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AVIATION SAFETY ANALYSIS

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1. Introduction

Just as the aviation system is complex and interrelated, so is aviation safety. Aviation safety involves design of aircraft and airports; training of ground personnel and flight crew members; maintenance of aircraft, airfields, en route and terminal area navigation and communication facilities; definition and implementation of Federal Aviation Regulations (FARs); air traffic control procedures; and much more. Ultimately, every part of aviation has a safety aspect. No other transportation mode has its safety record so rigorously scrutinized. In part this is due to the general societal (and media) fascination with infrequent large disasters; in part because U.S. legislators have a personal interest in air safety, as they rely upon aircraft for their seasonal commutes to Washington; and in part because people in the industry are aware that their paychecks ultimately depend on their customers' perception that travel by air is as safe as possible. (Various airlines still conduct aircraft familiarity classes for travelers who have a fear of flying, although as the younger generation of Americans gains experience with airlines, this particular phobia should become less prevalent.)

Aside from the industry's self-enforcement attempts, the Federal government tries to assure safety of the traveling public through regulation. The National Transportation Safety Board (NTSB) investigates all major air carrier accidents and subsequently makes safety recommendations to the Federal Aviation Administration (FAA) — which the FAA may or may not choose to accept. One of the long lasting standoffs in aviation safety is between the NTSB (backed by Congressional committees), whose sole concern is safety,and the FAA, which must also take the economics of safety regulations into account-unless it wishes to run into a buzzsaw of industry reaction every time it changes (or issues) a FAR. On the international side, the International

Civil Aviation Organization (ICAO) issues technical rules affecting aviation safety, although such decisions as its upcoming ruling on twinjet aircraft over-water flights may be tinged with economic considerations as well.

But for safety regulations, whether external or internal to the aerospace industry, to make any sense, they must be grounded, to some degree, in reality, i.e. they must be backed up by some technical, statistical, or economic factors which people can address on their own merits. The more quantitative the supporting data are for rule justifications or changes, the greater the likelihood is that the regulations will be successfully promulgated and accepted by industry.

Thus aviation safety analysis came into existence. Most broadly stated, the purpose of safety analysis is to improve safety. The spectrum of analysis ranges from the investigative to the predictive. At one end of the spectrum is the after-the-fact investigation of accidents and a search for causes; at the other end is the attempt to seek out likely causes (or, more typically, combination of causes) of system failure before the system is put into operation. However, the great quandary of aviation system analysis is the lack of sufficient data to make probabilistic statements - even while the goal of this analysis is the elimination of the very accidents that provide the data. Practitioners of classical statistics, who have grown up considering probability as the likely outcome of an event based on a large number of repeated trials, face a mental hurdle when asked to accept the concept that an event which has never taken place can nevertheless be assigned a 0.95 probability of success. This is essentially the dichotomy between the investigative and the predictive ends of safety analysis - one is based on few accidents (but real accidents nonetheless), the other is based on more subjective probabilities of system (and subsystem) failures.

But safety analysts cannot throw up their hands and say that there is insufficient data after only one accident occurs and simply wait for the next one to happen. They must combine forces with their predictive brethren and attempt to head off the next accident. Only when this becomes the rule will aviation safety analysis rest on a sound base. Until this millennium, however, much remains to be done to improve safety analysis at each end of the analysis continuum, and also where the two occasionally intersect by chance.

The investigative techniques depend on data: of incidents, accidents, near misses, and the like. The FAA, NASA, NTSB, ICAO, aircraft manufacturers, airlines, etc., all maintain various types of data bases, most of which are incompatible (in the sense that they keep track of slightly different variables). A further complication is that some bases are computerized (different data base management systems are usually involved) and some are manual. The safety analyst, attempting to establish broad trends, is immediately faced with this incompatibility problem. Still, if the focus of the investigation is narrow enough (for example, a failure of a mechanical part on a specific aircraft), it may be possible to extract enough information from the various data bases to find a definitive cause. This is especially true when the cause of the incident is, in fact, mechanical - it is here that repeated failures should be noticed, isolated, and corrective action taken. Flight International (1984) provides a typical example that an alert safety analyst (or system) should have anticipated and caught:

> "Mis-rigging of the baggage door operating mechanism and the failure of the door warning arrangements to give adequate warning of door safety led to the fatal crash of a Dan-Air BAe 748-2A in June 1981, according to the official report. The baggage door at the rear end of the cabin, blew out and became fixed on the tailplane, thus making the aircraft uncontrollable. Subsequently, the wings were overstressed and suffered structural failure.

> The condition of the door operating mechanism, says the report, made it impossible to lock the door fully using the outside handle. But it was probably by the outside handle that the door had last been closed. Crew checks failed to discover the fault because of "a combination of shortcomings in the design, construction, and maintenance of the door warning systems and the appearance of the visual indications".
>
> The report notes that there have been 35 instances of the 748 baggage door malfunction reported in the past".

Very rarely do accidents have such obvious design-induced crew error precursors. Most accidents result from interactive causes, rather than one specific factor, and one of the causes is, invariably, a human being - the pilot, the air traffic controller, or the maintenance worker. These acts of human beings do not fit readily into data banks, there to be identified by a specific parts number, and the safety analyst must now switch to the other end of the spectrum and try to isolate the <u>sequence</u> of events that lead to "pilot error".

These accidents involving human performance usually turn out to be one-of-a-kind events - and it should be the aim of the safety analyst to ensure that they remain so. Data unavailability and incompleteness, however, are always present and it is up to the skill (and luck) of the analyst to uncover the sequence of events leading to the accident. If a procedural error is found, it can be immediately corrected; more difficult are those amorphous incidents where it is not at all clear <u>why</u> there was human error. (If it were possible to obtain quantitative estimates of human performance, such as human error rates per task, it would be a simple matter to incorporate them into operational reliability equations to determine system reliability.) Just as the role of analysis of incident and defect reporting systems should be to find mechanical failures before they become accidents, the human incident reporting systems should be designed to cause humans to "confess" their incidents so that the analyst can isolate potentially dangerous trends and practices before they too become accidents. (The Aviation Safety Reporting System (ASRS) managed by NASA is a step in the right direction.)

It is the purpose of this report is to discuss various aspects of aviation safety analysis, ranging from general aviation to the public transportation system, and then to make some recommendations for improving the methodology of safety analysis.*

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2. General Aviation - How Safe Is It To Fly In Those Little Planes Anyway?

Although an airline crash is always good for large press, radio and television coverage, the typical general aviation accident is buried in the back pages unless a news photographer happens to take a fairly spectacular picture of the aircraft hanging in the trees; even then the story itself is still not front page material. This may be due to the perennial news media attention to occasional large accidents rather than repeated small ones; part of it may also be the media's perception that people who go up in small planes are taking their lives in their hands anyway - consequently it is not judged particularly newsworthy when a GA accident occurs.

Certainly the aggregate statistics might make the case that a certain amount of derring-do is required to use small aircraft instead of flying on scheduled carriers. Table 1 shows in 1983 that the GA accident rate (per 100,000 hours) was approximately 35 times the scheduled Part 121 carrier rate and 8 times the scheduled Part 135 carrier (i.e. commuter) rate. Fatal accident rates were similar. The good news is that 1983 had the lowest GA accident rate in the last ten years as shown in Table 2.

But is GA flying really a dangerous undertaking? Various studies have concluded that private flying is on par (per hour of exposure) with mountaineering, motorcycle racing, and rock climbing and can thus be considered as a self-imposed hazard (Stratton, 1974). Of the causal factors for some 30,000 GA accidents from 1971-77 in the NTSB data base, 67% are attributed to human factors, 14% to weather, 7% to the engine, 6% to the airport, 3% to the airframe and the rest to miscellaneous causes. Similarly, in the FAA's Accident Incident Data System (AIDS) (as of April 1983) of 32,712 records, 20,319 (62%) were related to human factors. Thus it is the pilot, rather than the machine, who is largely at fault. Why do so many accidents occur? Part of the answer may be a false perception of risk by the pilots.

Table 1

CARRIER AND GENERAL AVIATION 1983 ACCIDENTS, FATALITIES ***

	ACCIDENTS					PER 1000,000 AIRCRAFT HOURS		PER 100,000 departures	
	TOTAL	FATAL	FATALITIES	AIRCRAFT HOURS FLOWN	DEPARTURES	TOTAL	FATAL	TOTAL	FATAL
AIR CARRIERS									
Air Carriers Operating Under 14 CFR 121									
Scheduled	18	3	14	6,534,000	4,940,000	0.275	0.046	0.364	0.061
Nonscheduled	4	1	7	256,000	122,000	1,563	0.391	3.279	0.820
Air Carriers Operating Under 14 CFR 135									
Scheduled**	17	2	11	1,378,000	2,166,000	1.23	0.15	0.78	0.09
Nonscheduled	141	28	60	3,102,000	"	4.55	0.90	--	--
GENERAL AVIATION+	2091	548	1049	32,766,000	"	9.43	1.67	--	--

\+ Includes accidents involving aircraft flown under rules other than 14 CFR 121 and 14 CFR 135.

* Data not available.

Rates are based on all accidents, including those involving operators not reporting traffic data to the CAB. Exposure data estimate sources: CAB and FAA.

*** Source: NTSB

Table 2

ACCIDENTS, FATALITIES, GENERAL AVIATION OPERATIONS ***
1974-1983

	ACCIDENTS			**	ACCIDENT RATES # PER 100,000 AIRCRAFT HOURS	
YEAR	TOTAL	FATAL	FATALITIES#	AIRCRAFT HOURS FLOWN	TOTAL	FATAL
1974	4234	689	1327	27,773,500	15.2	2.47
1975	4001	636	1258	28,799,000	13.9	2.20
1976	4023	662	1226	30,476,000	13.2	2.17
1977	4083	663	1280	31,577,508	12.9	2.10
1978	4218	721	1558	34,887,178	12.1	2.06
1979	3825	639	1237	38,641,268	9.9	1.65
1980	3597	622	1252	36,401,663	9.9	1.71
1981	3502	654	1282	36,803,200	9.5	1.78
1982	3216	578	1161	32,094,623	10.0	1.79
1883P	3091	548	1049	32,766,000	9.4	1.67

P Preliminary data.

All operations other than those operated under 14 CFR 121 and 14 CFR 135.

\# Suicide/sabotage accidents included in all computations except rates (1974 - 2, 1975 - 2, 1976 - 4, 1977 - 1, 1978 - 2, 1979 - 0, 1980 - 1, 1981 - 0, 1982 - 3)

\# Incoudes air carrier fatalities when in collision with General Aviation aircraft.

\## Source of estimate: FAA
*** Source: NTSB

Although pilots may be aware of the overall hazards expressed as risk per hour of exposure, risk perception research indicates that "these comparisons will often not be very satisfactory. People's perceptions and attitudes are determined not only by the sort of unidimensional statistics used ... but also by a variety of quantitative and qualitative characteristics — including a hazard's degree of controllability, the dread it evokes, its catastrophic potential, and the equity of its distribution of risks and benefits". (Slovic, 1983).

Thus pilots may not realize the great variety of risks involved in different types of flying. Collins (1983) describes, admittedly based on limited exposure data, a potential ranking of risks. Collins gives a ranking of one to normal risk — clear daytime VFR flying. The rankings then range from infinity (when flying and drinking are combined) to ten times the normal risk for an IFR flight. This type of risk evaluation technique, if understood by GA pilots, would appear to have the potential to greatly decrease GA accidents and fatalities.

A more general safety issue is how much and how well pilot judgment and attitude can be modified through training. In the AIDS/NTSB GA accident cases causal and contributing factors include carelessness, inattention, misjudgment, lack of self-descipline, lack of skills, lack of supervision, recklessness, and various other kinds of mistakes. Many, if not most, of these factors imply an unsafe attitude on the part of the pilots. Thus the pilot's general attitude appears to be crucial factor in aviation safety, as important potentially as learning piloting skills and maintaining proficiency.

Certainly the FAA is aware of this and sponsors weekly Aviation Safety - Education Seminars for GA pilots around the country to counterbalance poor instruction. The GA training programs are weak because of economic considerations. Since potential pilots want to minimize their training costs, instructor pay is low. (Instructor pay is also low because of the large demand for instructor jobs.) Consequently, instructors are minimally qualified since they move on to better jobs after they gain experience. (GA licenses are also issued with the minimum required hours, for economic reasons.)

Computers may come to the rescue of the GA pilots and students. Computer-aided instruction (CAI) in the form of scenarios written on microcomputers for the student pilot (or for a refresher course) have the potential to focus on those high risk areas identified by Collins. The structure of the learning program would have to be interactive to allow the students to make mistakes and fly themselves out of their difficulties, as well as teaching the basic techniques of flying.

One step further is the idea of using simulators to complement CAI. Simulators are used as a matter of course for teaching airline pilots to get out of dangerous situations without sacrificing aircraft. Perhaps in GA pilot training some simulator experience, coming after completing a CAI course or a regular pilot license exam, could substantially reduce pilot error. On a simpler level, one of the most popular software programs for home computers is the "Flight Simulator", which is used by both game-playing and recurrent-training participants.

Human factors aside, some 30% of GA accidents can be attributed to other causes. For example, the Service Difficulty Reporting System (SDRS) of the FAA contains Malfunction or Defect reports from the GA community [70% of the total, or some 17,000 reports per year] plus Mechanical Reliability and Service Difficulty Reports from the air carriers. The FAA uses the SDRS primarily to help decide when to issue Airworthiness Directives (ADs).

Because the data base is so large, a potentially interesting use of the SDR System would be to attempt to determine whether any correlation can be established between airworthiness defects and accidents, incidents and fatalities. If such correlation could be shown to exist, then by creating an alerting system from the GA data base, aviation safety could be substantially improved. If any long-term trends can be established in the reporting of defects, perhaps grouped by specific part and aircraft type, such trends, even if not correlated with specific accidents, should lead to greater safety by pointing to potential aircraft defects before accidents take place.

When a "new" defect is introduced, a series of reports occurs at an increased rate in the SDRS. This would gradually provide evidence that a "new" defect exists. However, it is difficult to design a system which would automatically alert a safety analyst that a significant change has occurred, since the recent small sample of the SDRS could be an unusual coincidence, due to the random nature of defect reports. A pragmatic, rather than an automated, alerting process may be more proper which would first cause human intervention internal to the FAA (review and field work) before triggering a formal FAA Airworthiness Directive to the GA community.

Finally, the recommendation summarized by Hurst (1982) remains valid. Hurst addresses the issue of learning from accidents and incidents as follows:

> "Investigation, analysis, modelling, and simulation of aircraft accidents and incidents normally stop with the determination of 'probable cause', most frequently 'pilot error'. What caused the pilot to err is seldom discovered and even less often stated in accident reports, despite presentation of relevant evidence in public hearings. Although physical evidence of what happened in an accident is carefully searched for, collected, re-assembled and analysed, and the physical events are then modelled and re-created through simulation, investigation of physiological and behavioural events stops short of modelling and re-creation through simulation..."

This recommendation applies equally well to GA and air carrier operations, which will be considered in the next chapter.

3. Air Carriers - Safer than your home?

Airline pilots are fond of saying that the most dangerous part of their workday is the automobile ride to the airport. As usual, there are statistics which can be used to support or refute this statement, but there is no doubt that the pilots perceive that they are safer in the air than on the ground. (Certainly it is true that they are less likely to run into another vehicle up there.) However, there is a huge discrepancy in accident statistics between pilots who fly for pay and pilots who fly for fun. It appears that attitude toward safety may be the a principal reason for this divergence. Vehicle design may also enter into this situation, as well as training and the rules for operating aircraft.

An aircraft consists of several systems, i.e. the structural, engine and fuel, electrical, flight control, communication, and others. These systems are designed for a safe life (tested to many times their expected useful life and, as in the case of landing gears, replaced at regular intervals) or designed to be fail-safe (or fault-tolerant) such that a single failure within a system does not cause the complete system to become inoperative. In the avionic system fail-safety is generally achieved through duplication (2,3 or 4 times) of units - for example, there are usually three Inertial Navigation Systems (INS)on board, with the systems' output constantly voting to make sure they agree; when one does not agree with the other two, the disagreeing one is assumed faulty and its output is ignored. Where redundancy is not possible, such as in the structural system, the system is designed such that failure in one structural member leads to a redistribution of aerodynamic forces to neighboring members, the "alternate load paths".

In general, aircraft designers make use of a risk analysis technique known as failure modes and effects analysis (FMEA), an inductive analysis which details, on a unit by unit basis, all possible failure modes and identifies their effects on each system. Thus possible single modes of failure of each unit in a system are identified and analyzed to determine the effect on neighboring units and the whole system, with probabilities of occurrence assigned and the resultant criticality assessed (Henley, 1981). (This analysis technique is, in effect, the inverse of what takes place during an accident investigation.)

Designers have to make sure that an aircraft maintains its airworthiness under all conditions, although there is no wholly safe aircraft - the required redundancies would make it too heavy to fly economically. Designers also try to minimize the effects of human error by anticipating problems that pilots and mechanics might encounter, and, as much as possible, to solve them in the design stage and thus build aircraft which can forgive the occasional errors of the designers themselves, the manufacturers and ultimately, the operators. All in all, quality control procedures account for about fifteen percent of an aircraft's cost (Newhouse, 1982).

For example, the 747 was the first Boeing aircraft to have its own safety engineering group, providing essentially an internal airworthiness review (Ramsden, 1976). The aircraft was designed to be failure-tolerant from the start, a principle that has helped the 747 in its remarkable safety record, able to withstand such accidents as the San Francisco take-off collision with the approach-light pier, which disabled three hydraulic systems (of four) and two (of four) main undercarriage trucks. Boeing's customer support department also has accident officers which are assigned to assist national accident investigation authorities at the scene of the accidents and afterwards, and they insure that the accident reports do not sign off with such comments as "pilot error". Boeing, as well as other manufacturers, also helps assure safety through its Service Bulletins (sometimes supplemented by

FAA ADs) which alert airlines to potential dangerous conditions.

Pilot training is also included in the price of the aircraft, and the manufacturers attempt to make sure that the new airlines' pilots are aware of all safety procedures and have the proper type ratings before they return to the line. They also encourage each airline to report all operational incidents back to the manufacturer, that then can issue incident reports to all the operators to insure that potentially dangerous incidents do not get repeated. This incident reporting is especially necessary for airlines operating in countries where such procedures are not mandatory.

The usefulness underlying such a reporting system is the same as that discussed for trend analysis of GA incidents in the SDR system. McDonnell-Douglas notes that

> "if a data base is to be helpful in preventing accidents, it should be used to predict significant safety trends. Logic should be incorporated in the accident and incident data system to enable the frequencies of a particular type of occurrence to be calculated versus independent variables. Thus, the system would be able to detect an aircraft, a mode of operation, a part, a pilot profile or some combination of variables which has a higher than predicted accident potential frequency. These items would be automatically scanned at specified intervals and whenever new reports were added to the data base. Any specific events that occur too frequently to be considered a normally acceptable rate would then trigger an alerting system to warn of an impending problem." (Clauzel, 1982)

McDonnell-Douglas also notes that a major deficiency of current data bases on air carrier accidents is a lack of human behavior data before and during an accident - data which admittedly is difficult to obtain but which would help determine the reasons for the accidents and prevent further occurrences.

The airlines in general are split on the question of whether there should be an overall safety officer responsible for all safety functions - some see it as useful in having a department which focuses on safety and does not get immersed in day-to-day operations; some feel that safety should be everybody's business and not be shunted aside to a special division.

Another murky area is the relationship between an airline's profit and safety and its connection to human factors. Inferences have been drawn in a number of approach and landing or takeoff accidents under marginal weather conditions that pilots acted with the bottom line rather than safety being foremost - they took off (or landed) to meet the schedule and try to deliver the (paying) customers rather than wait (or divert). However, no correlation has ever been shown linking an airline's profitability to its safety record.

Unless it is a spectacular airworthiness failure (the DC-10, most recently), the popular press focuses not upon aircraft design but on other, somewhat exogeneous, aspects of airline safety, most recently the ATC environment and post-crash survival. Particularly since the 1981 Professional Air Traffic Controllers Organization (PATCO) walkout, the ATC system safety level has been under intense observation by various news organizations, the NTSB, and, at least at the beginning, by the ex-controllers who were determined to prove that the system was now unsafe without them. However, the FAA was able to alleviate the effects of the strike by immediately going to restrictions on flights at major airports (slots) and implementing flow control procedures. Flow control, which limits the numbers of aircraft departing for a specific airport, also saves fuel since airplanes are kept waiting on the ground, rather than in the air circling or a landing slot (and where controllers have to watch and vector them). To date there have been no strike-related accidents as the ATC controller force is being reconstituted.

The other recent major non-technical development in the airline business purported to affect safety has been the Airline Deregulation Act (ADA) of 1978. The Airline Pilots Association (ALPA) has been particularly vocal on this safety issue - "There's going to be a deregulation accident. It's just a matter of time ..." (Aviation Week & Space Technology, 1984) - is a fairly low-key example of ALPA rhetoric. This issue of safety was repeatedly raised in the great deregulation debates which preceded the Act; generally, however, the point that the FAA was going to maintain safety standards, regardless of the demise of the CAB, carried the day. Indeed, the Transportation Secretary's annual report to Congress specifically covers the effect of deregulation on air safety - no evidence of any adverse effects has yet been cited. A recent rash of "operational errors" (planes coming closer than five miles horizontally or 1,000 feet vertically) may be largely due to a new "quality assurance" computer program which is detecting many slight, technical infractions which the controllers would not have noticed in the past. These increases in operational errors took place at installations where modifications had been made to ATC computers to record operational errors automatically; now, controllers are more stringently interpreting the separation standards. The FAA contends, however, that the safety of the ATC system had never been impaired and that these "operational errors" do not mean potential danger to airplanes.

There is real debate whether the FAA's minimum standards of safety are enough. According to ALPA: "The established carriers have learned the hard way that they cannot operate at those minimum standards... Flight time, duty time, maintenance practices, operational practices and procedures - they are far and above the FARs" (Aviation Week and Space Technology, 1984). However, the FAA claims that there are no airlines operating at the minimums anyway, in effect making the whole argument moot.

One of the longest ongoing struggles between the FAA and the NTSB, with occasional kibitzing by Congress, concerns crashworthiness, in particularly the flammability of aircraft interiors. Between 1965 and 1979 some 480 people died in post-crash fires (1 out of 5 of all people killed in U.S. airplane accidents). The problem is not just fire, but also toxic flames. Whereas flame-retardent aircraft interior materials (for seat, rug, wall and ceiling materials), if and when made mandatory by the FAA, will delay the spread of flames somewhat, little can be done regarding toxic fumes: a man's wool suit, when burned, gives off enough cyanide to kill seven people; cotton emits carbon monoxide (Newsweek, 1984). Once a fire starts inside the cabin, all passengers become exposed to the dangerous fumes and quick evacuation becomes the only solution. (Some debate still continues about the proper number of exits required for rapid egress).

Finally, weather-related accidents continue to occur, amounting to some forty percent of all aviation accidents. Although airlines (and airports) normally halt operations in particularly bad weather, at all other times the decision to start or continue a trip is left to the pilots, who may feel themselves under psychological stress to meet schedules. It is at this juncture of unstable weather conditions and pilot judgement that pilot error is often said to occur and where safety analysis may be of potential help. The point of the analysis should be to understand why the pilots undertook a certain course of action, rather than just determining what had happened; whether it was fatigue, poor communications about weather phenomena, or other causes of poor human performance.

4. Are Accidents Necessary?

Since the goal of aviation safety analysis is to improve safety, the analyst is basically working to put himself out of business. But there have been spokesmen advocating the point of view that "accidents are necessary to maintain a certain level of safety" on the grounds that an absence of accidents results in careless supervision or less compliance with proper procedures (Interavia, 1979). This hardly makes sense if one accepts the normal definition of an accident as a combination (or series) of relatively trivial deviations from normal behavior, none of which would alone be the cause, but each of which is a necessary ingredient in the final outcome. (This of course excludes the approximately 10% of GA accidents attributed to alcohol.)

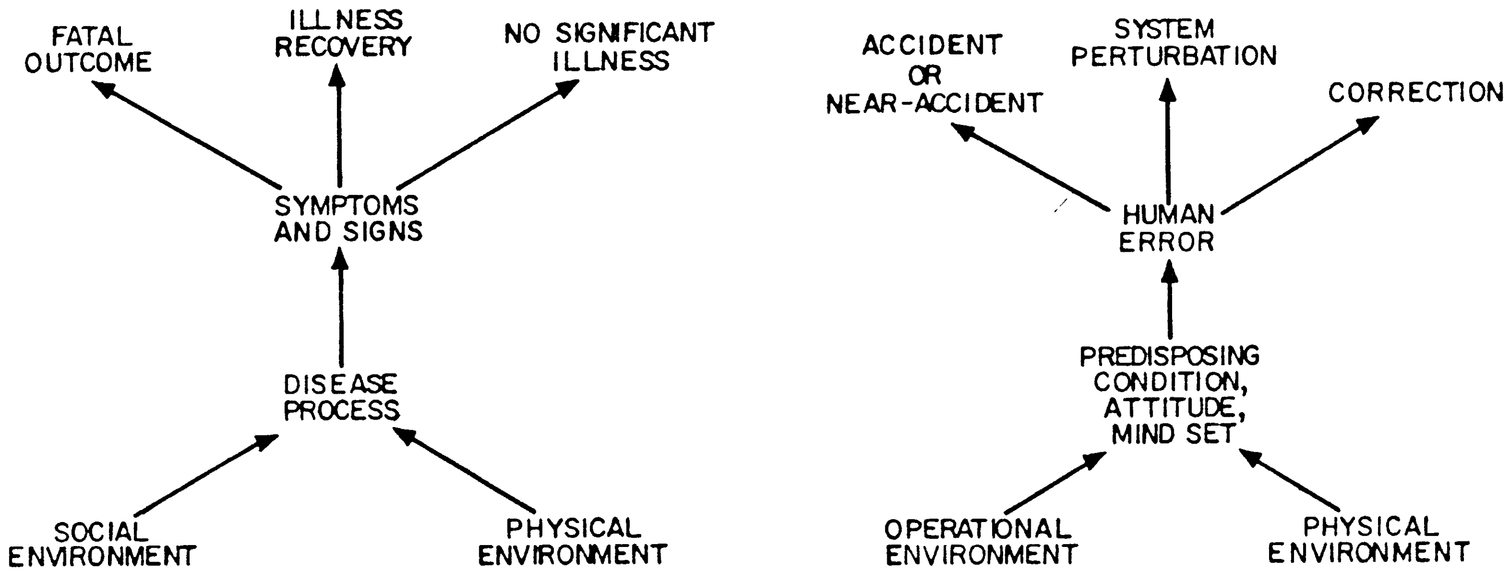
In a further effort to understand human error in aviation, researchers at NASA's Ames Research Center have attempted to use an analogue to the "epidemiology" model. This model, used to analyze the causes of disease propagation and its application to aviation, is shown in Figure 1. This model allows the analyst to trace the series of events which lead to a (near) accident, as shown in Figure 2. When analyzing the ASRS data base, the researchers found the following basic types of error:

a) Perceptual Failure: A fault in the cognitive behavior by which one gains awareness of the environment through physical sensation interpreted in the light of experience and accumulated knowledge; incomplete understanding of a situation.

b) Loss of Vigilance: A special form of perceptual failure wherein subject fails to maintain alert watchfulness to avoid danger.

c) Faulty Exercise of Discretion: The making of an incorrect choice among available alternative courses of action; poor decision making.

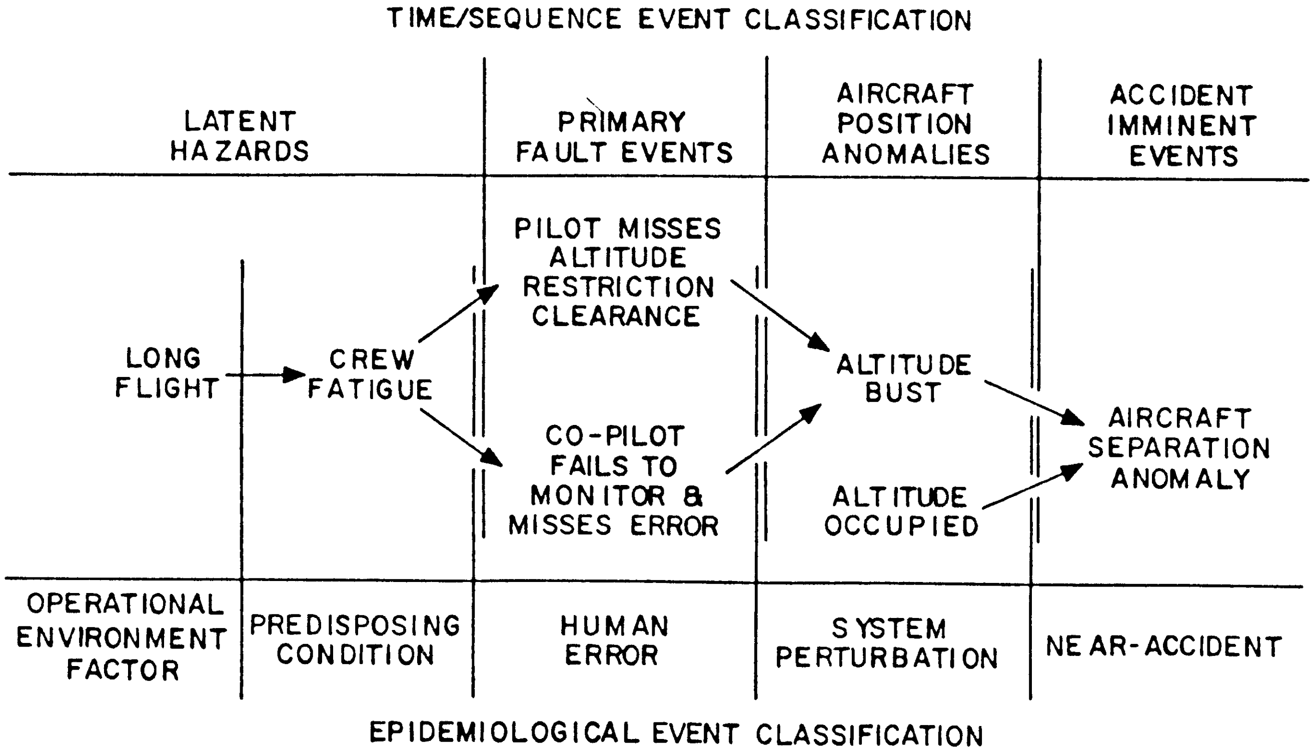
Figure I. The epidemiological model and its aviaton system analogy*



*Source: Cheaney & Billings

Figure 2 Event classifications*

AN OCCURRENCE AS AN EVENT CHAIN



*Source: Cheaney and Billings

d) Planning Failures: A special form of faulty discretion wherein subject either fails to develop beforehand a scheme, program, or method for accomplishing a goal, or adopts one that is flawed.

e) Failure in Operating Technique: Inadequate execution of an operational task; related to skill deficiency in controlling, monitoring, or communicating.

Further analyses of the ASRS data base may indicate which of these failures are capable of being through corrected additional training or attitude awareness.

When there are two aircraft involved in a potentially dangerous situation, the following events can occur, in order of severity (Billings and O'Hare, 1978):

1. Collision
2. Near Collision: perilously close to colliding (depending on size, type, speed of aircraft and relative courses). When occurrence is in the air, called "near mid-air".
3. Less than safe separation: a conflict occurs.
4. Recognized error: action taken in time to avoid conflict.
5. No conflict.

A useful way to summarize these occurrences is shown in Figure 3, which identifies the phase of flight at the time of the potential two-aircraft conflict. Analysis of the FAA's Near Mid-Air Collision Report data base using Figure 3 as a guide to place and frequency of encounters may suggest ways to reduce potentially dangerous mid-air situations.

Figure 3

Phase of flight at time of Occurrence*

Flight Phase, Aircraft 1

Flight Phase, Aircraft 2	Hold	Taxi R-T	Takeoff	Climb	Level Flight	Radar Vector	Descend	Approach	Land	Other
Hold										
Taxi- Runway										
Taxi- Taxiway										
Take off										
Climb										
Level Flight										
Radar Vector										
Descend										
Approach										
Land										
Other										

Source: Billings and O'Hara (1978)

5. What is to be done?

Further work appears warranted in the area of analysis of FAA and NASA data bases. These public bases may be supplemented, where possible, by data bases established by aircraft and engine manufacturers. Potential topics for analysis have been discussed during the previous four chapters; GA and air carrier data bases are different enough to warrant separate approaches.

Analysis of data bases is of course not the only area where analytical skills can be applied for potential safety improvements, but it is the most visible due to the vast amounts of data currently being collected. (Further analyses may suggest that too many, or the wrong type of, data are being gathered.) Nevertheless, other topics only briefly noted earlier also deserve further study.

These include issues within the ATC system, particularly separation standards, congestion, capacity constraints, and flow control; regulatory issues, particularly GA pilot requirements and commuter operations; and weather related topics, such as frequency and adequacy of advisories and forecasts, particularly of wind shear. Each issue is important - it is largely up to the FAA to set priorities.

Appendix A

by

R. John Hansman

Aviation Safety Analysis As Practiced by Aviation Insurance Underwriters

In an attempt to obtain an additional perspective into methods of Aviation Safety Analysis, several of the major general aviation underwriters were contacted. Discussions were held with individuals at varying levels of corporate hierarchy in an attempt to determine what type of analysis was used by the underwriters to determine rates and to avoid "bad risks".

The preliminary picture emerging from the discussions is that the underwriters are very limited in their formal safety analysis. They operate in what they describe as a "Seat of the Pants" or intuitive mode based primarily on the experience and judgement of their individual underwriters. It is, however, instructive to consider both the analysis that the underwriters do consider worthwhile and their reasons for not pursuing more formal safety analysis.

Some of the reasons given by the underwriters for their limited aviation safety analysis are:

1. Insufficient Base for Statistical Analysis

   With the general aviation fleet consisting of only 200,000 to 300,000 aircraft, and a large "spread" in their types and uses, it is difficult to establish a statistical basis with a large degree of confidence.

2. Large Number of Variables

   Any attempt to analyze GA safety is hampered by the large number of significant factors ranging from pilot experience, equipment on board, aircraft use, operational environment, weather and exposure.

3. Lack of Resources
   Aviation underwriters are limited both in financial and actuarial resources dedicated to safety analysis.

4. Competitive Market Considerations
   Inasmuch as aviation underwriting is a competitive business, analytical considerations clearly are secondary to competitive marketing considerations. "Bad risks" are expected to be screened by the individual underwriter and the rates are more or less set by the entire market. General areas of high risk (e.g. piston engine helicopters and light twins) will eventually be evident in higher rates across the whole market, but these areas are apparent even without detailed analysis.

5. Desire for Simplicity
   Because of the large number of aircraft which need to be quoted on, the underwriters are hesitant to increase complexity in the underwritting process by including too many variables. This results in requiring only a generally low resolution analysis process.

The underwriters use primarily two indicators to measure risk and underwritting success. They are:

$$\text{Burning Ratio} = \frac{\text{Value of the losses}}{\text{Value of the hulls}}$$

and

$$\text{Loss Ratio} = \frac{\text{Value of claims}}{\text{Value of premiums}}$$

A third indicator is the combined ratio which is the loss ratio corrected for business costs.

These indictors are analyzed by the underwriters, both internally using the company data and for the market as a whole using NTSB and FAA data. For analysis, aircraft are grouped into basic categories, examples of which we show in Table A-1. Analyses are also made by individual model types, as well as being integrated over the entire fleet. Type of use is also considered and typical categories are shown in Table A-2.

Detailed analysis is normally limited to the industrial aid category where there is much commonality of operation and the per unit hull costs are very high ([illegible] $1M). For the remainder of the GA fleet, analysis is primarily done in a triggered mode where some factor initiates the analysis of a specific model type. In one company, product liability claims often trigger an analysis.

In setting rates, no specific correction is made for exposure. It is assumed that exposure is uniform over a specific aircraft and use category, and that any anomalies will be averaged out.

Pilot experience is considered to be an important factor by the underwriters. In general, experience is expected to commensurate with the aircraft category and the intended use. A list of the primary pilot experience factors is shown in Table A-3. Normal breakdown is in 100 or 500 hour increments. It is interesting to note that such factors as recency of experience and instrument time are not normally considered, due to the low fidelity of the analysis. It was, however, noted by the underwriters that professional crew members (i.e. employees with no non-flying duties) and simulator-based recurrency training programs were considered to hve a strong positive effect on safety and were therefore encouraged, particularly in the industrial aid category.

Table A-1

Typical Aircraft Category Breakdown

Company A	Company B
Single Engine, Fixed Gear	Single Engine, Fixed Gear
Single Engine, Retractable	Single Engine, Retractable
Light Twin	High Performance Single Engine (Turbo)
Cabin Class Twin	Light Twin
Turbine	Heavy Twin
	Turbine

Table A-2

Typical Use Breakdwon

Business and Pleasure

Industrial Aid (Corporate)

Agricultural

Instructional

Manufacturers Hull and Liability

Table A-3

Primary Pilot Experience Factors

Ratings

Total Time

*Total Retractable Time

*Total Multi-Engine Time

*Only Important for that category of aircraft