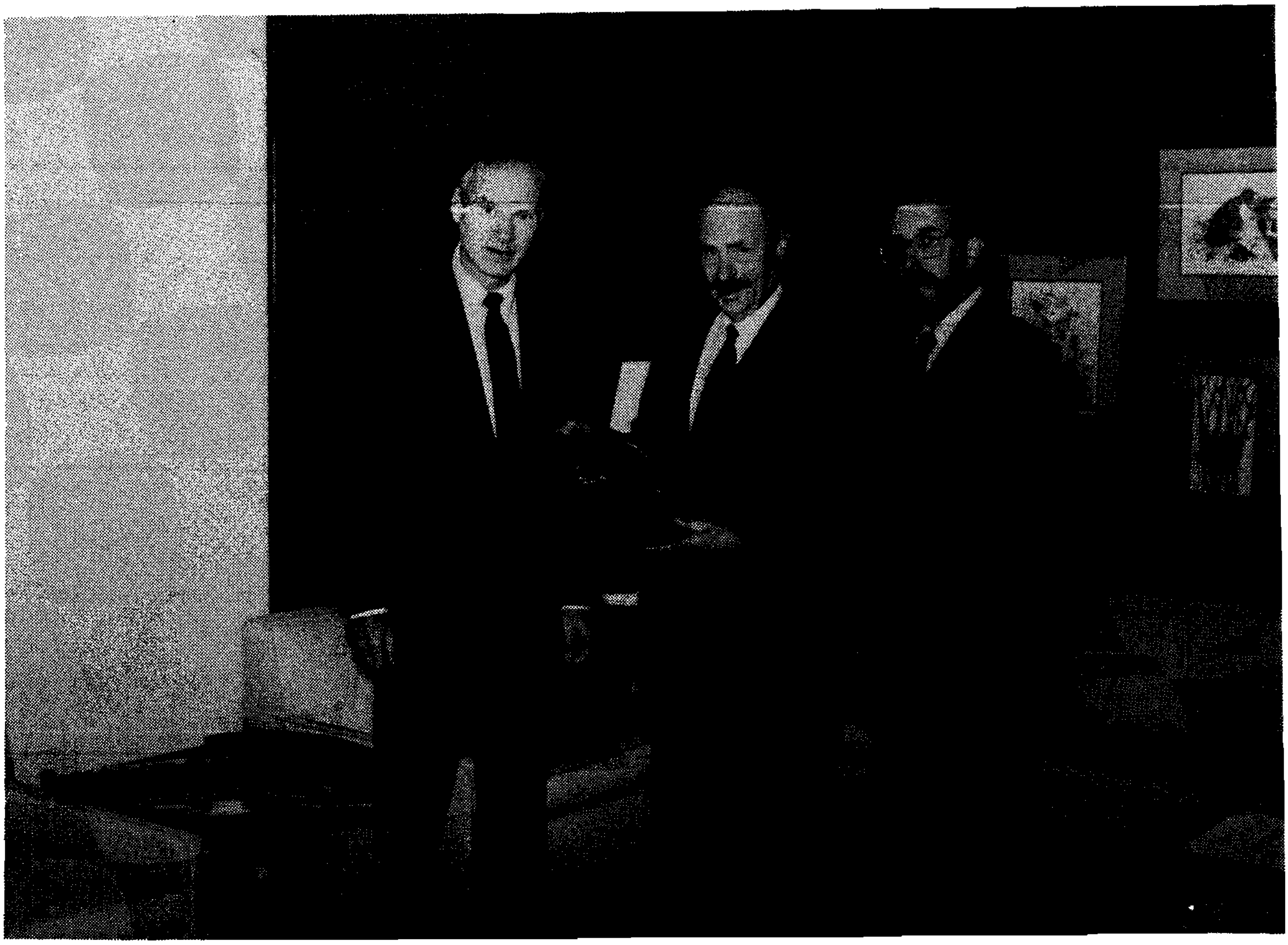
presented to

H. PRATER HOGUE

for

Outstanding Contributions to Technical Excellence

in Accident Investigation



Mr. Hogue has been involved in aviation for his entire professional life and has spent the past 25 years in the field of accident investigation. He pioneered the team concept of investigation at The Boeing Company, and freely shared his expertise with others through committee work, ISASI and university teaching. He has participated in the investigation of accidents on all Boeing models since the B-17, and has assisted various agencies on other military and civil aircraft. By leadership, example, and teaching he has produced outstanding contributions to technical excellence in accident investigation.

Accident to British Aerospace 748 at Nailstone

P.J. Bardon
Deputy Chief Inspector of Accidents
UK Accidents Investigation Branch
Bramshot, Fleet, Hampshire

My reason for selecting this accident for my talk to you is not only because the circumstances were somewhat bizarre, but more particularly because I wanted to detail the investigation techniques we employed which I thought would be of interest to this audience.

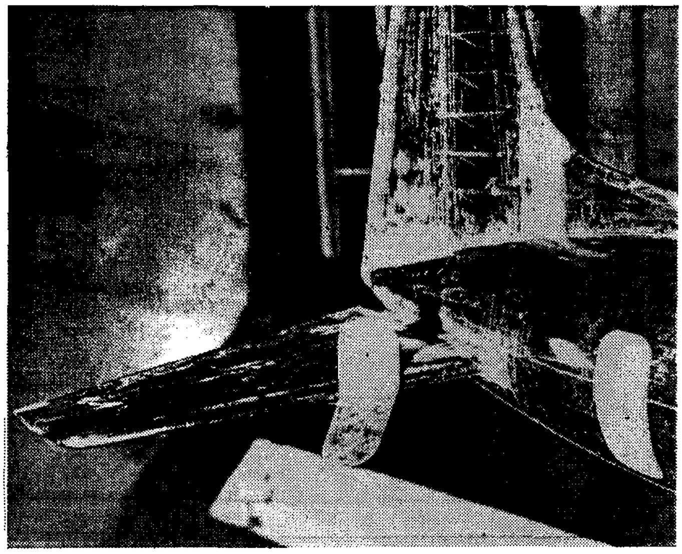
The accident happened in the UK to a British Aerospace 748 twin turboprop aircraft which was operating a mail run from Gatwick to the East Midlands Airport, a relatively short flight of just under one hour. There were on board just three persons, namely the two pilots and someone designated as a postal assistant. From the FDR and CVR, we were able to establish that the flight was quite routine for the first half hour. About 30 minutes before the accident, the aircraft began its descent, and shortly after that the PA could be heard to say that the rear cabin door was showing red. The pilot was obviously worried about the door coming off, and he was heard to say that he hoped that by reducing the cabin pressure, it would lessen the risk of this happening. He also hoped that by reducing speed, any impact damage to the tailplane by the door coming off would be minimised. (How wrong he was on both counts.) The airacraft was then given further descent clearance and the sound of the engines could be heard to decrease. The speed was 150 kts. As the aircraft was passing through 5,200 feet a noise could be heard consistent with a sudden loss of cabin pressure.

Thereafter, from the pilots' comments it was clear that something very violent was happening to the aircraft. This is confirmed by the FDR read out. I should digress here to say that the refined FDR output was displayed on a VDU in the form of flight instrument indications, which is the first time we have used this technique. It conveys, as no digital or analogue read out can convey, a dramatic reconstruction of the accident sequence. In fact, what we were able to observe was the addident sequence in real time. The crew put out a Mayday call and at the same time reported severe control problems, and that they thought they had lost the rear cabin door. The FDR shows that when the decompression occurred, the aircraft experienced a slight yaw and roll to the right. Shortly after, there occurred a series of violent pitch oscillations, which culminated in both wings becoming detached. Seven seconds later the aircraft hit the ground. Needless to say, the CVR was extremely harrowing to listen to, as they so often are. A number of other pieces of aircraft also separated, and the wreckage was spread across several fields over a distance of about 5 miles.

The investigation started therefore with the knowledge that the pilot had reported a violent decompression, possible loss of a cabin door and severe control problems. We also knew, of course, that the aircraft had broken up in flight. The wreckage in the area furthest down the flight path consisted of small fragments of plastic which were identified as having come from the rear starboard baggage door. However at the main site, all significant components of aircraft structure were found, including the starboard baggage door, though this was a few metres further from the main wreckage than were all the other doors. Examination of these other doors and hatches confirmed that they were closed at the time of impact. It was also apparent from the wreckage examination that the two wings and the port tail plane had failed in up-load and that the starboard tail plane had also failed in up-load, but had separated from the fuselage somewhat later in the sequence than the other components and had done so shortly before the fuselage had struck the ground.

It could be seen from an examination of the starboard baggage door aperture that it had been extensively damaged during impact whereas the damage to the door itself indicated that it had not been in position when the fuselage hit the ground. The door itself appeared to have been struck at approximately mid height and partly folded over. Deposits of rubber in the fold clearly indicated that it had been struck by the leading edge of the starboard tailplane, since the rubber deposits matched the deicing boot material. Therefore, fairly early on in the investigation, without positive evidence that it had in fact happened, the manufacturer was asked to carry out a wind tunnel test to determine the effect on the stability and control of the aircraft of the starboard baggage door becoming impaled on the leading edge of the starboard tail plane.

The results were as startling as they were unexpected. The tests showed that with the door in a stable position on the leading edge there was a marked discontinuity in the relationship between the pitching moment and the lift coefficient, equivalent to the instantaneous application of 7 degrees of elevator. This was accompanied by a violent shaking of the wind tunnel model. The effect would have been to produce an aircraft that was violently unstable with a reversal of elevator power; in other words a down application of elevator would have produced a pitch up. These wind tunnel test results became of acute interest when they were compared with the FDR read out which showed that such violent excursions in pitch had occurred and had continued until the aircraft broke up. There was good evidence upon which to base a conclusion that when the baggage door had come off, it had struck the leading edge of the tailplane and become hung up. In support of this conclusion was the fact that the door was close to the main wreckage, whereas had it separated from the aircraft and fallen clear, it would have been many miles from the main impact site.



The investigation had now reached the stage where it had established, with the fair degree of certainty, what had happened. It now remained to establish why the door had come off in the first place, and this led us into a form of wreckage reconstruction which we had not previously attempted. The aft baggage door is an outward opening door secured in the closed position by four claw type catches which act on fretting pads inside the door aperture. These catches have a geometry which causes the door to be drawn into the aperture by the over-centering action of links attached to the claws. In addition to this over-centering action, movement of the claws is prevented, once the door is closed, by the engagement of secondary locks which prevent further movement of the linkage. The movement of the door lock mechanism by either the external or the internal lever moves the secondary locks and the primary locks in the correct sequence as determined by a fixed cam under the inner handle. Also integral with the door lock mechanism are two indicator drums which give a visual indication of the position of the locking mechanism. The viewing windows of these drums were installed incorrectly, inside out; the significance of this I will discuss later.

Initially, it was thought that the loss of the door could have been due to elastic deformation of the door structure under pressure loads, causing the plungers to disengage in flight. The manufacturer therefore carried out a test on an instrumented aircraft to check the behaviour of the door with the primary locks engaged and the secondary locks disengaged. This showed that there was no significant movement of the plungers throughout the full range of cabin pressure differentials and therefore the possibility that elastic deformation of the fuselage in flight had caused the loss of the door was discounted. The next thing we did was to rebuild the door from the accident aircraft, with all the mechanical items re-installed in their original position. When this was done, it was found that the various rods constituting the lock mechanism could not be joined together with the claws in the locked position. This was not due to any deformation caused during the impact sequence. When all the rods were connected up, it was found that the door could be closed if sufficient force was used on the inner handle, but if the external handle only was used, only the bottom pair of catches would lock. The top catches could not be over-centered, however much force was used, though the claws were engaged. In this position, of course, the secondary locks were not in engagement.

This was clearly evidence of some significance. Another 748 baggage door was obtained and its mechanism adjusted to conform exactly to the geometry of the accident aircraft; that is, with the top catches not over-centered. A rig was constructed to enable forces to be applied to the door claw catches representative of cabin differential pressure loads. It was found that on reducing the load after having applied progressively higher initial peak loads, the behaviour of the mechanism began to alter when the load was reduced from a peak pressure of 2.5 psi. Finally, when the load was being reduced from a peak pressure of 3 psi the door locking mechanism suddenly opened when the pressure reached 1 psi and the door dropped clear of the rig.

We had at last arrived at the answer which, to summarise, was as follows:

1. The door had been shut from the outside, and the outer handle was inherently incapable of over-centering the top catches, due to the internal rigging of the door lock mechanism.

2. The door in this condition would not come open whilst the cabin pressure was applied to it but would do so when the pressure was reduced from a value of 3 psi.

3. When the cabin differential was reduced to 1 psi by the pilot, in the belief that by so doing he would lessen the chances of the door coming off, the locking mechanism disengaged.

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5. As a result of the pitch excursions due to the extreme instability, both wings and tail planes failed in overload and the aircraft crashed.

As an endpiece to this sad tale, I have to record that door losses from the 748 had occurred on 37 previous occasions, but in each case they had fallen clear.

Somethings still remained unexplained. Why for example, if the door was not properly locked, did not the 'Door Unsafe' warning light illuminate. We have one possible explanation that cannot be proved, which is defective wiring. The significance of the incorrect installation of the mechanical drum indicator window is that, in that position, the unsafe RED sector could not be properly seen from the awkward viewing angle of someone examining the door indicator from inside the aircraft.

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Peter J. Bardon served in the RAF in Transport Squadron in Far East and Photo Reconnaisance Squadron in Europe. After attending the test pilot course in 1955, he was on test flying duties to 1968, having served the last three years as Chief Test Flying Instructor at the UK Test Pilot School. He joined the Accidents Investigation Branch in 1968, and has carried out some 40 investigations.

Psychological Stresses in the Lives of Pilots which can Predispose Fatal Accidents

Richard K. Brown, Ph.D. CP0037
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Los Angeles, California 90089-0021

Laymen commonly refer to psychology as an "inexact science." There are few generally accepted psychological laws and, certainly, complex behavior patterns are hard to quantify in a statistically valid manner. The human factors, therefore, further complicate the work of the accident investigator who is already faced with a myriad of possible causal factors.

This paper will express some ways investigators can examine human factors particularly as they create stress on pilots. An actual case study provides a dramatic example of how we can work with human factors problems. It is based on the analysis of the investigators.

A pilot and crew of a high performance aircraft took off on a routine training flight late one afternoon. During the course of the flight the pilot performed a high angle of attack rolling maneuver which resulted in an excessively nose-low attitude, precluding recovery above the minimum prescribed altitude of 10,000 feet MSL. There was a 7,000 foot undercast and the pilot, while attempting to recover above the clouds, performed an improper dive recovery and placed the aircraft in a high angle of attack, low air speed, flight regime as it entered the undercast. He then attempted to reduce the angle of attack and gain back airspeed as the aircraft descended through the clouds. The pilot failed however to use optimum techniques for recovering the aircraft from the descent and it descended below the clouds in an area of hilly terrain and leveled at a very low altitude, 100-200 feet AGL. Instead of climbing to safety above the clouds the pilot elected to maneuver below the very low ceiling and in so doing, inadvertently encountered rising terrain which could not be cleared with the energy available. The aircraft impacted the ground and was destroyed. All crew members were fatally injured.

An analysis of this chain of events will indicate several specific points at which critical judgments had to be made. The pilot evidently misjudged how near he was to the clouds and also his proximity to the minimum authorized altitude. He apparently lost situational awareness while watching a nearby aircraft. The rolling maneuver would have been tactically sound at higher altitude but in this situation it was a critical error.

He also did not employ optimum dive recovery technique for his situation and probably did not transition correctly to the instruments as the aircraft entered the weather. The result was an unnecessary turn in the clouds contributing to an excessive loss in altitude and airspeed. Spatial disorientation probably contributed to the pilot's wasting aircraft energy during the pull-out.

Next, the pilot chose to maneuver to an area of rising terrain when, instead, he could have flown down a valley or climbed above the weather. The slight downslope could have been interpreted as level flight. In such a case the crew members would not have realized they were descending. Visual perception problems might also have been created by relatively low light, reduced visibility under the clouds and the snow cover, making it difficult to judge the terrain height. Task saturation at this point was unremitting.

We are all aware that most accidents result from a combination of circumstances rather than from a single cause. The aircraft structure or aerodynamics may be involved, the environment frequently and certainly the pilot. Similarly, the series of decisions required of the pilot to cope with an unusual situation may reflect poor judgment. Ontiveros, Spangler and Sulzer (1978) developed what they termed the "Poor Judgment Behavior Chain"[1] (PJ Chain) and have established four principles of the PJ Chain.

1. *One poor judgment increases the probability that another poor judgment will follow.* Since judgments are made on information about oneself, the aircraft, or the environment, the pilot is more likely to make a poor judgment if the input factors are not accurate. One poor judgment provides an erroneous bit of information which the pilot must consider when making subsequent judgments.

2. *The more poor judgments made in sequence, the more probable that others will continue to follow.* The reasoning for this principle is the same as that in the previous principle, except that it is concerned with multiple poor judgments in sequence. The more erroneous information used by the pilot to make judgments, the more likely it is that the pilot will make subsequent poor judgments.

3. *As the PJ chain grows, the alternatives for safe flight decrease.* It is *a priori* that if a pilot selects one alternative among several, the option to select the remaining alternatives may be lost. For example, if a pilot makes a poor judgment to fly through a hazardous weather area, the alternative to circumnavigate the weather is lost once severe weather is encountered.

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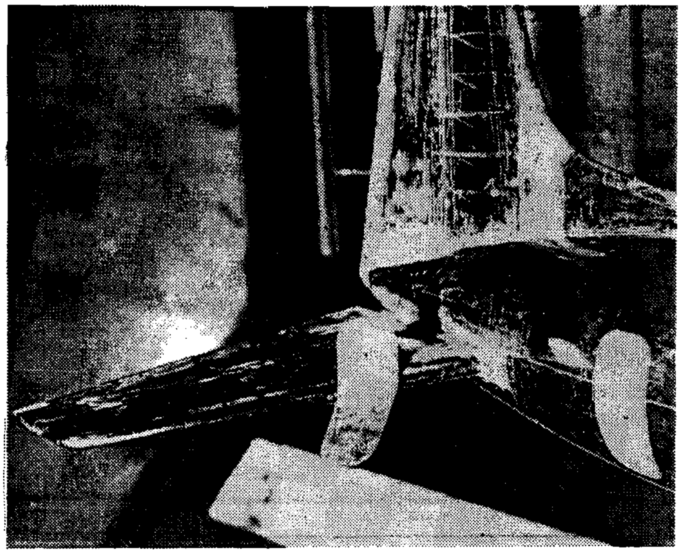

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4. *The longer the PJ chain becomes, the more probable it is that disaster will occur.* As the PJ chain grows longer, fewer and fewer alternatives for safe flight are available to the pilot. As the alternatives for safe

flight become fewer, the greater the chance becomes that an accident will occur.

Clearly our pilot aberrated a dangerous situation into a disaster by his chain of poor judgments. But this knowledge alone is inadequate. The investigator must now determine why the judgments were poor ones. Personal stress resulting from a series of life events may be of compelling significance as a contributor.

It has been shown that the effect of accumulated stress is often manifested in impaired speed and accuracy of sensory perception and the mental evaluation of those perceptions. The speed and quality of the decisions made as a result of the perceptions, as well as the implementation of the decisions, are also affected by accumulated stress or fatigue.

The accident investigation board postulated that this pilot's ability to get out of the situation in which he found himself was immeasurably impaired by the occurrence of several recent stress inducing events of significance in his life. They were:

1. Marital separation.
2. A recent move to a different home, with change in lifestyle.
3. Concern about son's school failure.
4. Recent termination of a liaison with another woman.
5. Anticipated completion of a required course of instruction.

Doctors Thomas Holmes and Richard Rahe[2] have developed a list of life events which they have found to correlate with many diseases. Dr. Holmes interviewed over 5,000 patients to determine what life events preceded their illnesses. Table I reflects the events reported. Dr. Rahe weighted these events listed most frequently by asking 394 persons to rate the amount of social readjustment required for each. A weight of 100 was assigned to the event given the highest ranking by the judges and other weights calculated by the rank order method. (Table I)

Using the Life Events table developed by Drs. Holmes and Rahe, we compute about 210 Life Change Units (LCU). According to their studies, 51% of the subjects with LCUs totaling between 200-299 reported health changes including injuries.

Use of the Holmes-Rahe scale in accident behavior analysis is not yet widespread. Although it was designed to determine the life events that most frequently preceded illness, its application to accident potential has also been demonstrated. If life events can so materially affect one's health, they can also markedly contribute to accident potential. We have long known that overstressed individuals often experience loss of discriminative skills and mental efficiency both of which predispose accidents.

Equally as important as an individual's stressors or life events in accident causation is the additive effect of several. Whatever the magnitude of each individual stressor, the overall effect of the combined stresses is said to be additive.

Dr. Anchard Zeller, Staff Psychologist in the Division of Life Sciences of the U.S. Air Force Inspection and Safety Center at Norton Air Force Base, California, conceived of the interaction of causal variables and the additive nature of the human factors many years ago. Dr. Zeller postulated in the 1950s that only two variables cause an accident. One, the level of ability and the other the level of demand. The point at which the demand exceeds the ability is the "accident zone."

N.H. Haakonson[3] elaborates the same concepts and refers to a similar diagram he calls the Fassold model. This demonstrates clearly the effect of "additive fatigue factors" or "life change events" on performance at crucial periods of demand. (Figure 1)

Although the events in our pilot's life may be common to many still alive, and may have gone unnoticed prior to the accident, they probably provided the strong undercurrent influence which invariably detracts from one's ability to function. Some persons tolerate better than others but all of us have the potential to exceed our ability to cope. Here is our pilot's profile of life events and performance demands as they converged into an accident zone.

RANK	LIFE EVENT	POINTS
1	Death of Spouse	100
2	Divorce	73
3	Marital separation	65
4	Jail term	63
5	Death of close family member	63
6	Personal injury or illness	53
7	Marriage	50
8	Fired at work	47
9	Marital reconciliation	45
10	Retirement	45
11	Changes in family member's health	44
12	Pregnancy	40
13	Sex difficulties	39
14	Gain of new family member	39
15	Business readjustment	39
16	Change in financial state	38
17	Death of close friend	37
18	Change to different line of work	36
19	Change in number of arguments with spouse	35
20	Mortgage over $10,000	31
21	Foreclosure of mortgage or loan	30
22	Change in work responsibilities	29
23	Son or daughter leaving home	29
24	Trouble with in-laws	29
25	Outstanding personal achievement	28
26	Wife begins or stops work	26
27	Begin or end school	26
28	Change in living conditions	25
29	Revision of personal habits	24
30	Trouble with boss	23
31	Change in work hours, condition	20
32	Change in residence	20
33	Change in schools	20
34	Change in recreation	19
35	Change in church activities	18
36	Change in social activities	18
37	Mortgage or loan under $10,000	17
38	Change in sleeping habits	16
39	Change in number of family get-togethers	15
40	Change in eating habits	15
41	Vacation	13
42	Christmas	12
43	Minor violations of the law	11

TABLE I

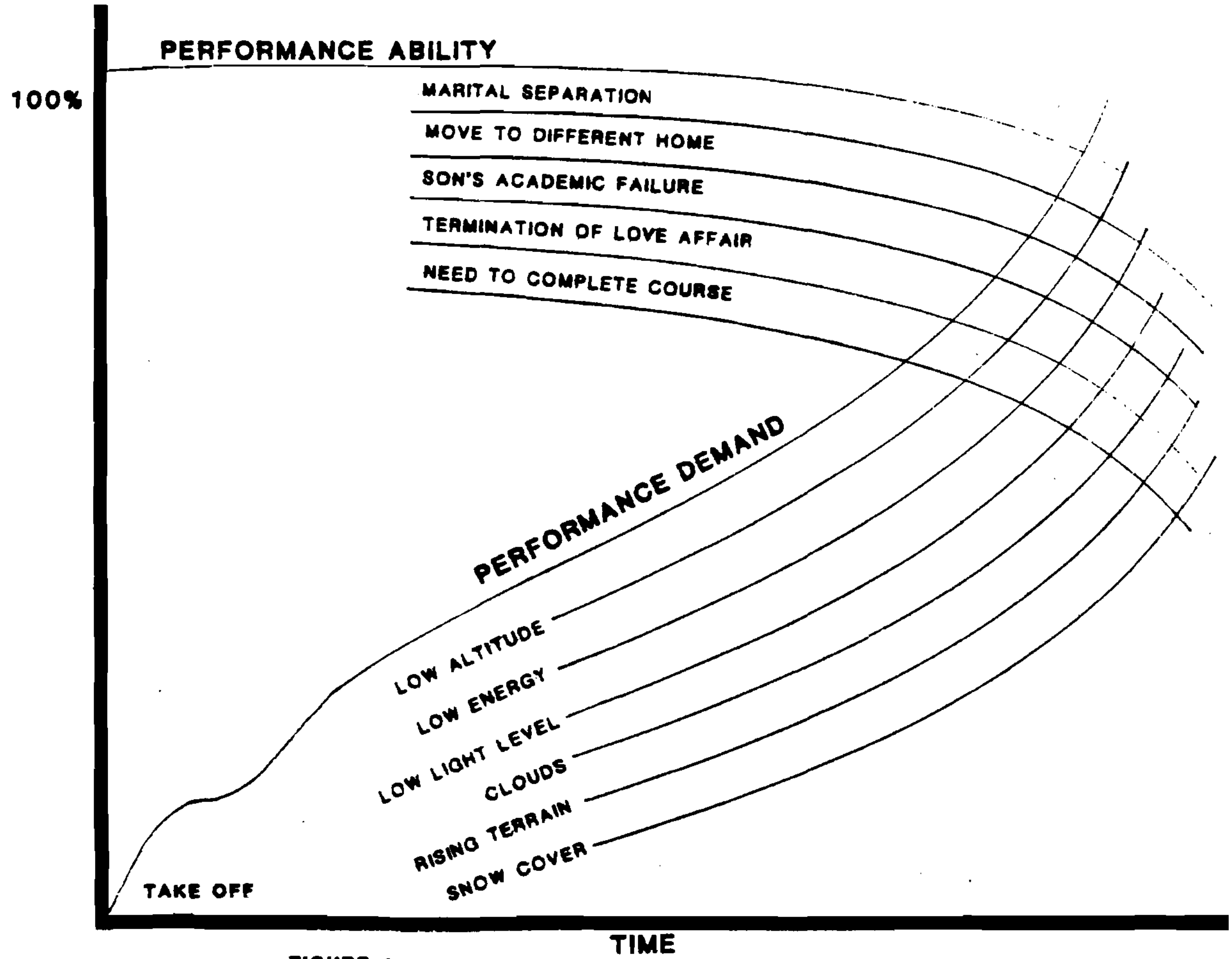

FIGURE 1

Haakanson says:

In this model it is necessary to first presume that each individual has a hypothetical performance ability which begins at 100 percent and decreases gradually over time, whether that time be the hours of a day or the years of life. Next we assume that every flying operation requires a performance demand specific to that operation. (The margin of safety is the difference between the demand and the ability.)

Performance ability may be decreased by any number of stressors by a quantity which, at this point, is immeasurable. It is important to remember that, whatever the quantity of each individual stressor, the overall effect of the combined stresses is cumulative. Through the same reasoning, it is possible to hypothesize increased performance demand, by some immeasurable quantity. Again, each individual increase in demand, when combined with other demands, is likely to be additive.

The area where the performance ability overlaps the performance demand is the accident zone and it is here that the accident or incident occurs.

In considering the human factors involved in accident causation we mut also keep in mind the particular characteristics of pilots which have been documented so many times.

Professor Chaytor Mason,[4] internationally known aviation psychologist and lecturer from the University of Southern California, says that there is consistency among the numerous measures of pilot personality characteristics which strongly suggests that pilots really do fulfill their stereotype of being active, masculine individuals—strong, competent and adventuresome—who enjoy their working life of coping with nature. His contention is supported in part by research at two Michigan universities suggesting that, "the time-honored Hollywood stereotype of the aviator as a romantic, dauntless he-man may be quite true." These researchers administered the Edwards Personal Preference Schedule (which measures the interest and motivations of individuals) to Navy jet pilots, general aviation pilots, and non-flyer adult U.S. males.

The authors found that pilots differ little from other pilots, but differ markedly in personality characteristics from non-flyers. Both general aviation pilots and Navy pilots scored significantly higher on five factors areas, and significantly lower on seven factors, than the average U.S. male. Both pilot groups scored high on Achievement, Exhibition, Dominance, Change and Heterosexuality and relatively low on Abasement, Nurturance, Endurance, Deference, Order, Succorance, and Affiliation. These areas with descriptions and mean scores are shown in Table II.

All this may lead one to believe these people to be stress resistant. There is considerable literature on the subject of subsets of persons who, because of some personality patterns such as those discussed above, resist the negative effects of stress on performance. There is nothing in the literature to the best of my knowledge however that conclusively supports the notion that there exists a group, identifiable on the basis of special characteristics or properties, which shows less stress or

PERSONALITY PROFILE — TRAIT DOMINANCE

	Personality Factor	Navy Pilots Rank Order	Navy Pilots Mean Score	General Aviation Pilots Rank Order	General Aviation Pilots Mean Score	US Males Rank Order	US Males Mean Score
	Achievement: To accomplish tasks	3	17.96	3	16.30	3	14.72
	Exhibition: To talk personal adventures	6	14.46	7	14.24	13	12.75
HIGH	**Dominance:** To argue one's point of view	1	19.47	1	17.04	7	14.50
	Change: To do new things	4	17.09	2	16.59	11	13.87
	Heterosexuality: To be interested in the opposite sex	2	18.34	4	16.13	15	11.21
	Abasement: To accept blame	15	10.27	14	11.78	5	14.59
	Nurturance: To assist others	14	10.95	13	11.97	2	15.67
	Endurance: To work hard at a task	5	15.27	5	14.98	1	16.97
LOW	**Deference:** To do what is expected	13	11.55	12	12.10	8	14.19
	Order: To have things organized	12	11.67	11	12.14	4	14.89
	Succorance: To have others provide help	16	8.65	16	9.19	16	10.78
	Affiliation: To participate in groups	10	13.21	10	12.21	6	14.51

TABLE II

better performance than an existing comparison "stress prone" group.

The stresses placed on pilots today may come from an exhaustive list of all those that might affect an individual at any given time. The task of the human factors investigator is to quantify as best he can those readily identifiable factors that may have influenced inadequate pilot performance. There has been some recent scientific work attempting to verify the reliability of the Holmes-Rahe scale in accident investigation. It was found that the individual's own ability to cope is more important than the stressors themselves. The investigator must then scrutinize each case to substantiate a finding that a particular pilot was unable to cope with the stresses bearing on him in the "accident zone."

Plotting these events to show their additive weight against the performance demands leading to the accident can however graphically demonstrate the relationship and impact of stressors during a critical performance period. It also clearly portrays why an accident occurred during one particular occasion when it did not occur during other seemingly identical circumstances.

Aircraft accident investigators need all the tools they can acquire to overcome the public suspicion of psychology and human factors. Hopefully the procedures described herein will help.

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4. Chaytor Mason, Associate Professor of Safety, Institute of Safety and Systems Management, University of Southern California.

Biography

Dr. Richard K. Brown, Director of Extension and In-Service Programs at the University of Southern California's Institute of Safety and Systems Management, has had extensive experience in specialized education. He served as Chief of the education branch of the U.S. Air Force Directorate of Aerospace Safety, Director of Academics in Pilot Training and Director of Personnel Plans at the Air Force Academy before coming to the University of Southern California. He served as Associate Director of Degree Programs in the Institute for several years before assuming his present duties.

His professional affiliations include the Americal Psychological Association, the Human Factors Society, Phi Delta Kappa, American Society for Training and Development and the International Society of Air Safety Investigators.

Dr. Brown earned his B.A. in Psychology at the University of Colorado and his M.A. and Ph.D. in Psychological Foundations of Education from the University of Denver.

Problems of Large Aircraft Accident Investigation in Antarctica

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The ICAO Accident Investigation Manual behooves us to ensure as much preplanning for an accident investigation as practicable is completed by the established aircraft accident investigation organisations. This is of course excellent advice but there are some situations which tax severely the flexibility of such planning and the accident involving an Air New Zealand DC-10 on Ross Island in Antarctica was such a case.

I will not comment on the intimate details of the accident as these were reported fully in the ISASI *FORUM*. Suffice to say the DC-10 on a sightseeing flight with 257 persons on board collided with an ice covered slope at 1500 feet AMSL in white-out conditions. All on board were killed. My intention is to acquaint you with the problems I encountered in investigating as the Investigative Authority of the aircraft's State of Registry in a territory where no one state's sovereignty had been recognised.

The fact that the DC-10 was missing was not made known to me for some 8 hours after it first failed to make a scheduled position report. I had stressed to the New Zealand Rescue Coordination and Air Traffic Control Centres, on several earlier occasions, that we must be notified in accordance with Annex 12 to the Convention on International Civil Aviation (Chapter 5, para 5.2.4 j) which states "when an aircraft is believed to be in distress, or when a distress phase exists, the Rescue Coordination Centre shall:

> "(j) Notify the appropriate accident investigation authorities."

While this requirement is allocated 10th priority in the actions to be taken, once the distress phase has been declared this was not the reason for the untoward delay. The United States Navy Air Traffic Control Unit at McMurdo on Ross Island had responsibility for the flight following of the DC-10 and duly advised the New Zealand Air Traffic Control authorities of the Uncertainty, Alert and Distress Phases. However, the primary search datum was in the US Navy's area of responsibility; i.e. south of latitude 60°S. The US Navy believed that the Accident Investigation Authority in New Zealand would have been advised of this major accident by the local civil aviation authorities, but in any event it was by no means clear just who was the appropriate investigating authority in the early stages. With an aircraft missing, but with over five hours endurance remaining, it could have come to grief anywhere within 2500 miles of its known position.

The accident occurred at 0050 hours GMT and I was eventually notified at 2020 hours that the aircraft was overdue and that, by that time, it would have had dry tanks. This report came from the airline's operations centre at the same time as my young daughter was endeavoring to tell me that she had heard the same information in a news flash on her radio. This same night was my 25th wedding anniversary and to celebrate the event I had toasted a few glasses of champagne. In the course of conversation I idly discussed the problems of getting down to Antarctica if one of these well publicised sightseeing flights should come to grief. This was not too surprising as I was well aware that the series of flights was in progress and that on that day the last of these was airborne.

When I received the first advice of the accident I telephoned my officer in Auckland, the DC-10's point of departure, and instructed him to head for the airport to secure fuel samples, engineering records and copies of all the briefing information issued to the crew. I also began planning to set up an office in Auckland as I considered it probable, at that stage, that the aircraft was down at sea and we were about to start an investigation with little to work from other than background evidence. With this in mind I asked the airline if the Flight Data Recorder was fitted with an underwater locating device, but that information was not immediately available.

Shortly after contacting my Auckland office I was advised that the wreckage of the aircraft had been sighted. This information dictated an immediate change of direction in my planning. First of all, where was the position that I had just been given in latitude and longitude? I had a world atlas at home but the scale of maps of Antarctica was generally about 1:10 000 000; however I located the accident site as being to the north of Mt Erebus on Ross Island in New Zealand's Ross Dependency. As I mentioned before, although the area is divided for research purposes, no one nation's sovereignty is recognised in any of these divisions. Further, the area in which the aircraft was down was within an air traffic control area established and operated by the United States Navy. In these circumstances which was the state of occurrence? Attempts to locate an adviser at that time of night in our Ministry of Foreign Affairs were fruitless so I decided to assume this accident was to be my baby.

Our initial procedure on receiving advice of an accident is to ensure brief details are passed to the Minister of Transport, the Secretary for Transport and the Director of Civil Aviation. Calls to each of these individuals established they had been well aware of the event for several hours. I next telephoned the United States as the state of manufacture and found that they too were aware of the event but nevertheless there was much to be discussed. With commendable efficiency they appointed an accredited representative and confirmed with their State Department that they had no objection to New Zealand investigating this accident as the state of registry.

I then received offers of assistance from the United Kingdom and Australia. The United Kingdom offer of two inspectors was based on the premise that the aircraft accident had occurred in South Island New Zealand and was reconsidered when they were advised we were confronted with a site much further south. Nevertheless as with the United States they spared no effort in providing whatever technical assistance I requested subsequently.

The problem of travel to and in Antarctica was the next item to be resolved. I requested the assistance of the Royal New Zealand Air Force to get a team to McMurdo Sound. Fortunately they have been operating Lockheed C130 Hercules aircraft to this base for several years and were trained and equipped to assist us. Coincidental with travel to such a severe climate was the need for suitable personal equipment and clothing. The planning continued through the night, and early next morning a meeting was held in police headquarters to discuss the problems in recovering the 257 victims, investigating the accident and providing appropriate facilities for the news media. Only one C130 flight was available with 28 seats to take a New Zealand Police team, accident investigators, mountain guides and the media representatives. The police bid was for a team in excess of 40 and the news media, DSIR and I sought a similar number of seats in excess of the capacity. In the end it was decided to send a representative advance party and request assistance from the United States Operation Deep Freeze, which operates USAF and USN aircraft from Christchurch to Antarctica, for a supplementary flight at a later date.

The initial party included a team of police, mountaineers, news media, a politician and, with me in the accident investigation team, an engineering investigator, a senior pilot and engineer from the airline and one ALPA representative. The contemporary priorities are such that the news media representation exceeded that of the accident investigating team. The provision of clothing and equipment was nicely solved by the staff of a depot maintained for this purpose by the New Zealand Department of Scientific and Industrial Research who provided clothing of the right size for all passengers in approximately 2 hours. Shortly after lunch next day we departed from Christchurch on the 9-hour flight to Antarctica. This flight provided my first opportunity to get some sleep in 30 hours.

On arrival in Antarctica the United States Science Foundation, US Navy and New Zealand DSIR authorities met with us to discuss a plan of action. As background, the United States' base at McMurdo accommodates some 1000 persons and the adjacent New Zealand Scott Base less than 2 miles away has facilities for about 60 persons. The US Navy flies in support of the DSIR and US scientific research programmes with ski equipped C130 aircraft and twin engined UH-1H helicopters.

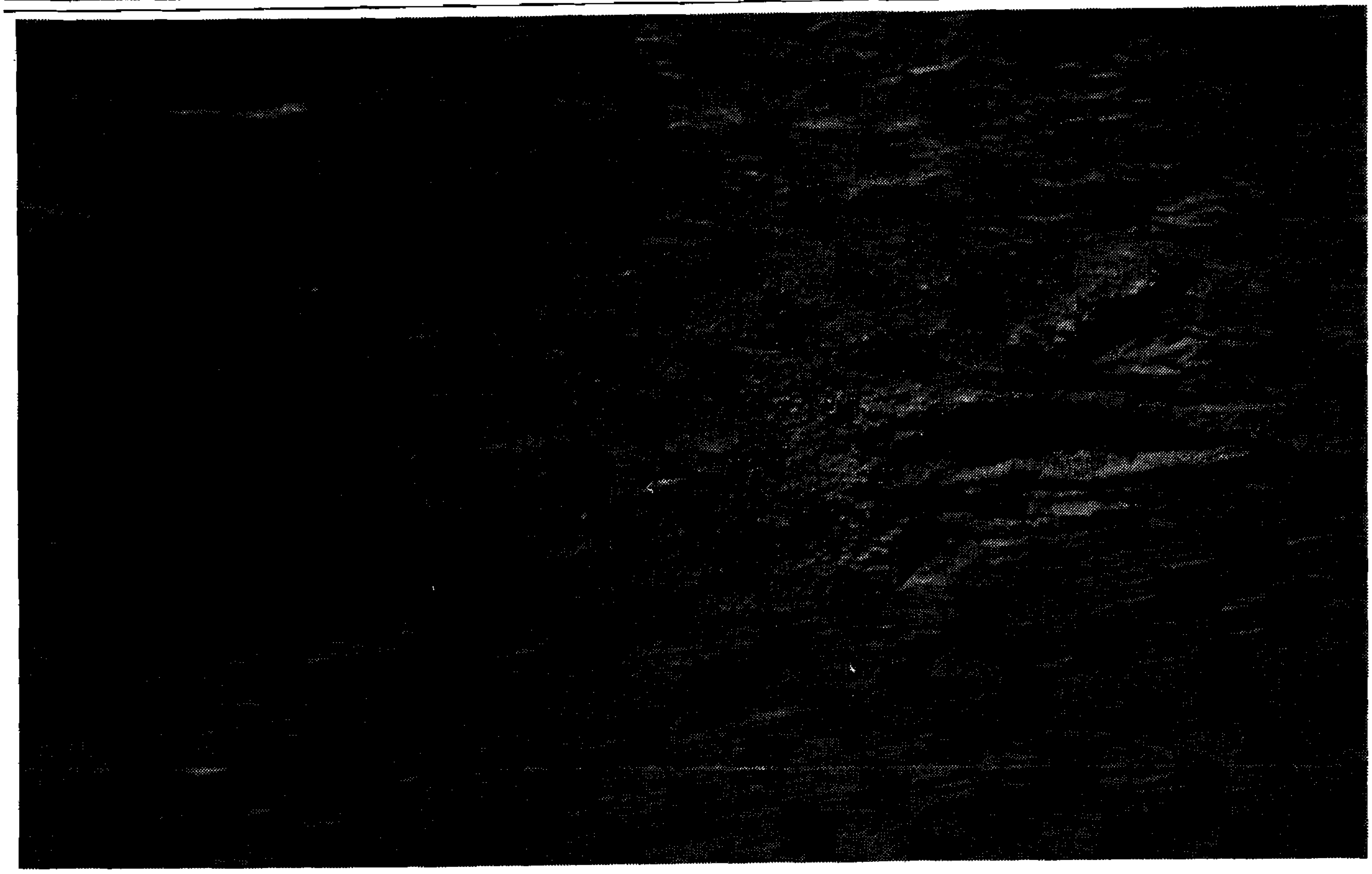
Our plan was to conduct an initial reconnaissance by helicopter, then commence a combined operation, the police

recovering the victims and the accident investigation team securing documentation and searching for the CVR/DFDR. No one apart from the initial reconnaissance team would be permitted on the site until they had completed a day's familiarisation course in cold weather survival and ice climbing techniques. It was essential for the scientific programmes to retain a considerable proportion of the flying effort for resupply of teams in the field and other essential tasks, but every effort was made to ensure our tasks were accorded as many flying hours as practicable.

The DSIR undertook to provide the necessary training and guiding for the police and investigation teams and the US Science Foundation released their helicopters to support the investigation and recovery operations. The flying time to the site by the direct route was some 40 minutes in a UH-1H even without an underslung load. The possibility of using dog sleds or tracked vehicles was considered but the coastal ice cliffs and the unstable sea ice ruled out any route to seaward of the coast. The badly crevassed area surrounding the accident site ruled out passage by vehicles over the intervening mountain passes. Although the publicity surrounding this accident indicated it was on the slopes of the active volcano, Mt Erebus, the accident occurred on the relatively gentle coastal slopes of the island at less than 1500 feet AMSL. The slopes involved were less than 15° and the main hazard was that of crevasses.

Shortly after arrival the Inspector in Charge of the police contingent and myself flew to the site to obtain an overall view of the site from which to plan our respective detailed activities. It was immediately obvious from the outline of the aircraft's impact crater in the ice that it had flown into the slope with its wings level, nose up and with both under wing engines in place. The latter fact was reassuring after the recent engine separation accident involving a DC-10 on take-off from Chicago. Other factors noted were the initiation of a fire at the time of impact, the long (600M) wreckage trail, the fragmentation of the wreckage, the spread of the locations of the victims and that the slope was too great for the helicopters to land. From this survey flight the plan of action adopted was as follows:

The mountaineers setting up the field camp would secure as much documentation as possible immediately as it was noted that strong westerly winds had already blown much of the light material into an inaccessible area. The police would join forces in the initial and immediate search for the FDR and CVR. The site would be surveyed and marked in 30 metre squares for plotting the location of victims and each piece of wreckage. The crevasses had already been identified by red flags. The accident investigators would then assist the police where any disturbance of wreckage was necessary to recover the victims.



This plan worked well but many areas of improvisation were needed. We were fortunate in that it was mid-summer in Antarctica and thus we had continuous 24-hour daylight. The ice runway at McMurdo normally breaks up about 14 December; that is, 2 weeks after we arrived, and it actually did become unuseable on schedule on 13 December. Thus we were working against the clock to complete the tasks in time to enable non-ski equipped aircraft to recover our party and the victims. The fact that a well established base equipped with helicopters was close at hand was a major benefit but the use of these helicopters seriously curtailed the US and New Zealand scientific programmes for that season.

The distance between New Zealand and Antarctica (9 hours flying in a C-130) posed a logistic problem but it did ensure a large measure of freedom from the immediate pressures of civilisation such as spectators, politicians and the media. The only two sour notes in the investigation related to the police forbidding the TV cameraman access to the site to film the area which would have been of great assistance to us later, and the police in New Zealand authorising without reference to me the attendance of a further ALPA representative who knew nothing of DC-10 aircraft when I was desperately short of local informed assistance. On the credit side, despite the absence of any formal agreement or established practice, the US Navy authorities permitted me unrestricted access to their ATC recording tapes and the ATC, meteorological and operations staff on duty at the time of the accident. The US Science Foundation and NZ DSIR made room in their accommodation and sacrificed their allocated flying hours for us.

Our situation was eased three days later when a USAF C141 Starlifter arrived with the US accredited representative from the NTSB, a senior pilot, structures and systems experts from the Douglas Aircraft Co., an FAA representative, the General Electric engine specialist, another of my inspectors and an NTSB FDR/CVR expert. Before the arrival of the US contingent we had located the CVR and FDR and the navigation data units from the aircraft's Area Inertial Navigation System. A meeting of the investigating team quickly decided that these items should be investigated without delay and my third investigator and the NTSB CVR/FDR specialist departed for Seattle after about 2 hours "on the ice."

The cold produced some problems with photographic equipment by increasing exposures due to stiffening of shutter mechanisms, but in general sufficient photographs were available to ensure coverage of all aspects at least once. The US Navy's photographic laboratory at McMurdo was able to process black and white film immediately and also Ektachrome slide film, which enabled us to process some of the passengers' film. This latter assistance provided an early lead to the weather conditions at the time of the accident and showed a low cloud base but good visibility beneath the cloud. It also enabled us to confirm the existence of large breaks in the cloud at that time.

We were fortunate in the fact that the NZ Lands and Survey Department had a surveyor available at Scott Base, he was able to establish a grid of flags on the site to define the area in a series of 30M squares. He also confirmed the height of the impact point and the exact location of the accident in the featureless and shifting terrain.

The CVR record was played back to my inspector as soon as he reached Seattle and the result conveyed to me by telephone shortly thereafter. This record established that we were not looking for a powerplant, structures or systems problem with the particular exception of items associated with the navigation of the aircraft. Later preliminary reports of the DFDR readout at the NTSB Laboratory in Washington DC and the navigation data units in Cedar Falls eliminated the possibility of defects in the AINS. At this stage we felt confident in reassuring the civil aviation authorities that this accident did not arise from any airworthiness shortcomings of the DC-10.

Out on the site things were not completely straight forward. The fickle weather closed in during a changeover period and kept two teams on the site for 4 days with dwindling supplies of drinking water. We had decided that where possible teams would be worked 12 hours on and 12 hours off to economise on transport and achieve the maximum effort in the time available at the site. The two engineers worked almost without respite for 4 days in the continuous daylight to identify and plot all of the items of wreckage. The drinking water problem relates to the necessity to melt ice to provide the water and the large quantity of fuel required for this process. When things become desperate some liquor stocks from the aircraft were used but the beer and the water in the aircraft's survival packs were both frozen solid. Apart from the obvious stress of living and working among the remains of 257 people which were regrettably being attacked by scavenging birds, there were the problems of limiting work periods when continuous daylight was available and a job to be done, and the overpowering smell of soot and kerosene which lay over the site throughout the investigation. All persons at the site were roped to guides until they became accustomed to working on the slippery slope. After this, one guide was allocated to keep an eye on the safety of each pair of police or investigators.

The recovery and preservation of the victims was particularly difficult. While the cold preserved them initially they thawed soon after they were wrapped in the plastic body bags. Another problem was the disruption of the bags by the sharp ends of broken bones. To assist the police and to compile a synopsis of the distribution of injuries I established an open air mortuary site at McMurdo to receive the bodies which were transported in nets as underslung loads from the site. To maintain a sense of propriety the reception party was kept to a minimum and spectators kept at bay by local military police. As explained above the body bags proved inadequate and labels tended to become unreadable during the flight. Two padres, one doctor, two aircraft loaders, two administrative officers and myself rewrapped, documented the injuries and crated the 24 tonnes of remains. Despite the cold latitudes we had considerable difficulty in retaining the bodies at sufficiently cool temperatures. This was attempted by covering each container and placing it in a revetment cut into a snow bank but even then it was difficult to retain the temperature near freezing point.

Regular meetings were held each day to coordinate the various teams and the ALPA representatives were not only given full access to these meetings but co-opted to work as team leaders as were the various members of the US party. This was essential in view of the time scale limitations and the difficulty of obtaining more suitable members from New Zealand. In the event despite their partisan interests I could not have wished for a more cooperative and hardworking team. Nevertheless I would have preferred to have worked with the more conventional team leaders. Prior to leaving Antarctica I ensured that the US accredited representative and myself had a wind up survey of the wreckage and site environment.

We left from the site direct onto the aircraft departing for NZ due to the probability of the runway's demise and our desire to extract the maximum possible advantage from the time available to us at the site.

There are, I feel, many lessons to be learnt from this investigation including the following:

It is difficult to ensure in the case of an accident overseas or across an international boundary that the investigative authority of the state of registry will be notified prior to other authorities. We had anticipated this problem and believed procedures were established to ensure we received early advice from New Zealand authorities. But the shock of such a large accident unseated the organisation. The largest single factor appeared to be the desire of individuals to spread the word to the top themselves rather than depend on our organisation. While it is unlikely that an exactly similar case will arise again, the nature of long distance international flying has with it an inherent potential for a mishap in a remote area which, if it is not without sovereignty, may well be without the resources necessary to mount and equip a suitably qualified investigative party. We were indeed fortunate in the time of year and in the fact that the support units already established in Antarctica were able to equip and transport us to the site. Darkness and logistic problems could well stymie an immediate investigation into even a disaster of this magnitude if it occurred in the polar regions in winter.

Crevasses formed a potential trap not only for the investigators but for vital items of evidence. Fortunately the CVR and DFDR did not fall down one of the cracks in the ice, but the extent of the crevassing to the east of the site prevented a search for the aircraft's navigation records which were vital to some aspects of this accident investigation. It was realised right from the start that loss of documents was a problem and all parties were instructed to secure loose paper on sight.

The problem of supplying and accommodating an investigative party at a remote site can be considered in relation to each authority's area of responsibility, but it must be borne in mind that adaptable as investigators normally are, they may well be taken out of their more familiar environments by such an event and require further training and a substantial support expedition.

The transport of large items of wreckage may be impossible and if necessary the facilities for examination may have to be transported to the site. Recorders may be buried in snow or other natural cover and need specialist search equipment. Had this accident occurred only a few hundred yards to the east a monumental search could well have been required in that extensively crevassed and hence extremely hazardous area.

The absence of a mortuary is another problem but an associated area for thought is the desire of various states to recover the victims and in some cases to actually visit the site as a requirement of the particular religious persuasion. While this might be considered a state police, coroner's, or even airline responsibility, an investigator may well get embroiled when transportation and logistic support is severely limited and he is bidding for a major portion of that which is available.

There are probably many more aspects in which you are interested and I am willing to discuss any aspect of the investigation of this accident with members personally but I do not wish to enter into any discussion on our investigation at this time. I would like to pay a tribute to all those American and New Zealand personnel who assembled at Scott Base and McMurdo and who, without exception, gave unstintingly to facilitate the investigation of this accident in such inhospitable surroundings.

Biography

Ron Chippendale is Chief Inspector of Air Accidents in New Zealand. He served 24 years in the Royal New Zealand Air Force as a transport aircraft pilot, flying instructor and safety officer; joined the New Zealand Office of Air Accidents investigation in 1974, and was appointed Chief Inspector in 1977.

He completed USAF Flight Safety Officers' Course at the University of Southern California in 1970 and the British Accident Investigation Course at Cranfield Institute of Technology.

Ron is a Fellow of Royal Aeronautical Society.

The Use of Air Traffic Control Radar as a Tool in Accident Investigation

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

INTRODUCTION

For several years the Safety Board has recommended to the Federal Aviation Administration to no avail that lightweight, state-of-the-art flight recorders be required equipment on board general aviation turbine-powered aircraft. It has been the Board's experience that the lack of this equipment prevented pinpointing the probable cause of accidents involving these type aircraft. An example involves several recent accidents of the 20-series Gates Learjet. These accidents occurred as a result of a loss of control during approach and landings and from high altitude cruise flight. Investigations of the latter type of accidents have been particularly frustrating because there have been no survivors or witnesses, impact forces were extreme causing near-total destruction of vital evidence, and none of the aircraft were equipped with flight recorders. Additionally, two such accidents resulted in water impacts where only portions of the wreckage were recovered.

This paper is intended to consolidate some of the information on the subject of using ATC radar data as a means for determining and analyzing aircraft motions, and to educate the investigator in the use of this technique. It will briefly describe the ATC Enroute System (this paper is limited to the Enroute Radar only) the kind of computer-generated radar data available, how it is used, and its analytical limitations. It will briefly discuss the computer program used for expanding and "smoothing" the radar data which was developed by the National Aeronautics and Space Administration (NASA) in coordination with the Safety Board. It will also describe how the Safety Board is using the computer-generated radar information as a tool to assist in the investigation of these types of accidents in the absence of flight recorder data.

DESCRIPTION OF THE NAS

Development of the National Airspace System (NAS) by the FAA is an evolutionary process. The increased volume of air traffic and its complex nature necessitated a form of automation within this system in order to provide for the safe and efficient use of the airspace. For these reasons the FAA decided to establish a fully automated air traffic control system. The implementation of this system involves several stages and its full development is dependent on the availability of new equipment. The first stage in this development is termed "NAS Enroute Stage A." It was designed to significantly automate the 20 standard Air Route Traffic Control Centers (ARTCCs) within the Continental United States. The NAS Enroute Stage A program provides for the capability to increase air traffic handling. This objective is accomplished by automating the processing of flight plan information, establishing and maintaining radar identification of aircraft, displaying altitude information and by the development of the complex processing capability to form the basis for future automation improvements in the system. The two main subdivisions within NAS Enroute Stage A are the Flight Data Processing (FDP) and the Alphanumeric Display Systems (ADS).[1]

The FDP system provides the automation capability to accept and store flight plans, print and distribute flight plan information, calculate and update flight plan data, and transfer data within the ATC facility and to adjacent facilities. The ADS system incorporates automatic aircraft tracking, visual flight information display, and automatic radar handoff capabilities. The investigator should also become familiar with the function of the following hardware items: Primary and Secondary Radar, Common Digitizer, Data Receiver Group, Central Computer Complex, Central Clock System, and Computer Display Channel. (Figure 1)

Primary Radar

Long range search radars are used for primary radar (skin paint) detection. The aircraft's range and azimuth data are detected from the ground based antenna site and relayed to the Common Digitizer and the Aviation Weather Subsystem.

Secondary Radar

Secondary radars (beacon code) are used to obtain pressure altitude and identity code data from aircraft equipped with mode C and 4096 and 64 code, mode 3/A transponders respectively. This data is also transmitted to the Common Digitizer.

Common Digitizer (CD)

The CD is installed at each radar antenna site and it accepts broadband inputs. Its primary functions include: automatic target detection, target quantization, target correlation, message formatting, and message output control. The CD assembles the target position and beacon data and converts this data into digital messages that are transmitted via digital data lines (narrow-band communication channels) through the Data Receiver Group to the Central Computer Complex. This action takes place for each aircraft being tracked with each revolution of the antenna. The messages are transmitted at the rate of 2400 bits per second (bps) to the Central Computer Complex.

Data Receiver Group (DRG)

The DRG is located at the ARTCC facility, provides buffering, and checks the value of the messages received from the CD. It determines and maintains the synchronization of the messages and provides outputs for maintenance purposes.

Central Computer Complex (CCC)

The CCC is an IBM 9020A or D, solid state multiprocessing computer system controlled by the ATC Operational Program. It is the heart of the ATC system and is the central point for the collection, processing and distribution of all data in the NAS Enroute Stage A. Its primary function is to process air traffic operations. It also performs nonoperational functions which are:

Computer Program Maintenance
Preprocessed Flight Data
System and Subsystem Maintenance
Data Reduction and Analysis
Training
Administration Support

Central Clock System (CCS)

The CCS provides digital time-of-day data to the CCC. It also provides this synchronized time-of-day to the control console clocks, to the DRG and to the voice recorder to permit time correlation between radio transmissions and radar data. The time is established by tuning radio receivers to a time broadcast source (WWV). The reliability of the system is maintained by incorporating redundant coded time source units.

Computer Display Channel (CDC)

The CDC receives the data display messages from the CCC and generates alphanumeric, symbolic and map data for presentation on the radarscope.

The overall computer program contains all the necessary instructions used by the CCC to execute the ATC Operational Program and system support functions.

The FDP function of the CCC accepts, checks, processes and distributes flight data received from prefiled, pending and active flight plans. This flight information can be modified by the CCC receiving manual inputs, interfacility messages from other computer-equipped ARTCCs, or by the computer program associating flight plan position with the radar derived position of the aircraft. These features allow the computer to display the radar data with associated alphanumeric information on the radar scope and the FDP function aids in the tracking process. Multiple radar data processing and tracking are also provided. A number of radar sites might be involved in tracking a particular aircraft. Where overlap occurs, primary radar and beacon code signals from the radar site that provides the best coverage are designated as preferred signals and are used by the computer to track the aircraft. Signals received from the radar site providing the next best coverage are designated as supplementary and are stored for use as necessary. An essential function in the tracking of an aircraft is the correlation and prediction process. The tracking is either initiated automatically or manually. The radar data is examined and the

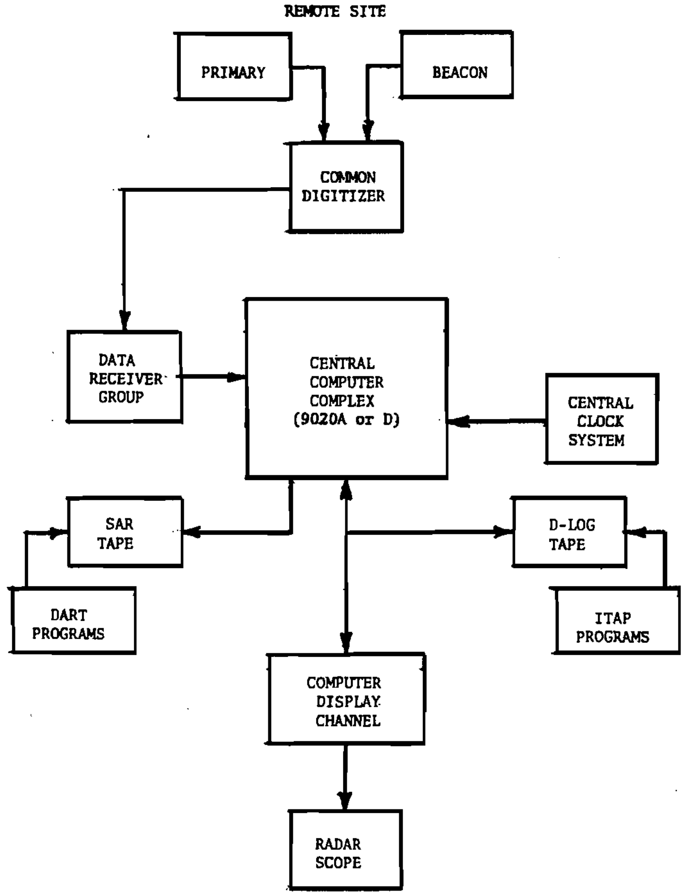

Figure 1

datum which corresponds to the predicted position of a track is selected for further processing. The computer uses either the flight plan route and speed or previously correlated radar data to determine the predicted position and velocity of a target. When difficulties in this tracking process are encountered, the computer track is placed in a "coast" mode. This coast track is maintained by the computer using the previous radar data derived velocity or flight plan route. After a predetermined amount of time has elapsed, the computer drops the track provided no update information is received.[2]

Although the foregoing information provides only a general working knowledge of the NAS Enroute Stage A system, the investigator need only concern himself with obtaining X,Y, and altitude data from which the aircraft's position in space can be determined. He must also insure he obtains an accurate time correlation of this data. The accuracy of this information can vary. The X, Y position can range from approximately 1/32 to 1/4 mile (165 to 1320 ft.) and mode C altitude is rounded off to the nearest 100 ft. This data can best be obtained from the DLOG tape which records the messages transmitted to the CDC. The computer program used to retrieve this data from the DLOG tape is termed the Interim Track Analysis Program (ITAP).

Originally, the ITAP computer program was termed DPICT and was developed by the Kansas City ARTCC in order to analyze radar data prior to the implementation of full radar data processing. This program became rapidly useful in recreating conditions prior to systems errors and other incidents involving missing aircraft. The program was obtained by other ARTCC facilities and was subsequently modified to suit their needs. Approval was given for National use and the Denver ARTCC's DPICT 08 was used as a basis for this system. Following recognition of the program as a valuable tool for search and rescue purposes by other ARTCCs, the program was reidentified as the Track Analysis Program (TAP). The Kansas City ARTCC was assigned the support responsibilities for TAP. However, since TAP had several limitations, there was increasing demand for additional enhancements in order to increase the useful data available until the National Track Analysis Program (NTAP) could be developed and released. Furthermore, TAP was released as an interim measure and therefore, in order to differentiate between this initial program and the one which incorporates the enhancements, the second program was termed "ITAP." The data from this program is frequently requested by the Search and Rescue Coordination Center at Scott AFB for support of their missions.[8]

The ITAP product provides a readable presentation of radar computer-generated data for a given period of time and for a designated geographic area. A high-speed plot type printout is provided of the displayable data on any radarscope during any period of the recording. The following is a list of the ITAP options available:

Primary Target	Full Data Blocks
All or Selected Beacons	Datum X, Y
Discrete or Non-discrete Beacons	Latitude, Longitude
Tracks	Time
Limited Data Blocks	Weather Outlines

EXPANSION OF ATC RADAR DATA

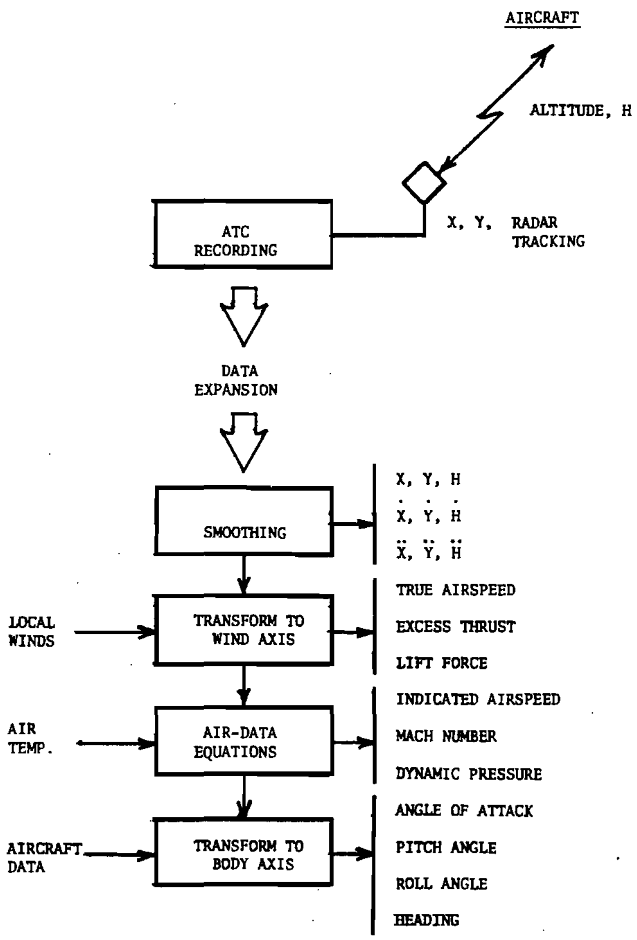

Figure 2

There are presently 5 ARTCC facilities which do not have a DLOG capability. These facilities are Cleveland, Chicago, Fort Worth, New York and Washington. In those cases, the investigator must request the information from the System Analysis Recording (SAR) tape. This tape records all functions of the CCC. The computer program used to retrieve the necessary data from the SAR tape is termed the Data Analysis Reduction Tool (DART). This program has 15 different options, but again, the investigator need only be interested in obtaining X, Y, and altitude.[4] (Appendix 1 contains a list of options provided by the DART system.)

The investigator should be aware of the inaccuracies in the computer-generated radar data. The following are some factors which effect the accuracy:

1. The tolerance of the radar - 1/32 to 1/4 mile and altitude to the nearest 100 ft.
2. The sampling rate of the radar target - every 10 to 12 seconds
3. The slant range correction applied to the target
4. The radar signature of the aircraft
5. The performance of the transponder
6. Aircraft maneuvers which may blank out its antenna
7. The aircraft's distance from the antenna
8. The effect the tracking program has on determining the aircraft's position
9. The timing errors (3 seconds) within the system

NASA's Aircraft Motion Analysis Program

The development of aircraft motion analyses using ATC radar data by NASA has been instrumental in providing this technique to the accident investigator. Their excellent work in this endeavor cannot be overemphasized. The initial work appeared in October 1976 with the publication of "Accident Investigation Analysis of Aircraft Motions from ATC Radar Recordings" by R.C. Wingrove (NASA SP-416)[5] which was presented at the NASA Aircraft Safety and Operating Problems Conference at Langley, Va. The product of the Safety Board's initial work in this area was entitled, "Use of ARTS-III in Aircraft Accident Investigation," by C.O. Miller and W.G. Laynor, presented at the Air Traffic Control Association Annual Meeting at Miami, Florida, on October 16, 1973. Since that time additional work has been accomplished by NASA which has provided increased knowledge and improvements in the application of this technique. As a result a higher level of confidence prevails today. The attached list of additional references[6,7,8,9] concerning NASA's program on this subject will be beneficial to the investigator.

The objective of the NASA program is to expand the radar data to reveal the aircraft's attitude, velocity and performance. The method used involves a "smoothing" program based on a nonlinear, fixed-interval calculation. With the inclusion of meteorological data (wind and temperature) and aircraft aerodynamic data (W/S, α_0, and C_{L_α}) an expanded set of motion time-histories along the aircraft's trajectory can be derived.[10] (Figure 2)

NTSB's PROGRAM

The NTSB's program of using ATC computer-generated radar information is currently an evolutionary process. We are able to do many things with the data, but the computer programs are not yet developed to point of satisfaction. The Laboratory Division (TE-60), responsible for this work, is headed by Dr. Carol Roberts. Jack Macidull and Monty

Montgomery are directly involved in development of the system. The FAA's NAS Enroute Stage A system is expected to be modified soon with the implementation of NTAP. Although the terminal radar (ARTS III) data is more standardized, FAA personnel staffing problems have resulted in sporadic implementation of the recording system across the country. We will not be able to realize full potential in the use of this technique until the ATC system growth plans are completed. In the interim, we are attempting to consolidate our knowledge and information on the subject and solidify our programs.[11]

The NSTB Laboratory has modified NASA's Aircraft Motion Analysis Program for our use. The Safety Board's version is called "MANATN" and the principle differences from NASA's are:

1. The output file created by our version is in a format compatible for input to our CALCOMP plotting equipment.

2. The smoothing technique used in the original program required that the input radar data be evenly spaced in time. Our experience shows that this is not always reasonable. Consequently we have removed this constraint by the implementation of a more general smoothing technique.

Our program requires two input files, and creates an output file for plotting and an output listing. The output listing can be directed to the terminal or to the line printer. The first file contains the aircraft's performance characteristics, smoothing intervals, and wind and temperature information. The second file contains the radar track information from which the aircraft performance trends are to be derived. This program data can be either Enroute or ARTS-III data. The program assumes that all the data is oriented to true north. (Figure 3)

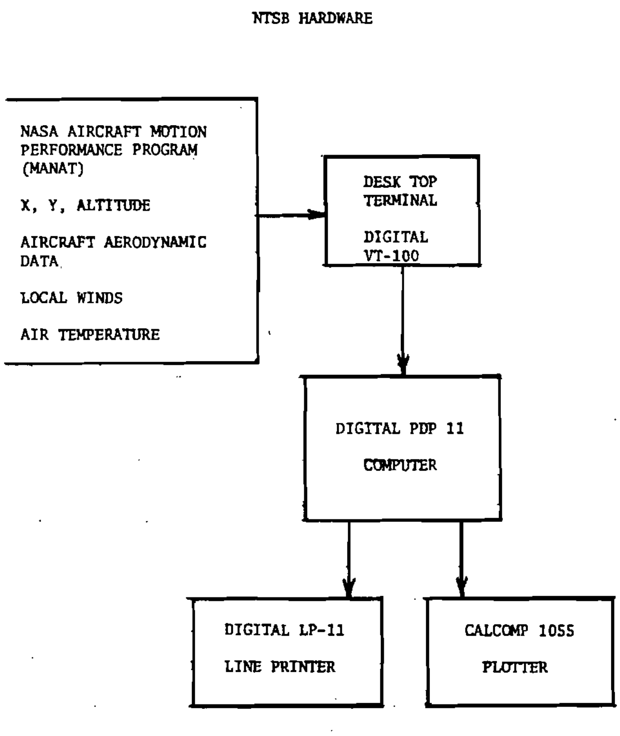

Figure 3

APPLICATION IN SOME RECENT ACCIDENTS

On April 11, 1980, a Gates Learjet 25B was on an air taxi flight at FL 410. The ARTCC heard the sounds of a keyed microphone and a Mach overspeed warning horn with a lot of background noise. It was apparent that the flightcrew was in difficulty. The pilot attempted to identify himself and asked for a lower altitude, but did not make any further discernable transmissions. The airplane entered a steep, high speed descent and crashed. The airplane was completely destroyed by extreme impact forces.[12]

On May 19, 1980, a Gates Learjet 25D was on a positioning air taxi flight. About 2½ minutes after the flightcrew reported the airplane level at its cruising altitude of FL430, the ARTCC received an unusual staccato sound transmission over the frequency, followed 18 seconds later by a report from the copilot, "Can't get it up . . . it's in a spin . . ." About 33 seconds after the first staccato sounds, radio and radar contact with the airplane was lost about 104 miles west of the coast of Florida and the airplane crashed into the Gulf of Mexico. Floating debris was located by a search aircraft and was later recovered; the flightcrew was not found. There were no known witnesses to the crash. The depth of the water was 600 ft. in the area of the crash site. An extensive underwater search for the wreckage was unsuccessful.[13]

On October 1, 1981, a Gates Learjet 24 was on a business flight at FL450. The flightcrew and one passenger were on board. About one minute after the flightcrew failed to respond to a frequency change instruction, the airplane's transponder beacon code was lost. The ARTCC controller made several unsuccessful attempts to contact the aircraft. Witnesses heard the airplane overhead at very high speed; one witness, who saw the airplane momentarily, stated that it was in a descent angle of about 45° before it struck the ground.[14] The crash site was about 30 miles northwest of the site where the Learjet 25B crashed.

In the foregoing accidents, all three airplanes entered steep, high speed descents from which recovery was not accomplished, and probably was not possible. A review of the ATC radar computer-generated information disclosed that in all three cases the airplanes were in level cruise flight at average speeds of Mach 0.76 and 0.78. The radar data showed there was a slight perturbation in altitude (a climb and descent) before the airplanes made a descent of about 1000 ft. to 6000 ft. at average rates of about 3000 to 8000 ft. per minute. This loss of altitude occurred 17 to 48 seconds from the time of the altitude perturbation until the time the mode C altitude readout was lost from altitudes of 42,300 ft. to 37,800 ft. No further mode C information was received from the airplanes.

On May 6, 1982, a Gates Learjet 23 was in level cruise flight at FL410 with two passengers aboard. The airplane was just north of an airway intersection when the ARTCC cleared it to descent to FL390. The copilot acknowledged the clearance and the controller observed the radar target begin a descent. One minute and 27 seconds later, the copilot transmitted that they were descending from FL410 and at this time a warning horn sound was heard in the background. Seconds later the controller lost the radar target at an altitude of 37,900 ft. About 2 minutes later, the crew of a fishing boat observed a large water geyser on the surface of the ocean, 20 miles off the Georgia coast. On arrival at the scene they only found pieces of the fuselage skin and cabin interior material from the airplane. The main wreckage came to rest in relatively shallow water and an underwater search was successful in locating the wreckage, most of which was later recovered.[15]

A review of the radar information in this recent accident disclosed that the airplane departed its cruise altitude in a manner similar to the previous three accidents. Prior to beginning the descent, the airplane was in level cruise flight at an average speed of Mach 0.76. On the descent, during the 1 minute and 27 second period following the ATC clearance, the airplane descended 800 ft. at an average rate of 666 ft. per minute before the copilot's last transmission. It was at this point that the warning horn sound was heard. More significant, however, is the fact that we were able to recover radar information from ATC down to an altitude of 4,200 ft. msl. This is the first time we have been able to obtain this data on a Learjet under these accident circumstances. The airplane descended from the point of the last radio transmission, 35,800 ft. in 2 minutes and 46 seconds, an average rate of descent of 12,939 ft. per minute. The rate of descent was expected to have been much higher. However, because of some significant pitch-up oscillations indicated by the radar data, the average rate of the uncontrolled descent was reduced significantly.

CONCLUSIONS

In using ATC radar data with real-time input, the investigator can determine with reasonable certainty the aircraft's position in space. Its ground track, flight path, average ground speed and rate of climb or descent can also be calculated. Furthermore, knowledge of the existing wind direction, speed and ambient air temperature will permit determining Mach number, true and indicated airspeed. It is evident that the accuracy of these speed calculations will depend on the amount and validity of the weather information available. For these reasons it has been helpful to investigate the number and type of aircraft flying in the vicinity of the occurrence in order to obtain from flightcrews valuable data such as temperatures, airspeeds and the characteristics of the weather existing at the time of the accident. (On this particular point, it should be pointed out that a turbulence SIGMET is not generally issued unless a pilot reports encountering turbulence.) Flight recorder data from a transient airplane can prove to be an invaluable addition to the accident investigation. The timeliness of the accident notification, and the extent to which the investigator coordinates with ATC personnel will determine to a great extent the successfulness of this type of inquiry. Therefore, it may be prudent to spend more time ascertaining the circumstances of the accident when the notification is received before launching to the accident scene.

As you can see, use of this ATC radar data in conjunction with NASA's Aircraft Motion Analysis computer program along with existing weather conditions and aerodynamic data from the aircraft, permits further exploration of the aircraft's motions along a given flight trajectory. Considering the present potential litigation environment surrounding these Learjet accidents and our relatively limited knowledge in the use of this data up to the present time, I hesitate to draw any further conclusions from the information presented. Suffice to say, we at the Safety Board are continually evaluating this smoothed data with respect to its accuracy and the emphasis to be placed on this evidence in arriving at causal and contributing factors in accidents.

Since most general aviation business/corporate and commuter air carrier aircraft are not equipped with flight recorders, the method of applying ATC radar to determine an aircraft's flight path and motions provides the only other available means to do so. Further improvement in analytical techniques and in ATC hardware and software will increase our capability to apply this technique successfully and improve the accuracy of the derived data. The increased complexity of investigations of sophisticated general aviation aircraft accidents requires the use of ATC radar as a tool in aircraft accident investigations.

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13. NTSB Aircraft Accident Report - "Northeast Jet Company, Gates Learjet 25D, N125NE Gulf of Mexico, May 19, 1980," (NTSB-AAR-81-15.)
14. NTSB Aircraft Accident Report - "Sky Train Air, Inc., Gates Learjet 24, N44CJ, Felt, Oklahoma, October 1, 1981," (NTSB-AAR-82-4)
15. Aircraft Accident - IBEX Corp., Gates Learjet 23, N100TA, Atlantic Ocean, near Savannah, Georgia, May 6, 1982, (Under investigation)

APPENDIX 1

Dart Option Functions—Definitions

INPUT/OUTPUT LOG

Provides a meaningful listing of all input and output messages recorded on the SAR tape for an evaluation of tests performed against the NAS program during development and an historical record of events occurring during an operational period.

FLIGHT PLAN DATA BASE PROGRAM OPERATION

Provides all the necessary data for a complete analysis from the SAR tape. Specific aircraft can be examined by selecting the print program.

TRACK

Provides a convenient method of reducing the track data base of a NAS operational system run and correlates it with the flight plan data base. A time-ordered listing of the track data by aircraft is also provided.

HISTORY

Provides a detailed chronological history of specific tracks in the NAS Operational System.

LOG COMPARE

Provides a means of comparing two sorted edited SAR tapes to determine any discrepancies in the message content fields.

TRACKCOMP

Provides the ability to compare two edited SAR tapes produced by the TRACK function. Aircraft data is listed.

HISTORYCOMP

Provides the ability to compare two edited SAR tapes produced by the HISTORY function. Aircraft data is listed.

IOSUMMARY

Provides a summary of the input and output messages reported by the LOG function. Facility work load and I/O Checks are also summarized.

CLUTTER/MIN

Provides reports on the amount of overlap occurring between full data blocks or full data blocks and tabular data blocks displayed on the PVD. The minimum separation function reports on any aircraft which have insufficient lateral and vertical separation limits.

RESPONSE

Provides a report on the amount of time required by NAS to produce an output message in response to an input message.

PEAKDAY

Provides a summary of NAS activity in several areas: Airport, Airway, Diversion, Hold, Life, Performance, Sector.

CONFLICT ALERT

Provides output track data and calculated track pair data for all aircraft pairs in conflict during a specific time interval. This will routinely monitor the performance of the track algorithm by calculating present and predicted separations among all tracks in the system based on recorded tracking data.

CONFLICT PAIR

Provides outputs of track/altitude data for requested aircraft pairs during a specific time interval. Provides supporting data from the SAR tape for detailed analysis/explanation of any alerts that have been identified during operation of the system.

ENROUTE MINIMUM SAFE ALTITUDE WARNING (E-MSAW)

Provides outputs of track/altitude data consisting of four different reports in a time sequence: Violation, Alert-List, Statistical, Status.

Flight Crew Education: Fact vs. Rumor

Captain Henry A. Dykhuis A01382
United Airlines
Cleveland, Ohio U.S.A.

About 1815 PST on December 28, 1978, United Airlines Flight 173 crashed into a wooded, populated area approximately 6nm southeast of the Portland, Oregon International Airport.

The flight had delayed southeast of the airport at 500ft. MSL for about one hour while the crew coped with a landing gear malfunction and prepared the passengers for the possibility of an emergency evacuation. The crash destroyed the aircraft but there was no fire. Of the 181 passengers and 8 crew members aboard, 8 passengers, the Second Officer and the First Flight Attendant were killed. The Captain, First Officer and 21 passengers were seriously injured.

Speculation was, as it is following serious mishaps, rampant. The fact that a landing gear problem caused the Captain to delay landing was known. It was our intent to present factual information to our employees as it became available. Information such as the known landing gear problem was posted on Company bulletin boards immediately. Additional information and progress reports were posted almost daily. It became apparent early in the investigation that fuel exhaustion preceded the crash. It was also obvious that the Flight Attendants did an excellent job preparing for and conducting the evacuation.

What is the best way to use the lessons of the most costly experience—an accident? What follows is the effort of my company, United Airlines. You will notice there is no discussion of probable cause. It was our intent to present the facts in such a manner that pilots and flight attendants could picture themselves in the same situation.

The first presentation you will see is the 32-minute program that was shown to all pilots and dispatchers.

Next, you will see the 31-minute program developed for Flight Attendant use. The 4 surviving Flight Attendants returned to the crash site 3 days after the accident and again went through their wrecked airplane. Their narratives were made shortly after this.

The third presentation is a 13-minute tape recapping the lessons learned from the Flight Attendants' viewpoint.

The crew members you will see and hear are the actual crew of Flight 173. "Frosty" Mendenhall and Joan Wheeler are, respectively, the Second Officer and First Flight Attendant who were killed.

About the Author

Captain Henry A. Dykhuis is Manager of Flight Operations for United Airlines' Regional Operations Center at Cleveland Hopkins Airport.

He soloed in 1964 at age 16, and joined United Airlines in 1956. He has flown the CV-340, Viscount, DC-6, 7 and 8, Caravelle, B-737 and B-727.

Since 1973 he has served as a management pilot. He was Manager of Flight Safety prior to his present assignment as the Chief Pilot at United's Cleveland base.

Hank currently flies the B-727, and also holds a flight engineer certificate and a mechanic certificate.

Manufacturers' Responsibility to Communicate Safety Information

Daniel R. Gerard CP0045
Chief Investigator, Safety Committee
Flight and Support Directorate
Airbus Industrie

Availability of adequate communications vary considerably depending on which part of the world we consider. Since I was asked to make a presentation on this subject, particularly as it concerns manufacturers' responsibilities, I will try to cover the Airbus views on the subject. I have to apologize if an important part of what will be said is already well known to some of you, and particularly the U.S. and U.K. manufacturers. I am not a specialist in communications but will do my best to explain what is available, how it works in Europe, and some of the problems we have to face.

I propose to develop the following points:

1. Available means (Transmission/Reception)
2. Written information
3. Airbus relations with Authorities (France and others)
4. Airbus/Operators relationship
5. A.D. - Safety Messages: Distribution or Relay
6. Responsibility of airline and manufacturer's representatives to provide/disseminate information.

Means of communication

Many systems can be used to receive or transmit information. Among the most well known are:

- TELEX (SITA or regular)
- telephones (automatic or switchboard)
- radio-telephones
- telecopiers, letters, etc.

Let me explain briefly the SITA circuit since it is a very important if not the most important means of communicating in our airline world. SITA stands for Societe Internationale de Telecommunications Aeronautiques. This private company was formed 25 or 30 years ago by some European airlines looking for better, more reliable, eventually quicker and definitely cheaper way of communicating internally or between themselves worldwide. The headquarters are in the Paris area and the Communication Center is all computerized. SITA is formed of 258 airlines in 154 countries. It is run and managed by the airlines for the airlines. Because of the Airbus close relationship with many international airlines and the permanent presence of many airline representatives in Toulouse, it was accepted that Airbus be linked to the Paris Center and therefore to most of Airbus operators via SITA.

Now some figures: approximately 5 billion messages are dealt with yearly by SITA. The Paris computers handle incoming/outgoing messages for worldwide destinations on the basis of first in/first out except that QU prefixes (U stands for urgent) are given priority. ZZ prefix is seldom used (only for accidents and emergencies) and is given top priority.

The other TELEX system available is linked to Post Offices. You are probably familiar with it. The message is transmitted to a TELEX number attention Mr. "addressee". With SITA each addressee is assigned a code which reflects city-department-airline (example: BOMEUIC is the code for the Chief Engineer of Indian Airlines in Bombay). Codes are chosen within the airline and correspond to a function or a group. If used in an accurate manner it minimizes the errors and delays. As for Post Office TELEX there is generally only one number assigned for hundreds of persons, thus the necessity to mention the name and title of the addressee.

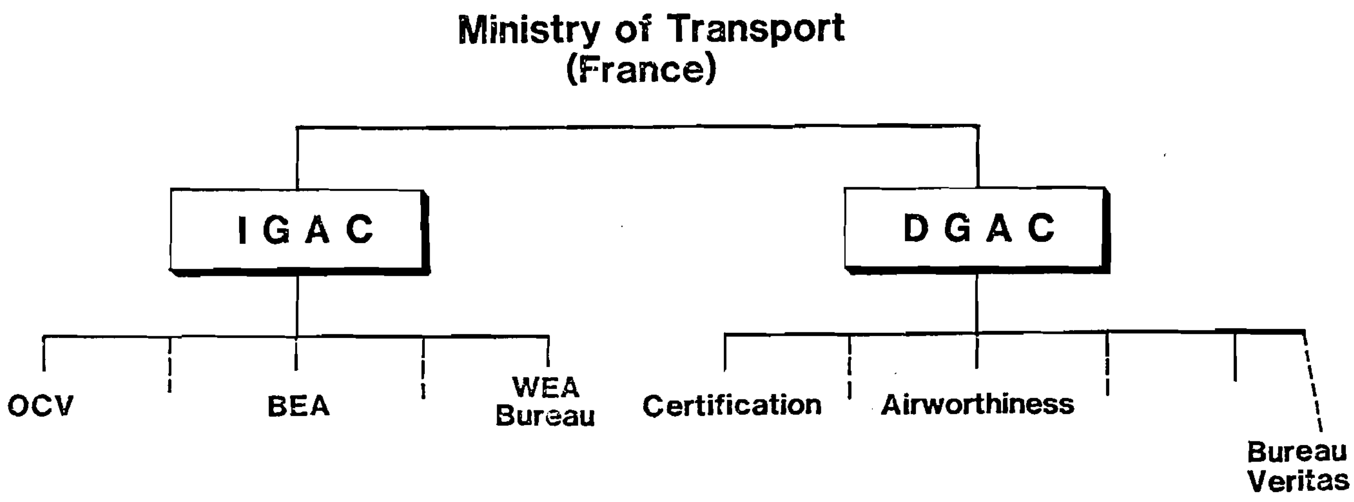
Both systems have advantages and inconveniences but generally SITA is more reliable and much less expensive than the official system. Since SITA covers only airlines' needs, all other messages: manufacturer to/from Government Agencies, Authorities, vendors, partners, sub-contractors, etc., have to go Post or private network.

I will not cover in detail telephones and telecopies, they are well known. Let it be stated that telephone can be the best but also the worst (lines busy, bad connections, delays, misunderstandings, costly, language problems, no record, etc.).

Manufacturer's written information related to safety

Depending on the degree of urgency and action to be taken, various types of information can be considered. The most important ones are:

- AOT (All Operators TELEX) used to inform airlines of actual or potential technical problems and normally requir-



ing action/inspection before a deadline. They are issued with an "urgent priority" and must reach the right person very quickly.

- Alert Service Bulletin.
- Accident/Incident information.
- OEB (Operation Engineering Bulletin)
  Normally not sent by TELEX since it usually is a reminder of existing procedures. Serves to emphasize operational recommendations which, if not strictly adhered to, could jeopardize safety.
- SIL (Service Information Letter) also sent by mail and covering mainly engineering or maintenance aspects.

Manufacturer's relations with Authorities

They can vary considerably depending on countries and local agreements. Inasmuch as the US system is well known I will not talk about it, but I think it is interesting to spend a moment on the specific arrangement in Europe and France. It is important to know that today very close contacts and agreements exist between the various Certification/Airworthiness Authorities worldwide. The regulations are basically the same all over with very few exceptions (special conditions, interpretations, etc.). We will come back in a few minutes on the specific subject of exchange of information concerning safety between those various administrations.

Manufacturer's relation with Operators/ Customers and receptivity of information by users.

Communications between Airbus and operators are fairly clear but, as may have been understood, the possibility exists that the information will sometimes not reach the right person, be delayed or, in extreme case, be lost. When safety is involved it is the manufacturer's responsibility to ascertain that action is being taken. Therefore, the message is sent to the designated person in the airline and duplicate to our Technical Representative. The latter acknowledges receipt and is responsible for follow-up within the airline. In some cases where inspections and/or limitations are required/set, a copy is also sent to the local Authorities depending on agreements. One must be very careful concerning timing of distribution of AOT. The sequence should be Manufacturer's Technical Representative, Airline and Authorities in order to avoid embarrassing situations. It must be emphasized that internal distribution and action plans are airline's responsibility. Any mishap should be reported as soon as possible to the Manufacturer. Human errors are today the biggest threats to safety and the tendency to minimize or hide a pilot or mechanic mistake should be fought. *If it has happened, chances are it will happen again.* Upon receipt of an information which is safety related the Safety Committee will convene and evaluate the importance of the event. Quick action may be desirable to avoid recurrence.

Airworthiness Directives, distribution and monitoring

It is not a subject that is as simple as it sound. In our case the aircraft is assembled, test flown and certificated in France. As outlined before, the certification is dual France/Germany. The French Authorities are responsible for the airworthiness of the aircraft and the investigation of accidents/incidents. An A.D. issued in France is automatically applicable in Germany and in the majority of all other countries that have signed agreements. Very close links for instance exist between FAA and the DGAC. There are some few exceptions and the case of the DC10 in Chicago is worth being mentioned.

Cooperation and exchange of information represent the key to quick and efficient reaction when safety is at stake. In recent years there have been numerous cases of HPT failures due to cracks and the worst one for consequences was the Yemen accident on March 17, 1982. In that case the FAA/NTSB/GE/Airbus/Airlines and French Authorities worked quickly together to take preventive action. The A.D. issued on GE engines by the FAA was simply retransmitted by the DGAC. GE also issued an All Operators TELEX to the airlines flying aircraft equipped with CF6-50 engines. The operator or overhaul agency had on this instance 2 if not 3 different sources of information. No interpretation or confusion can exist as was the case during the DC10 grounding.

Before closing the subject of governmental information I would like to mention what we call Chapter V of the Maintenance Manual, which is the only part of that manual to be approved. It concerns the life or cycle limitations which are the results of static or fatigue testing or which are set by the Authorities while awaiting final results of those tests.

As is the rule in international relationship any official document/correspondence issued by the French Authorities is in French language. However, an English translation is usually attached. In that particular case there is no language problem. Since we are only concerned with manufacturers' responsibilities I will not mention the serious problems that can affect safety in air/ground communications.

We are concerned with training and some big improvements have already been achieved by using audio-visual aids, learning carrels, cockpit procedure trainers, system trainers, simulators, etc. All these aids reduce the use of basic conversation and thus minimize the possible misunderstandings. I would be unfair to hide the fact that there have been some potential emergencies due to language problems in cockpits during flight training and I am sure that our friends from Boeing, Douglas or Lockheed have had some similar cases. On the positive side, however, most of the airlines send senior/instructor/supervisory personnel to attend the manufacturers' courses.

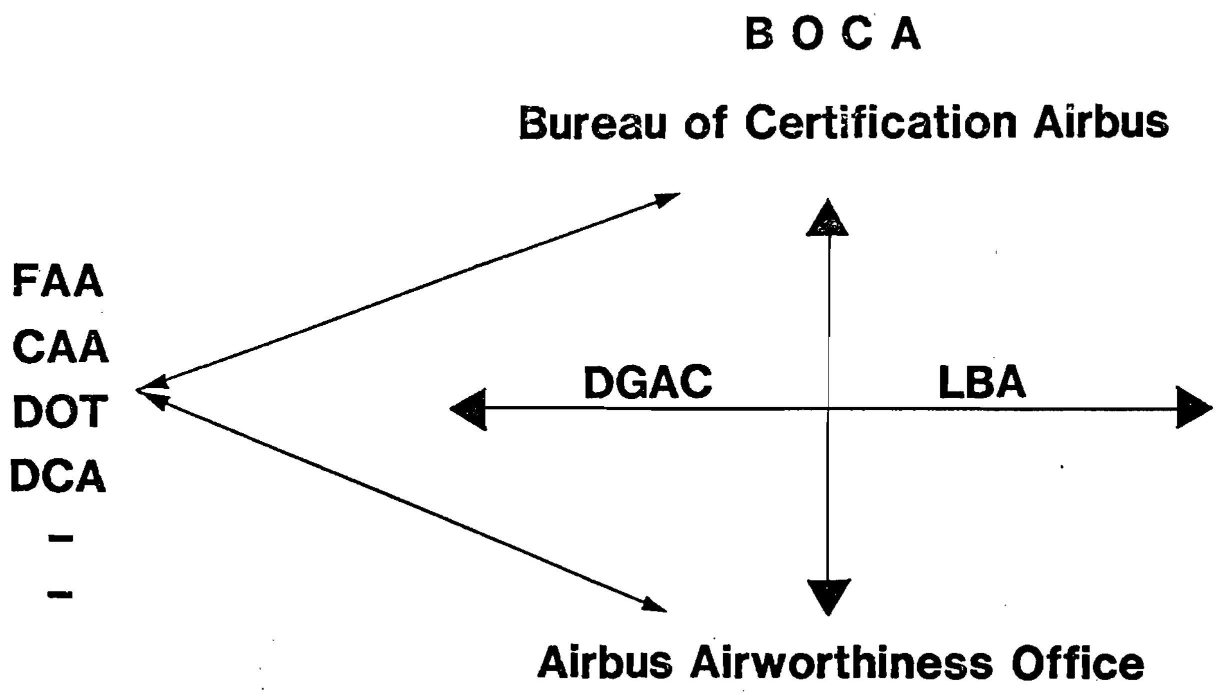
A final word concerning safety in relation to language: many manuals, working documents, job cards are translated by the airlines themselves for the use of their ground personnel.

Responsibility of Airline and/or Manufacturer Representative for providing safety related information

This again varies considerably with the airline and the individual concerned. Generally, the information from the operator's main base is regularly provided by either Operations or Engineering/Maintenance and is adequate. In case of serious incident or accident and in order to beat the press or the news media, we insist that preliminary factual information be transmitted to us by quickest means (telephone or TELEX). A more detailed description of the event will follow later. Apart from the negative impact that TV, radios and newspapers sometimes have, I think it is of the utmost importance that operators, Authorities, sub-contractors, etc. receive the known facts rapidly. No one can exactly measure the psychological effect of deformed or erroneous information which is spread following a fatal accident. Manufacturers have to know quickly of an incident, particularly those due to a human error. The airline can and will take local action, even fire the man who is responsible but there is a tendency to keep the secret in-house (it is a normal psychological reaction). But think of the possible consequences, think that hundreds of similar airplanes are flying and that the odds are for repetition. Only the manufacturer has the possibility to tie things together, evaluate the possible design improvement, study fool proof solutions, originate fleet modifications if need be and, in any event, advise all concerned in order to prevent recurrence and thus improve safety.

Airlines talk to each other, but not each airline talks to all the others. The focal point is the Manufacturer. We are taking our responsibilities and our primary concern is to have a good product that is safe to operate and fly. We need the help of the airlines. We need to communicate freely with no mental reservation. We need accurate, factual, concise, quick information in order to improve the reliability, increase the confidence and reduce drastically the errors that jeopardize safety.

COMMUNICATION IS ONE OF THE MAJOR FACTORS ENABLING US TO REACH OUR MAIN GOAL = PREVENTION.



Biography

Daniel R. Gerard graduated from French University with degrees in Mathematics and English (a long time ago). He joined the FAF (French Air Force) and flew many types of French US and German airplanes during the Indochina "war" in 1949. He resigned from the Air Force for personal reasons and joined TWA in Paris in 1951 in Flight Operations for the International Region.

In 1962 he joined Nord Aviation, the parent company of AEROSPATIALE, and was in charge of training and support of the new programmes NORD 262 and TRANSALL C160. He supervised the training of SAAF (South African Air Force) in 1968 and 1969. In 1971 he was coordinator for the Corvette Business Jet, spending 18 months in Washington, D.C. as assistant to the V.P. of AAC (Aerospatiale Aircraft Corp.) in charge of technical and flight. He was called on the Airbus Programme in Toulouse in 1977 as Customer Relations Manager within the Flight and Support Directorate. He participated in setting up a Safety - Accident/Incident Investigation Committee of which he is a permanent member. In this respect he is representing Airbus Industrie in FSF and ISASI.

Prevention of Death and Injury in Aerial Spraying

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I. *Introduction*

For air safety investigators, finding out what caused mishap, crash, injury or death in aerial spraying can very often be compared to asking which straw broke the camel's back. This paper is concerned with those straws which are of medical concern, and which should be part of the total checklist of factors involved in the special environment of aerial spraying. Despite this somewhat selective perspective, we should never forget that whatever the apparent or attributable circumstance of an individual near miss, mishap or crash, and the injuries sustained in such an episode, the safety investigator's work should be structured to promote the elimination or reduction of all the other circumstances. In short, ferreting out the last straw should never distract us from the others on the camel's back.

Agricultural spraying, as practiced in Israel, involves multiple hazards and dangers. Early work hours, 4-5 hours of flight time, at least 10-15 takeoffs and landings each workday, a 5-to-6 day work week, low altitude runs—sometimes as low as 1.5 meters above ground—frequent 180 degree turns generating forces on the pilot, passes under and over telephone and power lines, and exposures to noise, vibration, heat stress and pesticides are the major problems.

In aerial spraying, the safety investigator's task is to sort out the various problems that could create a load where the proverbial last straw will break the camel's back. To do this, he or she should start out using an approach which is not confined to the circumstances in a single individual mishap or crash, but considers all other mishaps and crashes occurring within defined populations and periods of time. In the absence of such an approach, it is often difficult to determine whether the findings of a set of circumstances in an individual episode is coincidental or causal.

What has just been described, of course, is application of the epidemiologic method to the study of aircraft accidents; there is nothing new in its routine use in annual reports, surveys and studies. Epidemiology is the discipline involving the study of the distribution and determinants of a condition or problem in a population; an epidemic is considered to be present when the condition or problem is observed to occur more frequently than expected. By comparison of the problem's distribution between and within population groupings defined by person, place and time, the epidemiologic approach—blunt, quick, but inexpensive and incisive—helps to search out "hot spots", "high-risk situations" and clues. This approach complements the more meticulous, time-consuming and tedious investigation of the individual mishap or crash. It is unfortunate that so much of the epidemiologic data on aircraft accidents which are routinely published are not studied more carefully for the leads they provide as to risk and "hot spots".

II. *Spray Pilot Crashes in Israel: Some Epidemiologic Clues*

What was striking about the accident data available to us, when compared to another place—the USA—were the progressively rising rates in the years 1974 to 1977 (Table I). During the same period, the number of hours flown annually rose, and with it, the use of pesticides. Table II, in which the data are analyzed by *time*, shows the high rates for accidents per 100,000 hours flying time during the summer months (August-September) compared to the remaining 10. August and September are hot, work loads are heavy, and, in recent years, they have been the months when parathion, an organo-phosphate pesticide sprayed to control cotton pests, is used. These data begged an explanation involving both organophosphates and heat.

III. *Organophosphates: Their Effects*

Organophosphates, if inhaled, swallowed, or absorbed through the skin, are potentially lethal pesticides. Exposure and absorption can result in anything from a mild headache, loss of alertness, problems with vision, dizziness, nausea, vomiting, diarrhea, sweating to extreme difficulties with breathing, convulsions, loss of consciousness and death—all in a matter of minutes to hours. It was these effects which led to their development as nerve gasses for chemical warfare. Treatment has to be prompt; pilots in Israel are required to carry with them self-injecting syringes containing atropine should there be a suspicion of sudden exposure, as may occur in a crash. For routine monitoring of lower level exposures, there are blood tests exploiting the fact that organophosphates inhibit the same enzyme in the blood, cholinesterase, that is inhibited at nerve endings; these tests are also used to confirm

TABLE I.
Crashes and incidents during agricultural flights, Israel, 1974-77

Year	No. of Crashes	No. of Incidents	Total	% reported due to pilot error	Total accidents per 100,000 flying hours Israel	USA
1974	4	12	16	62	23	22
1975	6	24	30	57	33	20
1976	11	18	29	62	55	17
1977	6	11	17	65	27	

Data in the Table taken from: "Briefs of Accident involving Aerial Application Operations." U.S. General Aviation Report No. NTSB-AMM-78-10, Washington, D.C., National Transportation Safety Board, 1976; and "Red Letter", Newsletter of the Israel Civil Aviation Authority, 1976-77.

diagnosis of acute episodes after the fact, although no physician confronted with a suspicious episode would wait for the result before injecting the antidote.

What is not so well-known, even in the medical world, is that repeated low level exposures which may not produce symptoms or depressions in blood cholinesterase levels may nevertheless result in low level subtle changes in nerve conduction, and these changes may be involved in impairment of pilot alertness, performance and skill; field methods for monitoring such changes using portable non-invasive electro-myography are now available, but their application has not been widespread, despite the advantages of simplicity, quick results, and sensitive evidence of low-level exposure.

Another point, all too often overlooked, and of considerable practical significance concerning pilots involved in aerial spraying, is that a droplet containing organophosphates which splashes on the eye may cause the pupil to contract, also affecting accommodation. The result is impaired vision, which can be treacherous for pilots flying 1-2 meters above ground level and just over and under power lines. Because the effect is "topical" we cannot rely on the use of various tests of total body absorption, excretion or effect (blood cholinesterase,

TABLE II.
Crashes/incident rates (including wire-cutting episodes) among aerial spray pilots in Israel.

	Aug-Sept			Other 10 months			Whole Year		
	Acc. (no.)	Hours (no.)	Rate/ 100,000 hours	Acc. (no.)	Hours (No.)	Rate/ 100,000 hours	Acc. (no.)	Hours (no.)	Rate/ 100,000 hours
1977									
Total	14	9,936	141	4	12,064	33	18	22,000	81
Wire-Cutting	8		84	2		17	10		45
1978									
Total	14	9,723	144	22	14,277	154	36	24,000	150
Wire-Cutting	5		51	8		56	13		54
1979									
Total	18	8,439	213	4	7,674	52	22	16,113	137
Wire-Cutting	12		142	4		52	16		99
1980									
Total	10	8,000	125	15	9,000	166	25	17,000	147
Wire-Cutting	7		87	8		88	15		88
1981									
Total	9	8,000	112	8	18,000	100	17	16,000	106
Wire-Cutting	5		62	4		50	9		56

Aug-Sept: peak work loads and peak period for parathion.

urine alkyl phosphates, nerve electromyogram) to ensure that the effects have been prevented.

IV. *Organophosphate Exposures: An explanation for pilot crashes?*

The data we were able to pull together on episodes of acute intoxications among ground crew workers, the reports in the literature on the effects of low level exposures to organophosphates, and the accident data already described led us to carry out studies of air and skin exposures to parathion among pilots and ground crews. Our studies involved laborious and difficult personal air sampling procedures and gas chromatography. They showed that pilots in the cockpits were exposed to parathion, and the levels of exposure seemed to be associated with flight patterns in which there were U-turns and flying back through a cloud of sprayed aerosol. (Table III) This was an inference drawn from comparison of cockpit parathion levels during short and long sampling periods.

TABLE III.
Parathion exposures airborne - cockpit (Summer, 1977)

Sampling period	Greater than 100 $\mu g/m^3$
<30 min.	7 of 12 instances
>30 min.	2 of 19 instances

Ground crew workers had far more severe exposures, mainly from skin absorption during loading operations, washing down contaminated aircraft and maintenance and repair. There was the suggestion that the washing down operations themselves resulted in contamination of the cockpit. Most of our findings on ground crew exposures corresponded with impressions from walk-through visits. These visits drew our attention to a problem which air investigators might tend to overlook: the adverse effects of low-level and high exposures to organophosphates on the performance of ground crew workers in maintaining aircraft. We were not certain whether we would be able to investigate this possible influence on aircraft maintenance, but it would be unjustified not to do everything possible to eliminate or reduce exposures for the ground crew workers themselves. One additional vexing problem, of course, was how to prevent skin exposures and absorption without the use of workclothes which produce heat stress; recent developments in workclothes technology appear to offer partial solutions.

Our investigations had the effect of pinpointing "hot spots", sources and routes of exposure for pilots and ground crews. They were a factor in a several-year program undertaken by the aerial spray companies to eliminate sources of exposure on the ground through better drainage and neutralization arrangements. Pilots became more aware of the advantages of box-flight patterns rather than U-turns. More and more powerlines were marked with colored plastic spheres. There was also a trend towards the use of substitute agents for parathion and other highly toxic organo-phosphates, although their complete replacement by malathion, a far less toxic agent, was unsuccessful for reasons having to do with its apparent lack of effectiveness against cotton pests. We would like to see the introduction of "closed loading systems", preferably operated remotely, so as to eliminate exposures to ground crew workers.

However we were unable to draw any conclusions as to a cause-effect relationship between organophosphate exposures and accident trends.

V. *And Jonah Fainted...*

The studies on parathion exposure were carried out in 1977, and although we were unable to determine whether they were a factor in spray pilot accidents in Israel, we were prepared to go further with them. Then, in 1978, in the peak hot months, 4 pilots were killed in a series of apparently unrelated accidents. In one case, a pilot took off with near-empty gas tanks; in another a pilot crashed into powerlines; in a third, mechanical failure was suspect; and in a fourth, the circumstances were unclear. This cluster sent us back to the literature, which drew our attention to the effects of heat stress and strain in pilot performance.

We ourselves had not been sure that parathion exposures were the only "physiologic" variable in a situation involving an array of pre-crash, crash, and post-crash factors having to do with the environment, and the aircraft as well as the pilot. One reason for our suspicion that other factors had to be looked for were questionnaire data we had collected from pilots on their work routine and *subjective* perceptions of alertness and performance. There were complaints of fatigue, declining alertness, thirst and inadequate supplies of fluids to drink during the workday. These were findings suggesting that heat stress and dehydration had to be considered as factors in aerial spraying accidents.

In Israel, especially in late summer, when the sky is cloudless, the contribution of what is known as radiant heat—the direct effect of the sun's rays—to standard measures of heat stress is high, and all the more so inside places like cockpits, where there are greenhouse-type effects. Anyone sitting inside a car on a hot summer day readily appreciates the effect of high radiant temperatures. All these effects have been described in the charming tale of Jonah and the gourd tree: "And God smote the gourd tree... and it withered... And the sun beat upon the head of Jonah, that he fainted... that he requested for himself that he might die..." (Jonah 4:9). There was a need for a sharp change of direction in our research.

TABLE IV.
Heat stress and heat strain (Summer 1978)

WBGT index exceeded 26.7 °C (TLV for continuous moderate work), for 7 of 10 aircraft for periods of up to 3.5 hours	—10 of 23 pilots with T_{rectal} greater than 37.5 °C at end of work day. —Average daily weight losses during workshifts of 0.6-1.2% of total body weight in 6 of 7 pilots —Thirst and low fluid intakes in 6 of 9 pilots.

In August and September 1978, we carried out a second set of field studies, proving that heat stress, an environmental variable of external heat load and heat strain, a physiologic variable, were highly prevalent (Table IV). By *heat strain* we specifically meant rectal temperatures greater than 37.5 °C, weight losses of .6-1.2% of total body weight, thirst and low fluid intakes. Our environmental measurements inside the cockpits showed especially high values for globe temperature —a measure of radiant heat. Air conditioning was an emergency recommendation resulting from these studies.

Many of the aircraft have subsequently been air conditioned. Recent preliminary studies show a reduction in temperatures, and pilots report improved stamina, alertness, comfort and well-being. These improvements, together with those aimed at reducing exposures to parathion, lead us back to the obvious question: Was there a reduction in accidents?

VI. *Back to Epidemiology*

In 1980 and 1981, there were marked drops in our rates for aerial spray craft accidents during the hot months. However, the results of air conditioning, as well as those having to do with abatement of pesticide exposure, while gratifying, were by themselves not proof of whether elimination of heat stress itself eliminates or reduces the risk of accidents related to pilot error.

To answer the question as to whether the drop in accidents was influenced by air conditioning, we would have to determine whether the rates for accidents and incidents per hours flown is lower for air conditioned aircraft than for non-air conditioned aircraft. We are beginning to collect data on this question.

Whatever the results of air conditioning, reduction in exposure to organophosphates including parathion, and other measures—more fluid intake, reduced workloads—aerial spraying, especially when pilots make their runs at low levels, will always be risky. No matter how effective or comprehensive the preventive strategies (see Table V) there will tend to be crashes. For this reason, the most important measure is the total elimination of risk of deaths and injury via the use of aircraft with crash-proof cockpits. The second priority—a precrash measure—is the elimination of inherent near-miss situations produced by power and telephone lines near sprayed fields. Table II tells us that without such power lines, 63 (53.3%) of 118 accidents in years 1977-81 *would never have occurred*, with or without exposure to parathion, heat stress, and the other physiologic hazards—e.g. stress, noise, and vibration. In short, investigation of some of the medical hazards associated with aerial spraying should not blind us to the lessons of the axiom about a fence at the top of the cliff being better than an ambulance at the bottom.

Afterword

We have looked backward into time as far back as Jonah. We can also glimpse a not too remote future in which pilotless spray craft will be radio-controlled, and loading, washing and maintenance will be operations carried out by robots. What, however, will be the problems of the workers who sit at the control panels? This is a question to be asked by the epidemiologist of the next decade.

TABLE V.
Summary of measures to prevent deaths in aerial spraying.

	COMPONENT			
Stage of Intervention	**Aircraft**	**Environment**	**Pilot**	**Groundcrew**
Pre-crash	—aircraft cooling/filter technologies	—elimination or marking of wires	—fluid intake	
			—medical screening	
	—wire-cutting apparatus	—drainage pits with sodium hydroxide for neutralization of parathion	cholinesterase determinations	—cholinesterase determinations
		—other environmental controls for parathion exposure	urinary alkyl phosphate	
			EMG	
		—substitution?	psychometic testing (?)	
Crash	—cockpit energy absorbing design			
Post-crash			—atropine	
			—syringes	
			—first aid —rescue arrangements	

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Biographies

Dr. Elihu D. Richter is a lecturer in the Department of Medical Ecology in the Hebrew University School of Public Health. He earned his MD degree at New York University School of Medicine (1963) and MPH degree at Harvard School of Public Health. After completing his residency at Mount Sinai Hospital in New York City, received his specialty boards in Preventive Medicine (USA) and Public Health (Israel). He has published work on exposures of aerial spray workers to organophosphates and heat stress, and has served as an invited participant and consultant to various agencies and committees, including the World Health Organization and US Air Force School of Aerospace Medicine.

Dr. Milton Gordon was involved in aviation medicine in the United States from 1939-1974, and has been Civil Air Surgeon for Israel CAA since 1974. Aviation experience: single and multi-engine land and sea ratings; instrument flight instructor, free balloon rating; commercial license, 5500 hours. Dr. Gordon's education includes a B.A. from University of Pennsylvania and M.D. from Jefferson University; International Medicine Certificate from University of Pennsylvania Medical School, and aviation courses at FAA/Oklahoma and various universities. He is a Fellow and former Vice President of the Aerospace Medical Association; Member of: International Academy of Aviation and Space Medicine, Air Transport and Air Safety Committees of the Aerospace Medical Society; and ICAO Medical Study Group.

Aircraft and Thunderstorms Don't Mix Well

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A hazard of thunderstorms which has not previously been explored but which may have contributed to a number of worldwide accidents involving turbojet aircraft is the aerodynamic effect of heavy rain. This paper analyzes what is currently known and what further research is being conducted in the context of recent U.S. accidents.

On July 9, 1982, Pan American Flight 759 was bound from New Orleans, Louisiana to Las Vegas, Nevada, and San Diego, California. On board was a full load of passengers, fuel and cargo so that the aircraft was operating at nearly its maximum allowable takeoff weight. Aware of th performance limitations because of the plane's weight, Captain McCullers ordered the cabin air conditioning turned off so that maximum power would be available to the engines. The aircraft lifted off at 4:08:33 p.m., C.S.T., and entered the cell of a thunderstorm located just off the end of Runway 10. After twenty-seven seconds the aircraft struck a tree at an altitude of 53 feet and crashed approximately seven-eighths of a mile from the end of the runway. The aircraft impacted into six square blocks of the City of Kenner, Louisiana. There were 138 passengers and a crew of 7 who died along with 8 residents of the City of Kenner.

Within ten seconds after the crash, and unaware of it, the flow controller at the Houston Air Traffic Control Center telephoned Moisant (New Orleans) Tower Clearance Delivery and suggested that the weather he observed in the New Orleans area via the Slidell (Louisiana) remote radar "looked nasty" and "could shut down" the airport arrivals and departures because of being below the minimum visibility standards.

Since man first flew, thunderstorms have presented a threat to safe flight. Airlines throughout the world caution flight crews to avoid thunderstorms on takeoff, landing or enroute. Since it is apparent that the pilot in command of Flight 759 elected to take off, we intend to examine some of the factors that contributed to his decision, and point out deficiencies in the system which may have led to the fatal aircrash.

Forty-nine minutes prior to the crash, the Houston FAA Air Route Traffic Control Center meteorologist telephoned Moisant tower, advising of very strong to intense thunderstorms which were southwest of the field, drifting toward the airport. These were observed from the Slidell radar antenna site thirty-one miles from the airport. Indications pointed to the likelihood of severe turbulence as well as hail. The records showed that thunderstorms soared nearly ten miles high, to altitudes above those at which commercial airlines operate their aircraft. The Houston meteorologist asked the tower to "keep an eye on" those thunderstorms; however, no written record was made of Houston's concern in the form of a Center Weather Advisory (CWA). In fact, the FAA has never set up—despite earlier NTSB recommendations—any procedures for handling Center Weather Advisories. (The FAA had promised to do so nearly a year before this fatal accident.)

Wind shear alerts were furnished by New Orleans Ground Control only to pilots who requested them, rather than by Local Control initiating the Low-Level Windshear Alerts without request, as required by the Air Traffic Control Procedure Handbook. The FAA failed to broadcast the latest Automatic Terminal Information Service (ATIS) information GOLF on both ground control and local frequencies, which would have insured that all aircraft using the airport would have heard that wind shears were present in all quadrants four minutes prior to the takeoff of Pan Am 759.

The cockpit voice recorder transcript does not indicate any acknowledgment from the crew of Flight 759 which would indicate their knowledge of the wind shear alerts. Although wind shear alerts were discussed on three occasions by other aircraft using the runways only minutes prior to the takeoff of Flight 759, there was no indication that its crew had listened to the broadcast of wind shear advisories that were made to other aircraft.

New Orleans has had not one, but at least two, Boeing 727's depart in the last seven years and experience a fatal crash in a thunderstorm. Before Flight 759 was Eastern Airlines Flight 66 that took off from New Orleans in June, 1975, and crashed into the approach lights during a thunderstorm while attempting to land at JFK Airport in New York. The crash of Eastern 66 prompted a new and intensive technological look at thunderstorm phenomena. This led to new theories of wind shear as the probable cause of that crash. Out of the wind shear analysis of the Eastern 66 crash came new techniques which taught pilots, for instance, that if they experienced a rapid rate of descent of the aircraft during landing approach, to raise the nose of the aircraft to control the descent.

A significant breakthrough may come from the Pan Am 759 crash with the knowledge of the effects of heavy rain as distinguished from wind shear, due to the research of staff scientists J.K. Leurs and P. Haynes of the University of Dayton Research Institute. In earlier NASA funded studies, they concluded that heavy rain was at least as significant a factor as wind shear in some accidents and may have been a primary cause. Their research grew out of studies on frost and ice having the effect of destroying lift—as the US learned in the Air Florida Boeing 737 accident on takeoff from Washington National Airport on January 13, 1982.

The airfoil, which provides the lift for flight, operates efficiently only if it is smooth. Encountering heavy rain, particularly at high angles of attack which are flown during slow airspeed maneuvers such as takeoff and landing, can have lift reduced by as much as 30% due to the presence of water on the wings and fuselage. Heavy rain builds up and puddles on the leading edges and surfaces of the wings, making an irregular surface similar to that of ice or frost. This can have a devastating effect on the ability of the wing to produce lift and cause stall speeds to be dramatically increased. If an aircraft were embedded in heavy rain to the extent that the amount of water aerodynamically roughened the airfoil, this would affect the turbulent friction coefficient of the airfoil as well as thickening the boundary layer. Drag increase and premature stall could result. In addition, flying into a wall of water increases drag and slows down the aircraft at a critical time. Raising the nose of the aircraft, the procedure recommended for windshear, may be the wrong thing to do if the heavy rain theory proves correct. In fact, it may only aggravate or precipitate a more extensive stall resulting in total loss of control. We think the most significant penalties are those due to a roughened airfoil. Figure 1 shows typical lift and drag curves for fixed, sandpaper type, roughness elements. These curves show that the drag coefficient for a roughened airfoil is larger at all angles of attack than for a smooth airfoil. The lift coefficient is also decreased, especially at high angles of attack. A decrease in maximum lift of ten to forty percent can occur. In addition the stall angle, at which maximum lift occurs, is 2 to 6 degrees less for a roughened airfoil.

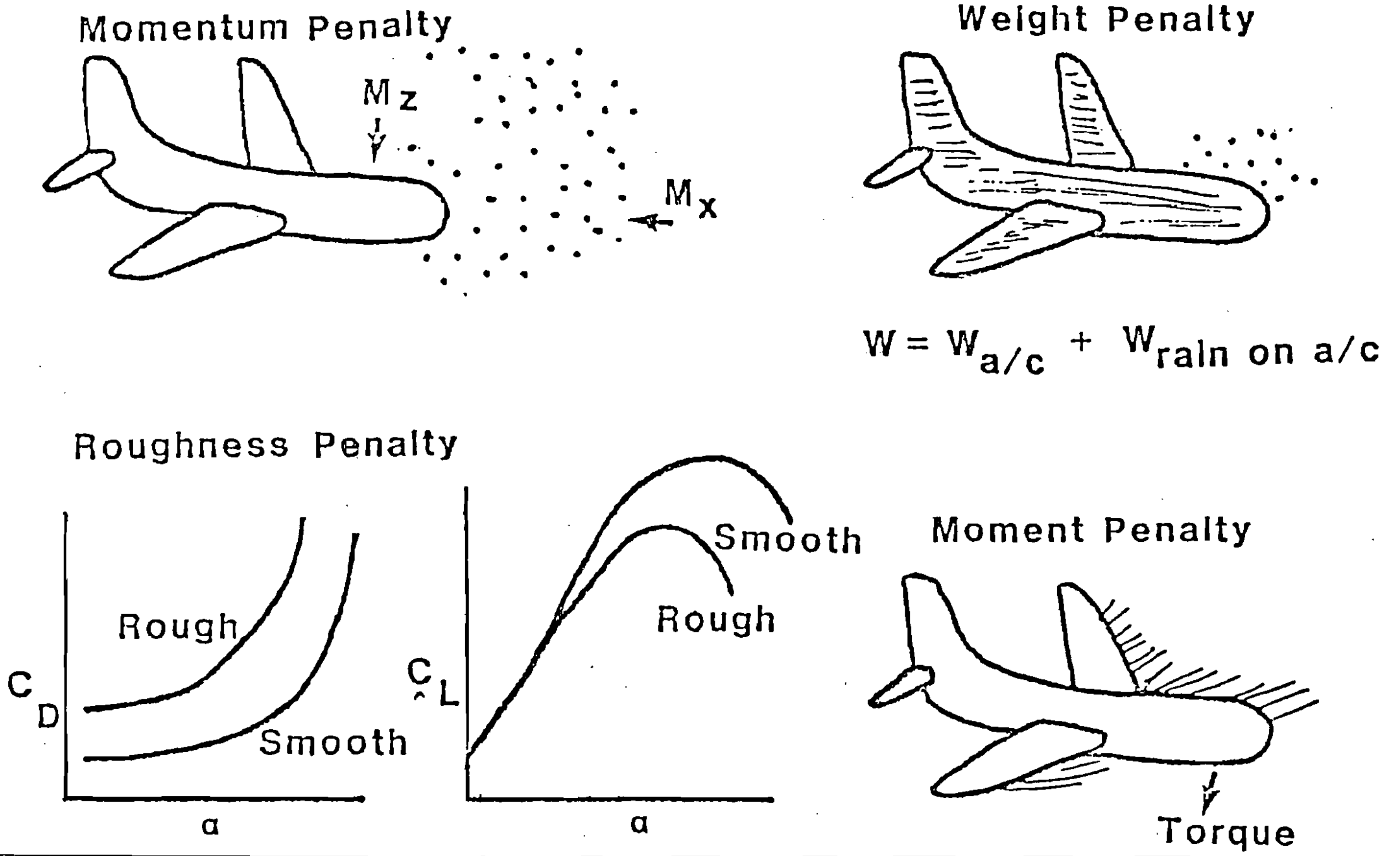
There are two components of the roughness penalty. One is due to the waviness of the film, the other is due to the cratering of drops on impact. To model the waviness one first must calculate the water film thickness. In Leurs & Haines research, they attempted to model the trajectory of the droplets as they impacted the airfoil for various rainfall rates. They computed a mass balance between the incoming water drops and the water exiting off the end of the airfoil to determine an average water film thickness. This film thickness was related to an equivalent sand grain roughness, and used experimentally derived lift and drag curves based upon sand grain roughness to convert to lift and drag penalties.

The second component of roughness is due to drop impacts. When a drop impacts the airfoil, a crater forms and each crater produces a distinct roughness element. Those roughness elements also contribute to an equivalent sand grain roughness. Equivalent sand grain roughness was derived from both drop impact catering and for the waviness of the film, and converted to a corresponding lift and drag penalty. Significant drag and lift penalties on the order of five to thirty percent resulted.

Pan American published precautions in its Flight Operations Manual more than a year prior to this accident, which were to be observed in avoiding turbulence, wind shear and hail associated with thunderstorm activity. Their standards provide that when significant thunderstorm activity approaches within fifteen miles of the airport, the Captain should consider conducting the departure or arrival from a different direction or delaying the takeoff or landing. The precautions require use of all available information for this judgment, including pilot reports, ground radar, aircraft radar, tower reported winds, and visual observations. Ground radar information concerning the location and severity of the thunderstorm had not been passed on by the New Orleans tower, which had knowledge of this condition for nearly an hour prior to the crash.

It is ironic that the only color radar weather displays affecting Flight 759 were in the weather departments of two New Orleans television stations, whereas the National Weather Service displays in Houston were in outmoded black and white, as were the FAA Air Traffic Control radar displays. Contracts for installation of color radar weather display screens by May 1982 across the entire United States had been entered into by the FAA. Even today, not a single FAA color radar weather screen is operational.

Pan Am 759, like all commercial air carriers, was required to have, and was equipped with, airborne weather radar aboard the aircraft. We don't know whether this radar was in use, as the Cockpit Voice Recorder transcript makes no mention of it. The only mention of bad weather was an announcement from the captain to passengers two and a half minutes before takeoff, stating that "We'll be maneuvering around, circumnavi-



gating some thunderstorms out there." However, twenty minutes prior to the crash, Southwest Airways Flight 860, a Boeing 737 bound for Houston, said his airborne weather radar showed "a cell above us extending 8-10 miles off the end of Runway 10. Heavy contour level 3 on our radar." The Captain also stated that he observed Pan Am 759 pass the departure end of Runway 10. At this time according to the captain. "...(the) cell is still in area, little movement with heavy contour." This would indicate severe turbulence, possible lightning and heavy precipitation.

Records of rain gauges in the area within one mile of the crash indicate that the rainfall was approximately one to two inches per hour, which would constitute "heavy" rain. Pan Am's Flight Operation Manual states aircraft radar "...should be used to analyze surrounding weather conditions prior to takeoff...mature storms...may require the use of a different runway, or possibly a delay in takeoff until the storm has passed." With regard to landing approaches, the Manual states, "Heavy rain may have an effect as significant upon airplane performance as wind shear."

Ground witnesses, according to the NTSB, observed the aircraft in a normal climbing attitude to an altitude between 100 and 200 feet in the rain. They then observed the nose of the aircraft rising, indicating an increase of pitch attitude, followed by an immediate descent of the aircraft to the point of the impact with a tree. Flight crews are taught, as part of training in conquering wind shear, that if they experience a descent which they may attribute to the effects of a downdraft they should stop the rate of descent by raising the nose.

The Boeing 727 being flown by Pan Am was equipped with a stall warning device known as a "stick shaker." This gives the pilot a warning approximately three degrees below a stalled condition, so that the pilot can take action to lower the nose to avoid the stall. There was no sound of the stick shaker detected on the Cockpit Voice Recorder of Flight 759. The reason may very well have been that the wings of the aircraft had already stalled at a point before the advance warning system was programmed to operate—because the factor of heavy rain had not been taken into account. The ground witnesses who observed the raising of the nose were probably observing the flight crew's utilization of wind shear procedures which would only have aggravated the critical situation caused by heavy rains. The last words of the Captain were, "Come on back, you're sinking Don, come on back." The nose being raised would have been in response to a backward movement of the control yoke resulting in the aircraft changing its pitch attitude to nose high.

The aerodynamic effect of heavy rain may also have been a significant factor in at least five other accidents. Table I shows aircraft accidents in which heavy rain may have played a vital role. Leurs & Haines have analyzed several of the accidents in detail. They think that heavy rain may also be a factor in the other accidents listed. One accident occurred only 19 days before the Pan Am 759 disaster. In that case an Air India Boeing 707 attempted to land at Bombay Airport in the torrential monsoon rain. The aircraft crashed short of the runway, splitting into three pieces and killing many aboard.

To pursue the implications of this important potential breakthrough, VISTAS is contributing support to the Aerodynamic Effects of Heavy Rain Simulation (AEHRS) study by Leurs and Haines of the University of Dayton Research Institute, which will use volunteer test pilots in cockpit simulators. Computers will provide simulated effects for lift, drag and momentum penalties encountered in heavy rain. According to Leurs, each accident will be reviewed to establish the rain intensity that was likely to have been experienced by the aircraft. This rain rate will then be related to lift, drag and momentum penalties that affect the aircraft peformance. The aerodynamic penalties will be input into a flight simulator and qualified pilots solicited to fly the accident's new scenario. The approximate six month research program has two objectives: to provide definite conclusions concerning the influence of heavy rain and windshear attributed accidents, and to investigate proper pilot procedures for flight in heavy rain in order to minimize rain-induced penalties.

Flight simulators today provide most of the training a pilot needs to handle any environmental situation in which he finds himself. However flight simulators have not yet included performance degradation penalties that occur due to airfoil surface roughness. Surface roughness may result from nocturnal frost accretion on an aircraft, large accumulations of insect debris, extreme situations of burred rivets or chipped paint on an airfoil, and, as postulated by Haines and Leurs, rain-induced roughness on an airfoil when an aircraft penetrates a heavy rain cell. Lift and drag penalty curves have been derived to take into account these roughness effects. The inclusion of the equations in flight simulator control programs could assist in training a pilot in proper procedures for flying an aircraft when known or suspected roughness elements may exist on the airfoil. Flight simulator test results with roughness effects included could lead to revised procedures for aircraft takeoff, landing and go-around maneuvers under severe environmental conditions.

TABLE I

WIND SHEAR/HEAVY RAIN ACCIDENTS

1. Pan Am 759, B-727, New Orleans, LA, July 9, 1982
2. Air India, B-707, Bombay, India, June 20, 1982
3. Eastern 66, B-727, JFK, NY, June 24, 1975
4. Eastern B-727, Atlanta, GA, 1979
5. Allegheny DC-9, Philadelphia, PA, 1976
6. Jordanian B-727, Qatar, 1979
7. Eastern B-727, Raleigh, NC, 1975

OTHER POSSIBLE WIND SHEAR/HEAVY RAIN ACCIDENTS

Salt Lake City, UT	6-8-68
Naha, Okinawa	7-27-70
Ft. Lauderdale, FL	5-18-72
New Orleans, LA	7-26-72
Chicago, IL	6-15-73
St. Louis, MO	7-23-73
Chattanooga, TN	11-27-73
Pago Pago, Am. Samoa	1-30-74
Houston, TX	12-14-74
St. Louis, MO	11-29-75

Biography

William Jennings is Safety Advocate with Volunteers in Service to Aviation Safety *(VISTAS) a non-profit foundation. For 14 years, he was Director of Aviation Safety for the International Airline Passengers Association. He has testified before U.S. Congressional aviation committees on subjects ranging from crashworthiness and hijacking, to the airworthiness of the DC-10. His flight experience began by soloing 27 years ago with the U.S. Air Force. His aircraft accident investigation training was through University of Southern California Aerospace Safety and the Royal Institute of Technology, Stockholm, Sweden. He is a graduate of the University of California, Berkeley School of Law and has been specializing in Aviation Law for the past twenty years.*

Electronic Interference with Airborne Navigation Systems

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At the outset, I wish to thank two people who were a great help in compiling the technical data necessary to the completion of this paper. Gerald J. Markey is the Chief, Frequency Engineering Branch of the United States Federal Aviation Administration. Steve Corrie is a long-time friend and air safety investigator for the National Transportation Safety Board of the United States of America.

For those of you who fly in sophisticated electronic environments, you have come to rely without question on modern electronic navigation aids; i.e. VOR, TACAN, DME, ILS, etc. The accustomed accuracy of these systems sometimes allows us, as pilots, to forget that they are "aids" only.

Many members of this prestigious organization have flown in areas which were not so sophisticated and, at times, even hostile. It is a common tactic to set up false navigational transmitters or jammers to confuse attacking aircraft. Similarly, poorly maintained transmitters and/or receivers may produce erroneous navigational readings in the cockpit. In these situations, the pilot is alert to such an erroneous reading. However, in the sophisticated environment, complacency and misplaced confidence can lead to disaster.

The purpose of this paper is to bring the potential hazards to aviation, from expanding electronic media, to the attention of the world-wide aviation community. Unfortunately, these hazards to be the cause of an air disaster. As aircraft accident investigators, the recognition and understanding of electronic interference may help resolve that case where the aircraft was off-course.

There are three principal sources of electronic misinformation to airborne navigational receivers. The first is installation error; e.g., inoperative antennae. This first source will not be addressed herein. Neither will the second source be addressed, terrain and physical obstruction effects on signal strength. What is the concern of this article is the impact of secondary external electronic radiation on what is displayed in the cockpit.

The classic example of this third source is the Juneau aircrash of Alaska Airlines Flight 1866 on 4 September, 1971. Below is the computer summary of the National Transportation Safety Board showing the FAA response:

Report No. AAR-72-28, Log No. 0416:

Abstract: "Alaska Airlines Flight 1866, a Boeing 727, N2969G, crashed while attempting a nonprecision instrument approach to the Juneau Municipal Airport, Juneau, Alaska, at approximately 12:15 P.D.T., on September 4, 1971. The flight had been cleared for a localizer directional aid (LDA) approach to runway 8 and had reported passing the final approach fix inbound to the airport. This intersection is located 10.2 nautical miles west of the airport. No further communications were heard from the flight. The aircraft struck a slope in the Chilkat Mountain Range at about the 2,500 foot level on the approximate localizer course at a position 18.5 miles west of the airport. All 104 passengers and 7 crew members were injured fatally. The aircraft was destroyed. The National Transportation Safety Board determines that the probable cause of this accident was a display of misleading navigational information concerning the flight's progress along the localizer course which resulted in a premature descent below obstacle clearance altitude. The origin of the erroneous navigational information could not be determined. The board further concludes that the crew did not use all available navigational aids to check the flight's progress along the localizer nor were these aids required to be used. The crew also did not perform the required audio identification of the pertinent navigational facilities."

FAA Response, 19 January, 1973:

"Response from the FAA to say that their tests show no effect on a receiver of the type involved in the accident investigation due to extraneous harmonic radiation. A comprehensive report is presently being compiled on these tests and will be available by March, 1973. They further state that they are continuously alert to possible detrimental effects to airborne receiver operation caused by modifications to ground facilities. Such investigations will, therefore, continue to be a part of their program for upgrading ground VOR stations to meet further needs."

Recommendation No. A-72-205:

"The FAA continue the tests now in progress concerning extraneous harmonics on the doppler signal and initiate research into their possible hazardous effects on navigation receivers and associated instrument displays."

The secondary source of electronic radiation may effect radio reception (Oklahoma City accident) and VOR reception (Hanover, New Hampshire accident). Excerpts of the record on these accidents are contained below:

Accident Date: February 27, 1969 at Oklahoma City, Oklahoma. Log No. 69-0109:

Abstract: "The board has received a report of frequent instances of radio interference on the primary control frequency of the Wiley Post Airport control tower, Oklahoma City, Oklahoma. The interference has been identified as music transmitted on a strong signal from an unidentified commercial FM radio station. The interference is of such volume that pilots find it necessary to turn their radio control volume down. In so doing, these pilots are then unable to hear the tower's transmissions. In the case where the pilot does not adjust his volume control, the tower transmissions are garbled or are unintelligible because of high volume interference."

Recommendation No. 69-029:
"The board recommended that the FAA and FCC if necessary determine the cause of the radio interference on the primary control frequency at Wiley Post Airport control tower, Oklahoma City, Oklahoma and consider if other airports are similarly affected."

Response of the FAA 3/11/69:
"The FAA had replied that they had monitored the tower frequency with a ground unit for three days and with a DC-3 flight inspection aircraft one day and found no interference. 5/12/69 further tests by FAA revealed that there was in fact radio interference on the primary control tower frequency. The subject control tower frequency was changed by FAA.

Report No. AAR-70-7, Log No. 69-0048A.
October 25, 1968 accident at Hanover, New Hampshire:

Abstract: "A Northeast Airlines, Inc., Fairchild Hiller FH-227C, N380NE, crashed at approximately 1817 E.D.T., October 25, 1968, near Hanover, New Hampshire. The aircraft, Flight 946, had been cleared for an approach to the Lebanon Regional Airport, West Lebanon, New Hampshire, at 1808. The aircraft crashed 3.8 nautical miles northeast of the VOR station at an altitude of approximately 2,237 feet M.S.L. At this point in a standard instrument approach, the aircraft should have been no lower than 2,800 feet M.S.L. Witnesses on the ground and survivors of the accident reported that the mountain top was shrouded in cloud or fog at the time of the accident."

Recommendation No. 69-013, October 29, 1968:
Recommended that: "(a) the FAA conduct long-term radio frequency monitoring of the Lebanon VOR area for signal interference; (b) priority consideration be given to the installation of dual navigational facilities at those locations where a single facility could exhibit characteristics of the type found during our investigation of the Lebanon accident; (c) a review of the design concept of the Wilcox Model 806A receiver and its compatibility with other airborne instrumentation and ground station navigational equipment to assure standards of airworthiness. Furthermore, this compatibility problem may be general in nature and consideration should be given to reviewing all pertinent standards for compatibility of ground and airborne navigation components; (d) the FAA should provide the leadership in developing and implementing an industry wide operational incident reporting system for an interim period, and that early attention should be given to insuring a wider dissemination of existing operational incident data among the elements of the FAA; and (e) an Advisory Circular, or similar type bulletin, be issued reemphasizing positive station passage indications."

Response of the FAA 10/07/68:
"Currently, a telegraphic Operations and Maintenance Alert was sent to all regions, area offices, and Flight Standards offices on October 29, 1968, requesting that all known users of this receiver be advised that erratic operation and false reversals have been reported. Restrictions on the use of the 806A receiver for en route operations and VOR instrument approaches were also requested. In addition, the manufacturer was requested by telegram to also alert all known users of the equipment as soon as possible. A copy of our Alert Notice to the field office is enclosed. We believe that the above precautionary action substantially parallels your recommendations."

Log No. 69-0048
Abstract 69-0117: "Our recent investigation of the Northeast Airlines, Inc. FH-227C, N-380NE accident, near Hanover, New Hampshire, on October 25, 1968, has disclosed several areas where improvements to aviation safety are needed. Our investigation has indicated that the possibility exists that the Northeast accident flight experienced false indications of station passage while making a VOR approach for landing at the Lebanon Airport."

Recommendation No. 69-017, December 13, 1968:
"We would, therefore, recommend that the FAA conduct long term radio frequency monitoring of the Lebanon VOR area for signal interference. The board recommends that priority consideration be given to the installation of dual navigational facilities at those locations where a single facility could exhibit characteristics of the type found during our investigation of the Lebanon accident. The board recommends that a review be made of the design concept of the Wilcox model 806A receiver and its compatibility with other airborne instrumentation and ground station navigational equipment to assure standards of airworthiness. Furthermore, the facts disclosed during our investigation of this accident indicate to us that this compatibility problem may be general in nature and that consideration should be given to reviewing all pertinent standards for compatibility of ground and airborne navigation components. FAA should provide the leadership in developing and implementing an industry wide operational incident reporting system for the interim period. In moving toward this objective, we would hope that you would give early attention to insuring a wider dissemination of existing operational incident data among the elements of your organization. Our final recommendation concerns the reemphasis of what cockpit indications constitute positive station passage during a VOR instrument approach."

FAA Response 1/14/69:
"1. Signal interference effects on the Lebanon VOR facility. We have investigated the possibility of radio frequency interference effects at Lebanon from co-channel stations. Data derived in coordination with ESSA, U.S. Department of Commerce, shows that, considering ducting and superrefraction, there is one chance in fifty that a maximum signal of ten microvolts could be received in the Lebanon area for a total of 50 minutes a year from the nearest co-channel VOR at Elmira, New York. This signal would be useable only in the absence of the Lebanon VOR, but would be about 20 decibel lower than the Lebanon VOR signal in the flight area in question. This radio would cause less than one degree of error. Extensive tests conducted at Lebanon indicated the Clarksburg effect to be quite prevalent in the Lebanon area. This effect results from the presence of low-frequency signals (5Hz to 20Hz) in the receiver indicating circuits. The signals are the result of the aircraft passing through a region where the VOR direct signal intensity is altered by signals from a reflecting surface. The actual low frequency signals generated by this action is a function of the aircraft's ground speed and its varying angular relationship to the upward reflected signal. Therefore, the irregular occurrence of deviations from the Clarksburg effect is explainable and we cannot conclude that RF interference is indicated. However, we will give further consideration to the need for

the recommended long term frequency monitoring. Performance of receivers which exclude the effect by meeting the standard of AC 91-18 will be a factor in this determination.

"2. Need for additional navigation facilities at Lebanon. The FAA has a policy to improve navigation aids when necessitated by unsatisfactory performance. In the case of VOR this usually involves relocation or conversion to doppler VOR. In any event, an additional navigational aid such as DME is primarily installed to provide additional operational benefits; i.e., lower landing minima or reduction of flight time, rather than support of facilities having unsatisfactory performance. The flight inspection tolerances specified for VOR facility performance in the United States Standard Flight Inspection Manual (USSFIM) conform to international standards and are adequate to support the VOR instrument approach procedures. The Lebanon VOR performs within these tolerances and, therefore, should not require an additional facility to support the instrument procedures. Nothwithstanding budgetary constraints, we would like to see a DME located at every VOR site. However, our ultimate objective is to provide vertical guidance, as well as directional, at all air carrier airports.

"3. Operating characteristics of the Wilcox 806A navigational receiver. Wilcox Electric Company is now developing a design change to their equipment to minimize the difficulties experienced during flight checks at Lebanon. The restriction discussed above on the model 806A receiver will be rescinded when the equipment has been modified."

These reports raise the question of recognition of the problem. Informally, the aviation community is receptive to investigation of the problem, while publicly there is some reluctance to admit existing systems are not foolproof. Below is an excerpt from an FAA regional response to an inquiry by the author:

"Interference to localizer or glide slope signals may come from very strong off channel signals causing crossmodulation in the airborne receiver, or by direct on-channel interference from a transmitter with spurious outputs. Direct on-channel interference from citizens band radios, wireless telephones, etc., which you mentioned in your letter, typically do not occur. Over the past 20 years, our navaids staff in the . . . region are not aware of any such occurrence.

"Prevention of interference to the airborne receiver, from crossmodulation or spurious receiver response, is accomplished by FAA manufacturing Technical Service Orders (TSOs), which set acceptable limits on these effects. ILS receivers also are protected from interference by the instrinsic characteristics of the ILS system, which uses 90Hz and 150Hz modulation frequencies for navigational information. Before any interference can cause navigational errors in an ILS receiver, it must have 90Hz or 150Hz modulation components. The receivers filter out all frequencies except 90Hz and 150Hz.

"Another way FAA prevents harmful interference to all our services is through coordination of airspace action with the Federal Communications Commission (FCC). Applicants for licenses to transmit must submit FAA Form 7460-1 to the FAA prior to FCC license approval. In this way, FAA monitors the installation of transmitting equipment which might affect any FAA service.

"Perhaps our most effective way of controlling harmful interference is through our pilot reporting and investigation system. Any pilot report (usually verbal) to our Air Traffic Control facilities of any irregularity of any navigational aid is documented by Air Traffic personnel, and forwarded to the Airway Facilities Division. These reports are carefully examined, and all are investigated."

The foregoing was issued in 1982 subsequent to the accident reports quoted above. The final paragraph of the excerpt echos the necessity for education of the members of the aviation operational community to the potential hazards of electronic generated misinformation to navigational equipment in the cockpit. Just as the NTSB Recommendations from the accidents reflected above urge notification of users of potential hazards, the purpose of this paper is to notify the international aviation community of the growth of the potential for such hazards by the expansion of the electronic media. The allocation of the radio frequency bands available is shown in Figure 1. These are normally uniform under ICAO, but may have some variations. The specific numbers are not so important as is the way different sources relate to each other; i.e., "intermodulation." This phenomenon will be examined herein in relation to FM transmission because that is where the most extensive investigation has been conducted. An illustration is shown in Figure 2.

There are other sources of electronic interference and the main problem results from the interface of controlling governmental agencies who have different objectives and priorities. An example in the United States is the Federal Aviation Administration and the Federal Communications Commission. Any source of radiation may impact airborne navigational systems; i.e., citizens band radios, FM stations, cable TV systems, or microwave transmitters. The source which poses the immediate problem will vary with the country. For example, Great Britain has recently legalized citizens band radios. It will be facing problems the United States has seen, while the United States is confronted with expansion of cable television systems, to include microwave transmissions. European FM stations in 1978 were allowed to expand their coverage to 108 MHz, which is adjacent to the aeronautical band.

Representative John Dingell, Chairman of the House Energy and Commerce Committee's Subcommittee on Oversight and Investigations, last year echoed the complaints of the Federal Aviation Administration that the relaxation of restrictions on cable TV frequencies that border those utilized by air traffic control may endanger aviation safety. From a story reported in the Washington Star, 6 March, 1981: since 1976 there have been 5 documented cases in which radiation leaks from cable television systems have interfered with communications between air traffic controllers and pilots or with instrument landing systems.

This leaking may result from normal radiation emitted from the shielded cables. Also, a boost in power can generate additional emissions. A similar situation results when citizens band radio power is boosted without increasing the filter strength/efficiency. You have all experienced citizens band radio broadcasts being played over your TV set, sometimes referred to as "brute force" interference.

With the expansion of frequency utilization, it is not illegal signal boosting or signal overspill into another band that is critical. The potential for intermodulation between legally transmitted signals is the cause for concern. This process is well analyzed in FAA Report No. FAA-RD-78-35; July, 1978: *Interference in Communications and Navigation Avionics from Commercial FM Stations*

The purpose of this project was to determine distance/frequency separation criteria required between communication and navigation avionics and high powered frequency modulated (FM) commercial stations operating in common

RADIO FREQUENCIES AVAILABLE TO THE AERONAUTICAL SERVICES

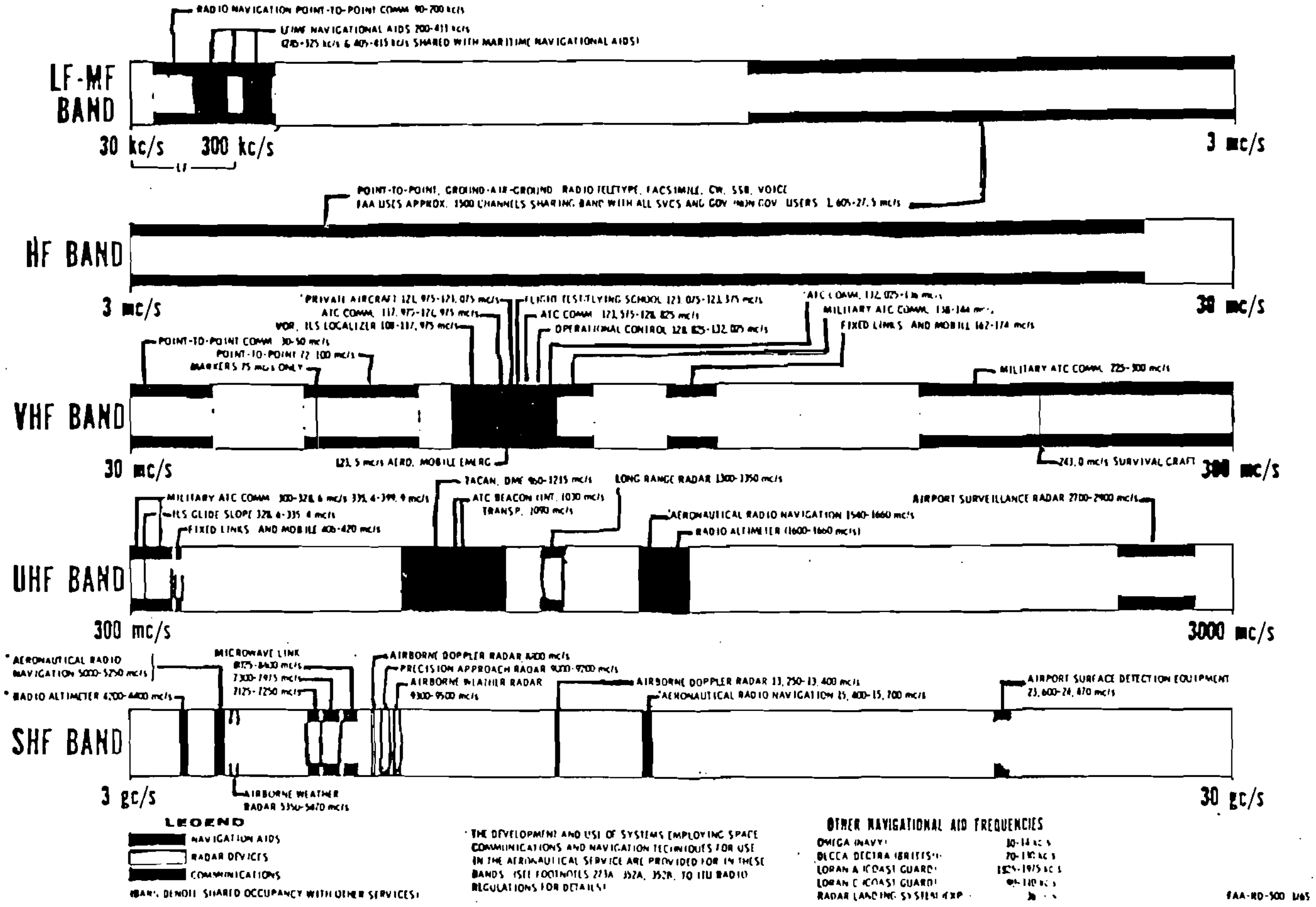


Figure 1

geography. Distance criteria are necessary to limit FM signals to tolerable signal levels, to avoid "brute force" spurious interference. Frequency planning details are required to avoid intermodulation or other spurious interference. For the FM study, the FAA flew tests in Atlantic City, New Jersey; Indianapolis, Indiana; Kansas City and Topeka, Kansas; Denver, Colorado; Albuquerque, New Mexico; San Antonio, Houston, Dallas and Ft. Worth, Texas; Birmingham, Alabama; and Opa Locka, Florida.

The Mark 12 and Bendix receivers were used to give a comparison of the RF interference effects on navigational communication receivers. The communication receivers were not as susceptible to FM interference compared to navigational receivers. The Genave 100 receiver was the most susceptible, of those tested, to the interference. This receiver is a low-cost, general-aviation type receiver.

The CDI (Course Deviation Indicator) displays the indicated course error resulting from the phase difference between the "reference" and "variable" 30Hz and the amplitude difference in the 90 and 150Hz modulation. Interference from FM signals will affect the modulation resulting in errors in CDI reading. If strong FM signals desensitize the receiver where reduced amplitude of modulation is received a flag will appear. Some levels of FM signals even produce a shift in the flag conditions of "To" or "From". The Bendix was shown to move to a false indication with a strong FM signal.

Interference can be predicted. The laboratory tests conducted by the FAA revealed that the FM signal levels for intermodulation interference need not be of equal dBm levels. The equation for intermodulation is as follows:

$$AF_1 + BF_2 - CF_3 = F_i$$

Where:

A, B, and C are = coefficients 0 to 3

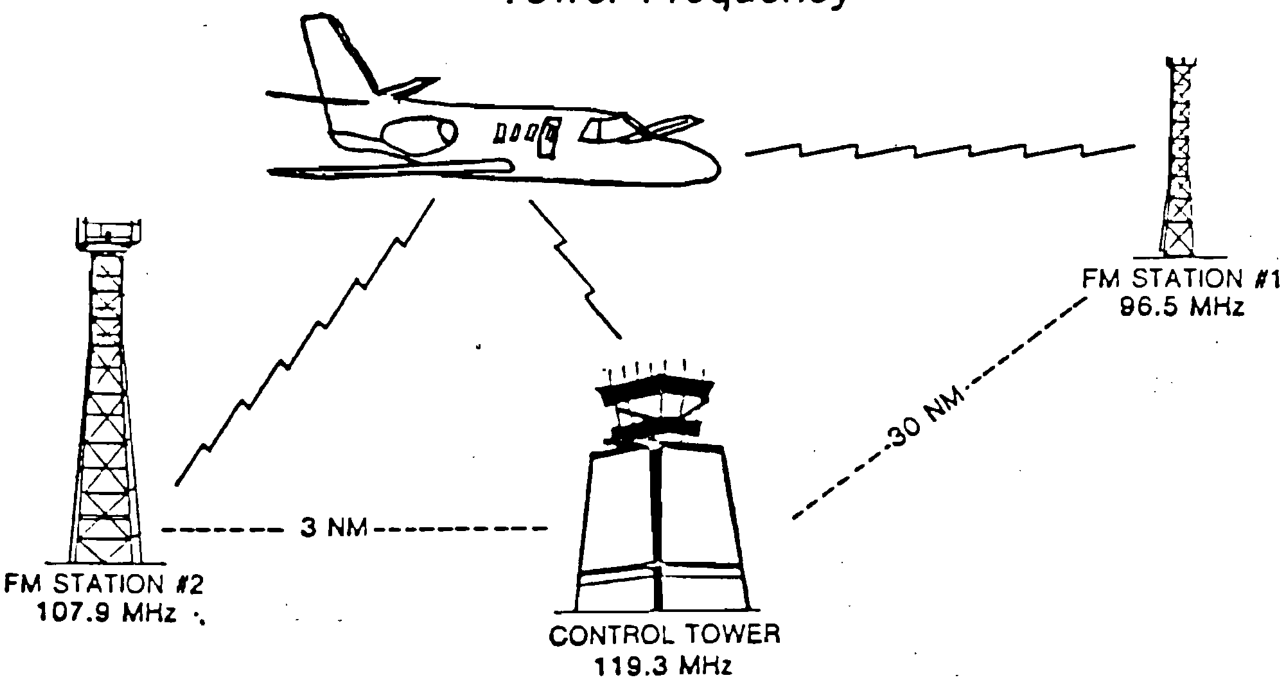
F_1, F_2 = radiated interference frequencies

F_i = interference frequency of intermodulation.

The primary/secondary levels required for each coefficient for a few of the combinations are listed in Table I. These levels place a third criterion, power level, as a function of the coefficient on the area of potential interference. One of the several signals (Table I) must be at a high level (prime) with a signal of approximately -10dBm for communication receiver input and -20dBm for a navigation receiver, except in the presence of the interfering ELT when lower levels will produce interference. The other signals (secondary) of the intermodulation combination (Table I) may be 10 to 20dB lower and produce a significant interference on most low-cost general aviation receivers.

The above information plus an assumption that most FM

Intermodulation: How Two FM Stations Generate a Tower Frequency



FM Station #1, 30 nm northeast of the airport, is operating on 96.5 MHz. It may produce no interference to airborne receivers—until FM Station #2 is built 3 nm from the airport, well within the 20-mile service volume of the control tower.

As an aircraft flies near FM Station #2, its com receiver is overdriven by the 107.9 MHz signal, causing the receiver to generate a second-harmonic signal on 215.8 MHz. When the receiver is in this condition, it is susceptible to 96.5 MHz signals of FM Station #1. The airborne receiver now contains the following mixing products:

FM Station #2:	**(2 X 107.9) =**	215.8 MHz
FM Station #1:		-96.5
	Tower:	**119.3 MHz**

The pilot hears music, voice, or noise on the tower frequency. Other combinations may produce spurious signals in the navigation band. For example:

FM Station #1:	**(2 X 107.9) =**	215.8 MHz
FM Station #2:		-103.9
	Localizer frequency:	111.9 MHz

Potentially harmful interference based on FM station power, distance from airport, frequencies and other factors can be predicted by a Venn diagram, part of the new RTCA document.

Figure 2

antennas radiate omnidirectionally has led to the Venn diagram solution of where FM signal combinations might be expected to produce intermodulation interference. For the Venn-type solution, it was necessary to determine the distance at which the FM station signal at receiver input would be attenuated to -10dBm for communication receivers and -20dBm for navigation receivers. The above two calculations would be the high level or prime FM signal required for a configuration. Appropriate distances must be calculated for secondary level signals of -20 and -30dBm in intermodulation combinations. The space loss formula was used to calculate the distances:

$$L_s = 38 + 20\log(d) + 20\log(f)$$

Where:

d = distance in nm

f = frequency in MHz

A HP-65 calculator program has been written for FM and TV brute force interference calculation which may be used to determine (d) in the above equation and is available on request from the author.

TABLE I.
Expected Power Levels for Selected Coefficient Combinations of Intermodulation Equation

Intermodulation equation AF_1-BF_2-CF_3 = Intermodulation Frequency

Coef. A	Level F_1	Coef. B	Level F_2	Coef. C	Level F_3
2	Prime	0	—	1	Secondary
2	Prime	1	Secondary	2	Prime
1	Prime/Sec	1	Prime/Sec	1	Prime/Sec
3	Prime	0	—	2	Secondary

NOTE: Levels may be interchanged as a function of harmonic output from an FM station and characteristic of the receiver.

If (d) is used as the radii of circles, they may be presented as in Figure 3. The value of (d) will vary as a function of frequency due to the antenna response. In Figure 4 the shaded areas indicate where the conditions are met for potential interference based on power levels from FM stations A and B, where -10dBm is the prime signal level and -30dBm the secondary. In Figure 5 the prime level is reduced to -20dBm while the secondary level is held at -30dBm. The shaded area again indicates the potential area of interference.

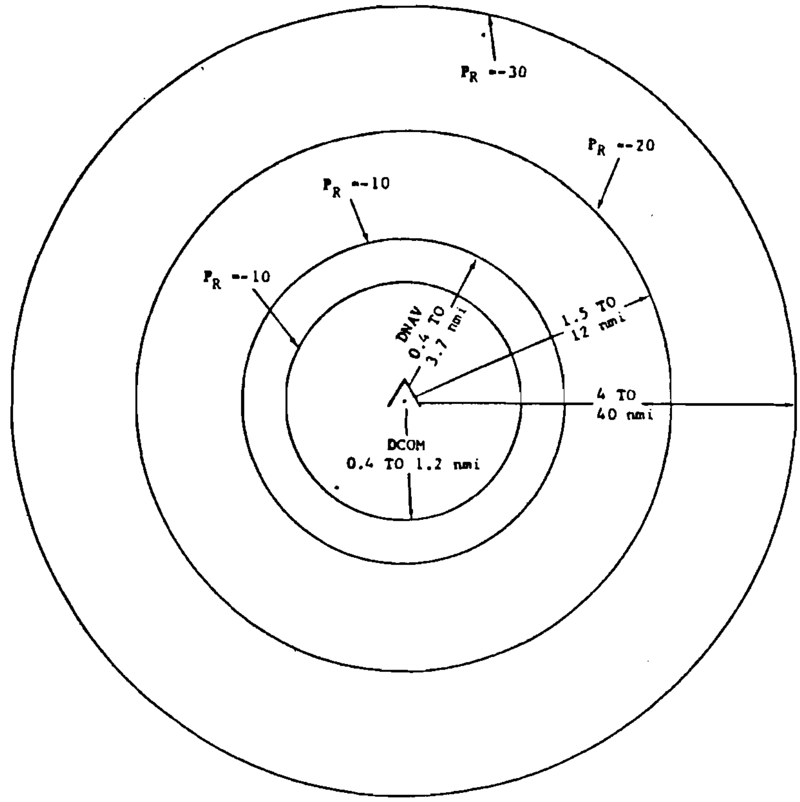
Figure 6 illustrates the Topeka, Kansas, area for which power circles have been drawn around the local FM stations. Based on the required combination of KSWT, KTOP and KTPK for an intermodulation frequency of 121.7 MHz, the figures should be studied to determine the expected area of interference (crosshatched). Interference should be expected in the area common to that overlayed by the PR = -30 (DCOM) circle of KSWT, the PR = -20 (DCOM) circle of KTPK, and the PR = -20 circle of KTOP. The area defined as common to these three circles would be a conservative prediction of interference area for communication receivers. Recorded data for Topeka indicated that the predictions were substantially correct. Within the area, the effect of antenna radiation lobes causes the interference to appear to be intermittent, depending on the course the aircraft was flying through the area. The duration of interference is frequently only a few seconds, which reflects the lobe condition of radiation.

Not all areas of radiation may be predicted by the described technique. As described in NAFEC Technical Letter Report, NA-77-41-LR, "High Power FM Station Interference to VHF Avionics, Topeka, Kansas," radiation levels from high-gain FM antennas may at times far exceed the level calculated from the effective-radiated power of the FM station and the assumption of uniform omnidirectional radiation due to reflections and lobing in the airspace. High-gain FM station antennas are usually designed to radiate a pattern no more than $\pm 10°$ from the horizontal. However, based on flight test data, high-level signals are usually measured directly above FM antennas.

Loss of Sensitivity. The laboratory tests conducted with single FM signals into the receivers showed a loss of sensitivity of as much as 10dB for high-level FM signal inputs. The loss should not, however, adversely effect reception in the terminal areas where signal levels are normally expected to be greater than -75dBm unless there is an intermodulation frequency present due to the presence of appropriate frequencies. There would not be any audible interference as a result of the single high-level FM signal. Multiple FM signals at high levels result in sensitivity loss equivalent to single signals.

Emergency Locator Transmitter Effects. The adverse effect of the ELT used in laboratory tests and during the flights tests is evident in much of the data presented. The level of FM signal required to cause interference from the ELT is at a minimum between -5 and -0dBm. Below the -5dBm level, the ELT ceased to adversely affect its environment. Solutions to the ELT problem have not been considered. Appropriate action to correct the problem is necessary as the ELT is a unit covered by a Technical Standard Order (TSO).

Brute Force Interference. One type of "brute-force" interference is a condition which results from the proximity of the FM band and the ILS band. The FM frequencies extends from 88MHz to 108MHz where it interferes with the low end of the ILS band. This type of interference will most often occur only if the separation is a few hundred kHz; thus, it is present only at the low end of the navigation band. The FM interference is present due to radiation of on-frequency power within the FCC authorized levels. Proper frequency engineering will prevent authorization of this condition. The conforming FM emission is: "Between 120 and 240kHz removed from the carrier, any emission must be at least 25dB below the unmodulated carrier. Between 240 and 600kHz removed from the carrier, any emission must be at least 35dB below the unmodulated carrier. Any emission removed from the carrier by more than 600kHz must be at least 80dB below the level of the unmodulated carrier or at least $40 + 10\log_{10}P$ whichever is the lesser attenuation ('Reference Data for Radio Engineers,' ITT, Fifth Edition)."



KEY:

P_R =-10 DCOM WITHIN THE SIGNAL LEVEL OF P_R =-10, DCOM INTERFERENCE TO COMM RECEIVERS WILL PROBABLY OCCUR WHEN ONE OR MORE OTHER STATIONS HAS A P_R =-30 CIRCLE WHICH OVERLAYS IT.

P_R =-10 DNAV SAME CONDITION FOR NAV RECEIVERS AS FOR COM RECEIVERS BUT CIRCLE OF GREATER RADIOUS DUE TO AVIONIC ANTENNA FREQUENCY RESPONSE.

P_R =-20 BETWEEN P_R =-10 AND P_R =-20 INTERFERENCE MAY OCCUR IF THE CONDITION OF OTHER OVERLAYING STATIONS ARE MET.

P_R =-30 THE MINIMUM SIGNAL LEVEL WITHIN WHICH INTERMODULATION MAY BE EXPECTED.

77-44-230

Figure 3
Receiver Signal Level Diagram for PRDCOM and PRDNAV

A second type of "brute-force" interference is where the strength of signal is the critical parameter. Protection against this form of interference is particularly critical for navigation receivers. The protection procedure should establish distance from the FAA facility within which interference levels should not exist. The level must consider the standards for receiver performance. The scope of the project did not seek to establish such a level.

Finally, no brute force audio modulation was observed during laboratory tests. The maximum input which could be achieved in most cases was approximately +5dBm. Rarely, during flight testing, were FM signal levels on the spectrum analyzer observed to exceed 0dBm.

The report from the Federal Aviation Administration present eight conclusions and three recommendations which are listed below. Again the specific frequency numbers are not so important as the relationship between the potentially interfering radiation sources.

CONCLUSIONS

1. Intermodulation interference from FM stations was found to be present at most locations where flight testing was conducted at low altitude. The locations were in or near cities which had several high-power FM stations serving the cities. The interference was most severe near major FM radiation areas used by several stations. The interference recorded affected both communication and navigation receivers.

2. A 10dB increase of rejection in the avionic receivers to FM signals would nearly eliminate intermodulation interference.

3. Receiver sensitivity and selectivity are significantly reduced by high-power FM signals.

4. The presence of an FM signal at the prime level in a terminal area diminishes the number of channels in the VHF avionics band available for avionic use which will be free of interference to all but high-performance avionics.

5. Due to avionic antenna frequency response to the FM band, avionic receivers are less subject to interference of FM signals near 88MHz.

6. Intermodulation interference at the high end of the VHF communications band is less frequent and less severe based on receiver response to laboratory interference tests.

7. Expected intermodulation interference can be effectively located through the use of Venn diagram circles whose radii

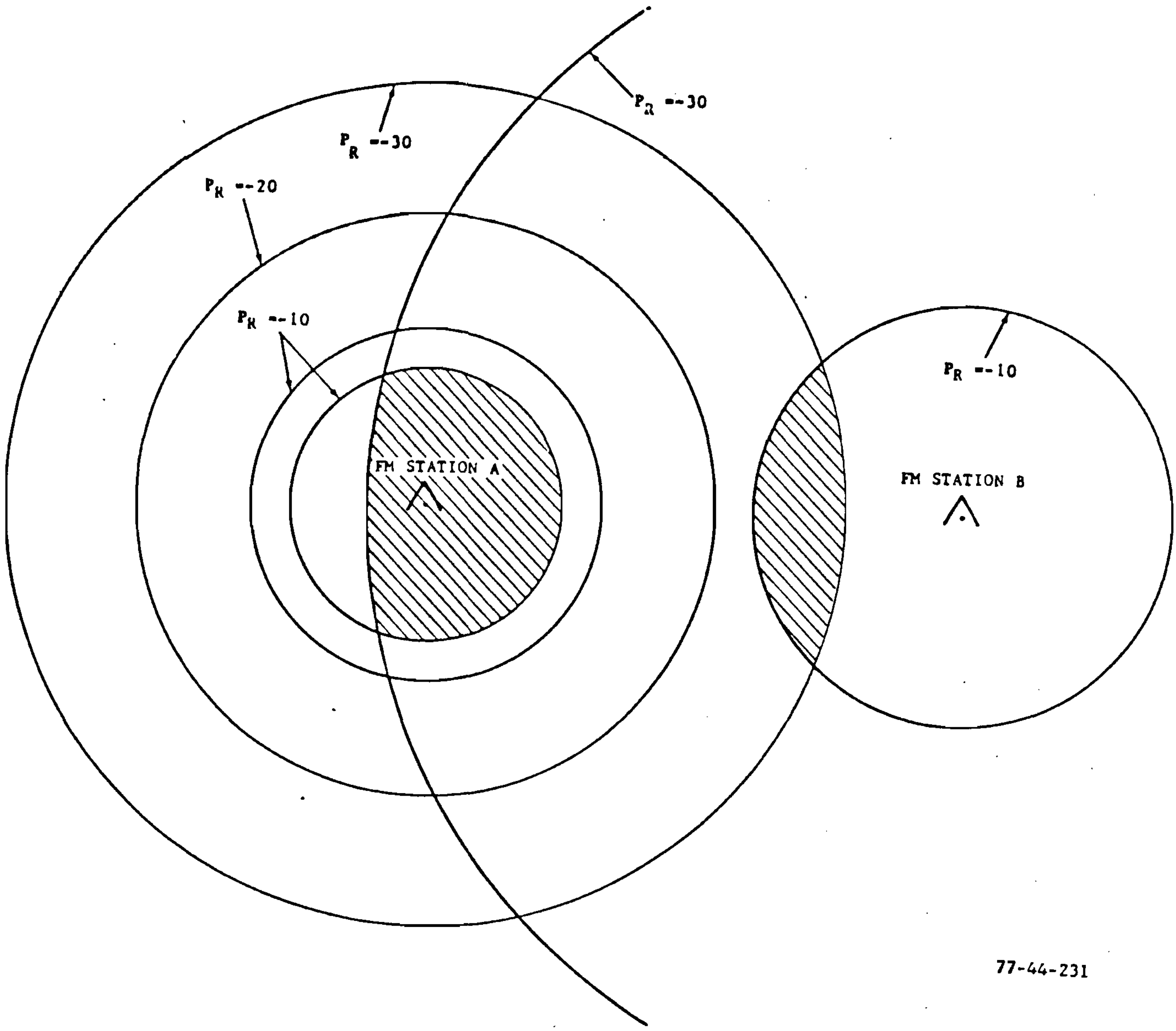


Figure 4
Two FM Station Interference Areas for PR = -10 and PR = -30

are based on receiver input power level. However, interference may occur when reflections and radiation characteristics of an FM antenna cause an FM signal to be present at an intermodulation power level even though calculated radius based on ERP would indicate that it should be beyond the range of interference level.

8. Certain ELTs increase the amount of intermodulation interference from FM stations to VHF avionics due to diode action on FM signals within the ELT and reradiation of the modified signals to avionic receivers via the ELT antenna.

RECOMMENDATIONS

1. Protect from "prime" level FM signals the ILS and VOR approaches to airports and also those air spaces near airports where communication intermodulation interference is considered hazardous to general aviation. A "prime" level signal in these areas will adversely affect most general aviation avionic receivers and establish the condition which will cause intermodulation with the presence of an intermodulation "secondary" FM signal.

2. Implement a procedure for analysis of expected FM station interference from proposed FCC action. The procedure should include both "brute force" considerations as well as intermodulation prediction based on the Venn diagram approach of this report, in order to adequately protect the communication and navigation frequencies of the VHF avionic band.

3. Establish a flight test program by Flight Standards Service to determine the FM spectrum signature and power level at airports which may be subject to FM interference. Current information on FM airspace power levels is inadequate to perform frequency management assignments free of FM intermodulation interference (particularly for navigation receivers).

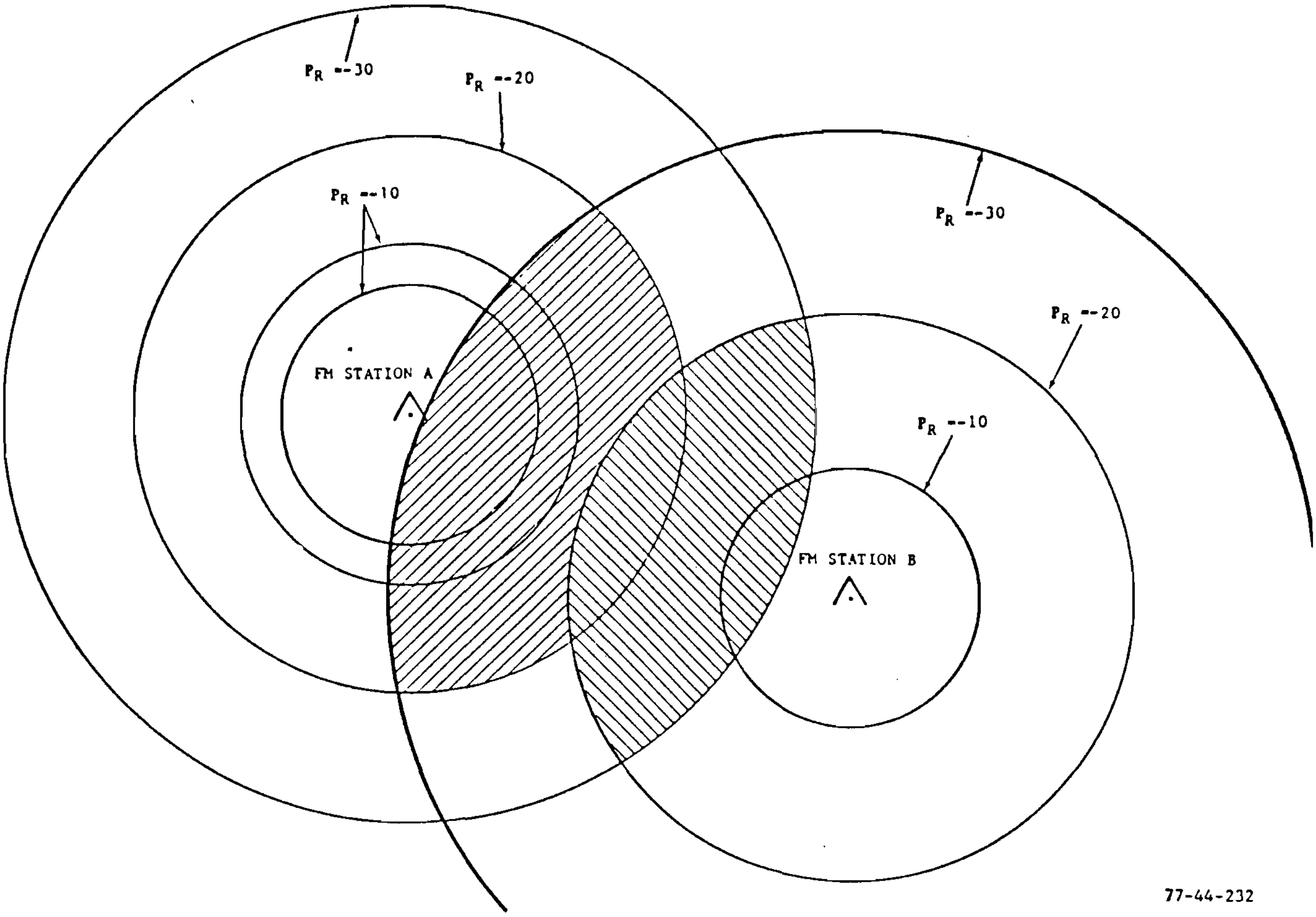


Figure 5
Two FM Station Interference Areas for PR = -20

As technology spreads, further demands will be placed on the limited communication frequencies. It is important that information be exchanged regarding effects of different incursions into the aviation frequencies. The FAA report referred to above is merely the initial step.

In addition to cable television expansion, wireless telephones and wireless cable TV systems have just been approved by the Federal Communications Commission in the United States. What effect will these have on the aviation community? FM stations had been in operation for many years before FAA Report FAA-RD-78-35 was commissioned. Hopefully, it will not be so long before a similar study is conducted on wireless TV and wireless telephone systems.

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Biography

James Francois Leggett graduated from Flight School in June, 1968, and became a F-105 Combat Pilot. He flew 150 missions over North Vietnam as a Wild Weasel Pilot, and also served in Korea and Thailand. He was admitted to the Washington State Bar in 1976, and practice before the Washington Supreme Court. He holds a B.A. from the University of Puget Sound; an M.S. from the University of Southern California, and a J.D. from University of Washington.

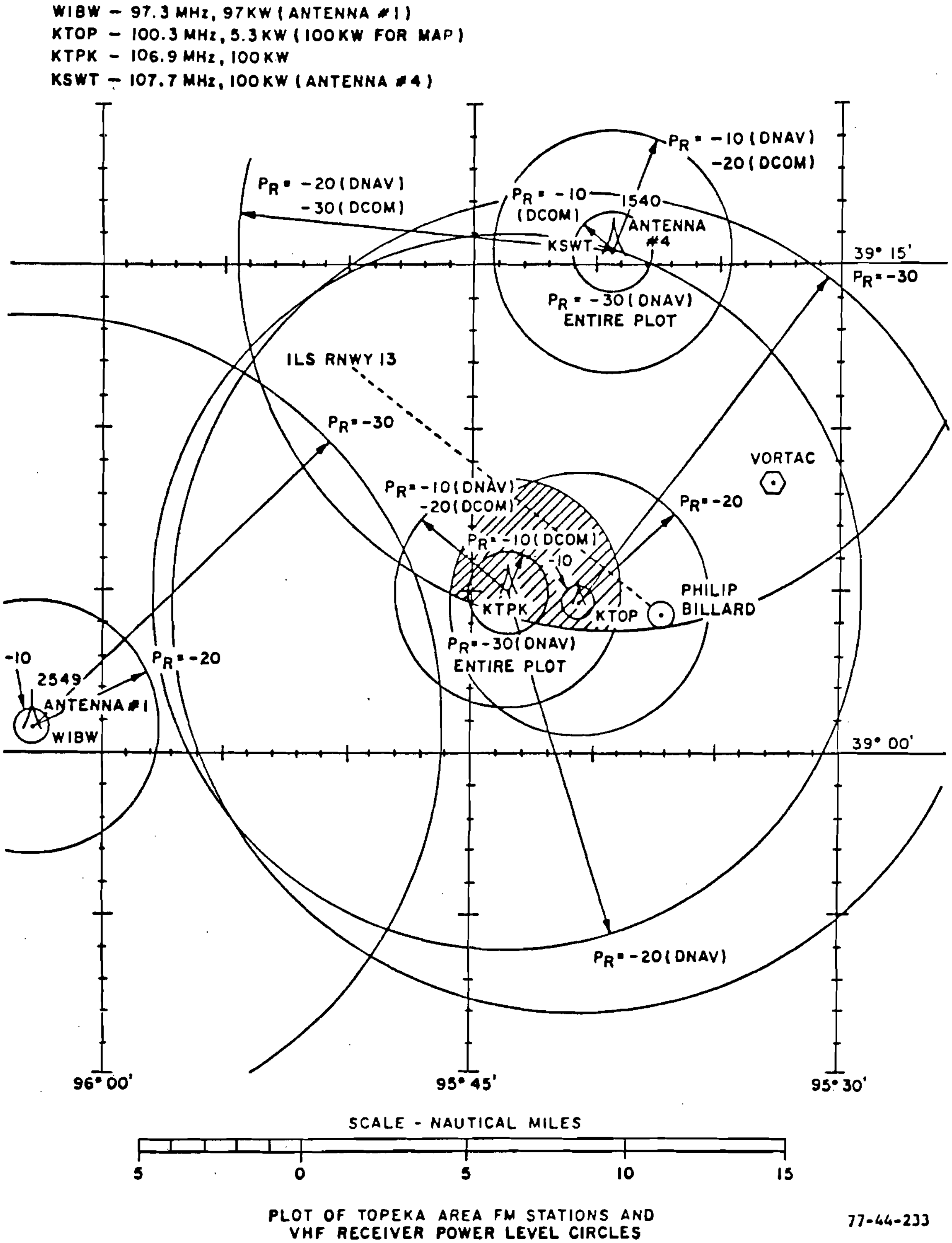
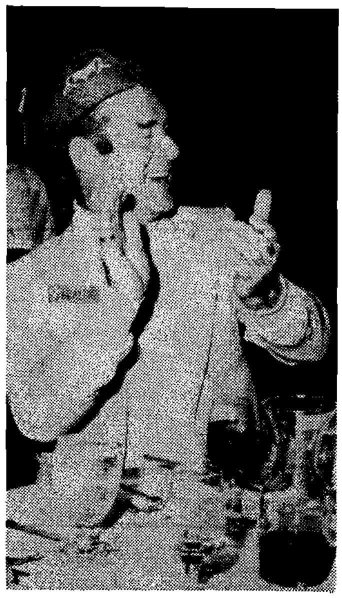


Figure 6
Topeka, Kansas FM Station Radiation Power Circles



Control Cab Video Recorders: A Pilot's Viewpoint

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At the last Seminar, a paper was offered by Mr. William Shumate espousing the concept of a Control Cab Video Recorder (CCVR). Mr. Shumate explained in his talk that the objection to a CCVR comes mostly from the flight crews. I stand before you today impaled upon the horns of a dilemma. I wish to try to explain to you why Mr. Shumate is correct when he states that most pilots are opposed to the cockpit video recorder concept without offending either Mr. Shumate or my friends at the NTSB. I know it is not an easy task which I have set out to accomplish. But I will try to set forth some of our frustrations, concerns, and fears without making it sound like a complaint letter. We are all on the same team here, and since the new administration has come to the NTSB, we at the Air Line Pilots Association have been very gratified that a new spirit of cooperation has made itself evident between our organizations, both at the Board level, and at the staff level. I wish to say nothing here today that would jeopardize that long desired relationship. I therefore ask that you accept what I am about to say in the spirit in which it is intended, and realize that we do have a problem.

Mr. Shumate initiated his proposal with a pair of analogies. The first concerned a doctor; the second a bank robber. I want to comment briefly concerning those analogies, because they make two very important points in my argument. Let's take first the analogy concerning the doctor, I will attempt to draw an interesting parallel. Does anyone know how many people died upon an operating table in the world last year? And how many of those might be attributed to "doctor error"? Dr. Samuel Garth, a celebrated physician of times past, loved to drink wine to excess. A companion once said to him, "Really, Garth, you ought to quit drinking and hurry off to your patients." Garth replied, "It's no great matter. Nine of my patients have such bad constitutions that all the doctors in the world can't save them, and the other six have such good constitutions that all the physicians in the world can't kill them." I wish to cast no aspersions upon those gentlemen of the medical profession who might be with us, but I believe that I would be on very safe ground to state that the number of airline passengers killed last year by "pilot error" would be small when compared to the number of persons who died unnecessarily on operating tables around the world. Yet do we hear a clamor for voice and video recorders in the operating room? The same arguments could be made that are made for the CCVR. It could prove that a doctor did not commit malpractice. It could exonerate him. Every doctor should demand one in the operating room. And if he did err, the films could be used as training films to train other doctors in what not to do. At most, it would reveal an "honest" mistake on the part of the doctor. I know many of you do not remember the wording used by Mr. Shumate, but trust me when I say that in general, I have merely substituted "doctor" for "pilot" and "operating room" for "cockpit". But you and I are well aware that these suggestions will never come to pass, because doctors would fear misinterpretation of their actions and intentions. And the life and death decisions which they had to make in scant seconds would be analyzed for months and even years by courts, lawyers, and other experts who have never held the scalpel in their hands.

The second analogy concerns a bank robber who is apprehended because of the bank video recorder. Mr. Shumate asks, "Why not take a picture of the scene and of the culprit?" May I say that this analogy is a chilling example of the mind set that seems to us to exist with respect to the use of recording devices. "Catch the crook and punish him."

The comment is made, "No one likes to blame the flight crew." I must respond that this statement has not been borne out by experience. Look at the advantages of that approach. First, since a mechanical problem was not identified, no costly redesigning and refitting must be done. Second, public confidence in the aircraft is maintained or restored. And third, liability of the manufacturers, the government, and ofttimes the companies is avoided. May I give you an example. A few years ago, an aircraft crashed in the fog during a non-precision approach. The co-pilot survived. He testified under oath that he misread his altimeter by 1000 feet. Why? Nobody asked. Why didn't the captain catch the fatal error? His life literally depended upon it. Nobody asked why. Why weren't these vital questions asked and answered? Because the CVR revealed some extemporaneous conversation by the crew several minutes before the accident. From the moment the CVR was read out, the probable cause became crew inattention, and we lost an opportunity to correct an altimeter known to be subject to 1000 feet misreads, and which the Air Force rejected as inadequate over 20 years ago. Unfortunately, only the last 10 minutes of the tape were read out for the report. Had the previous 20 minutes been read, it would have revealed that the captain had made several references to his extreme fatigue, including the comment, "I'm so tired, I can't wait until I get to the hotel so I can rest." So, we also lost an opportunity to study fatigue and scheduling rules. Here, the CVR performed a function opposite to its intended purpose in that it caused the investigation to be suppressed. Of course the crew made mistakes—fatal ones—but we never really explored why, and thus our primary mission of accident prevention was denied.

Mr. Shumate makes the point that the CCVR certainly cannot incriminate the innocent. May I counter that statement with another example. A twin-engine prop-jet lost an engine on takeoff and immediately began a turn toward the dead engine. The aircraft was successfully landed in a field with minor injuries and no fatalities to the occupants. Due to a misinterpretation of an almost unintelligible comment on the CVR, the investigating authority determined, despite crew testimony to the contrary, that the crew crashed while attempting to return to the airport, at which the weather was below landing minimums. Once again, the CVR had stymied, not aided the investigation. Subsequent engineering and flight tests conducted by some of the interested parties on an identical fleet aircraft revealed that the wing-fuselage gap straps had not been maintained properly, and the wing-walk material was improper, degrading the performance of the aircraft until stall speed was 14 knots higher than the book value. In addition, the rudders, which were not gust locked at the gate, had been blown about by taxiing aircraft, resulting in the rudder cables being stretched to the point that full rudder movement was no longer available—a primary requirement in an engine out situation. Approximately the same conditions existed for all aircraft of that type in the fleet. The rudder stops on many of the aircraft had been broken away. There was a vital clue. The structures group documentation revealed that full rudder travel was not available on the accident aircraft. But the CVR had cut short the investigation, and the evidence was lost when the aircraft was cut up for removal. The words "gear up" could not be located on the voice recorder, but the retract cyclinders were found in the nearly retracted position. The crew was accused of delaying the gear retraction until too late. Subsequent investigation revealed that the hydraulic bypass handle was not in the stowed position, which was not readily discernible to a crew member. Later flight tests indicated that a substantial increase in gear retraction time resulted from the bypass handle being in this position. A passenger seated in a position to watch the gear reported that the gear started retracting immediately after takeoff, but seem to hang after it started up. The passenger was an hydraulic engineer. And last, the output from the hydraulic pump was found to be below tolerance. But this evidence was uncovered by the interested parties after the investigation had been cut off by the investigating authority because the words "gear up" could not be located on the CVR. The test aircraft was found to be unflyable on one engine, yet the report blaming the crew still stands. Here, we believe, is an almost undeniable case in which the voice recorder incriminated the innocent.

In another case, the investigative research was halted when it was discovered that the CVR had been erased at the end of an eventful flight, even though the event in question occurred some 45 minutes prior to the end of the flight and the information desired would not have been on the CVR even had it not been erased. In spite of the fact that the captain maintains that he does not recall erasing the CVR, and in spite of the fact that a CVR mechanic has given evidence that the mere act of switching to ground power sometimes causes the tape to be erased, a crew that we believe to be innocent was blamed in this case because of the *lack* of CVR data. And as I have said many times before, I believe a potential killer still lurks in this aircraft type, and I can only selfishly pray that I am not the next one that encounters the same problem. Once again the CVR stymied the investigation. Again I'll quote Mr. Shumate, "As it stands, the incident is unexplained, corrective action cannot be taken, and another occurrence is possible."

Mr. Shumate makes a further point that "the CCVR would exonerate the crew, or at worst, might reveal that an honest mistake had been made." It is an unfortunate fact of life that at least up until now, no credit has been given for "honest" mistakes. And I point to United at Portland, United at Salt Lake City, Eastern at Charlotte, Eastern at Raleigh, National at Pensacola,—the list could be extensive. All of these flights involved "honest" mistakes on the part of the flight crew. But in each case, the CVR provided the damning evidence, and the crew was blamed just as they would have been had their actions been deliberately careless. This is not to say that they should not have been blamed. But honesty and intent are not presently considered in accident reports around the world.

Another major concern of airline pilots is the release of CVR transcripts to news media, whose only purpose for possessing this information is to sensationalize it. CVRs have been played on the radio and television for widows and children of the decreased to enjoy. The public hearing had not even been held before the entire transcript of the CVR on the Pan American New Orleans accident was printed in Aviation Week. Was the release of the transcript to the media instrumental in the determination of the probable cause, or did it contribute to accident prevention? It was not, and it did not. The CVR is a private document, owned by a private corporation, and recorded by persons employed by the private sector. Several states have taken the position that so-called Freedom of Information legislation requires that this information be released. I do not believe that private documents need to be released, simply because they are used in a government investigation. A precedent for this position is the treatment of proprietary material. "Proprietary" seems to be a magic word. Mention it, and the information is never released. Why could not that same philosophy be applied to voice recorder tapes and transcripts. I urge each of you to press for legislation that would exempt CVR data from Freedom of Information type legislation in each of your countries where this is a problem.

The uses to which the CVR has been applied have progressed far beyond the original concept. When the CVR was first proposed, we were assured it was for use only in the case of catastrophic accidents in which the flight crew did not survive. (Some states apply that policy today.) It was never suggested at the outset that the CVR would be substituted for crew testimony or that it would be used to impeach the testimony of surviving crew members, as in Kalamazoo. Additionally, both company and government officials routinely remove and examine the tape for such mundane incidents as aborted takeoffs, turbulence encounters, engine failures, and firm landings. We fear that a similar propagation of the original CCVR concept would be inevitable. We already routinely watch astronauts in space from the comfort of our living room. It is well within the present state of the art to view and record cockpit activities from the ground. The next logical step would be to view and record this information from a ground station. Then it wouldn't matter if the camera were destroyed in an accident! The record would be preserved. You might suggest that this is far-fetched. But when the CVR was proposed, present usage would have seemed unthinkable.

It has been said that a pessimist is a man who thinks all women are bad. An optimist is a man who hopes they are. I am by nature an optimist and a believer. When the CVR was first proposed, I was at the forefront in attempting to obtain pilot acceptance. I felt it was a tool that was sorely needed. But an optimist is also described as a guy who has never had much experience. And at that point in time, I hadn't much experience. I also think of myself as a purist where accident investigation and accident prevention are at stake. Some of you may feel that this opinion is another prime example of gross pilot error. If I could prevent an accident by pronouncing a pilot at fault, I would do so without hesitation. Experience has been a harsh teacher for me, and where cockpit recording devices are concerned, I am no longer a believer, nor an optimist. I have in fact come full circle to believe that we would probably have more complete and carefully researched accident investigations if the CVR did not exist. But the greater effect would be that many more problems would be identified, and more corrective actions would be taken.

The International Federation of Air Line Pilots Associations has adopted the following policy: "IFALPA does not recognize as valid the use of Cockpit Video Recorders at this stage in view of the history of the use of flight recorders and the fact that adequate means of accident investigation are now available." The Air Line Pilots Association will consider the adoption of the following policy next month at their convention: "Due to the history of the abuse and misinterpretation of the flight and voice recorder data, the Air Line Pilots Association is opposed to the use of cockpit video recorders in the cockpit of commercial aircraft." As a purist, I found it personally very distasteful to have authored that policy for both organizations, and I offer my apology and regrets to my fellow purists in ISASI. Mr. Shumate could argue with considerable justification that some of my own arguments have demonstrated the need for a CCVR. I could not agree with him more. I am stricken by my conscience as an accident investigator that I must deny such a fantastic tool. But my other, pilot conscience will not let me stand idly by and watch arm-chair Monday-morning quarterbacking extend our distress into another dimension.

Are there answers to our dilemma? I believe there are. I would like to call it accident prevention by design. Let me explain. With modern aircraft engineering, the ratio of human error accidents to equipment failure accidents has increased considerably, until pilot error is today the number one cause of accidents by far. The difficulty lies in engineering humans to perform flawlessly. Several airlines have made a giant first step in that direction, notably United Airlines with their new human performance training. I wish every airline had that program. But the catch here is that no matter how well trained a pilot is, and no matter how often you tell him that he must not be complacent, and that he must always remain alert and attentive, somewhere, sometime, for whatever reason, some pilot will let his guard down momentarily, and it will bite him. So instructing flight crew members to be careful is not, and cannot be the answer. And to carry this line of reasoning one step further, pointing out that a crew had an accident because they were lax or inattentive will not prevent another accident from the same cause. They only remedy available to us is to design around the human frailties. We as an industry must, by engineering and design, make it more and more difficult for a lax or fatigued pilot to make errors. But before that can be accomplished, we must be willing and able to identify the reason that the pilot's inattention proved disastrous. For example, we must be willing to admit that some altimeter types are more easily misread than others, especially under conditions of stress and fatigue. Yes, I can read any altimeter you set before me at nine o'clock in the morning, in a test environment with a cup of coffee at my elbow. But test me some nights after a twelve hour duty day, in turbulence, in a dynamic situation, and I will guarantee you that I will occasionally misread my altimeter. And the easier the altimeter is to misread, the more prone I will be to misread it.

Another answer would be to record instrument readings. With the multi-parameter recorder, most of the information required is already being recorded. And plug-in recorders which record those extensive parameters are now available for present foil-type recorders. This change should be required by ICAO Standard and by the governments of the various States.

Ladies and gentlemen, it would give me great pleasure to be able to endorse the CCVR concept. But fool me once—shame on you. Fool me twice—shame on me. I hope that though you might disagree with us, you will understand why we feel compelled to take a position on this issue that is as onerous to us as it undoubtedly is to you. And I hope that collectively we can find a better resolution to this problem than we in our organization have been able to find.

Biography

Dale (Bud) Leppard has been a Pilot for Eastern Air Lines for the past 20 years, and Captain on B-727 for the past 10 years. He is Chairman—ALPA National Accident Investigation Board and Chairman—IFALPA Accident Analysis Study Group. He participated in more than 25 major accident investigations. He holds a B.S. in Physics from Fairleigh-Dickinson University and a M.S. in Mechanical and Aerospace Engineering from Rutgers University.

Classification of Pilot Errors As Needed by the Cockpit Designer

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I assume, that when talking to a forum of air safety experts, I do not have to start with convincing the audience that a large part of pilot errors could be avoided by better cockpit design. I am sure that you will also agree that a lot of information on pilot errors is available. It is about the best and most accurately documented information which exists on the topic of human error. For the past year, I have been trying to utilize the large data base on pilot errors to achieve better designed cockpits. I cannot claim any originality in this respect. On the contrary, let me point out an outstanding effort done in this area as soon as 1947. At that time Paul M. Fitts and R.E. Jones published two reports, which are considered classical:

A. Analysis of factors contributing to 460 "Pilot Error" experiences in operating aircraft controls.

B. Psychological aspects of instrument display. Analysis of 270 "Pilot Error" experiences in reading and interpreting aircraft instruments.

Even though the errors described above were committed on W.W. II machines, many of them are repeated by pilots today. The fact that the recommendations for reducing pilot errors by proper cockpit design, as given by Fitts and Jones in 1947, remain valid after 35 years is admirable.

Ever since W.W. II, many investigators tried to devise a meaningful classification of human errors. It is clear that gaining better understanding of how and why errors are made, improves our ability to avoid such errors in future systems.

I searched the literature dealing with human errors and their classification in hope to find a system directly applicable to cockpit design. Many classifications exist, their criteria set by the interior and/or profession of the respective investigator. Some typical examples:

Omission errors vs. commission errors

Reversible vs. irreversible errors

Random vs systematic vs sporadic errors

Though interesting, such classifications are not directly applicable to cockpit design. They can serve to analyze existing systems, but are of little use in synthesizing new ones. Their main advantage is in their being exhaustive; i.e., all "cockpit initiated" pilot errors can be represented in such a classification.

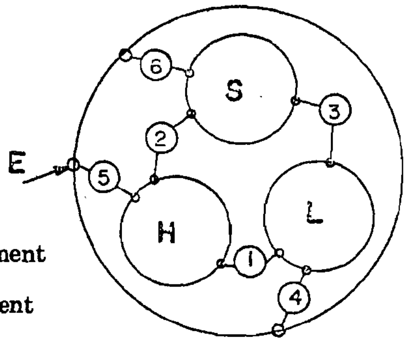
The cockpit designer can be presented with a huge computer data base, containing thousands of pilot errors, all of which he tries to avoid in his new cockpit. Unfortunately, while the engineer is busy with the design procedure, he is unable to cope with such an enormous amount of information. He wants to be presented with information relevant to the subsystem he is dealing with and which is appropriate to the stage of the design he is involved with at the moment. In other words, the cockpit designer wants the computer to present him a cross section (or a profile) of pilot errors relevant to the design task at any moment. Such a system should be exhaustive - all pilot errors of the data base, relating to the cockpit designed, should appear in the union of the cross sections called up.

Let us go back to the Fitts-Jones Report mentioned before. There we find the first classification, relating to Hardware: Errors connected with controls vs errors connected with instruments. Each of the two classes is further classified according to the main reason of the errors.

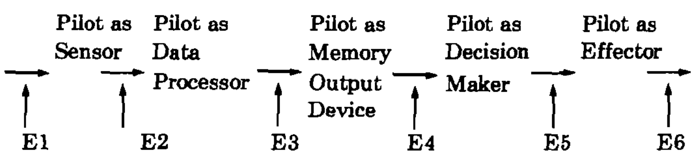
Control errors are divided into: confusion, adjustment, forgetting, reversal, unintentional activation, reaching... Errors connected with displays are divided into: multirevolutional, reversal, interpretation, legibility, substitution. Reading inoperative displays, scale interpretation, illusions, forgetting.

The Fitts-Jones Model is not exhaustive; for example, control-display interaction errors and errors stemming from interfaces are missing. Here is an additional classification based on the more recent SHEL Model can improve the situation. This model points to six interfaces in the Software, Hardware, Environment, Livewave system. All of the six resulting interfaces are relevant in cockpit design:

1. Man-Hardware
2. Software-Hardware
3. Man-Software
4. Man-Environment
5. Hardware-Environment
6. Software-Environment



When I gave up hope to find an existing error classification system to suit the cockpit designers' need, I devised one for that purpose. This system, and the IAI-Manor Classification, is based on a functional pilot activity analysis performed for checking pilot procedures. The results of the above analysis indicate a basic pattern of activity, which is the element in all modes of flight and situations the pilot encounters. This system describes five basic functional roles, which the pilot performs in each cycle of the basic pattern:



Any possible pilot error, E1, E2...E6 can be attributed to one and only one of the above functions.

E1 - Results in the failure to detect information

E2 - Results in the failure to discriminate information

E3 - Results in the failure to process information

E4 - Results in the failure to retrieve data from memory

E5 - Results in the failure to take correct decision

E6 - Results in the failure to react according to decision

The classification which resulted proved to be much of an improvement and was also exhaustive. Its only disadvantage was the excessive size of the error classes, which made an effective use difficult. As a result, a further classification was added; each of the six error types E1...E6 was classified according to one of four cockpit design activities: Control, Display, Location or Lay-out. This results in the classification of pilot errors into 6×4 = 24 types.

DESIGN ACTIVITY \ PILOT ERROR	E1	E2	E3	E4	E5	E6
CONTROL						
DISPLAY						
LOCATION						
LAY-OUT						

This classification is a good tool in the process of cockpit design. It's only visible disadvantage is that at some stages of design, not all the errors are relevant. For example, at the preliminary design stage, the engineer does not utilize errors resulting from inadequate scaling or pointer form on an instrument. On the other hand, at later stages of design such as detailed specifications of items, some errors stemming from location and/or lay-out are not relevant anymore. To oversome this, there is a tendency to add a third parameter to the classification; i.e., the stage in the design process: Preliminary Design, Mock-up, Detail Design, Simulator, Hardware Specs.... This results in 3 dimensional classification, in which the data base of pilot error is classified into 6×4×5 = 120 groups. Each of the 120 cross sections is described by the pilot function, by the design topic and by the stage of the design. This promises to ensure relevancy to immediate design situations.

Conclusions

A. Multi-dimensionally classified pilot error data bases are efficient tools for cockpit design.

B. The above data bases can also be efficiently used in the process of existing cockpit evaluation.

C. Engineers tend to transform pilot error lists into design check lists. If this transformation is correctly executed, no harm is done.

D. New concepts in modern cockpit design (Multi-purpose CRT's, Computers + Keyboards, HOTAS, etc....) introduce new errors. This dictates continuous updating of the error data bases.

About the Author

Yehuda P. Manor is Head of the Human Factor Engineering Department of the Israel Aircraft Industries. His main areas of activity and interest are cockpit design and Human Factors application to command and control rooms.

He graduated in the first Pilot Course in the Israeli Air Force, and during 21 years of service was in command of various R & D units.

He holds a B.Sc. in Physics, Mathematics and Statistics from hebrew University in Jerusalem, and completed graduate studies at the University of Michigan, with an M.S.E. in Aeronautical and Astronautical Engineering.

Engine–Out Flight Training Revisited

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More than ten years ago, in a paper entitled "The Case Against Engine-Out Flight Training",[1] it was pointed out that deficiencies existed with the method by which the minimum control speeds were determined during certification. As a result of these deficiencies and the lack of adequate margins applied during inservice flight training, it was concluded that the practice of training for engine-out procedures in the airplane was not worth the sacrifice of pilots and aircraft. Some individuals, however, argued that it was necessary to train pilots in engine-out operations even though the frequency of engine failure during scheduled operations was minimal. It is the purpose of this paper to review the training accident history and in particular during this last decade to show that passenger flight safety has not suffered by taking engine-out training out of the airplane and putting it into the simulator. It is also the purpose of this paper to caution those who may have become complacent or who may not have acquired the knowledge of the deficiencies in the V_{mc} certifications with the consequence that engine-out training accidents could recur.

ACCIDENT HISTORY

While training accidents have been caused by many factors, in the past the most severe accidents have been those associated with loss of control as a result of simulated engine failures. In particular, as will be discussed later, the 4-engine jet transport has been most susceptible to this type of accident. Although other aircraft types are certainly not immune, their aerodynamic characteristics tend to limit the exposure to the engine-out loss of control accident.

Appendix A contains a listing of all jet transport training accidents from 1958 to 1980. Table 1 shows the list of aircraft types reviewed for this study. From this list, all known engine-out training accidents as well as those which might possibly have involved engine-out operations were selected and are shown by aircraft type in Appendix B. Table 2 lists the jet transport engine-out training accidents for U.S. Air Carriers and Other Than U.S. Air Carriers. Table 3 lists the accidents according to the type of engine-out maneuver being attempted.

It should be noted that following the long series of engine-out training accidents in the 1960s, the FAA instituted a so-called moratorium on engine-out procedures in the airplane. While this moratorium allowed these maneuvers to be conducted in an approved simulator, it did not abolish completely the requirement for engine-out training in the airplane.

[1]Foxworth, T.G. and Marthinsen, H.F., "The Case Against Engine-out Flight Training" AIAA Paper 71-793

A result of this failure to ban engine-out procedures from the airplane caused several more accidents until the last air carrier 4-engine jet training accident in the U.S. occurred at Ontario, California, on March 31, 1971.[2]

At about this time, the industry was beginning to get the message and engine-out training began to be conducted more and more in simulators. However, the FAA never changed its rule which, even today, allows an FAA inspector or designated examiner to require th emaneuver be demonstrated in the airplane.

AIRCRAFT TYPES REVIEWED

GENERATION

1st	2nd	3rd
B-707	A-300	DC-9
B-720	B-747	B-727
DC-8	DC-10	BAC 1-11
CV-880	L-1011	B-737
CV-990		

TABLE 1

During the period 1958-1980, 65 jet transport training accidents[3] have occurred world-wide, (Fig. 1). Of this total, 31 have involved engine-out training, (Fig. 2). The severity of the engine-out training accidents can be seen in the data for the aircraft destroyed or the fatal accidents which have occurred in this phase of flight. (Table 4) While engine-out accidents accounted for only 46% of the total number of jet transport training accidents, the engine-out training accidents accounted for 81% of the destroyed aircraft and 83% of the fatal accidents.

[2]An additional accident, but not to an air carrier, occurred on 12/5/73 to a Jet Set Travel B-720 conducting a simulated two-engine out approach at Moses Lake, Washington. An FAA inspector was onboard giving a type-rating flight check. The aircraft experienced substantial damage.

[3]Accidents are classified as those occurrences in which the aircraft experienced at least substantial damage or persons onboard the aircraft suffered at least serious injuries.

TRAINING ACCIDENTS ENGINE-OUT JET TRANSPORT AIRCRAFT

U.S. AIR CARRIERS

25/2/59	PAA	B-707	Chartres
15/8/59	AAL	B-707	Peconic
23/5/60	DAL	CV-880	Atlanta
28/1/61	AAL	B-707	Montauk Pt.
13/9/65	TWA	CV-880	Kansas City
29/6/66	AAL	B-720B	Mojave
30/3/67	DAL	DC-8	New Orleans
28/4/68	CPT	DC-8	Atlantic City
26/7/69	TWA	B-707	Pomona, N.J.
11/2/70	PAA	B-707	Stockton
3/31/71	WAL	B-720	Ontario
9/2/79	EAL	DC-9	Miami

OTHER THAN U.S. AIR CARRIERS

4/12/61	DLH	B-720B	Ebershiem
30/12/63	JAL	DC-8	Okinawa
15/7/64	DLH	B-720	Ansbach
29/11/64	FAA	B-720	Oklahoma City
27/2/64	JAL	CV-880	Nagasaki
4/7/66	Air New Zealand	DC-8	Auckland
26/8/66	JAL	CV-880	Tokyo
21/11/66	BOAC	B-707	Bedford
20/5/67	Air Canada	DC-8	Ottawa
24/6/69	JAL	CV-880	Grant County
23/1/71	Air India	B-707	Bombay
8/3/71	BOAC	B-707	Prestwick
5/12/72	Egyptair	B-707	Beni Soeif
5/12/73	Jet Set Travel	B-720	Grant County
10/5/75	VARIG	B-737	Porto Alegre
17/3/77	British Airtours	B-707	Prestwick
23/3/79	Olympic	B-707	Athens
23/7/79	Trans Med	B-707	Beirut
11/9/79	China Airlines	B-707	Taiwan

TABLE 2

JET AIRCRAFT TRAINING ACCIDENTS INVOLVING ENGINE-OUT OPERATIONS 1958-1981

2 Engine-Out

25/2/59	PAA	B-707
15/8/59	AAL	B-707
28/1/61	AAL	B-707
4/12/61	DLH	B-720
30/12/63	JAL	DC-8
15/7/64	DLH	B-720
30/3/67	DAL	DC-8
20/5/67	Air Canada	DC-8
28/4/68	Capitol	DC-8
5/12/73	Jet Set Travel	B-720
23/3/79	Olympic	B-707

V_1 Cut

25/5/60	DAL	CV-880
13/9/65	TWA	CV-880
4/7/66	Air New Zealand	DC-8
26/8/66	JAL	CV-880
24/6/69	JAL	CV-880
8/3/61	BOAC	B-707
10/5/75	VARIG	B-737
16/3/77	British Airtours	B-707
9/2/79	EAL	DC-9
23/7/79	Trans Med	B-707
11/9/79	China Airlines	B-707

1 Engine-Out

21/11/66	BOAC	B-707
26/7/79	TWA	B-707
11/2/70	PAA	B-707
23/1/71	Air India	B-707
31/3/71	WAL	B-720

Miscellaneous

29/11/64	FAA	B-720
29/6/66	AAL	B-720
5/16/72	Egyptair	B-707

TABLE 3

When categorized according to the period in which various aircraft types were introduced into service, the following conclusions are evident:

FIRST GENERATION JETS

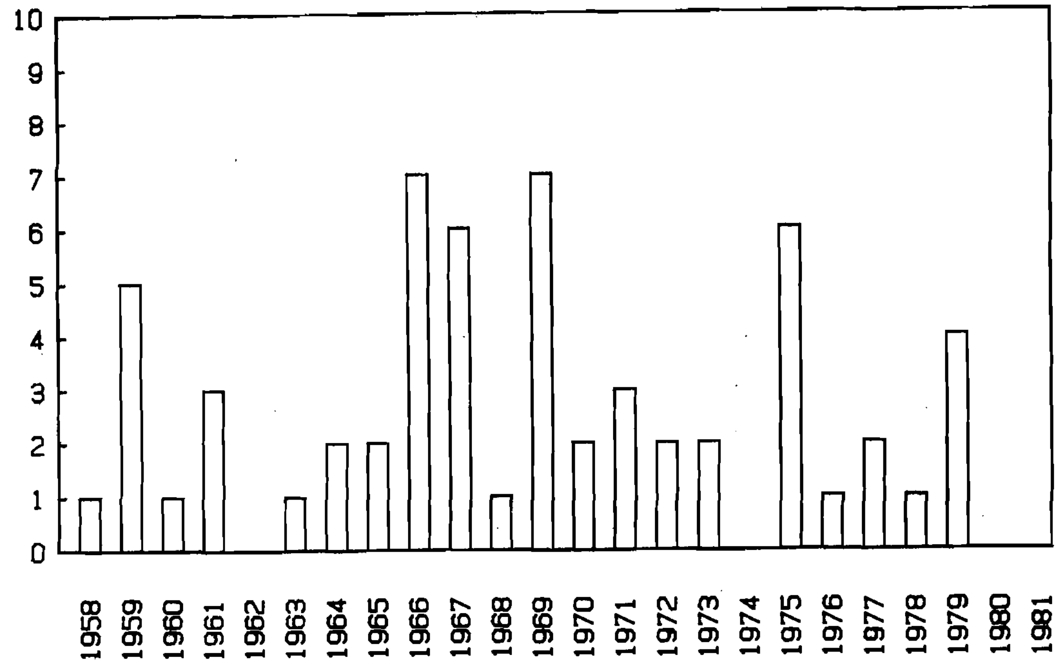
Because of the inherent aerodynamic characteristics of the 4-engine jet transports, they clearly accounted for the greatest number of engine-out training accidents, (Fig. 3). For the first generation of jet transports, the B-707/720, the DC-8 and the CV-880/990, there were 47 training accidents of which 29 or 62% were engine-out. Of the aircraft destroyed in training, 87% (20 of 23) involved engine-out procedures. Of the total fatal training accidents, 15 of 17 involved engine-out procedures (88%).

SECOND GENERATION JETS

The accident record of the second generation jet transports, which includes the DC-9, B-727, BAC 1-11 and the B-737, shows a remarkably improved engine-out training accident record with only 2 of the 14 total training accidents attributed to engine-out procedures. While the small numbers distort the percentage, it should be noted that of the two accidents involving engine-out operations, neither was fatal and only one aircraft of this second generation was destroyed (this accident to a DC-9 bears special attention and will be discussed further).

FIGURE 1

WORLDWIDE
JET AIRCRAFT
TRAINING
ACCIDENTS



THIRD GENERATION JETS (WIDE-BODIES)

The wide-bodied aircraft have experienced no destroyed aircraft nor any fatalities in only three training accidents.

Figure 4 shows the engine-out training accident percentages by aircraft.

What do the statistics show? First, the engine-out loss of control accidents have been for the most part restricted to the wing-mounted 4-engine airplanes (Table 5). Of the 31 engine-out accidents from 1958-1980, 29 of those are the 4-engine jet transports. There are several reasons for this. Following the large numbers of jet training accidents in the late 60s, more training has finally gone into simulator, thus the relative absence of engine-out training accidents in the second and third generation airplanes. Then, too, there has been a gradual phase-out of the older 4-engine jets in service and thus a reduction in the amount of training which takes place in those aircraft. But aside from these considerations, it should be clear that the 4-engine jet transport is especially susceptible to engine-out loss of control accidents in training because the training has attempted to match too closely the method by which these airplanes were certificated. The result is that training leaves virtually no margin for even the slightest error. Furthermore, it disregards other factors that were not considered when the certification tests were conducted; e.g., crosswinds. In essence, the training does not reflect the realities of line operations because it is so closely tied to the certification criteria where tests are conducted in a sterile environment.

FIGURE 2

WORLDWIDE
JET AIRCRAFT
ENGINE-OUT
TRAINING
ACCIDENTS

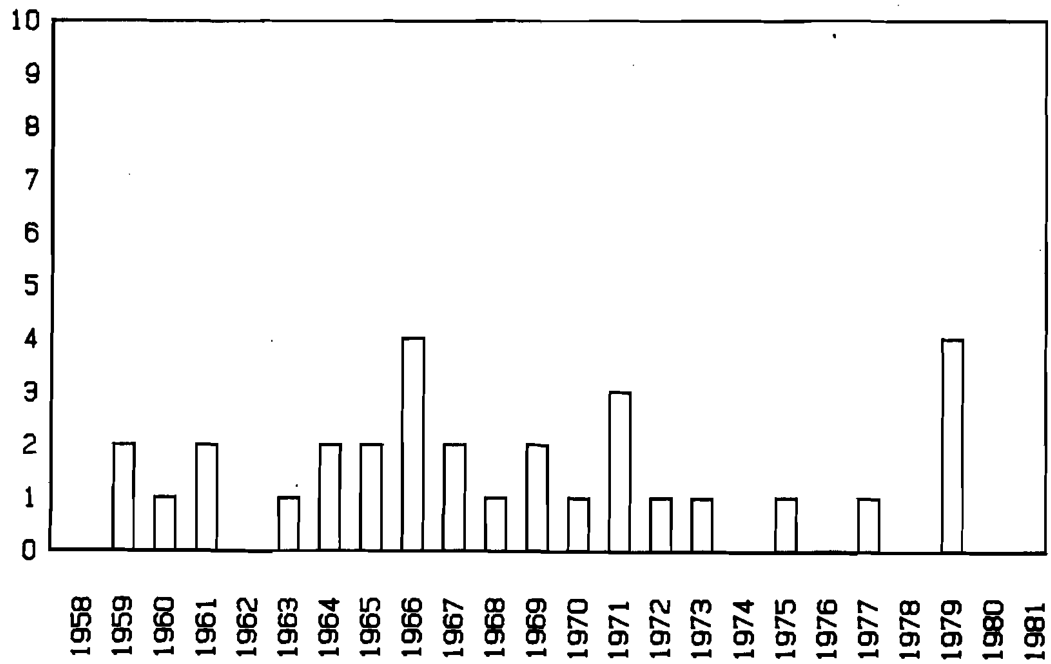
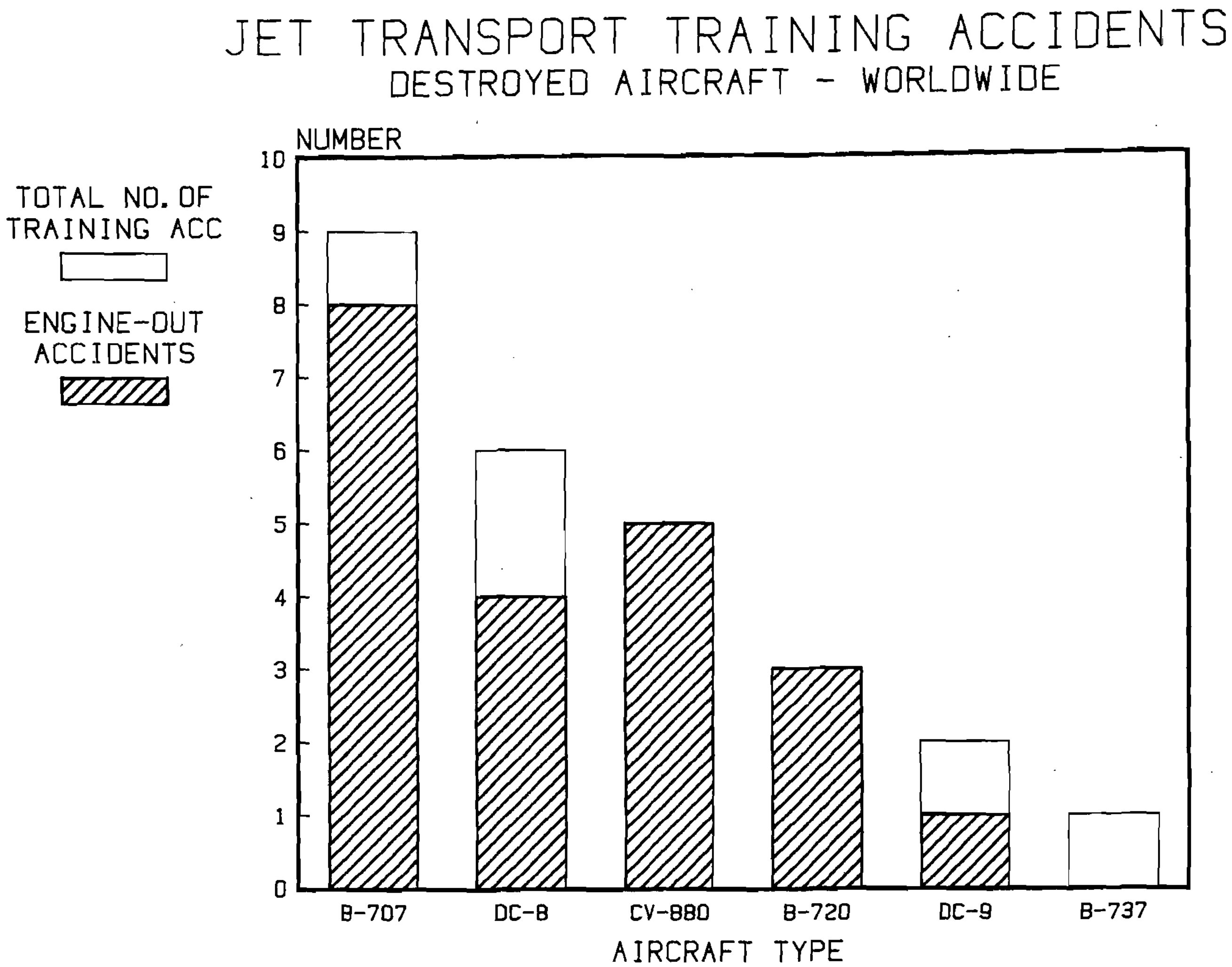


FIGURE 3



There are no known in-service air carrier jet transport accident which can be attributed to loss of control of the airplane as a result of an engine failure. Even after more than 20 years of jet transport operations, there has not been one accident in scheduled service that can be used to justify the practice of demonstrating* in the airplane *a pilot's ability to handle in engine failure.

Although engine failures have occurred in-service, pilots generally have not used the procedures taught to them in training but instead used a common sense approach of using all the margin available to them. For example, when an outboard engine has failed, the approach was conducted using high thrust levels on the two inboard engines so that minimum control speeds were substantially reduced, or using less than full landing flaps and carrying speed pads over and above those allowed in training. These are just some of the ways pilots have compensated to provide adequate safety margins. No doubt, some pilots would have failed the check ride with these procedures. The engine-out training accident record as we now know it is a result of poorly designed and improperly certificated airplanes from the standpoint of engine failure at low speeds. This hindsight conclusion is not meant to cast any aspersions on any one particular airplane but only to put into perspective the evolution of the design of jet transports in general.

There are many factors which determine the minimum control speed characteristics. The lateral placement of the engines from the fuselage centerline, the amount of thrust applied to operative engines and the size of the vertical stabilizer are just some of the aerodynamic design parameters which affect the minimum control speed. The design of the second generation jets was such that these parameters all contributed to improving minimum control speed capability, some to the extent that the published V_{mc} was below stall speed. The DC-9, BAC 1-11 and B-727 all have body mounted engines which substantially reduce the asymmetrical thrust moment arm. Then, too, the center, in-fuselage engine of the B-727, the DC-10 and L-1011 provides thrust performance with absolutely no contribution to the minimum control speed problem. Relatively larger vertical fin areas of the later generation jets certainly contribute to lowering minimum control speeds. While intuitively all of these design features are helpful, we still don't know the magnitude these features have in reducing $V_{mc's}$ simply because certification is still conducted under a cloak of secrecy and the resulting data is still considered proprietary.

But what was the real cause of all the loss of control training accidents? Some would have you believe that it was simply a case of pilot error. A more plausible explanation, as stated before, is that the early airplanes did not have sufficient margins to allow pilots to operate them under typical line operational training conditions. To understand this, it is necessary to review just how the aircraft were certificated for minimum control speed.

FIGURE 4

ENGINE-OUT TRAINING ACCIDENTS
BY AIRCRAFT GENERATION

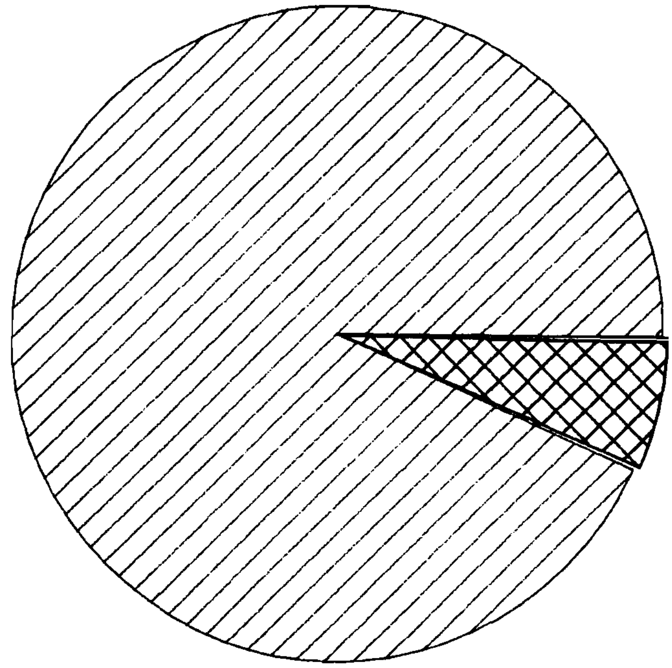


Figure 5 shows the possible range of conditions of bank angle, sideslip and rudder deflection under which it is possible to maintain straight flight. But note, by definition of V_{mc}, that the minimum speed is not reached until the limiting conditions of up to 5° bank angle and full rudder are reached. (A further limit is that the rudder pedal force may not exceed 150 lbs.) In certification, the tests are continued until all limitations—that is, until the lowest possible speed within these limitations is reached. It goes without saying that these tests are most demanding and are continued until the pilot cannot demonstrate a lower speed. The reason that the manufacturer attempts to push this speed as low as he possibly can is because this speed has a powerful effect on takeoff performance, since other takeoff speeds are referenced to it.

Much of what has been written concerning minimum control speed (V_{mc}) has been overly simplified and this in turn has led to a widespread lack of appreciation of how complex V_{mc} is and how many factors influence it. V_{mc} is usually given to the pilot as a simple, solitary number. But few pilots know what this number really means and fewer still have any idea if the conditions under which it was determined duplicate the conditions under which it will be used. During critical engine-out operation, the pilot is faced with a dual task: to achieve adequate *performance* which has been degraded by thrust deficiency and to maintain adequate *control* which has been degraded by thrust asymmetry. The V_{mc} determined in certification treats only the latter case. In virtually all engine-out approach accidents the problem first originated by trying to meet very specific performance requirements, and in coping with performance deterioration, asymmetric thrust was added which in turn led to loss of lateral-directional control. The insidious factor is that *none* of the victims seemed to recognize how close their airplanes were to loss of control, even upon the verge of losing it, and the loss occurred within scant seconds in virtually all the catastrophic cases.

To state the problem seems simple: maintain straight, unaccelerated flight following the loss of an engine, and V_{mc} should be the slowest speed at which this can be done with full asymmetric thrust. But it is not so simple. For *every* condition of asymmetric thrust there is a minimum speed below which it is not possible to maintain equilibrium by aerodynamic controls, but this speed will vary with thrust, and thrust varies with throttle lever position, altitude and temperature. What is not so well understood is that for any given *fixed* conditions of asymmetric thrust, the minimum control speed will also vary according to different combinations of bank angle, sideslip angle and rudder deflection.

Figure 5 illustrates the range of flight conditions under which it is possible to maintain equilibrium; that is, a condition in which the airplane maintains a straight flight path. Although secondary effects have not been considered in the analysis, the illustration does give a general view of the range of possible combinations. One should not necessarily apply the statement of V_{mc} expressed herein to any one airplane; each airplane has its own characteristics which can only be learned through testing. However, the general behavior of airplanes is as indicated in this paper. In the illustrations the left outboard engine is inoperative.

In Figure 5(a), the bank angle is zero and the sideslip is from the bad engine side. A large amount of rudder is being used and the turn and bank indicator would show the ball in the center, since the wings are level (no gravity to offset the ball) and the flight path is straight (no centrifugal force to offset the ball). The deflected rudder generates a side force which pushes the airplane sideways (from the pilot's viewpoint) developing a sideslip which generates an equal and opposite fuselage side force to establish equilibrium.

JET TRANSPORT
TRAINING ACCIDENTS
WORLD-WIDE
1959 - 1981

	TOTAL TRAIN	DEST	FATAL	ENG OUT	DEST	FATAL	ENG OUT TOT	DEST E.O TOT DEST	FATAL E.O TOT FATAL
B-707/720	32	12	10	19	11	9	54%	92%	90%
DC-8	8	6	4	5	4	3	63%	67%	75%
CV-880/990	7	5	3	5	5	3	71%	100%	100%
1st Gen. Tots	47	23	17	29	29	20	58%	87%	88%
DC-9	5(6)*	2(3)	1(2)	1(?)	1(?)	0(?)	20%	50%	0%
B-727	3	0	0	0	0	0	0%	0%	0%
BAC 1-11	4	0	0	0	0	0	0%	0%	0%
B-737	2	1	0	1	0	0	50%	0%	0%
2nd Gen. Tots	14	3	1	2	1	0	14%	33%	0%
A-300	0	0	0	0	0	0	0%	0%	0%
B-747	2	0	0	0	0	0	0%	0%	0%
DC-10	0	0	0	0	0	0	0%	0%	0%
L-1011	1	0	0	0	0	0	0%	0%	0%
3rd Gen. Tots	3	0	0	0	0	0	0%	0%	0%
TOTALS	65(65)	25(27)	18(19)	31(?)	21(?)	15(?)	46%	81%	83%

*( ) Figures in brackets include a USAF DC-9 accident at Scott AFB 9/16/72 (this accident is excluded from the percentages)

TABLE 4

JET TRANSPORT ENGINE-OUT TRAINING ACCIDENTS BY AIRCRAFT TYPE

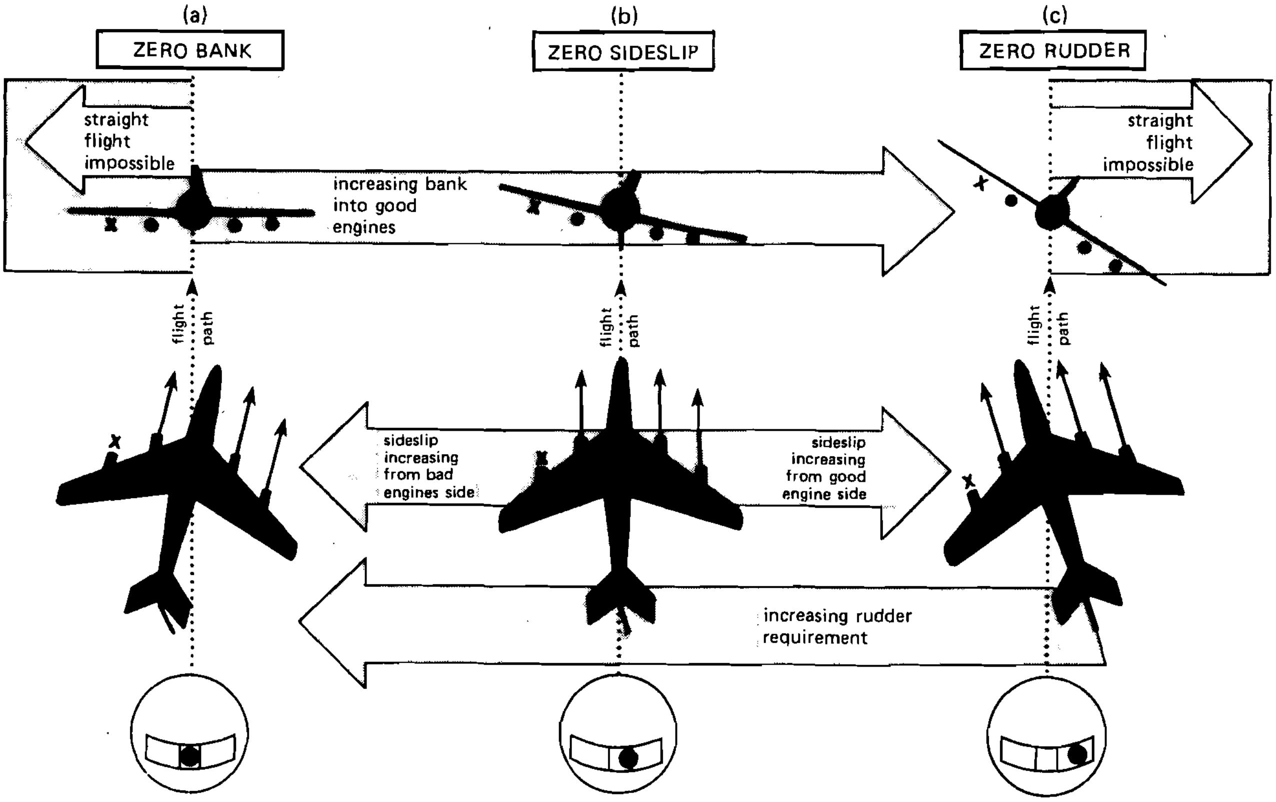
B-707/720	19
DC-8	5
CV-880/990	5
DC-9	1
B-737	1
B-727	0
BAC 1-11	0
A-300	0
B-747	0
L-1011	0
DC-10	0

TABLE 5

In Figure 5(b) the zero sideslip case is illustrated. This is the case for approximately least drag, hence maximum performance capability, and additionally is the case for minimum exposure to possible roll-due-to-sideslip coupling problems. It is the condition of flight the pilot would choose if he knew when it was achieved. The aircraft is banked slightly toward the good engine side, the amount of bank varies with airplane design. A lesser amount of rudder is being used than in condition (a), and the ball is slightly to the right. The side force generated by tipping the lift vector exactly balances side force from the rudder, and the fuselage centerline is nearly aligned with the flight path—hence little or no sideslip exists.

In Figure 5(c), a large amount of bank angle is being used with zero rudder deflection. The sideslip is now from the good engine side. The rudder pedals would be neutral with the yoke turned steeply toward the good engines and the ball far out to the good engines side. The fuselage side force generated by sideslip is offset by tipping the lift vector, pointing it in the opposite direction.

Figure 5



Between the bounds of crosshatching in Figure 6 exists the range of possible *steady-state* flight conditions; that is, in all cases, the airplane is flying along a straight flight path in a constant, unvarying manner. The flight conditions illustrated are not prescribed conditions for V_{mc}, although for each of the three situations illustrated, and for the infinite number of possible situations in between, there is indeed a minimum speed at which unaccelerated, rectilinear flight can just be maintained. This speed varies tremendously across the range of possibilities. For typical four-engine jet transports with wing-mounted engines, the minimum possible speed decreases at a rate of from 4 to as much as 8 knots per degree of bank, starting from condition (a), the zero bank condition. This rate continues through the zero sideslip point up to approximately 8°-10° bank angle, at which point the degree of sideslip from the good engines side becomes so severe that flow separation begins in earnest on the vertical tail. The minimum speed required to achieve steady-state flight then increases dramatically to avoid incipient vertical tail stall. (Figure 6(c)) Although the zero rudder condition is on the limit of possibility, the speed required to achieve it might be so high, especially in the case of 2 engines-out on one side, that it becomes strictly academic for any but airplanes with body-mounted engines.

The four-engine jet transports with wing mounted engines are the most critical from the standpoint of controllability, particularly with two engines out on one side. However, not all aircraft necessarily experience an irreversible, uncontrollable condition when the limits shown in Figure 6 are reached. On the contrary, assuming the aircraft has not experienced excessive drag because it is far removed from the zero sideslip case, when it reaches the limits shown in Figure 6 it will simply be unable to hold a heading. Within the possible range, all side forces tending to vary the airplane's flight path are balanced. For conditions outside this range, as indicated by the crosshatching, the side force acting on the airplane will force it to deviate from its intended heading; that is, the airplane will *yaw*.

It should be noted that yaw in these cases is *not* the same as sideslip. The terms yaw and sideslip are all too often used interchangeably—and all too often erroneously. For the purposes of this discussion, yaw angle is the angular displacement of the airplane centerline from some *reference azimuth*; i.e., yaw angle, by this definition can be read from changes in the compass heading. Yaw is assigned the shorthand notation (Ψ), whereas sideslip, assigned the shorthand notation (β), is the angular displacement of the airplane centerline from the *relative wind*. There is no way for the airline pilot to determine sideslip. Yet the sideslip angle, β, is essentially the airplane's directional angle-of-attack and is the primary reference for lateral and directional stability considerations. For example, during a 360° turn, the airplane yaws 360° but may have had zero sideslip throughout the maneuver. The term *yaw* is primarily used during the airplane time history studies and in wind tunnel work. The term *sideslip* on the other hand is more commonly used during flight tests, and it is sideslip—not yaw—that dictates the airplane's behavior.

Table 6 indicates the variance in $V_{mc's}$ for one representative model jet transport. Note the considerably lower $V_{mc's}$ in the 5° bank column as compared to the $V_{mc's}$ in the 0° bank column. Figure 7 shows flight test data acquired only after a recent accident in which the bank angle effect on V_{mca} for the B-707 was determined. This information has still not found its

SEA LEVEL, STANDARD DAY, TAKE-OFF POWER -- EQUIVALENT AIR SPEED KNOTS

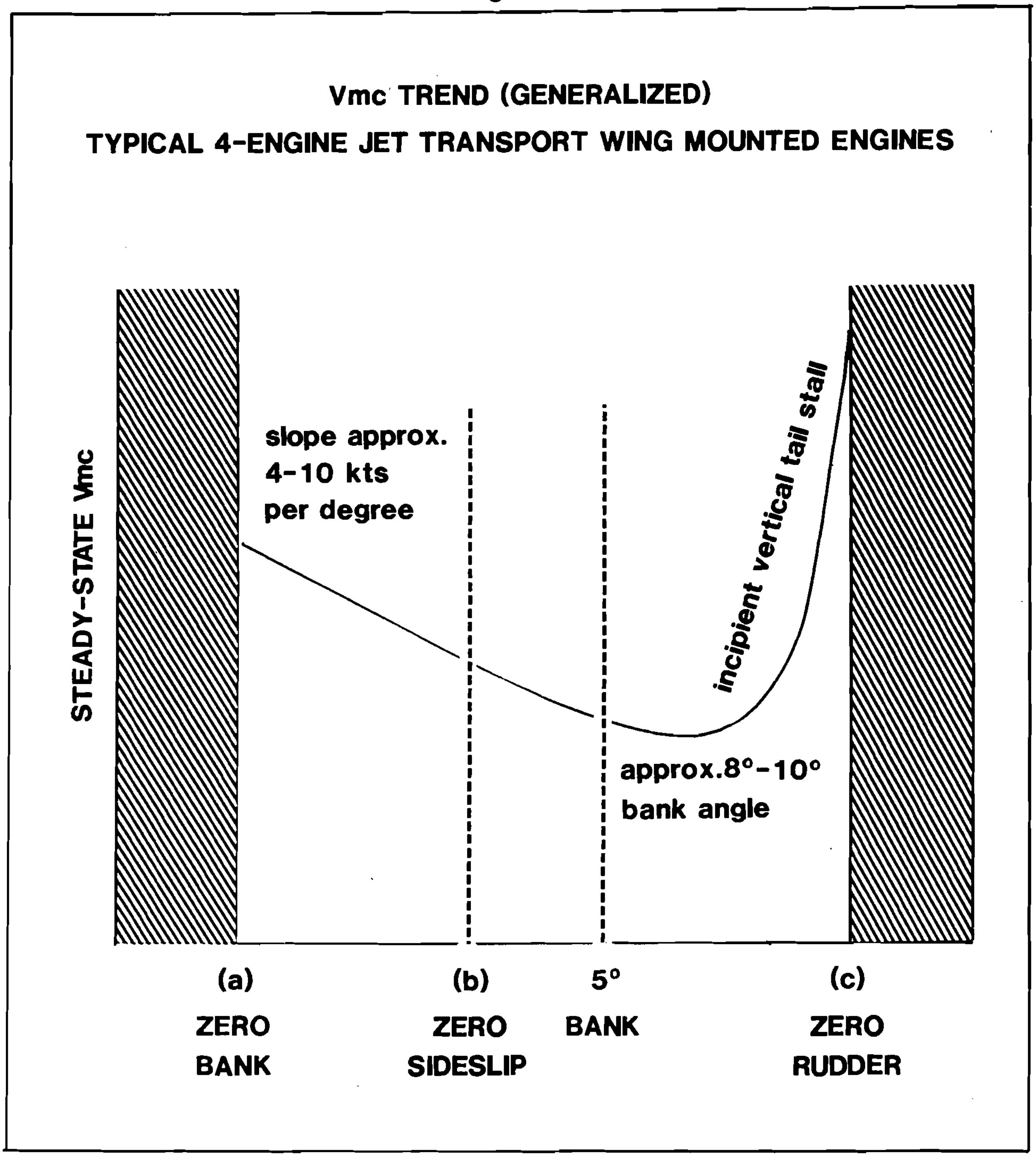
Airplane Configuration	Rudder Power Flaps Bank Angle	On Down 5%	On Down 0%	Off All 5%	On Up 5%
One Outboard Engine Inoperative					
Model	Engine				
DC-8 Series 20	P. & W. JT4A-3, -5	117	142	144	147
DC-8 Series 30	P. & W. JT4A-9, -10	122	148	152	154
	P. &. W. JT4A-11, -12	125.5	153	158	160
DC-8 Series 40	R. R. Conway R. Co. 12*	124	151	155	158
		(133)	(160)	(167)	(170)
DC-8 Series 50	P. & W. JT3D-1	110	142	144	146
DC-8 Series 60	P. & W. JT3D-3, -38	114	146	149	152
Two Engines On The Same Side Inoperative					
Model	Engine				
DC-8 Series 20	P. & W. JT4A-3, -5	153	188	204	Over 200
DC-8 Series 30	P. & W. JT4A-9, -10	160	197	217.5	"
	P. & W. JT4A-11, -12	166	204	229	"
DC-8 Series 40	R. R. Conway R. Co. 12*	170	200	220	"
		(182)	(212)	(240)	"
DC-8 Series 50	P. & W. JT3D-1	149	184	197	"
**DC-8 Series 60	P. & W. JT3D-3, -38	155	191	207	"

*The figures in parentheses for the R Co 12 engines are the minimum control speeds for sea level, cold day (-40°C), take-off power. The other engines listed are flat rated up to at least 15°C at sea level and the minimum control speeds at sea level are therefore independent of temperature below 15°C.

**DC-8 series 60 airplanes are certificated to same air minimum control speeds as the series 50.

TABLE 6

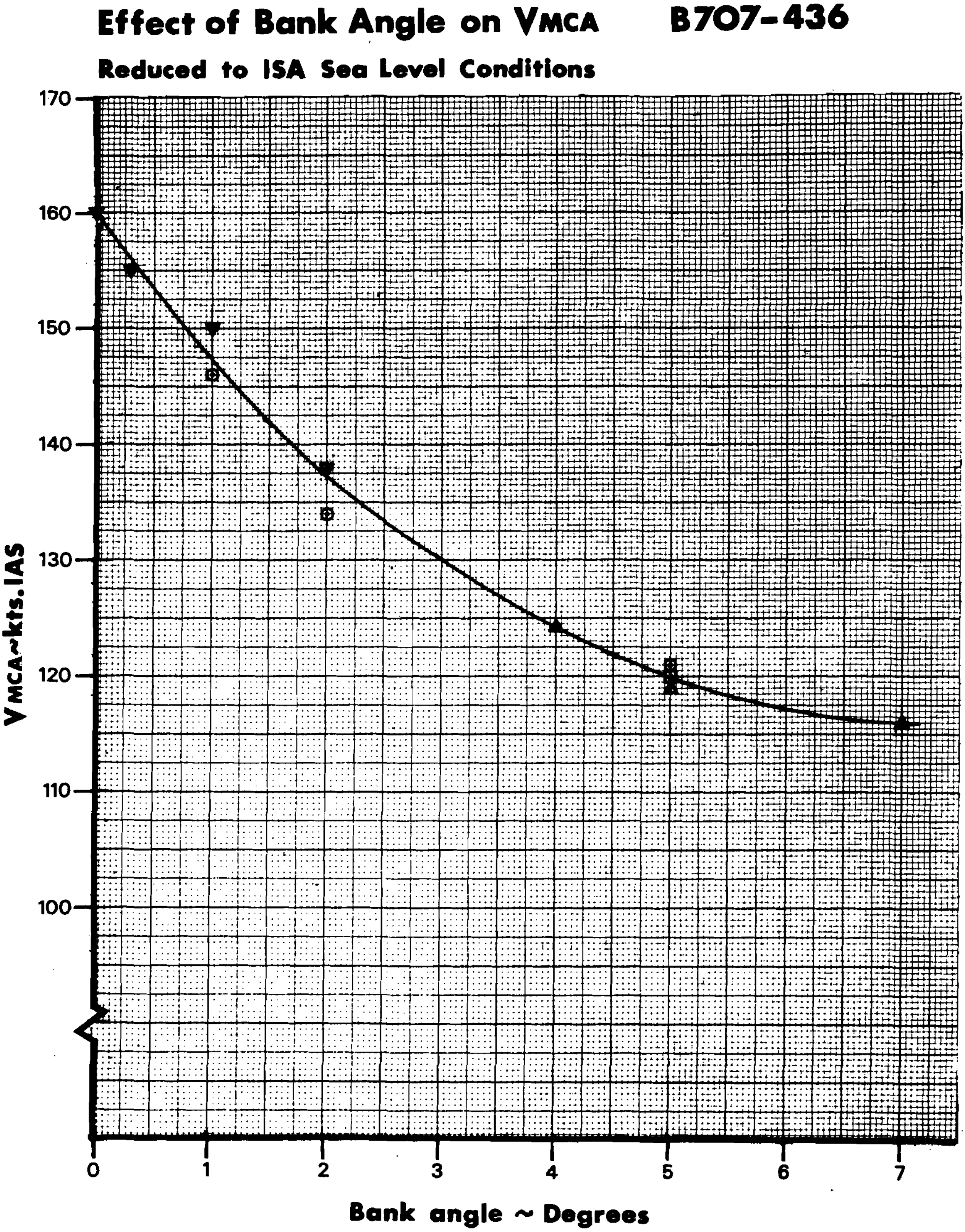
Figure 6



way into any of the flight manuals for the airplane. Other four-engine transports with wing mounted engines have comparable differences in the 5° versus the 0° bank angle $V_{mc's}$. The significant point is that the 5° bank $V_{mc's}$ are the values published in the flight manual and on the critical speed placard, while the 0° bank $V_{mc's}$ are the wings-level, ball-in-the-center values.

It should be emphasized that the pilot can be aware of bank angle and rudder deflection since he is directly controlling these. What he is *not* aware of is the degree of sideslip since there is no sideslip indicator in the airplane. Figure 5 clearly shows that *the ball does not indicate sideslip.* But swept wing jet transports are very sensitive to large sideslip angles and the dynamic conditions which are induced when sideslip is increasing at some rapid rate. When this happens several things can occur: (1) the vertical tail can lose its effectiveness and/or stall thus allowing the sideslip to suddenly increase even more; (2) the tendency for the aircraft to roll due to sideslip may be beyond the capability of the lateral control system; or (3) in some aircraft, the stall speed may be so near the published V_{mc} that the stall of one wing causes entry into a spin.

Figure 7



Effect of Bank Angle on VMCA B707-436
Reduced to ISA Sea Level Conditions
170
160
150
140
130
120
110
100
VMCA~kts.IAS
0
1
2
3
4
5
6
7
Bank angle ~ Degrees

Figure 8

CONDITION FOR MANUFACTURER'S Vmc

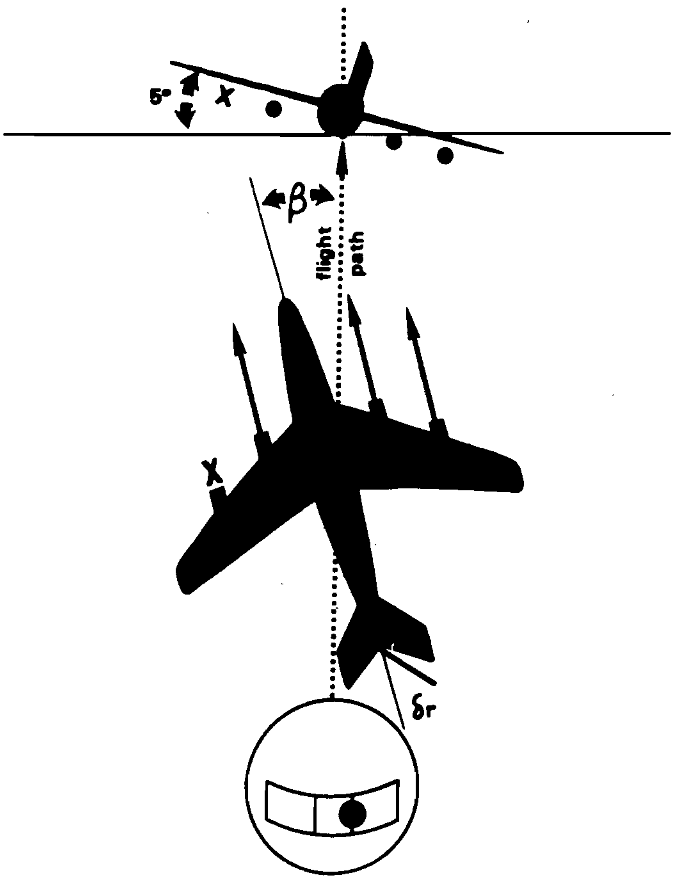


Figure 9

FALSE ZERO BANK POINT

equilibrium impossible

Referring once again to Figure 5, it should be pointed out that the V_{mc} determined by the manufacturer and presented in the flight manual is determined with the airplane in a steady-state condition of flight existing *between* illustrations (a) and (c). In short, the V_{mc} is determined by measuring the maximum applied yawing moment coefficient that the airplane can balance aerodynamically while using up to 5° bank to hold a constant heading. The method involves calculating Cn (the yawing moment coefficient) from the actual engine thrust at the minimum test speed and noting the bank angle. If the bank is less than 5° in a test condition, this means that the minimum authorized speed might not have been obtained, inasmuch as it would be possible to reduce the speed further while holding heading by increasing bank. Figure 8 illustrates this condition. The slowest steady speed at which equilibrium can be achieved with 5° bank and full rudder deflection is thus defined as the V_{mc} and it is this number presented in the flight manual. Note that the sideslip is from the good engine side and the ball is displaced slightly to the right. Indeed, to achieve the quoted V_{mc}, the 5° bank must be applied, and the ball displaced approximately one half width toward the good engines. During turns, the ball should be held in the *same* location, or perhaps returned toward dead center, but never should it diverge more-off-center.

However, note the similarity between this condition and the condition which is sometimes referred to as the *false zero bank angle point.* (Figure 9). Starting from the condition illustrated in Figure 5(a), if the rudder is relaxed the sideslip will shift and be from the good engine side. The new point may appear to be in equilibrium even though it is not. Compared to the true zero bank angle point illustrated in Figure 5(a), more rudder side force is now required, but it is obtained with less rudder deflection because of favorable sideslip at the tail. Rudder side force combines with side force generated by the fuselage and the aircraft is accelerated to the left. Equilibrium is impossible in this condition although it is difficult to see visually, especially since pilots generally try to fly in a wings level position when using the outside horizon as reference. But it can be recognized by a displacement of the ball to the right. If additional rudder is applied until the ball returns to the bottom of the race, the sideslip returns to the bad engine side and the original condition illustrated in Figure 5(a) will be re-established. The key point is that the only condition different between the false zero bank angle condition and the condition under which the manufacturer determines V_{mc} is essentially in the 5° bank angle used by the manufacturer. The speed at which loss of control would occur with bank angle zero and the sideslip from the good engine would be considerably higher. Pilots are generally not made aware of the condition under which the $V_{mc's}$ published in flight manuals are determined; in fact, it can be safely presumed that many airline pilots are not aware either that (a) 5° of bank is used in V_{mc} determination; or more importantly (b) what effect this 5° has on the V_{mc} presented in the flight manual.

The record clearly indicates inadvertent V_{mc} abuse because of inadequate appreciation by the pilot of potentially dangerous flying qualities near V_{mc} about which he is not properly made aware. The reason is simply that the V_{mc} in which the pilot is most vitally interested is *not* determined and presented to him.

So far we have considered only *steady-state* flight conditions. But V_{mc} is also very sensitive to *dynamic* effects. Indeed, violent deterioration of lateral-directional control which has killed so many air crews can be traced in large measure with lack of pilot appreciation of the relevant factors. In virtually all cases the yaw and roll were very rapid, disaster was very sudden, and the typical sequence of events occurred as follows:

1. The aircraft is in a critical flight phase such as takeoff or go-around when a large yawing moment due to asymmetric thrust appears very suddenly. The aircraft yaws rapidly through a large angle.

2. A large sideslip angle inadvertently develops because of the high yaw rate coupled with the surprise factor. A rolling moment into the bad engine is generated by the dihedral effect. This rolling moment is augmented by wing blanking on sweptwing configurations.

3. As the angular momentum builds in roll and sideslip, larger compensating moments over and above the steady-state requirements are required to arrest the motion. Large control deflections are required because of the reduced control effectiveness at slow speed, and adverse yaw adds to the forcing moment. If full control is insufficient to achieve equilibrium, a power reduction on the good engines will be required.

4. But a power reduction aggravates an already critical performance problem. Speed is difficult to maintain because of decreased thrust and increased drag.

5. If the down-going wing, which is at a high angle of attack because of the slow speed and the rolling velocity, is allowed to reach stall, the dynamic case may terminate without ever reaching equilibrium.

While the certification rules for jet transports require various measures of climb capability following engine failure, aircraft certificated under other rules may not. Those aircraft experience a two-fold problem, namely, a controllability problem due to the engine-out while at the same time a performance degradation which may exceed the capability of the aircraft. Generally speaking for four-engine transport aircraft, sideslip angle is not the limiting factor in the V_{mc} determination, except for the case with two-engines out on one side or one engine out, perhaps with the loss of rudder boost. When the vertical tail loss of effectiveness does occur first, the sudden increase in sideslip also results in exceeding the limits of lateral control. On aircraft types with engines mounted close to the centerline, engine-out operations do not usually result in lateral-directional controllability problems, but occasionally in performance problems due to thrust deficiency.

Engine-out training maneuvers in the airplane are dangerous for a couple of reasons. Not only are the prescribed procedures too close to the controllability limits due to the certification deficiencies previously pointed out, but there is also a greater exposure to *other failures* occurring during these procedures which leave no room for corrective action. A number of past training accidents involving unexpected additional failures are all too evident:

- Of interest is the DC-8 accident which occurred to Air New Zealand on July 4, 1966, at Auckland. The cause of the accident was the incurrence of reverse thrust during simulated failure of the #4 engine during takeoff. A rapid movement of the thrust lever generated an inertia force which caused the associated thrust brake lever to enter the reverse idle detent. After liftoff, the aircraft was destroyed and during the ensuing yaw and roll two crewmembers were killed.

- On March 8, 1971, during a BOAC B-707 training flight at Prestwick Airport, #4 engine was throttled back on takeoff. The aircraft came off the ground normally but immediately started to roll to the right and continued to do so despite the application of full left rudder and full left aileron. The training captain regained control by restoring power to #4 engine while reducing power on #1 engine. The rudder power control unit attachment lugs were found to have failed. The aircraft experienced substantial damage.

- Ironically, that same type of failure occurred to a Western Airlines B-720B just three weeks later during an engine-out missed approach at Ontario, California on March 31, 1971. The aircraft entered a yaw and roll which could not be controlled before the aircraft crashed inverted killing all on board.

- On July 26, 1969, a TWA B-707 was conducting a missed approach at Atlantic City, New Jersey, with the #4 engine power reduced to simulate an engine failure. A fatigue failure of the left outboard spoiler actuator downline caused the loss by hydraulic fluid from the aircraft's utility hydraulic system. The emergency procedures, which called for turning off all pumps was complied with. However, directional control of the aircraft was lost before power could be restored to #4 engine and the aircraft struck the ground in a right-wing low, nosedown attitude. All five crewmembers were killed.

- Another interesting case involves the only DC-9 engine-out training accident which occurred to Eastern Airlines near Miami on February 9, 1979. The DC-9 had just landed at a training field outside Miami and taxied to the opposite end of the runway for takeoff. Shortly after liftoff, during a simulated failure of the #1 engine, the left wing struck the ground, the aircraft then rolled to the right and the right wing contacted the ground. The aircraft broke up with the main wreckage coming to rest 750 feet to the left of the runway at a point 5700 feet from the runway threshold. Fortunately all crewmembers survived. What could have caused an uncontrollable roll on a DC-9 whose body mounted engines make the airplane relatively docile from the standpoint of minimum control speed problems? It is strongly suspected that a spoiler on the left wing remained deployed from the previous landing. A Service Bulletin relating the possibility of such an occurrence was issued subsequent to the accident.

These are just a few of the *known* cases where malfunctions have developed during engine-out operations to virtually insure a loss of control accident. While malfunctions such as these would present little problem in all engine operations, their occurrence in combination with the simulation of engine-out conditions seriously erodes any margin of safety. The above accidents should have alerted the industry to just how marginal engine-out training really was.

Needless to say, the real cause of engine-out loss of control accidents has not been recognized even today. The official records of these accidents still contain probably causes related to pilot error:

August 15, 1959, B-707, American, Peconic

"The Board determines the probable cause of this accident was the crew's failure to recognize and correct the development of excessive yaw which caused an unintentional rolling maneuver at an altitude too low to permit complete recovery".

September 13, 1964, CV-880, TWA, Kansas City

"Probable Cause: A loss of control during a simulated engine-out takeoff caused by improper use of flight controls. Inadequate supervision by the instructor captain".

March 30, 1967, DC-8, Delta, New Orleans

"The Board determines the probable cause of this accident was the improper supervision by the instructor, and the improper use of flight and power controls by both the instructor and the captain-trainee during a simulated two-engine out landing approach, which resulted in a loss of control".

May 20, 1967, DC-8, Air Canada, Ottawa

"Probable Cause: Failure to abandon a training maneuver under conditions which precluded the availability of adequate flight control".

June 24, 1969, CV-880, Japan Air Lines, Grant County

"The Safety Board determines that the probable cause of this accident was the delayed corrective action during a simulated critical engine-out takeoff maneuver resulting in an excessive sideslip from which full recovery could not be effected".

March 17, 1977, B-707, British Airtours, Prestwick

"The accident was caused by a loss of control by the pilots which resulted from their delay in taking full corrective action during a simulared failure of #1 engine during takeoff".

February 9, 1979, DC-9, EAL, Near Miami

Probable Cause: "Copilot—improper operation of flight controls, lack of familiarity with aircraft. Pilot-in-Command—inadequate supervision of flight".

In not one of the training accidents involving loss of control resulting from simulated engine failure has it ever been suggested in the probable cause that perhaps the engine failure certification criteria were deficient or that the training curriculum was improper for attempting to operate too closely to the certification criteria. In no one of these accident investigations did the certification process for determination of minimum control speeds ever come under scrutiny. No one ever questioned why airplanes were being operated at the virtual edge of the flight test envelope rather than under conditions which provided an adequate safety margin.

In the case of the B-707 accident at Prestwick, the U.K. Accident Investigation Branch did consider the certification criteria for V_{mc} and the differences between certification and line training. However, despite some startling revelations regarding these areas the AIB still blamed the crew. On March 17, 1977, a trainee first officer started a takeoff in a B-707-436 from Runway 13 at Prestwick, Scotland. The reported wind from the tower was 220°/15 knots although earlier data indicated 190°-230°/15 to 24 knots occasionally gusting to 30 knots. As the aircraft was being rotated, the training captain simulated a #1 engine failure by retarding the appropriate thrust lever and calling out "number one engine's failed".

After climbing to a height of 20 to 30 feet, the left wing suddenly dropped about 20° and the #1 engine nacelle struck the left edge of the runway. After the captain restored power on #1 engine, he intended to reduce thrust on #4 engine, but inadvertently also reduced thrust on #3 engine. The aircraft then began to yaw and roll to the right and to sink to the ground. The aircraft broke up as it tracked sideways down the runway and was eventually destroyed by the ensuing ground fire. There was one serious injury among the four crewmembers.

Based on the actual gross weight andthe prevailing conditions, the takeoff airspeeds were as follows: V_1 = 125 knots; V_r = 125 knots; V_2 = 142 knots; V_{mcg} = 125 knots; V_{mca} = 119 knots. During the course of the investigation, the U.K. Civil Aviation Authority flight tested the B-707-436 to determine the variation of V_{mca} with bank angle. The results of that test (Figure 7) show the non-linearity of V_{mca} as well as the increase of V_{mca} by 40 knots when going from the certification value of 5° bank to the wings level cases.

It is interesting to note the discussion which the CAA supplied with their test results:

> "In the event of an outer engine failure on takeoff at speeds of V_1 and above, the aircraft will diverge in heading and if airborne will roll. It is the most demanding of the first generation jet transport aircraft in this manoeuvre not only for its fairly marked roll with sideslip but also for its unusually small roll angle clearance on or close to the ground before a pod may scrape the surface. The yaw and roll divergences will increase rapidly unless control is imposed within the accepted period of 1 to 1½ seconds. The required forces are fairly high and the controls generally lack precision over small angles.
>
> "It should not be deduced that if the aeroplane is to the left of the curve—say wings level at 140 knots—that control is necessarily lost. The heading will of course be changing but the pilot will have something like another half lateral control range available with which to roll the aircraft to a bank angle at which he re-establishes full control including the ability to maintain heading. An aeroplane is not 'out of control' until all the available rudder and lateral control is used up; as the mean lateral control angle in the tests was around ⅓ to ½ there clearly remained ed much more available.
>
> "The increase of V_{MCA} with decreasing bank angle on a 707-436 is larger than is usually the case on more modern types with power-operated controls because the rudder, being only 'boosted' and not fully powered, will blow back at increasing airspeeds.
>
> "For United Kingdom certification V_{MCG} is established in a 7 knot cross wind component from the adverse side, the 'trade' for higher values varies considerably between types—a good conservative rule of thumb is to add 1.3 knots to V_{MCG} for every 1 knot of cross wind component in excess of 7 knots, up to a maximum component of 15 knots at normal training weights around maximum landing weight. Further extrapolation is not advised, because the greatly increased V_1 will then be incompatible with the V_R and V_2 speeds. The reciprocal use of this rule of thumb (i.e., reducing V_{MCG}) for an intended cut of a down wind engine is not permitted because the performance of the aircraft is not scheduled for any cut speed lower than the Flight Manual value. The 15 knot 'limit' would lift V_{MCG} by 11 knots making, in the case of the Boeing 707-436, a value of 136 knots."

The U.K. Accident Investigation Board found that:

(a) "During the takeoff sequence the trainee first officer did not take action in time to correct the yaw and subsequent roll which resulted from the retardation of No. 1 thrust lever by the commander, whilst simulating an engine failure."

(b) "In a situation which required very precise judgement the commander was just too late in taking full corrective action. By the time he did so the adverse yaw and roll had increased to the extent that the aircraft was substantially below its minimum control speed for the condition. Consequently, he was unable to effect recovery before No. 1 engine nacelle struck the ground."

(c) "Following the impact of No. 1 engine nacelle with the ground, control of the aircraft was lost and it crashed."

(d) "The commander inadvertently retarded No. 3 thrust lever when he made power changes to engines 1 and 4 in an attempt to recover from the yaw/roll to the left. However by this time an accident was probably unavoidable."

The analysis considered several factors in the crew's actions. These involved reaction time, appropriate controls for the wind condition and use of bank angle into the good engine side after liftoff.

The report noted:

"There is no doubt that the Boeing 707 is a most demanding aircraft to control in the event of an outboard engine failure on takeoff at or just above V_1, and that corrective action has to be quick—within a maximum of 1½ seconds from the time the thrust loss starts to take effect and the aircraft starts to yaw towards the 'dead' engine."

As stated earlier, the CAA had concluded from their flight tests that yaw and roll "will increase rapidly unless control is imposed within the *accepted* period of 1 to 1½ seconds". (Emphasis supplied)

The AIB never questioned *who* "accepted" a reaction time of 1 to 1½ seconds for recognition and corrective action. Was it ever determined that this short response time was sufficient to detect the yaw from the failed engine, determine the appropriate response and then manipulate the proper controls? Pilot response time tests indicate it may not be, especially for a case where yaw may be masked by the gusty wind conditions and the strong crosswind. The AIB's failure to consider this may have made the "1 to 1½ seconds" response time irrelevant and is particularly surprising since the report recognized the "gusty conditions may also have obscured the initial yawing effect caused by a failed engine, leading to a brief moment of indecision".

The analysis involving control input of the trainee first officer was a follows:

"Since the simulated engine failure was on the downwind engine and in fact did not occur until just after rotation, controllability on the ground was not a limiting factor. However, during the takeoff run the gusty conditions undoubtedly required considerable effort on the part of the trainee to maintain the aircraft on the runway centre line. Nevertheless, the aircraft's takeoff cross wind characteristics had been adequately discussed prior to taxying out, and the ground roll phase would appear to have been well conducted despite the difficult conditions.

"Following the simulated No. 1 engine failure as the aircraft became airborne, the correct procedure in this instance should have been to apply full rudder in the opposite direction to that which had been used during the ground roll, while still maintaining or increasing the amount of into-wind aileron in order firstly to prevent any tendency for the left wing to drop and subsequently to bank the aircraft towards the live engines as required to maintain directional control. The evidence suggests that the trainee took neither of these actions in time, so that the commander had to assume control."

The crosswind in this case was not adverse to V_{mcg}. The downwind engine was cut—thus the yawing moment due to the thrust asymmetry would tend to be balanced by the weathercocking effect of the crosswind. If the crosswind were strong enough, it might even require rudder into the bad engine side. However, just at rotation and liftoff, the rudder requirement would change considerably, even to the extent of requiring opposite rudder.

The AIB includes in the "correct procedure" the requirement "to bank the aircraft towards the live engines as required to maintain directional control". In other words, the crew was supposed to provide a control input not taught in training and whose value was not even known to the CAA until their flight test. The CAA subsequently issued a bulletin to operators which was prefaced as follows:

"Investigations into a recent Boeing 707 training accident have highlighted a handling characteristic of this aircraft that is not generally known. As it is probable that this characteristic is present in other contemporary aircraft the attention of operators is drawn to the following results of tests conducted on Boeing 707/436 aircraft by the Authority's Airworthiness Division:"

One interesting revelation from that accident investigation was the knowledge that the U.K. certification for V_{mcg} is established in a 7 knot crosswind component from the adverse side. No crosswind is considered in the determination of $V_{mcg's}$ in the U.S.

Even today not one aviation authority will admit it may have made a mistake in not recognizing the disparity between certification testing and line training for engine-out procedures. Yet, intuitively all must recognize the dramatic decline in the loss of lives and aircraft due to the limitation which some countries have put on engine-out training operations in the airplane.

Historically, the aviation industry keeps repeating its mistakes. It has been shown that the true cause of the engine-out training accidents have not been "officially" recognized. Therefore, there is almost a certainty that this type of accident will repeat itself. Those who have failed to recognize the reasons for this type of accident in the past will probably still cling to the original probable cause; i.e., pilot error, without ever having acknowledged the slightest implication of the certification procedures.

In the U.S., the FAA still allows engine-out training in the airplane. Their philosophy in this regard is as follows:

"The engine cut at V_1 is necessary and important. The maneuver is one of the most critical that a pilot can be called upon to make. A slow or incorrect response to a failed engine can result in loss of aircraft and life. Performing an engine cut at V_1 is necessary to assure that a pilot who has gone 90 days or more without demonstrating proficiency is capable of conducting safe operations under Part 121."

We now have a new generation of jet transports being introduced into passenger service. Indications are that the initial training in these aircraft, at least on some airlines, will be in the airplane itself because simulators will not be available. If this is so, caution is urged! There is first of all the question of whether or not the mechanical aspect of engine-out training is required at all. Perhaps it is sufficient to tell the pilots *everything* about V_{mc} and simply instruct them *thoroughly*, but verbally, in the procedures. There is no "evidence" that having the pilot manipulate the controls in an engine-out maneuver would contribute anything to a successful flight should the real thing occur, especially if the engine failure were to occur at V_1 on the takeoff. Engine failures at other times during normal flight are not critical since the thrust asymmetry is not that great. The only exception to this might be an engine failure during a missed approach. But even this case is not critical if the pilot is carrying the "normal" speed pads.

It is difficult to find any justification for requiring a pilot to demonstrate his ability to handle a simulated engine failure *in the airplane*. Even those who contend that pilots must show proficiency in this maneuver are hard pressed to show statistically that it is required. On a probability basis, an engine failure exactly at V_1 is an extremely remote possibility. Yet, the same persons who would require the V_1 cut demonstration in the airplane would be reluctant to require a maximum effort abort from V_1 in the airplane.

It has been said often that there are no new accident causes. Yet if the same type of accident continues to recur, has the true cause really been determined or have some people only assumed it has. The true cause of the past engine-out accidents has still not been universally recognized. One need only examine the past accident reports to find most of them have merely ascribed the accident to pilot error with virtually no consideration given to the deficiencies in the certification process for determining minimum control speeds or to the inadequate information presented in training with respect to the hazards associated with engine-out operations.

Both of these areas should be corrected. Certification authorities should require new aircraft to demonstrate more rigorous V_{mc} standards which are more realistic and pertinent to daily operations. Thought should be given to reviewing currently certificated aircraft to determine if published V_{mc}'s and engine-out procedures meet those same revised standards. Finally, operators should revise their ground school training and simulator training to reflect a common sense method of operating aircraft in the event an engine failure is experienced during line operations.

The concern is that some operators may not have learned the lessons from the past. It should be recognized that the number of engine-out training accidents diminished because the training was taken out of the airplane—not because the true cause of these accidents was recognized. Indications are that some operators may be starting or may have continued to do engine-out training in the aircraft. If this is correct, then we can surely expect to see a rise in the number of engine-out training accidents.

Biography

Harold F. Marthinsen is the Manager of Accident Investigation in the Engineering and Air Safety Department, Air Line Pilots Association (ALPA). He holds a B.Sc. in Aeronautical Engineering from the University of Illinois and has done graduate studies in Aerospace Engineering at the University of Southern California. He currently coordinates all ALPA accident investigation activities with the NTSB, FAA, and ALPA members, and provides engineering support to ALPA accident investigation committees. He has co-authored several AIAA papers. He has been involved in most major air carrier accident investigations over the past 18 years.

APPENDIX A

* denotes U.S. Air Carrier
• Engine-Out Accidents
P• Possible Engine-Out Accidents

B-707/720 TRAINING ACCIDENTS

Date	Operator	Inj	Damage
9/10/58			Subst
• 25/2/59	PAA*		Subst
16/4/59	PAA*		Subst
• 15/8/59	AAL*	F	Dest
19/10/59	Boeing	F	Dest
27/11/59	AAL*		Subst
P•28/1/61	AAL*	F	Dest
P•4/12/61	DLH	F	Dest
P•15/7/64	DLH	F	Dest
• 29/11/64	FAA		Subst
• 29/6/66	AAL*		Subst
20/7/66	FAA		Subst
21/11/66	BOAC		Subst
5/1/67	VARIG		Subst
31/13/67	BOAC		Subst
25/4/67	TWA*		Subst
30/4/67	CAL*		Subst
• 26/7/69	TWA*	F	Dest
33/8/69	AAL*		Subst
P•11/2/70	PAA*		Subst
• 23/1/71	Air India	N	Dest
• 8/3/71	BOAC		Subst
• 31/3/71	WAL*	F	Dest
P•5/12/72	EGYPTAIR	F	Dest
• 5/12/73	Jet Set Travel		Subst
18/2/75	AAL		Subst
25/7/75	BACD		Subst
• 17/3/77	British Airlines	S	Dest
14/11/77	PAI	F	?
• 23/3/79	Olympic		Subst
P•23/7/79	Trans Med	F	Dest
P•11/9/79	China Airlines	F	Dest

32 Total Training
12 Destroyed
10 Fatal (49 fatalities)

19 Possible Engine-Out
11 Destroyed
9 Fatal (45 fatalities)

* denotes U.S. Air Carrier
• Engine-Out Accidents
P• Possible Engine-Out Accidents

CONVAIR 880/990 TRAINING ACCIDENTS

Date	Operator	Inj	Damage
• 23/5/60	DAL*	F	Destroyed
16/6/61	DAL*		Substantial
• 27/2/65	JAL	S	Destroyed
• 13/9/65	TWA*		Destroyed
• 26/8/66	JAP	F	Destroyed
• 24/6/69	JAL	F	Destroyed
29/7/69	AAL*		Substantial (CV-990)

7 Total Training
5 Destroyed
3 Fatal (12 fatalities)

5 Possible Engine-Out
5 Destroyed
3 Fatal (12 fatalities)

DOUGLAS DC-8 TRAINING ACCIDENTS

Date	Operator	Inj	Damage
• 30/12/63	JAL		Substantial
• 4/7/66	Air New Zealand	F	Destroyed
13/8/66	Aeronaves	F	Destroyed
• 30/3/67	DAL*	F	Destroyed
• 20/5/67	Air Canada	F	Destroyed
• 28/4/68	Capitol*	S	Destroyed
16/10/69	Seaboard*		Destroyed
15/11/69	KLM		Subst

7 Total Training
6 Destroyed
4 Fatal (17 fatalities)

5 Possible Engine-Out
4 Destroyed
3 Fatal (11 fatalities)

DOUGLAS DC-9 TRAINING ACCIDENTS

Date	Operator	Inj	Damage
29/8/69	CAL*		Substantial
30/5/72	DAL*	F	Destroyed
21/1/75	SAS		Substantial
20/11/75	Swissair		Substantial
• 9/2/79	EAL*	S	Destroyed

5 Total Training
2 Destroyed
1 Fatal (4 fatalities)

1 Possible Engine-Out
1 Destroyed
0 Fatal

BOEING 727 TRAINING ACCIDENTS

Date	Operator	Inj	Damage
2/12/66	Mexicana		Substantial
5/12/66	NWA*		Substantial
27/7/73	FAA		Substantial

3 Total Training
0 Destroyed
0 Fatal

0 Possible Engine-Out
0 Destroyed
0 Fatal

BOEING 737 TRAINING ACCIDENTS

Date	Operator	Inj	Damage
• 10/5/75	VARIG		Substantial
4/4/78	Sabena		Destroyed

2 Total Training
1 Destroyed
0 Fatal

1 Possible Engine-Out
0 Destroyed
0 Fatal

BAC 1-11 TRAINING ACCIDENTS

Date	Operator	Inj	Damage
20/1/70			Substantial
21/2/73	BEA		Substantial
27/2/78	Monarch		Substantial
26/9/78	Lacsa		Substantial

4 Total Training
0 Destroyed
0 Fatal

0 Engine-Out

* denotes U.S. Air Carrier
• Engine-Out Accidents
P• Possible Engine-Out Accidents

B-747 TRAINING ACCIDENTS

Date	Operator	Inj	Damage
12/12/70	UAL*		Substantial
16/5/75	BOAD		Substantial

2 Total Training
0 Destroyed
0 Fatal

0 Engine-Out
0 Destroyed
0 Destroyed

L-1011 TRAINING ACCIDENTS

Date	Operator	Inj	Damage
1/6/76	TWA*		Substantial

1 Total Training
1 Destroyed
0 Fatal

0 Engine-Out

DC-10 TRAINING ACCIDENTS

Date	Operator	Inj	Damage

NONE REPORTED

A-300 TRAINING ACCIDENTS

Date	Operator	Inj	Damage

NONE REPORTED

APPENDIX B

* denotes U.S. Air Carrier

ENGINE-OUT TRAINING ACCIDENTS
B-707/720

Date	Operator	Maneuver	Result	Inj	Damage
25/2/59	PAA*	2 Eng. Out	Loss of Control	S	NF
15/8/59	AAL*	2 Eng. Out	Loss of Control	D	F
P 28/1/61	AAL*	2 Eng. Out	Loss of Control	D	F
P 4/12/61	DLH	?	Loss of Control	D	F
P 15/7/64	DLH	2 Eng. Out ?	Loss of Control	D	F
29/11/64	FAA	4 Eng. Out	Landed Short	S	NF
29/6/66	AAL*	4 Eng. Out	Landed Short	S	NF
21/11/66	BOAC	1 Eng. Out	Hard Landing	S	NF
26/7/69	TWA*	1 Eng. Out	Loss of Control	D	F
11/2/70	PAA*	1 Eng. Out	Ran Off r/w End	S	NF
23/1/71	Air India	3 Eng. Out	Loss of Control	D	NF
		1 Eng. Out			
8/3/71	BOAC	V_1 Cut		S	NF
31/3/71	WAL*	1 Eng. Out	Loss of Control	D	F
P 5/12/72	EGYPTAIR	?	Loss of Control	D	F
5/12/73	Jet Set Travel	2 Eng. Out	Loss of Control	S	NF
17/3/77	British	V_1 Cut	Loss of Control	D	NF
23/3/79	Olympic	2 Eng. Out	Loss of Control	S	NF
P 23/7/79	Trans Med	V_1 Cut	Loss of Control	D	F
P 11/9/79	China Airlines	V_1 Cut	Loss of Control	D	F

ENGINE-OUT TRAINING ACCIDENTS
DC-8

Date	Operator	Maneuver	Inj	Damage
30/12/63	JAL	2 Eng. Out	S	NF
4/7/66	Air New Zealand	V_1 Cut	D	F
30/3/67	DAL*	2 Eng. Out	D	F
20/5/67	Air Canada	2 Eng. Out	D	F
28/4/68	Capitol*	2 Eng. Out	D	NF

ENGINE-OUT TRAINING ACCIDENTS
CV-880/990

Date	Operator	Maneuver	Inj	Damage
23/5/60	DAL*	V_1 Cut	D	F
27/2/65	JAL	2 Eng. Out	D	NF
13/9/65	TWA*	V_1 Cut	D	NF
26/8/66	JAL	V_1 Cut	D	F
24/6/69	JAL	V_1 Cut	D	F

ENGINE-OUT TRAINING ACCIDENTS
DC-9

Date	Operator	Maneuver	Inj	Damage
9/2/79	EAL*	V_1 Cut	D	NF

ENGINE-OUT TRAINING ACCIDENTS
B-737

Date	Operator	Maneuver	Inj	Damage
10/5/75	VARIG	V_1 Cut	S	NF

Development of the ISASI Code of Ethics and Conduct

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Introduction

Provided as Appendix I to this paper is the "International Society of Air Safety Investigators Code of Ethics and Conduct" dated April 1982. On July 23, 1982, the International Council of the Society voted to adopt that Code "with the understanding that it will be reviewed for revisions as necessary after it had been presented to the General Membership meeting (in Tel Aviv) for approval."[1] In September 1982, the Code was included in a letter to all members of the Society from John McDonald, the Society President.[2]

Consequently, the purpose of this paper is to provide the background on how the Code was developed, an explanation of its rationale and a summary of comments already received concerning the April 1982 version. It is hoped that such information will assist the Membership in performing their review of the work done thus far and encourage suggestions for improvements in the future.

Historical Perspective

The International Society of Air Safety Investigators (ISASI) was originally incorporated in 1964 under the laws of the District of Columbia, United States of America. Subsequently, "Articles" were developed to form the basis of agreement between the International Society and Member Societies. Within those Articles, the parties agreed:

> "to abstain from conduct deleterious to the interests of the Air Safety Investigators profession or which falls below the standards established by the Code of Ethics of the International Society of Air Safety Investigators."[3]

The Constitution of the Society also speaks of a Code under Article VI, Termination and Reinstatement of Membership, as follows:

> "Section 5. Suspension and Expulsion
>
> A member of the International Society shall be subject to suspension or expulsion. . . for unethical professional conduct or for willful conduct contrary to the Code of Ethics of the International Society. . . "[4]

It is obvious from the foregoing that current Society functioning, let alone the precepts on which the Society was founded. presupposes the existence of a doctrine related to both the ethics and conduct of Society members, and the willingness of the Society to discipline breaches thereof.

However, it was not until 1974 through an article in the ISASI *Forum* by Bill McArthur that a specific plan of action was called for to develop a Code.[5] Following discussions at the Council level the next year, Stan Mohler undertook the task of preparing a draft of a Code. It was forwarded to the Council on June 1, 1976.

The record is a bit foggy thereafter until the ball ended up in Laurie Edwards' court. He amplified the Mohler work and forwarded a new draft to this author in March of 1981. The material contained a remarkable number of detailed standards of conduct. . . a tribute to the astute thought processes of Stan and Laurie.

The only problem then, at first glance at least, was the presence of too many good ideas. Thus the main task remaining was to structure the information so as to simplify matters (and add one's own ideas, which is the prerogative of the people who agree to be Committee Chairmen).

In preparation for the rewrite, reviews were made of codes pertaining to other fields of endeavor including the Code of Ethics for the (U.S.) Government Service, the Board of Certified Safety Professionals, the American Society of Mechanical Engineers, the American Society for Quality Control and the American Bar Association.[6-11] The inimitable Jerry Lederer even called our attention to a 1955 U.S. Military Transport (MATS) pilots code.[12] Other similar documents have been seen from time to time over the years.

The result was a decision to delineate Ethics from Conduct by keeping the Ethics broad, simple and few in number. As it is mentioned in the Preamble of Appendix I, Ethics are aspirational. They are goals towards which we all "should" strive. Being broad, they do not contain the kind of words that adequately reflect criteria against which a member's conduct could be judged for disciplinary reasons, if it ever came to that. Statements of Conduct fulfill that need. They are the "shalls" of Member behavior.

Examination of Appendix I reveals the logic developed which provides the items of Conduct as subsets of five Ethics whose keywords are Integrity, Principles, Objectively, Logic, and Accident Prevention. These categories are somewhat arbitrary and subject to challenges inherent in any classification system. The Ethics/Conduct hierarchy was deemed necessary, however, to ensure an organized approach to the forty-four statements of conduct which, if left standing by themselves, would cause undue reader confusion.

Review of the Code

During earlier drafts of Appendix I, liaison was maintained with Stan Mohler and Laurie Edwards. In addition, Gerry Bruggink and Les Kerfoot had shots at the material as did all members of the Executive Council as revisions were made. Finally, the April 1982 version, Appendix I, was sent to all the ISASI Chapters and National Societies by correspondence dated April 8, 1982. Copies were also given later to two particularly well-respected members of the safety profession, the aforementioned Jerry Lederer and Prof. Ludi Benner, formerly with the NTSB, now teaching accident investigation and other courses full time in the U.S.C. graduate level safety degree program in Washington, D.C.

From the above group, ten written responses and countless verbal comments were received. Only one expressed disapproval of the April 1982 Code in the total sense with the explanation, "Main reason: it is impossible to follow." A full recitation of the comments by each respondent is available from the author upon request. Suffice to say, no one appeared to attack the basic approach being used logic-wise. Some comments were substantive and most were of an editorial nature. A rather pointed example of the latter applied to Item 2.9. which states Members shall:

> "Transfer promptly to the Treasurer of the Society any funds or property coming into the Member's possession unless specific use thereof has been authorized under the Constitution or Bylaws."

Some Members (and their wives) thought it best to add "Society" between "any" and "funds".

The substantive comments tended to identify three issues which merit consideration during total Membership review of the Code as it now stands and/or as it is revised in the future. These include:

1. The overall degree of detail or complexity of the Code as presently constituted. Is it excessive?

2. The degree to which the Code relates to accident prevention rather than to pure fact finding tasks attendant to the investigative process. (e.g. Sections 2.1, 4.1 and all of Ethic 5)

3. The possible conflict between provisions of this Code and other obligations of members based upon their particular employment or other codes which they are obligated to follow. (e.g. Sections 1.4, 1.6 and 2.5)

It was this author's judgment, apparently concurred-in by the Executive Council with only one negative vote, that the comments in hand by last July 23rd did not merit further delay in getting Appendix I into circulation. The delays in processing the Code in the past appeared to result from infinite piecemeal attempts to improve the Code by a select few persons. Therefore, practical limits were established this time for again soliciting and incorporating comments. After two major rewrites, the point was reached where the Code was known to still merit changes, but none were deemed to be of such a nature as to require another draft before sending it to the full Membership.

Furthermore it was envisioned that 100% agreement on all aspects of the Code will never be obtained. That is the nature of any doctrine of human behavior. Hence, why not give everyone a chance to be heard?

Where To Now?

This paper is to be presented as part of the annual business meeting of the Society. Presumably, an appropriate motion will be introduced by someone for the Membership to accept Appendix I at least provisionally. It is this author's view, however, that three additional steps should be made implicit in such approval:

1. That the Executive Council commit to a review and appropriate modifications to Appendix I before the next annual meetings based on all Member comments already received and those received within the next six months.

2. That a Professional Ethics and Conduct Committee be formed separate from the Education and Professional Standards Committee under which the current Code project was conducted. Drop the "Professional Standards" from the latter. Assign all future work on the Code and its enforcement to the new committee.

3. That the new Committee be tasked immediately to develop procedures for handling and adjudicating alleged violations of the Code and the process should be in place no later than one year from now.

With regard to item (1) above, Appendix II to this paper is a form used by the author to log comments received on the Code in recent months. Added thereto now is the Society's mailing address to which further comments can be sent. It will aid in the prospective revisions of the Code tremendously if this form can be used to forward suggested changes.

One Final Thought

One of the documents not listed above but encountered in the course of this project was an unpublished paper examining "professionals" from a sociological and historical viewpoint. When discussing how professions formed, it noted in part:

> "A person did not 'learn' a profession. He *made* a profession. The profession was his free and open declaration of his acceptance of the duties of his calling... He stood in front of his townspeople and publicly professed that because of the special knowledge now reposed in him, he had a special duty to discharge on their behalf. He professed a duty of truth, of professional judgment as we might call it today, and a duty not to hide his substantial knowledge when they should require it.[13]

Those thoughts would seem to have a bearing on anyone still reluctant to place an ISASI Code of Ethics and Conduct before the public. Furthermore, "duty" speaks to those Members who are troubled over competing obligations as might be found in the Code. To resolve such a conflict, perhaps it is just a matter of how professional one cares to be.

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3. Articles of the International Society of Air Safety Investigators, as published by the Society, October 1976.

4. Constitution of the International Society of Air Safety Investigators, as published by the Society, October 1976.

5. ISASI *Forum*, Aug. 31, 1974.

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7. Orn, Michael K., "Ethics and the Safety Professional", *Professional Safety,* July 81.

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12. Military Air Transport Service, "Transport Pilot's Code", circa 1955.

13. Benson, Carol, "Ethical Considerations for the System Safety Professional" (Unpublished).

About the Author

Educated as a pilot, engineer, manager and lawyer, Dr. Miller's accident investigation experience spans nearly three decades. He directed the Chance Vought Aircraft Corp. accident investigation team from 1954 to 1962. He taught crash injury accident investigation at AvSer, 1962-63, and several air safety courses including accident investigation at the U.S.C. safety school from 1963 to 1968. He was the Director of the Bureau of Aviation Safety of the U.S. National Transportation Safety Board, thus responsible for the investigation of all U.S. civil aviation accidents and special studies related thereto, from 1968 to 1974. He has since remained active in the accident investigation field through consulting and teaching including being retained by the U.S. Nuclear Regulatory Commission for their investigation of the accident at Three Mile Island.

Appendix I

International Society of Air Safety Investigators

CODE OF ETHICS AND CONDUCT

April 1982

PREAMBLE

As noted in the ISASI Constitution, the purpose of the Society is "to promote the development and improvement of aviation accident investigation". Implicit therein is a requirement for a baseline of agreement between the Members and the Society as to what constitutes professional behavior of the Members. Indeed, Section 3 of Article V of the Constitution delineates a "contract" between the Society and its Members, wherein the Member covenants to support provisions of the Constitution as a prerequisite to membership in the Society.

Therefore, as an Appendix to the Constitution, this Code of Ethics and Conduct reflects behavior expected of ISASI Members. It has been prepared and adopted with the full realization that determination of the adherence or lack of adherence to these principles is a matter of judgment; judgment which can only be effected reasonably by peer review. Procedures governing adjudication of alleged violations of this Code are the responsibility of the Ethics and Conduct Committee as approved by the Executive Committee of the Society.

The Code has distinguished five Ethics and numerous related items of Conduct contained thereunder. Ethics are the axiomatic and aspirational major principles shown both on a separate page and as general headings in the Code of Conduct. They are broad goals towards which accident investigators "should" strive. The Code of Conduct is phrased in "shall" terms of expected Member behavior. The items constitute minimum levels of conduct which, if violated, constitute potential grounds for disciplinary action by the Society. Such disciplinary action can include expulsion from the Society.

It is recognized that provisions of this code will not apply to all members during the totality of their work activities. However, insofar as investigations are conducted for safety purposes, and this Code does not conflict with other codes of professional behavior, Members are expected to adhere to the ISASI Code.

In accordance with Article X, Section 1, the Code has been adopted by the International Council. Recognizing the desirability of continuous membership input to this Code, the Ethics and Conduct Committee shall report to the International Council annually the receipt of any suggestions for modifications of the Code and their recommendations therefor. Thus, the membership is encouraged to communicate with the Ethics and Conduct Committee in these matters.

ISASI CODE OF ETHICS

1. *INTEGRITY*

Each member should at all times conduct his activities in accordance with the high standards of integrity required of his profession.

2. *PRINCIPLES*

Each Member should respect and adhere to the principles on which ISASI was founded and developed under the provisions of its Constitution.

3. *OBJECTIVITY*

Each Member should lend emphasis during investigations to objective determination of facts.

4. *LOGIC*

Each Member should develop all meaningful cause-effect relationships based upon logical application of facts.

5. *ACCIDENT PREVENTION*

Each member should apply facts and analysis to findings and recommendations that will prevent accidents.

ISASI CODE OF CONDUCT

1. *INTEGRITY...*

Each Member should at all times conduct his activities in accordance with the high standards of integrety required of his profession. Each Member shall:

1.1 Not seek, or assist others to seek to falsify, conceal or destroy any facts or evidence which may relate to an accident.

1.2 Be responsive to the feelings, sensibilities and emotions of involved persons and shall take steps not to aggravate what may already be a delicate situation.

1.3 Not divulge fragmentary or unsupported information concerning the accident to external parties no matter how important publicly such parties may appear to be.

1.4 Avoid being perceived as favoring one party or another, particularly during the fact-finding phase of the investigation.

1.5 Establish and adhere to the chain of authority with attendant responsibilities throughout the course of the investigation.

1.6 Not seek to profit, nor accept profit, other than by normal processes of reimbursement which do not include fee-splitting in the absence of actual work performed or acceptance of contingency fees for investigative activity.

1.7 Remain open minded to the introduction of new evidence or opinions as to meaning of facts through analysis, and be willing to change one's own findings accordingly.

1.8 Avoid even the appearance of professional impropriety by continuously applying the foregoing principles to one's own endeavors and encouraging the application of those same principles to others associated with air safety investigation.

2. *PRINCIPLES...*

Each Member should respect and adhere to the principles on which ISASI was founded and developed under the provisions of its Constitution. Each Member shall:

2.1 Promote accident investigation as a fundamental element in accident prevention and encourage others to do so as well.

2.2 Assist other Members to carry out their accident investigation tasks.

2.3 Not use membership status to effect personal gain or favor beyond signifying qualification to published membership criteria.

2.4 Seek advice of the International Council—via the Secretary—in the event a situation arises where contemplated conduct may violate the Constitution, Ethics or Standards of the Society.

2.5 Encourage uninhibited, informal interchange of views among members; however, any sensitive information thus gained shall not be made public or transmitted to others without clear approval of the person from whom the information was gained.

2.6 Have an obligation to improve the professional image of the Society; however, he shall:

2.6.1 Refrain from unfounded criticism of officers of the Society either publicly or privately unless the matter is investigated thoroughly and brought to the attention of the President with reasonable time being allocated to review the situation and act accordingly.

2.6.2 Refrain from criticism of any fellow member unless that individual has first been apprised of the alleged basis for that criticism and given an opportunity for rebuttal.

2.7 Encourage and participate in the education, training and indoctrination of personnel liable to become involved in accident investigation.

2.8 Develop and implement a personal program for a continually improving level of professional knowledge applicable to air safety investigation.

2.9 Transfer promptly to the Treasurer of the Society any funds or property coming into the member's possession unless specific use thereof has been authorized under the Constitution or By-Laws.

3. *OBJECTIVITY...*

Each Member should lend emphasis during investigations to objective determination of facts. Each Member shall:

3.1 Ensure that all items presented as facts reflect honest perceptions or physical evidence that have been checked insofar as practicable for accuracy.

3.2 Ensure that each item of information leading to fact determination be documented or otherwise identified for possible followup by others.

3.3 Use the best available expertise and equipment in determining the validity of information.

3.4 Pursue fact determination expeditiously.

3.5 Follow all avenues of fact determination which appear to have practical value towards remedial, accident prevention action.

3.6 Avoid speculation except in the sense of presenting a hypothesis for testing during the fact-finding and analysis process.

3.7 Refrain from release of factual information publicly except to authorized persons, by authorized methods and then only when it does not jeopardize the overall investigation.

3.8 Handle with discretion any information reflecting adversely on persons or organizations and, when the information is reasonably established, notify such persons or organizations of potential criticism before it becomes a matter of public record.

4. *LOGIC...*

Each Member should develop all meaningful cause-effect relationships based on logical application of facts. Each Member shall:

4.1 Begin sufficiently upstream in the sequence of events so as to ascertain practicable accident prevention information.

4.2 Continue downstream in the sequence of events sufficiently to include not only accident prevention information but also practicable crash injury prevention and survival information.

4.3 Ensure that all safety-meaningful facts, however small, are related to the sequence of events.

4.4 Delineate those major facts deemed not to be safety-related, explaining why they should not be considered as critical in the sequence of events.

4.5 Be particularly alert to value judgments based upon personal experiences which may influence the analysis; and where suspect, turn to colleagues for independent assessment of the facts.

4.6 Express the sequence in simple, clear terms which may be understood by persons not specializing in a particular discipline.

4.7 Include specialist material supporting the analysis either in an appendix or as references clearly identified as to source and availability.

4.8 Prepare illustrative material and select photographs so as not to present misleading significance of the data or facts thus portrayed.

4.9 List all documents examined or otherwise associated with the analysis and include an index thereof.

4.10 Handle documents having connotations of national or commercial security in accordance with specified procedures for such documents.

5. *ACCIDENT PREVENTION...*

Each Member should apply facts and analysis to findings that will prevent accidents. Each Member shall:

5.1 Identify from the investigation those cause-effect relationships about which something can be done reasonably to prevent similar accidents.

5.2 Also, document those aviation system shortcomings learned during an investigation which, while not causative in the accident in question, are hazards requiring further study and/or remedial action.

5.3 Communicate facts, analyses and findings to those people or organizations which may use such information effectively; such communication to be constrained only by established policies and procedures of the employer of the Member.

5.4 Provide specific, practical recommendations for remedial action when supported by the findings of the accident having been investigated singly or as supported by other cases.

5.5 Communicate the above noted information in writing, properly identified as a matter of record.

5.6 Encourage retention of investigation records within the aviation system in such a manner as to form a baseline for further investigation of the given accident and/or facilitate analysis in connection with future accidents.

5.7 Demonstrate a respect for interpretation of facts by others when developing conclusions regarding a given accident which includes providing reasonable opportunity for such views to be made known during the course of the investigation.

APPENDIX II

Comments Re April 1982 ISASI Code of Ethics and Conduct

Mail to:
ISASI; West Bldg., Room 259;
Washington National Airport; Washington, D.C. 20001

☐ General ☐ Ethic No.________ ☐ Conduct Item No.________

Comment (Cite specific text where possible)

Suggested improvement (Correct text shown above or provide new text)

Name ________________ **Tel. No.**________

☐ General ☐ Ethic No.________ ☐ Conduct Item No.________

Comment (Cite specific text where possible)

Suggested improvement (Correct text shown above or provide new text)

Name ________________ **Tel. No.**________

Electromagnetic Interference in Aircraft

J. Rosenzweig
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Ben Gurion Airport, LOD, Israel

Background

There is an increasing awareness of radio frequency interference in aircraft resulting from the increase in numbers and complexity of electronic equipment on board. The increasing dependance of flight management and controls on electronic equipment results in potential flight safety hazards originating in electro-magnetic interference. Modern electronics are potentially more susceptible to EMI due to extensive use of microelectronics which operate at lower energy levels than previous generations of electronics. This paper describes briefly the mechanisms of electro-magnetic interference. Some specific cases are then described, including the steps taken to correct hazardous situations.

The mechanism of electro-magnetic interference (EMI)

The three basic elements of an emitting-susceptibility situation are:

1. Emitting source (by conduction or radiation).
2. Transfer medium.
3. Receiving element.

Typical examples for each element are shown in Figure 1. The emitting source may be inside or on the aircraft, or remote[1]. The most common interference problems which the aircraft manufacturers encounter are those generated inside the aircraft. Solving these problems will usually harden the aircraft against most remotely emitted interference as well.

Preventing mutual interference.

Eliminating interference problems starts first with the specification of each system. The specification should include the following points:

Susceptibility levels for both radiated and conducted interference.

Limits of noise levels permitted to be emitted from the equipment.

Test methods to verify the above 1 & 2 requirements.

Basic design guides and requirements which will enable system integration into aircraft in the best way from the EMC point on view.

A typical reference specification for EMC requirements is the R.T.C.A. DO-160A[2].

The second step taken to prevent interference is a careful integration design of an electronic system into the aircraft. This would typically include the following points[3-4]:

Mutual location of boxes (separation of noise sources from potential victims).

Wiring design (applying necessary shielding and other treatment; control of the wire routing).

Installation (provide firm electrical contact between equipment cases and aircraft structure to improve shielding effectiveness).

Filter application (protect sensitive equipment or suppress noise sources).

Transient suppression (provide the means to eliminate spikes at spike-sources).

Antenna locations (locate antennas so as to prevent antenna-to-antenna interference).

Electrostatic dischargers (electrostatic charges shall be provided with a silent path of discharge).

Grounding requirements (avoid ground loops which are sensitive to interference).

The last step is an overall integration test, which is intended to reveal all the interference situations still existing in a newly designed aircraft. This EMI test consists mainly of the systematic operation of all systems on board while observing the operation of all the systems considered susceptible. Any malfunction is then analyzed to find the corrective action needed. Each new installation in a currently produced aircraft is also checked for electro-magnetic compatibility. As for flight safety hazards to aircraft due to electro-magnetic interference, the causes to hazardous situations may be misleading instrument indications, erratic flight control movement or systems dropout at critical points in time.

Fuel control computer on Westwind 1124.

The IAI Westwind 1124 is powered with TFE 731-3 engines made by Garrett Inc. Each engine has a fuel control computer that drives the acceleration lever on the engine according to pilots input and engine parameters (rpm, temperatures etc.). The engine manufacturer was aware of the susceptibility of the computer to radio frequency radiation, and suggested extensive testing prior to first take-off. During the EMI test of the aircraft all radiation sources (VHF and HF COM transmitters) were operated in all available channels and modes. It was found that the L.H. computer failed, and transferred to manual mode, each time the HF transmitter was keyed in the frequency range of 21 to 25 mH_z. Further testing indicated that the interference coupling path was from the HF antenna to the power distribution network, and through the power supply of the computer to the inside circuits, which in turn recognized the interference as some malfunction. The corrective action taken was to add RFI filters on the power lines of the computers. No interference malfunction has since been reported in the system.

The transfer to manual mode of the fuel control computer causes some drop in engine thrust, which may be hazardous in critical take-off manoeuvres. The manufacturer of the fuel control computers reported incidences of much more severe interference in other aircraft models. The effect was engine RPM changes and engine shut-down due to VHF and HF transmission. The solution to the problem was the addition of a filter box on the computer harness that included 20 to 40 RFI filters in it.

Arava Auto Pilot.

The IAI Arava aircraft has an option of Auto Pilot installation. When the first Auto Pilot System (A Collins AP-106) was installed in a test aircraft we found that HF transmission in some frequencies caused uncontrolled commands in the Auto Pilot. These commands were in all three axes, and the A/P disengage circuit could not detect the interference. This situation was obviously unacceptable, especially from the flight safety point of view.

An intensive test procedure showed that the interference was the emission of radio frequency energy from the indoor portion of the HF antenna, which coupled into the Auto Pilot harness. This energy then flowed in the A/P wiring system into some of the amplifying circuits. The amplifiers detected the RF voltage in a way called parasitic rectification, and then these signals were processed as valid DC signals.

The solution included two methods: Reduction of source emission and increasing the interference path attenuation. The radiation from the indoor portion of the HF antenna was reduced by shortening this portion to a minimum and adding a grounding strip along that portion left. Increasing the attenuation of the interference path was done by re-routing the A/P harness so that instead of being 1 foot away from the HF antenna feeder it is now more than 3 feet away.

References.

1. *Electromagnetic Interference and Compatibility*, Vol 3. by D.R.J. White.

2. *Environmental Conditions and Test Procedures for Airborne Equipment.* Document No. RTCA/DO-160A, Jan 1980.

3. *Noise Reduction Techniques in Electronic Systems* by H.W. Ott.

4. *Practical Design for Electromagnetic Compatibility*, edited by R.F. Ficchi.

Biography

Joel Rosenzweig joined I.A.I. in 1974 after receiving his BSEE degree from Tel-Aviv University. Since 1978 he has led the Electromagnetic Compatibility Group in the IAI Engineering Division. His specialty fields are EMI, lightning protection of aircraft, electrostatic discharging in aircraft and EMP.

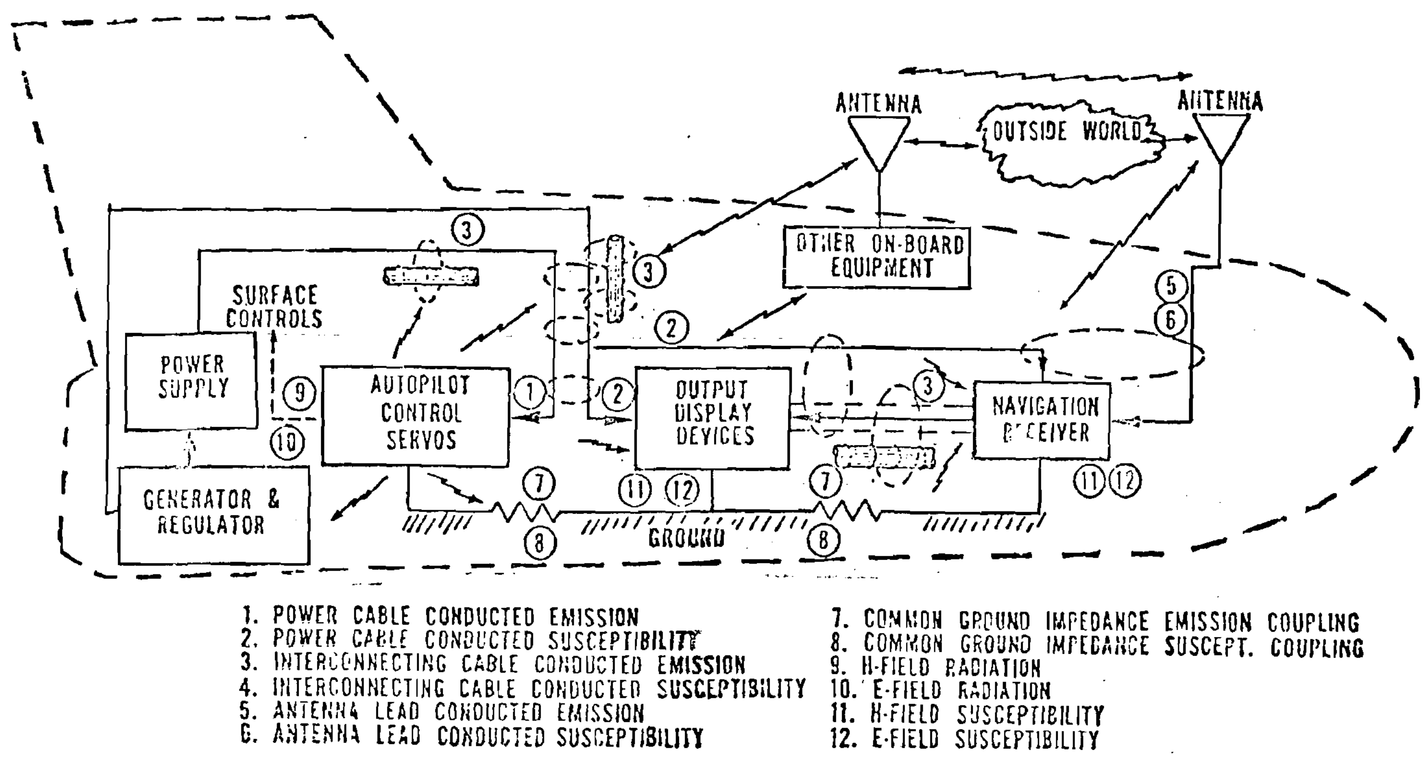


FIGURE 1.
Example of Inter-Aircraft Interference Problems

Eliminating Dangers of Lightning Strikes on Aircraft

P. Slezinger and J. Rosenzweig
Israel Aircraft Industries Ltd.
Engineering Division
Ben-Gurion Airport
Lod, Israel

Preface

Lightning strikes to aircraft are believed to be rare events. However, the consequences may have catastrophic effects if protective measures were not provided for. Lightning protection of aircraft strives for prevention of catastrophic effects from a lightning strike. In addition, protection usually is applied against extensive damage to structure and equipment of an aircraft which are not susceptible to catastrophic consequences. However, absolute exclusion of the lightning attachment tracks' influence on aircraft is practically impossible because of complications and high price. So we accept some probability of damage, and design protection against catastrophic consequences to the aircraft.

Let us consider, preliminarily, lightning effects on aircraft; and then, using the example of the Westwind 1124 aircraft, the design considerations of lightning protection and possible consequences of a lightning current through the aircraft.

Lightning effects on aircraft

Introduction

A lightning current that may pass across an aircraft may reach the value of hundreds of kilo-amperes[1]. The physical damage effects at the point of flash attachment to the aircraft are arc holes burned in metallic skins, puncturing or splintering of nonmetallic structures, and welding or roughening of movable hinges and bearings. If the attachment point is a lamp or an antenna the possibility of conducting some of the lightning current directly into the aircraft's electrical circuits is also of concern. These and other physical damage effects are called the Direct Effects. But there may be other Indirect Effects to equipment located elsewhere in the aircraft. For example, the operation of instruments and navigation equipment has been interfered with, and circuit breakers have popped in electric power distribution systems when aircraft have been struck by lightning. The cause of these effects are the electromagnetic fields associated with lightning currents flowing through the aircraft.

Direct effects on metal structures

Melting and burnthrough

If lightning attaches to a metal surface for a sufficient time, melting of the metal will occur at the point of attachment. Common evidences of this are the successive pit marks often seen along a fuselage or empennage, as shown in Figure 1, or the holes burnt in the trailing edges of wings or empennage tips, as shown in Figure 2. Most holes are melted in skin of 1 mm (0.040") thickness or less, except at trailing edges, where

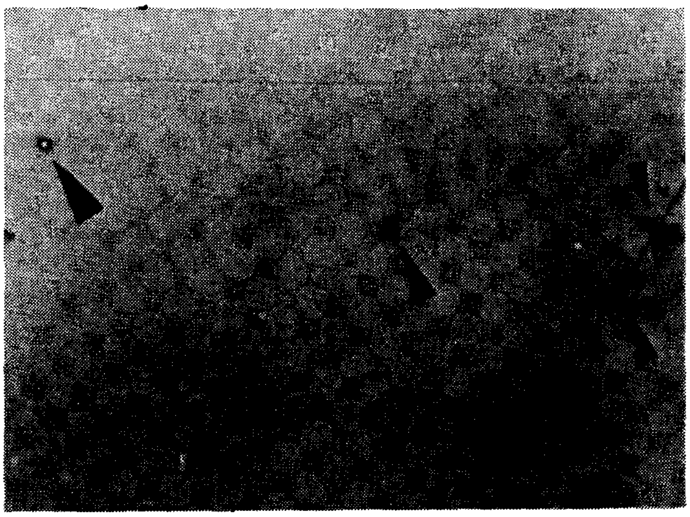


Figure 1
Successive pit marks extending backward from leading edge of vertical stabilizer. (USAF photo)

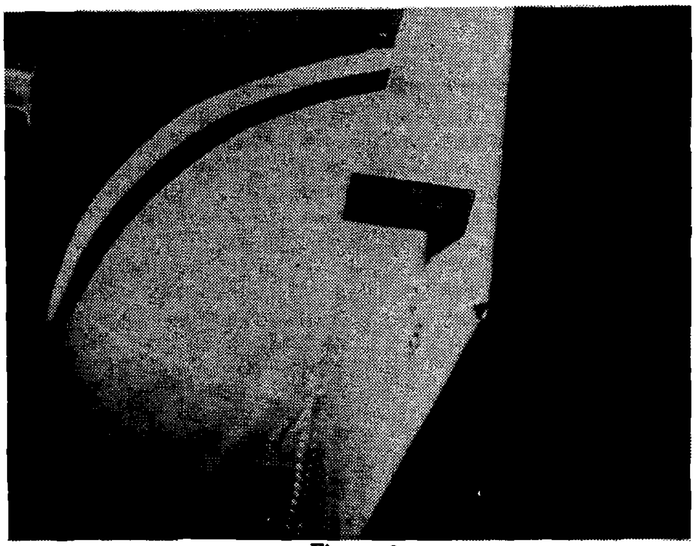


Figure 2
Hole burned in trailing edge corner of ventral fin. (NASA photo)

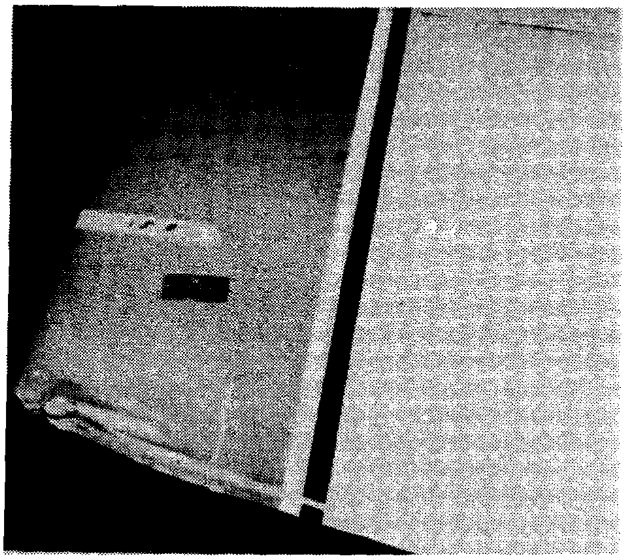


Figure 3
Example of magnetic pinch effect at lightning attachment points. (NASA photo)

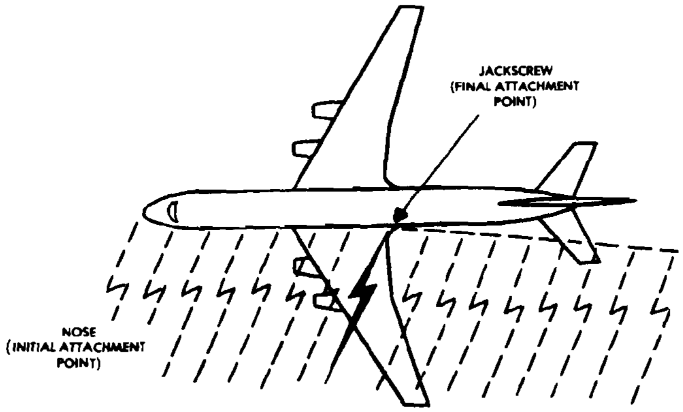
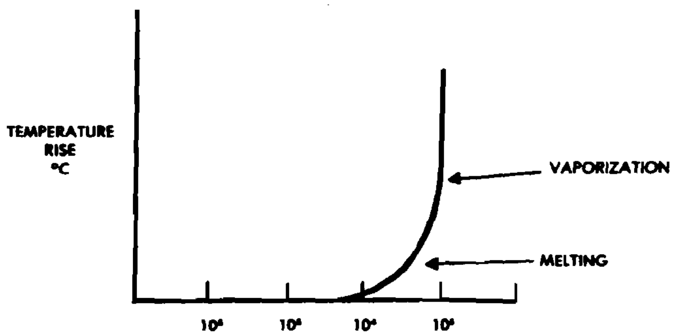


Figure 4
Swept-stroke attachment and inboard flap jackscrew attachment.



$\int i^2dt$ vs temperature rise in a conductor.

Figure 5

the lightning arc may hang on for a longer time and enable holes to be burned through much thicker pieces.

Magnetic force

Metal skins or structures may also be deformed as a result of the intense magnetic fields which accompany concentrated lightning current near an attachment point. It is well known that parallel wires with current travelling in the same direction are mutually attracted to each other. If a structure is not sufficiently rigid, pinching or crimping may occur, as shown in Figure 3.

Pitting at structural interfaces

Wherever poor electrical contact exists between two mating surfaces, such as a control surface hinge or bearing across which lightning current may flow, melting and pitting of these surfaces may occur. In one incident, for example, the jackscrew of an inboard trailing edge flap of a jet transport was so damaged by a lightning flash that the flap could not be extended past 15 °[1]. Since this jackscrew is located on the inboard side of the flap, the flash must have reached it after sweeping along the fuselage from an earlier attachment point near the nose, as shown of Figure 4. Instead of continuing to sweep aft along the fuselage, the flash apparently hung on to the jackscrew long enough to melt a spot on it.

Resistive heating

When the resistivity of a conductor is too high or its cross-sectional area too low for adequate current conductance, lightning current flowing in it may deposit appreciable energy in the conductor and cause an appreciable temperature rise. Resistive energy deposition is proportional to the lightning current action integral ($\int i^2dt$), and for any conductor there is an action integral value at which the metal will melt and vaporize, as shown in Figure 5. Consequences of resistive heating and explosive vaporization of conductors are shown in Figures 6 and 7. The damage is usually most severe when the exploding conductor is within an enclosure, which contains the explosion until the pressure has built up to a level sufficient to rupture the container.

Shock wave and overpressure

When a lightning-stroke current flows in an ionized leader channel, a large amount of energy is delivered to the channel in 5 to 10 μsec, causing the channel to expand with

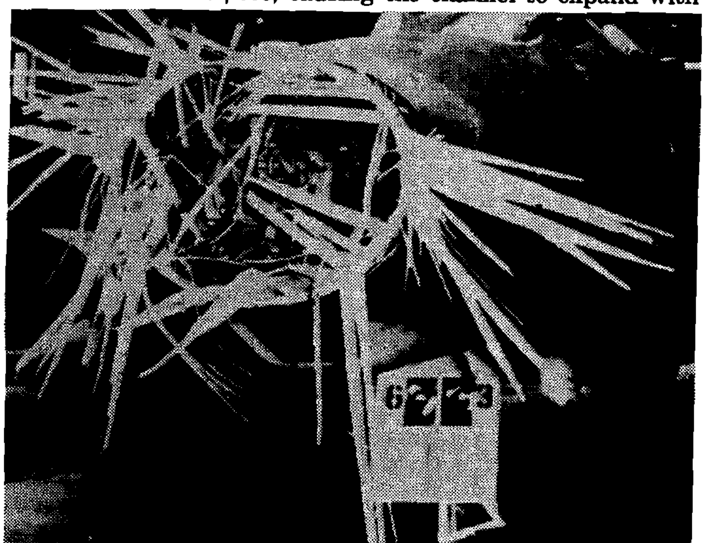


Figure 6
Lightning damage to radome—probably as a result of exploding pitot tube ground wire. (USAF photo)

supersonic speed. Its temperature has been measured by spectroscope techniques to be 30000 °K and the channel pressure (before expansion) about 10 atmospheres[2]. The cylinder shock wave propagates radically outward from the center of the arc, and, if a hard surface is intercepted, the kinetic energy in the shock wave is transformed into a pressure rise over and above that in the shock wave itself. This results in a total overpressure of several times in the free shock wave at the surface. If an arc is contained inside a structure, such as would occur when a nonmetallic assembly is punctured, its overpressure may cause additional damage to the structure. This may have been responsible for some of the damage to the radome shown in Figure 6.

Direct effects on nonmetallic structures

Nonmetallic material is nonconducting. Electric fields may penetrate it and initiate streamers from metallic objects inside. These streamers may puncture the nonmetallic material as they propagate outward to meet an oncoming lightning leader. This puncture begins as a pinhole, but as soon stroke currents and accompanying blast and shock waves follow, much more damage occurs. An example of a puncture of a fiberglass-honeycomb radome is shown on Figure 8. Transparent acrylics and polycarbonate resins are utilized for canopies, windows and windshields. These materials are usually found in zone 1 and zone 2[8] locations, where either direct or swept-lightning flashes may occur. Most of these materials are very good insulators, however, and so will successfully resist punctures by lightning or streamers. An example is shown on Figure 9.

Often the nonmetallic material (fiberglass) parts are lightning protected with external conductors, such as diverter straps or flame spray coatings. They may suffer considerable melting or vaporization in cases of insufficient cross section or thickness of coatings to a maximum current of lightning stroke.

Fuel system

Potentially, aircraft fuel systems represent the most critical lightning hazard to flight safety. An electric spark produced by only 0.2 millijoule of energy is sufficient to ignite a propagation flame in a near-stoichimetric mixture of hydrocarbon fuel and air[3]; yet lightning-flash current may deposit several thousand joules of energy in an aircraft. There are several jet and turbojet transport accidents on record which have been attributed to lightning ignition of fuel. Although the exact location of ignition in each case remains obscure, the most prevalent opinion is that lightning ignited fuel vapor at the wing tip vent outlets of these aircraft.[4,5] Another possible ignition source may be the melting through the integral fuel tanks due to swept lightning across the skin of such a fuel tank. The common way to prevent this effect is by using skins with thickness greater than 2 mm, so that no melt through is possible for swept lightning strokes.

Electrical systems

If an externally mounted electrical apparatus, such as navigation lamp or antenna, happens to be at a lightning attachment point, protective globes or fairings may break through and permit some of the lightning current to enter associated electrical wiring directly. In the case of a wing tip navigation light, for example, lightning may break through the protective globe and light bulb. This may in turn allow the lightning arc to contact the bulb filament so that lightning current may flow into the electrical wires running from the bulb to the power supply bus. Even if only a fraction of the total lightning current enters the wires, they may be too small to conduct the thousands of amperes involved and thus be melted or

Figure 7
Resistive heating and explosive vaporization of conductors. (USAF photo)

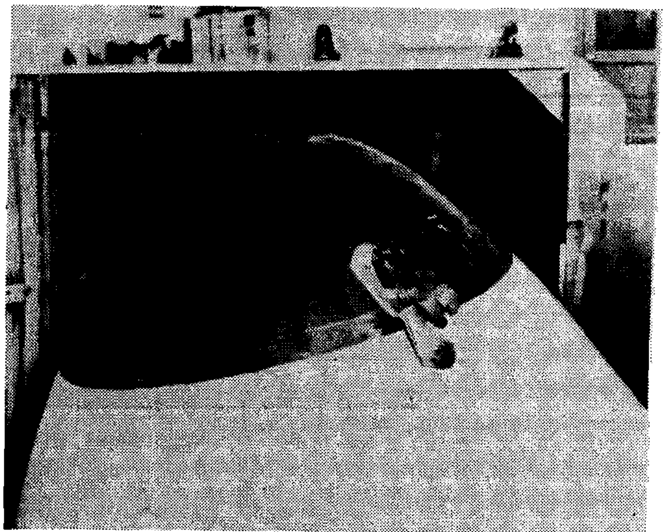


Figure 8
Puncture of a fiberglass-honeycomb radome. (UAL photo)

Figure 9
Evidence of lightning attachment to canopy fastener and scorching of canopy. (GE photo)

vaporized. The accompanying voltage surge may cause breakdown of insulation or damage to other electrical equipment powered from the same bus. At best, the initial components affected are disabled; at worst, enough other electrical apparatus may be disabled along with it to require evacuation of the crew and loss of the aircraft. There are many examples of this effect involving both military and civil aircraft. Externally-mounted hardware most frequently involved includes navigation lights, antennas, pitot probe heaters and trailing long-wire antennas that were deployed in flight for high-frequency radio communications. The latter were quite susceptible to lightning strikes, and since these wires were too thin to conduct the following currents, they were frequently burnt away. The high-frequency radio sets feeding these antennas were also frequently damaged, and cockpit fires were not uncommon.

Indirect effects

Even if the lightning flash does not directly contact the aircraft's electrical wiring, strikes to the airframe are capable of causing voltage and current surges in the wiring which may be damaging to aircraft electronics. The mechanism whereby lightning currents induce voltages in aircraft electrical circuits is illustrated in Figure 10. As lightning current flows through an aircraft, strong magnetic fields which surround the conducting aircraft and change rapidly in accordance with the fast-changing lightning-stroke currents are produced. Some of this magnetic flux may leak inside the aircraft through apertures such as windows, radomes, canopies, seams and joints. Other fields may arise inside the aircraft when lightning current diffuses to the inside surfaces of skins. In either case these internal fields pass through aircraft electrical circuits and induce voltages in them proportional to the rate of change of the magnetic field. These magnetically induced voltages may appear between both wires of a two-wire circuit, or between either wire and the airframe. In addition to these induced voltages, there may be resistive voltage drops along the airframe as lightning current flows through it. If any part of an aircraft circuit is connected anywhere to the airframe, these voltage drops may appear between circuit wires and the airframe, as shown in Figure 10.

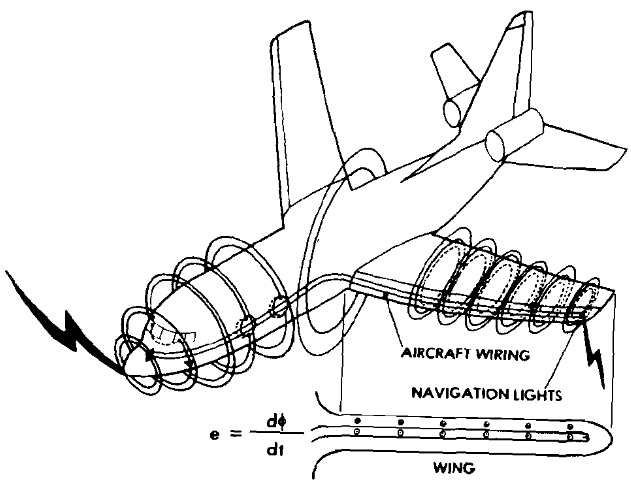


Figure 10
Magnetic flux penetration and induced voltages in electrical wiring.

Incidents of upset or damage to avionic or electrical systems, without evidence of any direct attachment of the lightning flash to an electrical component, are showing up in airline lightning-strike reports. Table I summarizes the reports of interference or outage of avionic or electrical equipment reported by a group of U.S. airlines for the period June 1971 to November 1974.[6]

EVIDENCE OF INDIRECT EFFECTS IN COMMERCIAL AIRCRAFT
(214 strikes)

	Interference	Outage
HF communication set	—	5
VHF communication set	27	3
VOR receiver	5	2
Compass (all types)	22	9
Marker beacon	—	2
Weather radar	3	2
Instrument landing system	6	—
Automatic direction finder	6	7
Radar altimeter	6	—
Fuel flow gauge	2	—
Fuel quantity gauge	—	1
Engine RPM gauges	—	4
Engine exhaust gas temperature	—	2
Static air temperature gauge	1	—
Windshield heater	—	2
Flight Director computer	1	—
Navigation light	—	1
AC generator tripoff	(6 instances of tripoff)	
Autopilot	1	—

TABLE I

The incidents reported in Table I occurred in 20% of the total of 214 lightning-strike incidents reported during the period.

Lightning protection on Westwind 1124 aircraft

The aircraft skin and structure are electrically homogeneous; all moving surfaces such as flaps, trims, control rods, power transmission elements, and all electrical and avionics components are electrically bonded to aircraft structure to divert lightning currents to main structure elements, avoid electrical shock hazards and minimize electromagnetic interference.

Metal pipes and cables that are located in a probable lightning current path (e.g.; along wings or along fuselage) are bonded electrically to aircraft structure.

Nonmetallic openings in aircraft skin, such as radomes, tip fuel tank, rear cover etc., are protected by diverting strips.

The fuel tanks and many other components of the fuel system are located in zones of high probability of lightning strikes. How is lightning protection achieved?

The thickness of aluminum alloy on tip tank skin is 2 mm and wing tank skins are 2mm and more. (The fuselage tank has its own skin inside the fuselage skin.) That skin thickness is enough to avoid melt through because of hot spot formation by lightning arc attachment.

The non-siphoning fuel filler caps recess inside the fuselage and are closed with doors which are electrically bonded to the fuselage. Such design excludes the possibility a lightning attachment directly to a filler cap, and the fact that caps are non-siphoning excludes the danger of a lightning attachment directly to the doors.

Fuel dump and drain outlets are protected by the dump and drain valves, which provide firm separation between the open air and the fuel system when closed

The main fuel vent outlets, located at the bottom of the tip of the wings, are in lightning protected zones created by the fuel tip tanks.

Possible lightning effects on Westwind 1124 aircraft

In spite of the fact that the 1124 aircraft is lightning protected against catastrophic effects, most of the lightning effects which follow are possible:

On the metallic surfaces of the aircraft there may occur melting points, as shown in Figure 1, but they will not burn through the skin. The same may be happening on the grounded antennas and the drain and dump pipes of the fuel system.

On the nonmetallic parts:

Where there are external diverter strips (nose radome and vertical stabilizer radome) the following is possible:

—melting and scorching of the areas from a point of lightning attachment to the nearest conductive strip;

—the diverting strips may be damaged and will have to be replaced after landing, in case of a 200 KA ($2 \times 10^6 A^2S$) lightning stroke, which is considered a maximum current for lightning strokes and is of a low probability.

Where there are internal conductive diverters there may be melting and puncture of the structure, which is extremely improbably, because attachment points will be at either antennas or static dischargers which are capable of conducting one maximum lightning strike or multiple medium strikes.

The windows and windshields may be scorched if a lightning stroke is swept across their area.

On the trailing edges of the flaps there may be pittings, if a lightning strike attachment point occurs at these parts of the aircraft.

The circuits of the position and anti-collision light lamps may be damaged in case of a direct lightning strike attachment to these points. The near-by static dischargers will most likely divert lightnings from the lamps.

On the aircraft the static dischargers provide exclusive lightning diverter elements - controlled path lightning diversion. These dischargers will have to be repaired when a large lightning current flows through them.

In the cases of poor electrical contact between some parts and the airframe, large heating from a lightning current is possible, up to the melting and vaporation temperature. The electrical bonding of such parts is supposed to prevent this effect.

On some sharp parts of the aircraft, such as trailing edges of the rudder and elevator, pinching may occur.

The indirect effects of lightning strike in the aircraft are difficult to predict. The following are examples of possible effects (only a few at a time are expected):

—deviation of compass magnetic system;

—circuit breaker pop out;

—generator trip;

—fuel control jumps to "manual" mode;

—disabled avionics (loss of the electronic memory or damage of data busses);

—damage to communication or navigation equipment due to antenna circuit damage;

—short-duration interference in most electronic systems;

—damage of some engine instrumentation.

Conclusion

It follows from the above that there is a wide field of research activity needed to achieve a reasonable and economical solution for eliminating lightning strikes consequences, which may be not catastrophic but, in many cases, undesirable.

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Biography

Dr. Peter Slezinger - Electronic Engineer at Israel Aircraft Industries, where he was a project leader and individual contributor in applied research and development related to control systems of electro-mechanical equipment. His interest and capabilities include analysis and development of control systems, especially based on analog and digital electronic instrumentation. He has lately been working in the field of electromagnetic compatibility of equipment and lightning protection of aircraft.

He has a BSEE and MSEE from the Novosibirsk Electrotechnical Institute (1962) in Russia, and a Ph.D. from the Tomsk Polytechnic Institute (1974).

Microwave Landing System (MIS): The New Approach Aid

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Introduction

The need for a new precision approach and landing system had been recognised by 1969/70. A report from the United States FAA and the Air Traffic Control Advisory Committee (ATCAC) recognised that the projected demand for air traffic control services would outstrip the capabilities of the current landing guidance system and concluded that a Microwave Landing System (MLS) was required. The ICAO AWOP also commenced work on the development of operational requirements for such a system in recognition of the need to develop a replacement for the ILS.

Historical Background

In April 1972, the Seventh International Civil Aviation Organization (ICAO) Air Navigation Conference established the All Weather Operations Panel (AWOP) as the designated body to develop Standards and Recommended Practices (SARPs) for a new Non-visual Precision Approach and Landing Guidance System, the MLS. ICAO followed a thorough process in the selection of this new system. Member ICAO States were invited to submit system proposals which were to be reviewed by the designated body of experts. The AWOP, consisting of ten members, was charged with the technical responsibility for the system selection. The selection technique included an orderly process of assessment of the system concepts and the test data derived from proposed hardware concepts.

The AWOP conducted its deliberations by setting up a working group and holding a series of seven meetings from 1973 through 1976. Assessment criteria were defined and preliminary system proposals were received during early meetings. In late 1975, definitive proposals were received from the United Kingdom, Australia, the Federal Republic of Germany, France and the United States. In April 1978, in Montreal, a Divisional Meeting of ICAO selected the Time Reference Scanning Beam (TRSB) MLS as the new International Standard for approach and landing guidance.

History and Status of the Current Standard Instrument Landing System (ILS)

The first commercial VHF Instrument Landing System (ILS) was demonstrated by the United States Civil Aeronautics Administration in 1939. The ILS was adopted by ICAO as the International Standard in 1949, and this sytem continues to provide satisfactory precision landing guidance at most airline airports. Currently, approximately 750 facilities are installed at airports within the U.S. However, of the airports with an ILS, approximately 26 per cent do not meet Category 1 requirements because of signal-in-space and/or obstruction constraints, or the lack of approach lighting.

The ILS is basically a single fixed path system providing vertical and lateral guidance from a pre-defined approach path. Range information is supplied by marker beacons installed at critical points along the path. The electronics system consists of localizer, glide slope, outer and middle (and sometimes inner) markers. The VHF localizer and UHF glide slope are assigned pairs of frequencies from a 20 channel set, although a reduction in channel spacing to 50 KHZ permits a doubling to 40 channels. Precise localizer guidance is provided within a narrow (± 3°) sector with clearance data furnished outside of these narrow limits to at least ± 35° from the runway centreline and at a distance of 10 nm. Whilst ILS has provided highly useful service over 30 years its design, technical and operational characteristics impose constraints which are becoming increasingly severe in the current and projected aviation environment.

Limitations of ILS Design

There are a number of limiting factors which preclude a future based on ILS as some operational requirements would not be filled. Failure to provide all the facilities needed is inconsistent with the need for higher safety, accuracy, cleaner signals and better reliability.

Channel limitations

The ILS currently uses twenty channels, spaced 100 KHz apart. Expansion to forty channels is possible by reducing channel spacing to 50 KHz but this would entail the replacement of avionics equipment with the highest cost impact on the general aviation user.

Operational inflexibility

ILS provides only a single approach path both in azimuth and in elevation. Multiple approach paths would provide the operational flexibility needed to match user requirements to improve terminal airspace utilization and to minimize the noise impact on communities located near the airport. Noise abatement procedures have become an ever more important consideration in airport operations.

Civil/Military incompatibility

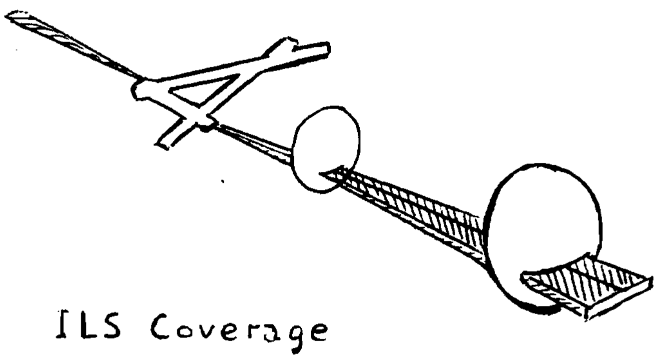
The ILS fails to satisfy military tactical requirements.

Adverse weather effects

The need for a highly stable ground platform for ILS results in adverse effects due to weather conditions. A significant number of outage hours consistently occurs in the winter months, often when the system is most needed.

Siting problems

ILS operates in the VHF and UHF bands. One resulting characteristic, which has become a major deficiency, is the susceptibility to interference from reflecting objects often found in the vicinity of airport runways. Terrain irregularities, large hangars and other structures, or large aircraft taxiing near the runway cause perturbations which are difficult or impossible to overcome in an economically feasible manner. Related to the susceptibility to interference from reflecting ob-



jects is the need for establishing a large area of well-controlled terrain conditions around the ILS antennas, especially for the glide slope which provides the critical beams in elevation. This requirement often necessitates extensive and costly site preparation before the facility can be commissioned. In some cases an adequate area cannot be made available at all. This can severely limit facility performance to less than that desired or preclude a facility altogether.

Need for Improved Signal Quality

Both manual and automatic instrument approach and landing operations will be facilitated by improved signal quality.

MLS System Characteristics and Relationship to User Needs

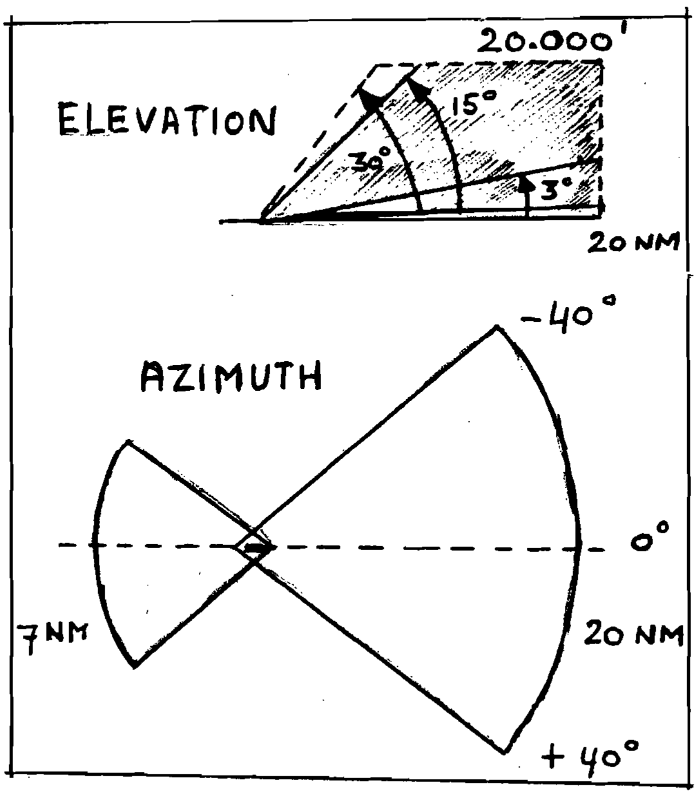
Time-reference scanning beams characterize the all weather microwave landing system that will eventually replace the current systems. In the most fundamental sense, TRSB MLS is a system approach to the landing guidance problem—it can meet a wide variety of diverse performance, economic and safety requirements and still supply a universal airborne receiver-processor able to operate with all ground systems. It must provide for present and future operational needs such as Categories I, II and III landings (200, 100 and 0 feet limits respectively) and also flexible approach paths and precision navigation in the terminal area for noise abatement and the more efficient use of the airport. Moreover, the system must be able to be installed easily at sites unable to accept ILS. MLS can achieve these objectives because of two major factors; the choice of an operating frequency in the microwave C-band, and the design of its signal format. The relatively short wave-lengths of the C-band permit the design of very narrow scanning beams with antennas of reasonable size that achieve high guidance accuracy in the presence of multipath (signals that are reflected from the airport structures). The beams provide freedom from siting effects and allow installation in difficult terrain. The channel plan provides for 200 channels of 300 KHz bandwidth in the 60 MHz between 5031 and 5091 MHz. The TRSB antennas are small enough to enable them to be placed in front of ILS antennas without affecting the performance of the ILS. This is an important consideration during the period of transition from ILS to MLS installations. It has already been demonstrated that the two systems can physically and electronically coexist during the transition period. I have flown the MLS-equipped FAA aircraft at Washington DC and performed both ILS and MLS approaches using the same cockpit instrumentation. There was no separate ILS and MLS indication, the only action required being to select the required approach aid.

The MLS has been specially designed to overcome the limitations of ILS and to provide greater flexibility. The MLS is capable of providing services to helicopters and short/vertical take-off and landing aeroplanes. Many of the limitations of ILS, particularly its sensitivity to siting conditions, surrounding terrain and weather effects can be attributed to the frequency band in which it operates. Therefore, the choice of frequency band for the MLS was a very important consideration. By moving the microwave frequencies (5.25 GHz band for angle and 9 to 12 MHz band for the range facilities) a number of major advantages can be realised. For example, it is possible to generate narrow, precisely shaped beams with physically smaller antennas, thus making the MLS signals much less sensitive to siting conditions and surrounding terrain. Also, there is a large increase in available frequency channels which will facilitate widespread deployment of MLS with channel assignments on a non-interfering basis. Nevertheless, there are some disadvantages inherent in microwave frequencies in relation to the ILS band which have to be taken into account. For example, line-of-sight propagation characteristics of the signals which give rise to poorer coverage of the system when shadowing conditions exist (such as on humped runways or in off-centre line regions where trees or building protrude into the coverage volume) are somewhat more severe at C-band frequencies than at VHF and UHF bands.

Description of the MLS

System Operating Technique

MLS comprises azimuth, elevation and distance measuring functions which provide continuous, accurate three-dimensional position information within a wide coverage volume. In addition, the ground-air data channel provides information directly associated with the system operation. The angle signal formed is based on time-division-multiplexing wherein each angle guidance function is transmitted in sequence and all are transmitted on the same MLS channel. A time slot is assigned for the approach azimuth, approach elevation, flare, and back azimuth angle functions. The preamble identifies the next scan function and also synchronizes the airborne receiver signal processing circuits and logic. The angle information is derived by measuring the time difference between the successive passes of highly directive, unmodulated narrow fan beams.



Ground Equipment

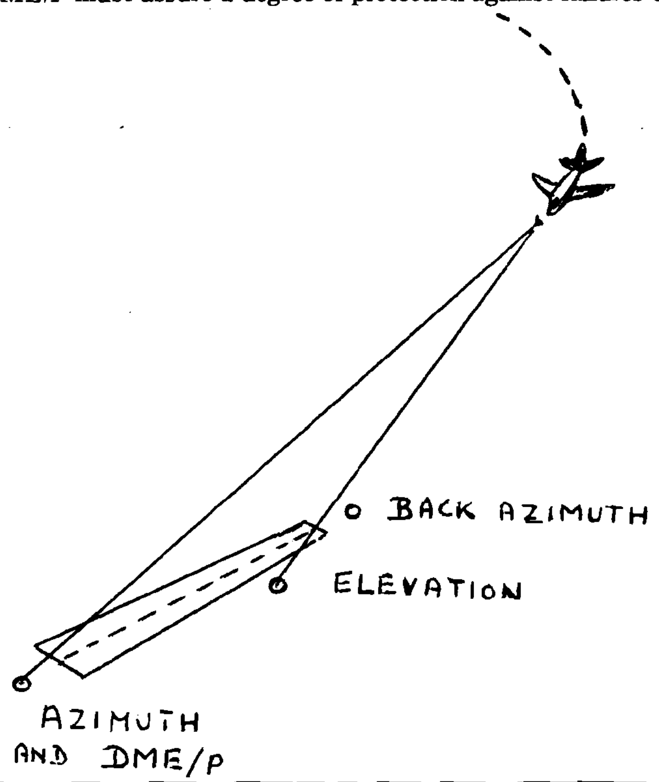
The antennas for approach and back azimuth guidance each produce a fan-shaped beam which is narrow in the horizontal plane and broad in the vertical plane. This beam is scanned clockwise, then counter-clockwise between the horizontal coverage limits at a precise rate, filling the entire coverage volume. The azimuth coverage volume is 40° left and right of runway centreline and 20 n.m. in distance. Each angle transmission consists of a TO (clockwise) scan followed by a FRO (counter-clockwise) scan. The elapsed time between reception of the TO scan and the FRO scan is directly related to the azimuth angle of the receiving antenna with respect to the line of zero azimuth angle. Where the proportional guidance provided is less than ± 40 degrees with respect to the runway centreline, clearance guidance is provided to extend the coverage sector out to that value by the transmitted fly left/right signals in the signal format for the azimuth functions. Proportional guidance is available in a minimum sector of ± 10 degrees.

Elevation Guidance Functions

The elevation antenna produces a fan-shaped beam which is narrow in the vertical plane and broad in the horizontal plane. This beam is scanned up and down between the vertical coverage limits at a precise rate filling the intended coverage volume. The elevation coverage volume is 40° left and right of the runway centreline over a distance of 20 n.m. and 15 degrees from the horizontal.

Distance Measuring Function

The distance information is provided by DME. This can be conventional DME or a new version of DME (DME/P) in cases where higher precision is required. The operational requirements (OR), as established by the Communications Divisional meeting of ICAO in 1981, call for the DME/P to be a part of the MLS. The DME/P should take over around a distance of 7 n.m. and coverage should be provided down to 2.5m above the runway surface. When operationally required, the distance to the stop-end of the runway should be displayed to the pilot. The DME/P must assure a degree of protection against failures or malfunctions sufficiently high to prevent jeopardizing the safety of flight.



Airborne Equipment

The MLS airborne equipment includes antenna, the angle receiver, the pilot interface equipment and the necessary interconnections. A separate interrogator/receiver with its associated antenna provides the distance information. A user may choose an omni-directional antenna and an angle receiver for use with existing ILS displays and, at the other extreme, a user equipped for autoland capability would select a redundant set of angle receiver/processors and DME interrogators operating with existing or advanced displays. As an example, I would like to mention the MLS approaches I flew with the FAA King Air aircraft fitted with standard flight instruments and second, a flight with the NASA terminal configured vehicle (TCV) where we flew coupled approaches and autoland using Cathode Ray Tubes (CRT) as the main flight instruments. These new avionics when used in the right way are a big step forward. The MLS is an "air-derived" system in which position is measured directly in the aircraft, rather than relying on a ground to air data link. Air derived systems provide navigation information separate from any surveillance function and thus achieve an added measure of integrity through system independence. Therefore, the pilot has the facility of selecting his own approach path, if necessary, or adhering to a publishing approach procedure, including multi-slope angles, with a great degree of accuracy.

Safety Benefits

Benefits of risk-reduction include the prevention of two kinds of accidents: non-precision approach accidents during IFR conditions and those occurring in VFR landing and runway conditions. Of these, the IFR approach accidents are by far the most costly, especially in numbers of aviation fatalities. It must be clear that safety benefits weigh more heavily than economic benefits. Investments in landing aids are a form of insurance against potentially disastrous accidents. The International Federation of Air Line Pilots' Associations favours the adoption of the MLS, which has the advantage of allowing installation at places where the ILS cannot provide the required full coverage. IFALPA has made it clear that the new MLS should be operationally tested and that the ICAO Standards and Recommended Practices (SARPs) should be subjected to a formal review following analysis of the results from the operational tests. MLS will improve the achieved safety standards of the International Civil Air Transport system and, to pilots, that is the most important factor.

Transition Plan

The purpose of the Transition Plan is to outline the optimum way to introduce the proposed MLS into the national and international airspace system as the replacement for the existing ILS. The total cost of MLS implementation in the USA is estimated at 1981 prices to be $2.0 billion: $1.1 billion for 1,250 ground systems and $0.9 billion for the associated avionics to be funded by aviation users.

ICAO MLS Transition Programme

Phase I (until 1990)
- —ILS standard protected until 1995
- —MLS optional
- —ILS may be installed until 1990

Phase II (1990-1995)
- —ILS standard protected until 1995
- —MLS recommended
- —unlikely to get more ILS installed
- —new aircraft already fitted with MLS

Phase III (1995-2000)
- —MLS standard protected to at least 2005
- —ILS optional
- —existing aircraft will be fitted with MLS or MLS/ILS

Phase IV (2000 onwards)
- —MLS standard protected to at least 2005

ICAO will re-examine before 1 January, 1985, in the light of the progress of introduction of MLS and other operational, technical and economic considerations, the need for further extension of the ILS protection date beyond 1 January, 1995.

By introducing the MLS we have to consider the following points:

> The need to provide MLS where requirements for ILS cannot be met for operational, technical or economic reasons; operational experience; the need to curtail the transition phase. The intention would be for MLS to be in general use between 1995-2000. The Transition Phase to MLS should be of the order of ten years.

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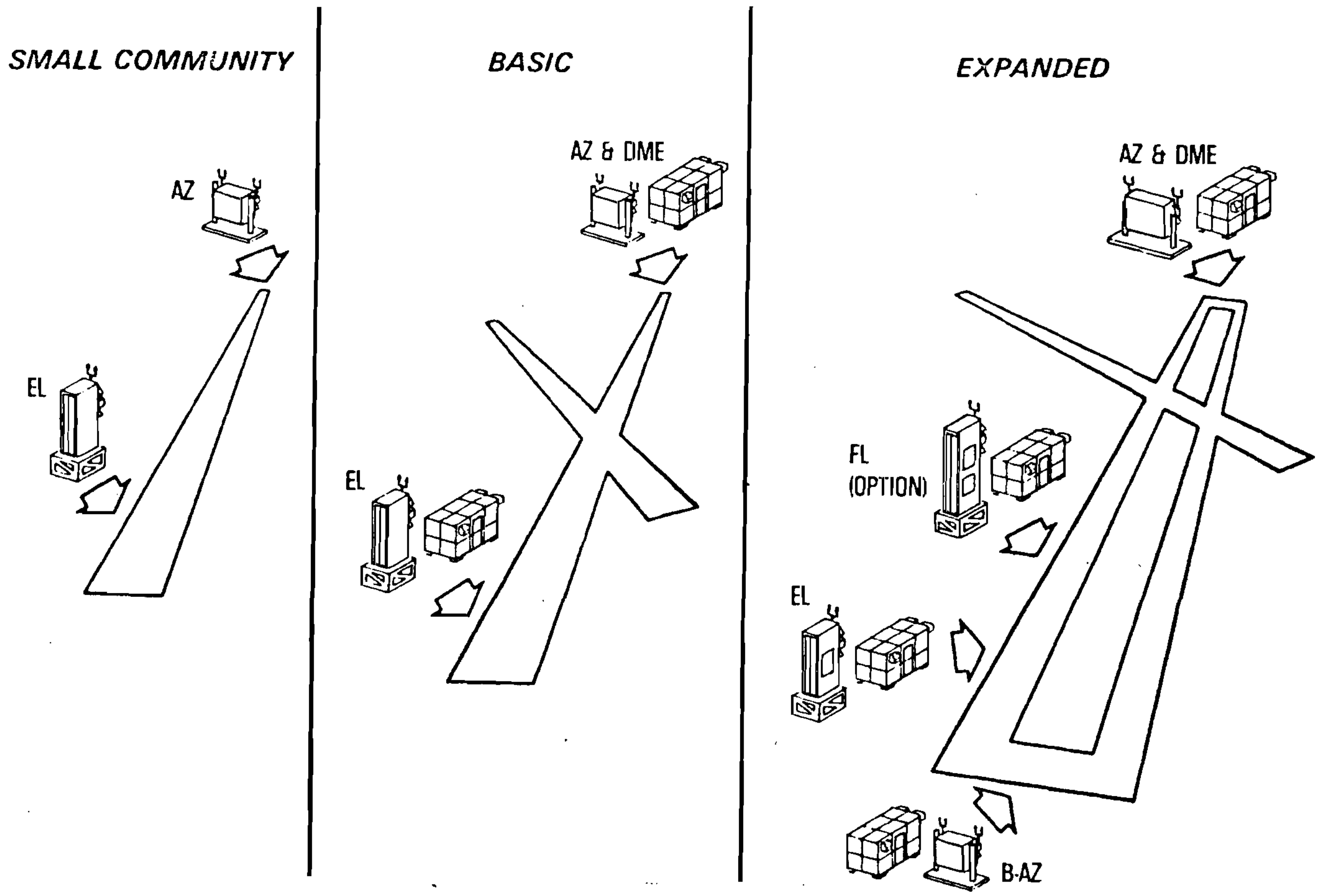
Biography

Captain Douwe W. Staal is the IFALPA Representative and Member, ICAO All Weather Operations Panel. He flew in the Royal Dutch Air Force as a fighter pilot and instructor, and has a degree in Aircraft Engineering. He studied at the University of Southern California and received the Certificate for Aircraft Accident Investigation and the Certificate for Human Factors. He has more than 12,000 flying hours, and is currently an active International Captain with SWISSAIR.



Diagramming the Wreckage Scene

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INTRODUCTION

Aircraft accident investigators talk about "diagramming the wreckage," but the actual results are a little inconsistent. In practice, the diagrams vary from superbly drawn engineering maps, to someone's pencil sketch of the wreckage as he remembers it, to no diagram at all—each bearing little relationship to the need for a diagram or its usefulness in the investigation.

This paper is written to put wreckage diagramming in perspective and suggest a simple, reasonably accurate method that can be managed by the individual investigator.

WHY MAKE A DIAGRAM AT ALL?

Why indeed? Is all this work really necessary? Or are we just blindly filling some requirement of our accident investigation forms?

Logically, if the accident and the crash are unrelated, meaning that the crash is merely the expected result of the accident, then there is little to be gained from an elaborate diagram. Examples of this type of accident might be mid-air collisions, fuel starvation, and inflight engine failure on a single engine aircraft. In each of these, the "accident" occurred somewhere else and the wreckage is merely the end result. The distribution of the wreckage and the dynamics of the impact are of relatively little importance.

On the other hand, if the crash and the accident are related; or if there is some question about the survivability of the accident; then a good diagram is not only helpful to the investigators, but is essential to those who must review the accident in later years. Since they never have the opportunity to see the wreckage as it once existed, the diagram and the photographs are their only links to the original situation.

In any event, the diagram ought to be a useful tool for the investigators as the investigation progresses; not something that is merely appended to the final report. For the investigator, the diagram can be a big help in crash survivability calculations. It is a useful device for inventorying the major parts of the aircraft and recording the crash sequence. It is also a handy way to plot witness locations and show where pictures of the scene were taken.

This need to have a diagram available in time to be of use to the investigators tends to mitigate against the accurately drawn surveyor's map of the scene. Beautiful as these are, they are seldom ready until long after the investigator has packed his bag and left for the next accident.

This raises some questions. How much accuracy is needed? What is a reasonable amount of time to spend plotting or diagramming wreckage? Can investigators be expected to do an acceptable job without professional engineering or drafting assistance?

HOW MUCH ACCURACY IS NEEDED?

It is the author's view that it is important to accurately locate the wreckage impact with respect to some fixed reference point on the ground and to get the various parts of the wreckage correctly located relative to each other. If the total dimensions of the crash scene are reasonably accurate and the parts are correctly depicted with respect to each other, then a few feet of error in the location of a specific part is not significant. Likewise, angular measurements within three degrees are accurate enough for most investigative calculations. Those of you who were in San Francisco at the ISASI seminar two years ago heard Fred Matteson give a fine paper on diagramming wreckage by triangulation. Even with that method, if you stay within the distance limits proposed by Dr. Matteson, measurements accurate to plus or minus three degrees should produce a reasonably accurate diagram.

HOW LONG SHOULD IT TAKE?

Unless there are unusual distances or terrain obstructions involved, it is the author's view that two people can diagram a large wreckage scene in less than a day and can have it plotted on a scale drawing that evening. The most time-consuming part is not the actual diagramming, but the identification of the wreckage parts. If the investigators are prepared to identify the parts as they go, then there is no reason why an accurate diagram can't be available for use the following day.

DO YOU NEED TECHNICAL ENGINEERING OR DRAFTING ASSISTANCE?

Not really. With a little planning and an understanding of the process, air safety investigators can construct reasonably accurate diagrams with the tools and techniques they learned to use as pilots or navigators.

WHAT EQUIPMENT IS NEEDED?

A 100-foot tape measure, stakes, markers for the stakes, a lensatic compass, an air navigation plotter (the combination ruler and protractor you plot navigation legs with), a notebook, some sheets of good quality hard finish drawing paper (size not important), some pencils, erasers, and a thin-line black pen. That's the basic equipment. In addition, of course, you need a parts catalog and some tags if you want to tag the parts as you go.

LET'S GET ORGANIZED

First, get the best information available about the area or the wreckage scene. Aerial photographs are invaluable and will significantly improve the accuracy of your final diagram. If you can't get aerials of the crash scene and your accident occurred in an urban area, there is an excellent chance that aerial photos of the area are already on file with the local government or an aerial mapping company. Even these will help. If the accident occurred on or near an airport, start with a scale diagram of the airport available through the airport manager or the governing aviation agency of that country. Almost all airports have had aerial photographs taken of them. These can be useful. If the accident occurred in a rural area, get the best available large-scale map of the area. These will not be aerial navigation charts, but will come from government agencies involved in land management, wildlife management, conservation, geology, etc. Find out what maps hunters and campers use. Check with local surveying companies and libraries.

Second, get your diagramming team together and discuss procedures. This technique can be managed by one person, but it goes faster with more people. Any number can play.

Third, pick a reference point. This should be a point you can later identify on the maps or aerial photographs and accurately locate by latitude and longitude or by distance and direction from a town, airport, or known map reference. Your reference point may be a road intersection, a telephone pole, a

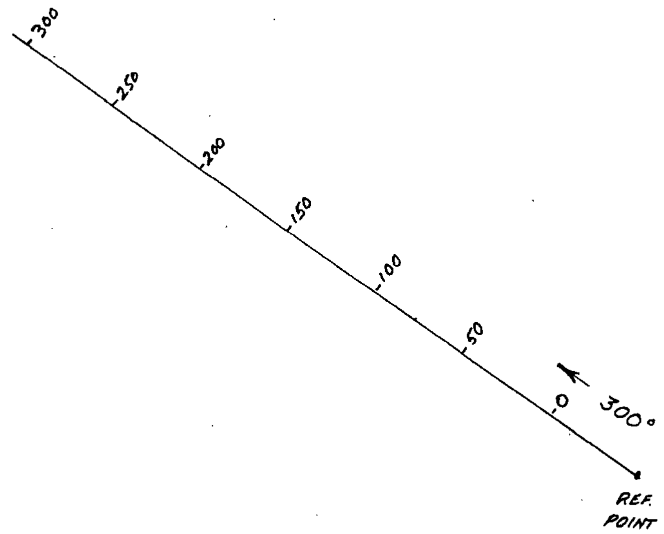


FIGURE 1
Start the diagram with the reference line.

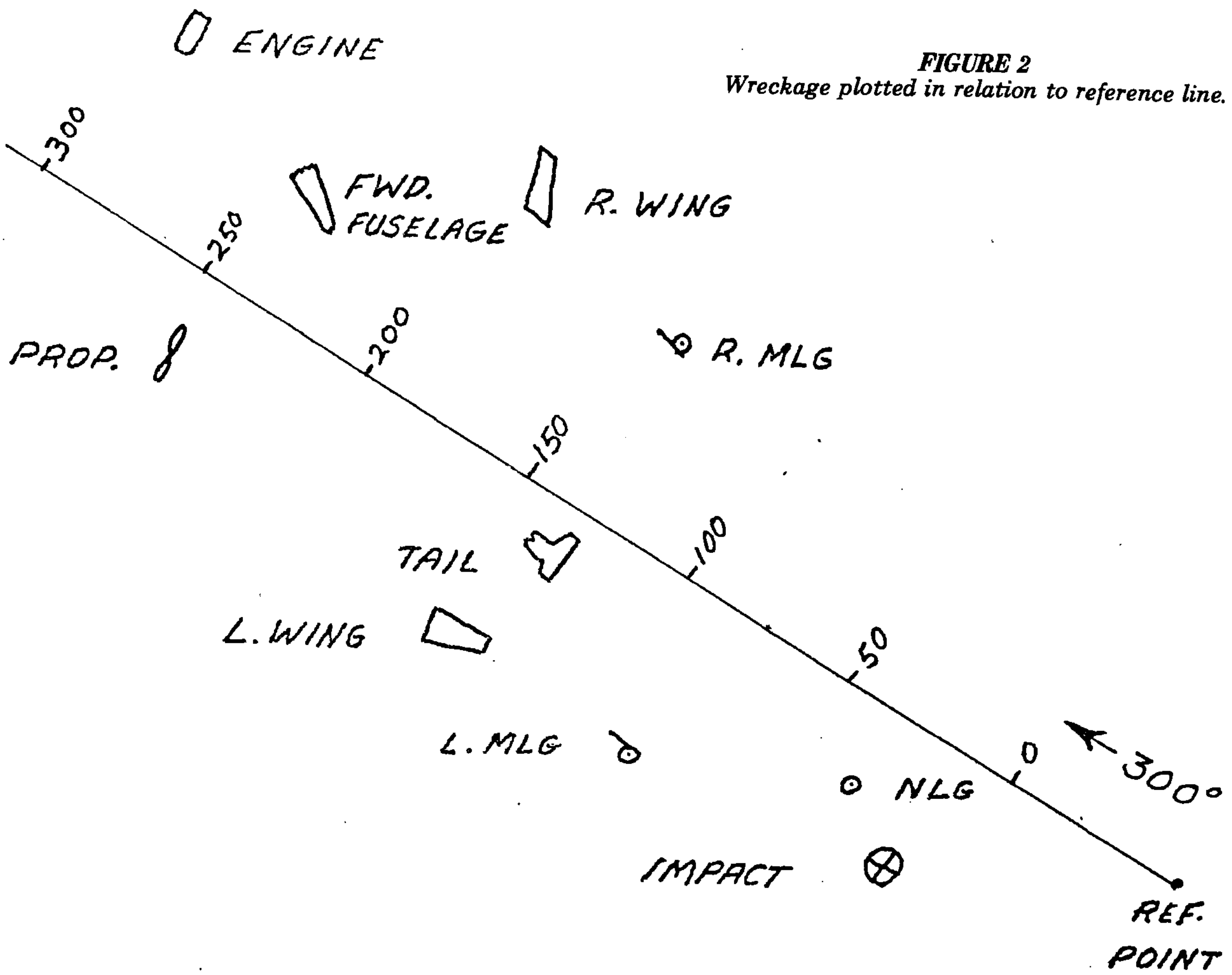


FIGURE 2
Wreckage plotted in relation to reference line.

corner of a piece of property, a prominent ground feature, a bend in a stream—anything that is identifiable. It doesn't matter where it is in relation to the wreckage as long as it is somewhere around it or in it and near enough to be within reach of your tape measure.

LET'S GET STARTED.

First, you are going to run a straight line of stakes generally through the center of the wreckage. It is important to understand that the stake line is related to your chosen reference point; not the line of flight of the aircraft at impact. Also, it makes no difference where you put your first or "zero" stake. The easiest thing to do is to start at the reference point and run the stakes through the wreckage so that about half the wreckage is on each side of the stake line.

If this is not convenient, then start the stake line at any suitable point and run it through the middle of the wreckage from there. Now you must take the extra step of locating your first stake to your reference point by distance and direction.

Regarding the stakes themselves, ordinary wooden stakes 3-4 feet long such as those used in agriculture or plant nurseries to support plants usually work fine. Ideally, they should be 50 feet apart. It really doesn't make any difference, but distances in multiples of ten simplify the final plotting and scaling of the diagram.

Next, stand behind the first stake and sight down the stake line with your lensatic compass. Note the compass heading of the stake line. Remember, this is merely a reference line; not impact heading.

Now, take whatever measurements of the slope of the terrain or the impact crater that you need. For angular measurements, use your air navigation plotter with a piece of string through the protractor hole and a weight on the end of the string. By sighting along the flat edge of the plotter and reading the angle where the string crosses the protractor, you are using a cheap (but fairly accurate) inclinometer. To obtain terrain slope, merely stand at the bottom and sight toward another investigator standing at the top. If the aircraft hit a tree prior to impact, stand a known distance from the tree and sight toward the broken branches. The height of the aircraft as it hit the tree would be the distance you were standing from the base of the tree multiplied by the tangent of the angle measured with your inclinometer. To measure an angle in the impact crater, lay a spare stake down the side of the crater to depict the average slope of that side and measure the angle of that slope by using your inclinometer and you are ready to plot the wreckage.

PLOTTING THE WRECKAGE.

For this, you need only a notebook, a means to identify the wreckage parts, and knowledge of a simple code. You are going

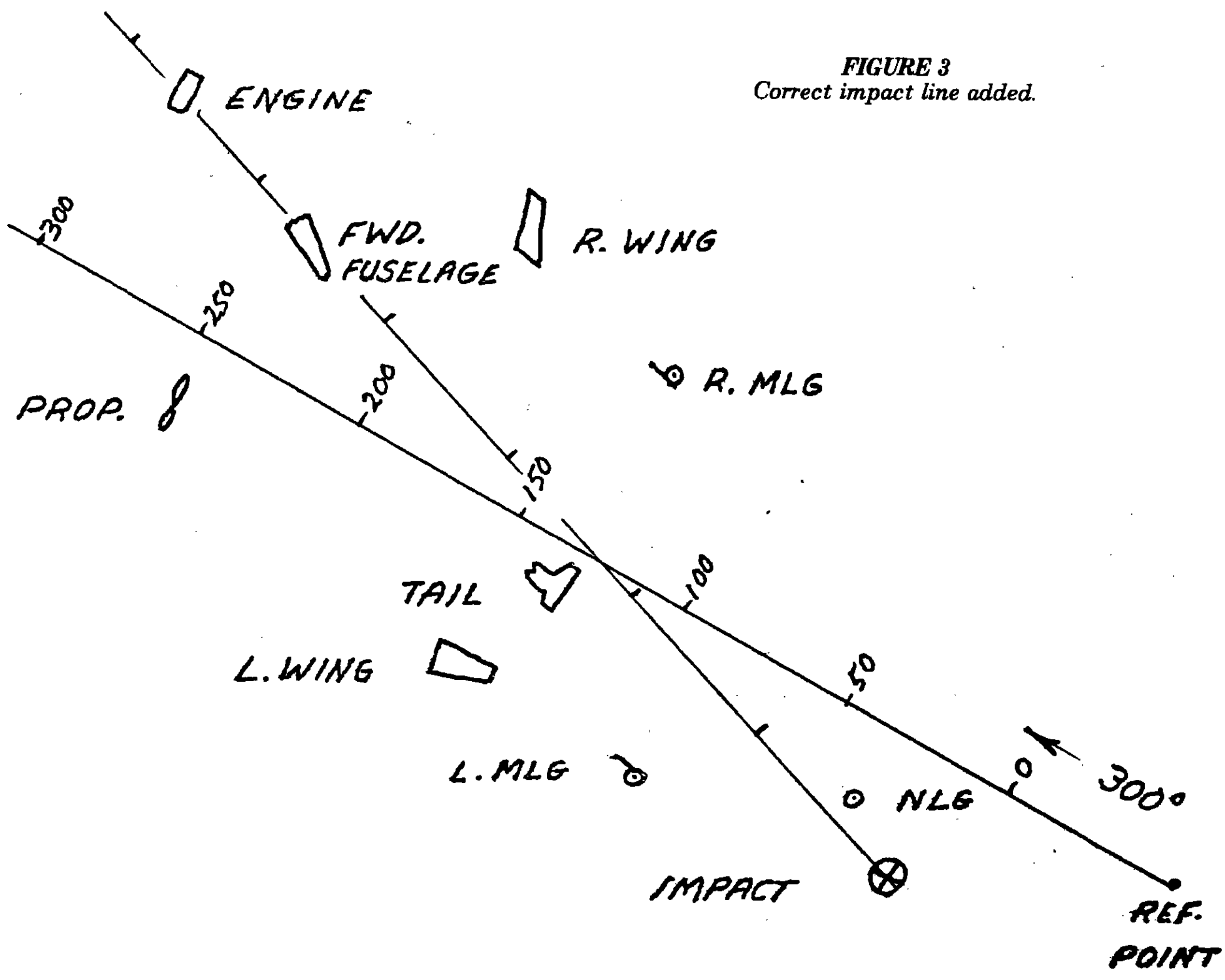


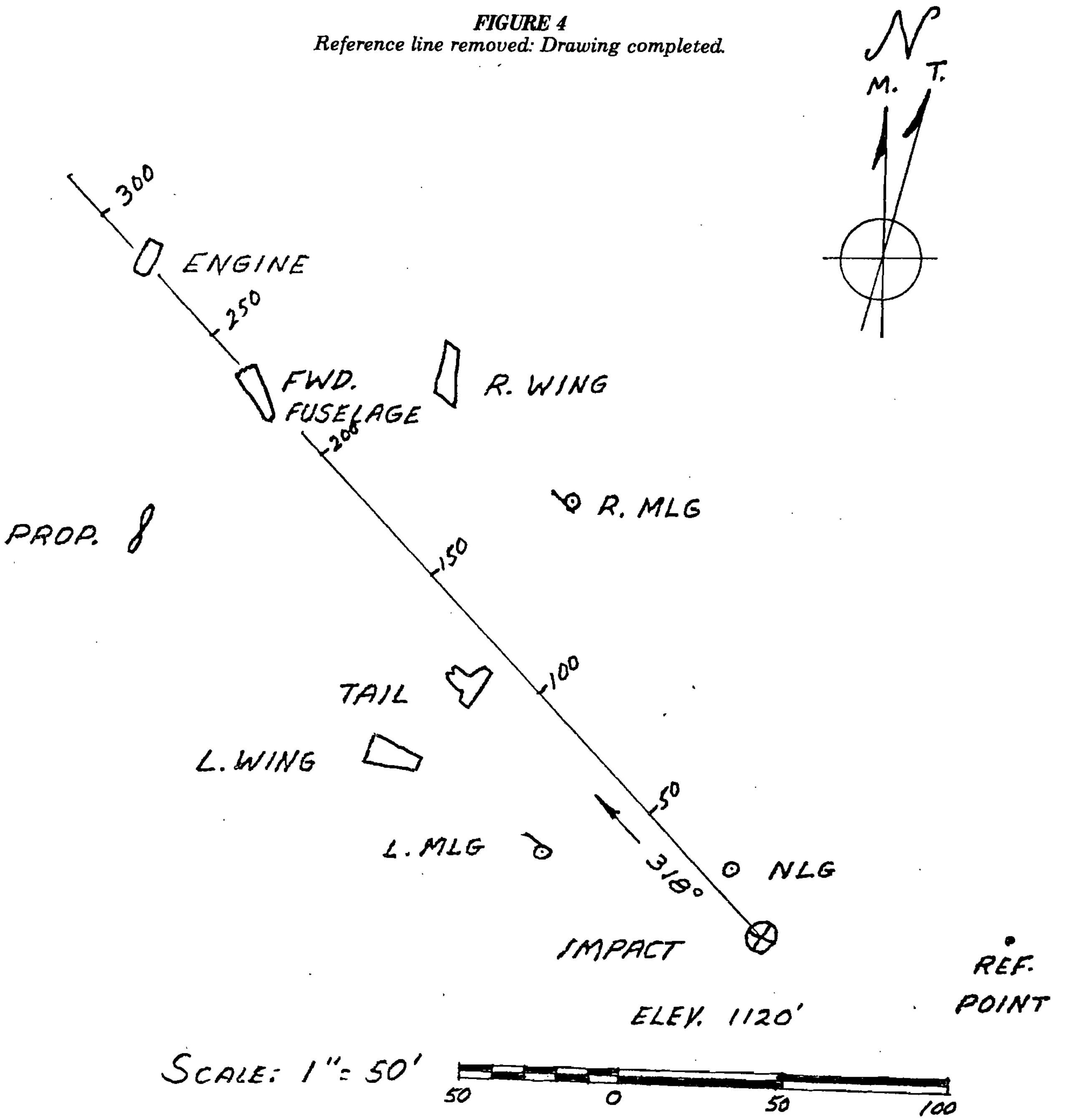
FIGURE 3
Correct impact line added.

to relate each significant piece of wreckage to your reference line by a distance from the starting point of the stake line and a distance right or left of it. Since your stakes are not more than 50 feet apart, you will be able to estimate the distance between stakes and be accurate within a few feet. For the distance from the stake line to the wreckage part, you will pace this off and, again, be accurate within a few feet. (Remember, correct relative position of the parts is more important than absolute accuracy.) Your entries in your notebook will look something like this:

(Distance from 1st Stake)	(Right or Left)	(Distance from Line)	(Wreckage Part)
15	L	35	IMPACT CRATER
35	L	22	NOSE LANDING GEAR
85	L	47	LEFT MAIN LANDING GEAR
130	R	50	RIGHT MAIN LANDING GEAR
135	L	15	TAIL
140	L	45	LEFT WING
185	R	65	RIGHT WING
240	R	35	FORWARD FUSELAGE
250	L	18	PROPELLOR
285	R	50	ENGINE
		(. . . and so on.)	

This means that you found the impact crater 15 feet from the beginning of the stake line and 35 feet left of it. The right main landing gear was 135 feet down the line and 50 feet right

FIGURE 4
Reference line removed: Drawing completed.



of it—and so on. There is no actual plotting or diagramming in the field—merely note the location of each significant part with respect to your reference line. This is all that needs to be done in the field. If you can teach several people this referencing technique and notebook code system, you can complete this part of the problem in a matter of a few hours.

DRAWING THE DIAGRAM.

The remainder of the work takes place at a desk or a table and takes an hour or so.

1. Using your air navigation plotter, draw, in pencil, your reference point and your stake line on your drawing paper. Pick a scale that will fit the entire line on the piece of paper you have. It is not necessary to draw the stake line on its correct compass heading (the line could be drawn vertically without regard to heading) but it is easier to understand this method of diagram drawing if the headings are correct. A sample reference point and stake line is shown in Figure 1.

2. Using the reference notes from your notebook, plot the wreckage parts on the diagram. This is shown in Figure 2.

3. Examine the diagram and determine what the actual line of impact (flight path of the aircraft) was. In the sample accident shown, the impact line was most likely from the impact crater through the center of the wreckage pattern to the engine. Here, you are determining impact heading from the diagram. This is just as accurate and, in some cases, more accurate than trying to do it at the wreckage scene. If, of course, you had positive evidence of impact heading (aircraft struck a tree prior to impact, for example) then you would use that as your impact line drawn from the impact crater. Figure 3 shows the impact line added to the diagram.

4. At this point, check your diagram for accuracy by comparing it, if possible, to an aerial photograph of the scene. Make any adjustments necessary.

5. Erase the reference line you used to start the diagram and add a distance scale to the impact line. Impact heading is, of course, derived by measuring the angular difference between the reference line and the impact line. This is still a compass heading and you can correct it, if you like, by applying local magnetic variation.

What you have now is a diagram that correctly locates all parts of the wreckage with respect to each other and to the impact line. The diagram is accurate enough to be used for scaled measurements and any impact dynamics calculations.

Now, you can begin adding the normal data you need on a completed diagram. This usually includes:

- Scale
- Elevation
- North Reference
- Date
- Location (Reference Point)
- Type Aircraft/Registration Number
- Investigation Authority

Figure 4 shows the completed diagram with some of this information added and the reference line removed.

SUMMARY.

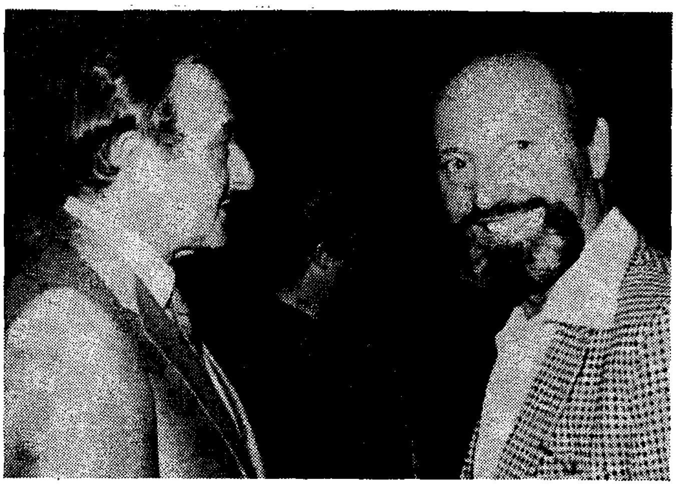
The method described is meant to be used by the field investigator. It is fast, accurate, and doesn't require any particular talent as a surveyor or a draftsman. It does not require any complicated or expensive equipment and it eliminates the problem of trying to sketch a diagram in the field at the scene of the accident. Furthermore, it can be rapidly taught to the other members of the investigative team. Once the reference line is established, they can all help identify parts and note distances along and from the reference line.

The keys to this method are, first, take full advantage of all available maps, charts, and aerial photographs. Second, realize that it doesn't really make any difference where the initial reference line is as long as it is straight and can be associated with a known reference point. Put it where it is convenient for you. Once you have the wreckage parts correctly referenced to a line, you can remove that line from the diagram and draw in a new line extending from the impact crater.

With this method, you should be able to produce a diagram that satisfies your needs as an investigator and can go into your report as an accurate record of the accident scene.

Biography

Dick Wood is a faculty member at the University of Southern California, Institute of Safety and Systems Management. His specialties are Aviation Accident Prevention, Aircraft Accident Investigation and Aircraft Accident Photography. He is a registered professional engineer and a certified safety professional. He has over 6,000 hours of flying experience as a pilot in a variety of aircraft, and has been active in aviation safety since 1963.



THE INTERNATIONAL SOCIETY OF AIR SAFETY INVESTIGATORS

Tel Aviv, Israel - October 11-16, 1982

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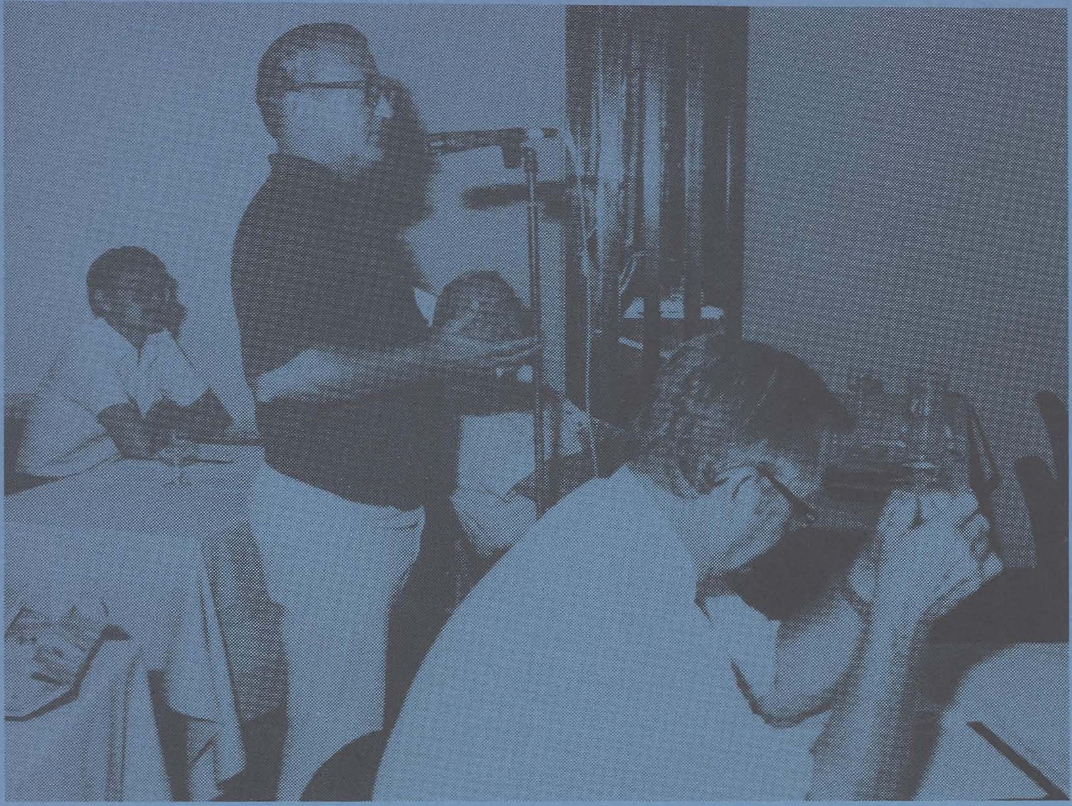

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