Crashworthiness, Ergonomics, Anthropometrics, Man Machine Interface, Human Factors, Design Induced Errors. An Investigators Viewpoint.

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A legal Investigator of an airplane crash is looking for far more than simplifying an accident into a series of computer words to conclude probable cause and contributing factors. For the most part that is all the N.T.S.B. does. In fact it feels as if it has failed its job if it is unsuccessful in assigning a probable cause. Too often in order to close out a file they opt for pilot error and stash it neatly away in a pile that burdens the statistical treatment of accidents with invalid misinformation. Statistics would be better served when the N.T.S.B. admits that there are several possible causes and refuses to assign probable cause. You truly have to marvel at the incompetence of the board as to experience. To say they are incompetent political hacks is extreme. To say that they have little or no aviation experience is as correct as saying that they have no accident investigation experience as well.

As an example, one of the better N.T.S.B. Chairman was a traffic court judge who showed up at a crash site in penny loafers (a muddy peanut field). He was enthusiastic and a willing learner. A Recent NTSB Board member was an insurance defense lawyer, who has defended innumerable aviation insurance companies. In fairness he used to be an officer and gentleman in the Marine Corps and he was an F-4 Phantom Pilot.

A Legal investigation of an airplane case is far more comprehensive, complete and accurate. Part of the reason is that the legal investigation continues longer than any local or N.T.S.B. investigation. Thus the legal investigation has the benefit of the N.T.S.B. Factual Report as a starting ground.

Much of the data has been saved and retrieved for the first investigation and thus some time and effort has been saved. The legal investigator is investigating to a far higher standard than the United States Government. The legal investigator is investigating to a standard of proof, whereas the N.T.S.B. is investigating to a level of trustworthy speculation. A legal investigator must realize that every fact he gathers be documented in a form sufficient to meet the RULES of EVIDENCE and that his investigation to be appointed with correctness must prevail in the legal tests of sufficient evidence to sustain a verdict by preponderance of the evidence.

Another reason a legal investigation is more complete is because the expert witness investigators involved are almost always more experienced, more educated, and more technically competent than those employed by the N.T.S.B. In fact many of the experts are retired N.T.S.B. investigators so they have the experience. Others are college professors and professional people. Since there is a large disparity between corporate and civil service salaries many good investigators who have gotten their original training from the N.T.S.B. or military opt for jobs with manufacturers, insurance companies and as independent consultants.

Very often in a lawsuit the same investigator of the manufacturer that was made part of the N.T.S.B. investigation (because of his superior knowledge of the product) becomes one of the many experts defending that product. Additionally the manufacturer often supplies in house most knowledgeable engineers to consult and testify in defense of their product. The N.T.S.B. doesn't go to this extent in its investigation. One time I showed an N.T.S.B. investigator a manufacturer's investigation report done by the same manufacturer's representative who had participated in the N.T.S.B. accident investigation. The manufacturer's investigator had turned in three pages of notes to the N.T.S.B. Back at the factory he had a 27 page report, and three annotated photo albums that we got through discovery. When shown this the N.T.S.B. investigator just chuckled.

By the time a legal aircraft accident investigation has been completed in a product's liability case it is not unusual for thousands of engineering reports tests and drawings to be routinely but thoroughly scrutinized.

I have been involved in one aviation crash case of a Kingair aircraft where the investigation and litigation costs to the plaintiff approached $800,000. I have been told that the Defense costs exceeded two million dollars. This to achieve a settlement after a hung jury.

Since an investigator in an Aviation Law case is involved in a legal process he is looking far beyond what the N.T.S.B. does. Below I list the functions of aviation accident investigators. These are listed one to seven. The italicized are additional duties and standards that a legal investigator works to beyond the functions of the N.T.S.B.

1. Gathering of facts
1. ***Gathering of facts in a legally admissible form***
2. Viewing the evidence
2. ***Viewing the evidence without spoliation***
3. Gathering factual documents pertinent to the accident report
3. ***Gathering documents and engineering treatise additional***
4. Writing the factual report with enclosures
4. ***Writing a report to comply with Federal Rules, answering discovery and providing documents that will be relied upon.***
5. Board assigns cause
5. ***Investigator studies Board's assignment of cause***
6. NTSB completes numerous tests, studies, tear downs as required.
6. ***Legal investigator grades papers of completed NTSB work and then adds more as needed .The Investigator orders tests, test flights, wind tunnels, metallurgy, pathology, engineering analysis, system safety analysis, whatever is needed to substantiate claims.***
7. N.T.S.B. investigator testifies once by deposition as to fact.
7. ***Legal Investigator testifies as to fact an opinion, by deposition and at trial***

Almost everything that the legal investigator does is in excess of the work accomplished by the N.T.S.B. When the N.T.S.B. does a good and thorough job it simply defines a starting point closer to the real goal of the legal investigator. The legal investigator is trying to determine several things:

1. Factually what exactly occurred?
2. Who and what was at fault that caused the event to happen. (Studied within the frame work of existing available law)
3. Was there human conduct that caused the accident to occur?
4. Was there a defect in one or more products that caused or contributed to the cause of the accident?
5. What level of investigation will be sufficient to meet the legal requirement of preponderance of the evidence?
6. Is the data retrieved as part of the investigation in a format such that it will meet the RULES of EVIDENCE and not be excluded?
7. Were there many causes and contributing factors that teamed to cause the accident?

Areas usually not pursued with vigor by the N.T.S.B. are the crashworthiness aspects, Human Factors aspects, ergonometrics, and induced design error aspects. Crashworthiness is couched in words of survivability by the N.T.S.B. Whatever happens after the crash, can never be the probable cause of the crash. Thus the N.T.S.B.s' emphasis is usually focused on the accident itself, and not the second impact theory. That is not to say that the N.T.S.B. and the F.A.A. are not active in these areas of survivability.

The F.A.A. criterion for airliner certification does force the manufacturer to demonstrate full aircraft evacuation in darkened conditions in a time period. The F.A.A. does have criteria on flammability of cabin materials as well as toxic products of combustion. The F.A.A. does have seat strength and restraint system criteria. Every airliner must carry certain equipments, flashlights, megaphones, first aid kits, life vests and rafts for over water flights. There must be at least one emergency radio per one of the rafts.

Escape doors must be easily opened, so a passenger can be expected to be able to accomplish this. The F.A.A. certification criterion is not yet held to the same standard that military approval is. F.A.A. certification does not provide immunity to the manufacturer. Depending on the jurisdiction it may signal some proof of safety. There has been some push by the defense bar to have it be a rebuttable presumption of non defectiveness. Most places the certification represents evidence of compliance with minimum government requirements.

Within every concept imaginable of crashworthiness comes a perfect application of the product law's Risk vs. Utility test. Every decision of a crashworthiness nature inherently includes an engineering trade off if at the time of design all alternatives were thought through. One of the nicest white haired patriarch defense lawyers of a general Aviation Manufacturer regularly gave speeches that summed up their perception of the defense bars' concept of crashworthiness.

> *"Why of course we could build a crashworthy airplane. By the time we got through putting all the advancements my brethren of the plaintiff's bar feel is necessary the airplane would weigh so much it would never fly. It would cost so much nobody would buy it, and we'd call it a tank. Gentleman everything is an engineering trade off"*

Applying the Risk vs. Utility test of defect to a product is appropriate in the crashworthiness context:

1. At the time of design was there an alternative design available within the state of the art?
2. Was the alternative design competitive from a cost standpoint?
3. Would the alternative design reduce the hazard?
4. Would the alternative design not have a deleterious effect on some other aspect of safety?

If questions one through four are all answered affirmatively one can conclude the aircraft was defective. It can then be argued in accordance with the majority viewpoint that the design may be defective from a crashworthy standpoint. Here the engineering tradeoff and risk utility form a perfect team, that even the defense bar would grudgingly concede as appropriate application of principle.

Crashworthiness Doctrine in the law is also known as the second impact theory or the enhanced injury theory. Designers have known how to design crashworthy vehicles for years and years. Look at N.A.S.C.A.R. and the Swedish SAAB. Their designs are simple and effective and not difficult to understand. First you build a crush proof cocoon around the occupant so that no structure will collapse in a foreseeable and survivable impact. Second you provide the occupant with a very effective restraint system that is still single point, one hand releasable. Third you provide an egress path that will not collapse and be blocked and fourth you provide fuel systems that are not fire hazards an integral part of which is a firewall between occupant and fuel tank.

The very same concepts that work in automobiles apply to airplanes. The goal should be that if the initial impact was survivable from a g standpoint, then nothing in the design of the machine should exacerbate or cause further injury. Obviously the military ejection seat is the ultimate crashworthiness vehicle. In truth egress is a very real concept in safety. That is the reason for Emergency exits in theaters and airplanes. In the case of airplanes the victim must be ambulatory to utilize the escape path provided.

The investigator should investigate each accident from crashworthiness - survivability aspect for two reasons:

1. If there is a second impact defect or failure that caused or enhanced the injury there may be a recovery for the victim that might otherwise be impossible.

2. If the victim lived, and his injury was caused by the second impact then there may be the additional damages of pain and suffering and the conscious recognition of impending death.

The investigator after determining whether the crash was survivable should then expand his investigation into crashworthiness aspects. Injuries enhanced by seat collapse, restraint system failure and overhead bin collapse are fruitful areas.

The United States Army redesigned their helicopters in the Viet Nam war to be much more crash resistant to fires. This was accomplished through readily available

sealing fuel tanks, frangible fuel line connections that sealed after separating and routing all fuel lines away from pilot and passenger compartments.
Egress was insured by adequate escape doors and hatches. For a while the army bragged that they never lost a soldier to post crash helicopter accidents where the crash itself was survivable. This technology was available in the late sixties and early seventies. Much of their accomplishment has not been incorporated in general aviation, corporate aviation or air transport aviation.

DESIGN INDUCED ERROR

Pilots are human. Humans make mistakes, and this trait is foreseeable to every design engineer who ever worked a T square. It is incumbent on the designer to understand the human behavior patterns.

Flying airplanes is a little bit like swimming or bicycle riding. Once you learn how your skills may diminish from lack of practice but you never forget how. That is true for so long as the airplane is similar to the predecessor. Put a fixed wing pilot in a helicopter, a gyrocopter or a Blimp and that's a different ball of wax.

In an emergency it is often the case that a pilot may revert to emergency procedures drilled into him from the airplane that he has the most experience in. This is called transference and sometimes plays a part in accidents when the pilot has only recently changed airplanes.

In one recent series of accidents there is an automatic flight control system that is connected through the autopilot. In this particular airplane when the system is turned on the yoke control and throttle control is canceled. (Basically non functional)Every other airliner in the world's auto flight system moves the yoke and throttles when it is being controlled by autopilot. Furthermore a pilot simply overpowers the flight control or throttle movement if he so desires and this action turns off the autopilot and the pilot returns to manual flight.

In my opinion this is retrogression to insanity. Te pilot must first throw a switch to turn off the autopilot. Moving the controls does nothing. Design Induced Pilot Error. This insidious change violates everything every airline pilot has been taught about flying up to transition to this electric marvel. There are many such examples in aviation design. Fuel tanks that are separate and the pilot must switch the tanks periodically. The switch can be thrown to an intermediated position where the engine will fail because of fuel starvation.

Another manufacturer in a similar switch only wants it to be turned back and forth between the two tanks. If it is rotated 330 degrees to the other position the valve won't sit properly and the engine fails due to fuel starvation.

It took a 727 crash before Boeing installed a warning light for pitot static system operation.

It took an L-1011 settling into the everglades before a manufacturer retrofitted autopilot disconnect warning lights and audio to alert to the auto pilot failure. The pilots were all absorbed in trying to solve a gear light problem and no one was minding the store.

Man Machine Interface

Anthropometry is utilized in Aviation Design to optimize the pilots work space from an Anthropological viewpoint. Thus cockpits are designed for Human beings whose size and shape vary a lot. Many studies have been done to decide what the average man size is (50 percentile man) and then to run the percentiles to the extremes.

Measurements are taken of all sorts of variables to include, sitting height, arm length, leg length and a dozen other measurements. From the tables of measurements a definition of average sizes emerges. Believe me these tables are used by the clothing industry. Once the designer is told what percentile man he must design for he then knows how to start designing the cockpit workspace.

Probably the most important part of the design is to create an adjustable, Lumbar Support chair, which is not so comfortable as to induce sleep. The seat should be adjustable so the pilot can move it so as to position his head at the Design Eye Position. This point in space is chosen as optimum by the cockpit designer for a person to be able to see all the critical flight instruments.

It is designed so the pilot's head is in a position perpendicular to his instruments and about 28 to 36 inches from them. Critical function flight instruments and critical warning lights are placed within the pilots directed line of sight. A cone about 15 degrees all sides of the pilots focus of straight ahead.

Within this area where the pilot can see utilizing his foveal view as opposed to peripheral view, the designer must place the instruments deemed most critical to flight and the mission. Lesser instruments and switches are placed accessibly within human anthropometric areas. Since these instruments and switches are not within the line of sight, they need attention grabbers when they fail. It is usual to have one MASTER WARNING light and possibly one MASTER CAUTION light illuminate within the pilots directed line of sight. This in turn directs the pilot to a Teleprompter panel of warning and caution lights that establishes which systems are bad. In Glass cockpits the pilots is directed to Prioritized and colored alert lists on his glass EICAS displays.

Designing with Ergonomics in mind is essential. This is a discipline and study of utilization of controls, switches, handles and the like for ease and comfort of usage. Some people simply call it Knobology. It is far more than that. In aviation you can imagine that you want to design systems to operate easily and to facilitate such operation you want to design the controls so they act naturally and easily. The idea is the switches and controls are so easy and logical to manipulate that they do not detract materially from the operators' concentration and other duties. On the other hand certain critical items that could cause extreme harm should be designed so that they require positive and perhaps multiple actions to initiate.

For instance a pilot has an emergency lighting system in a 727. In flight this system should always be armed in case the lights fail. To insure that it is and to insure that it can't be turned off unintentionally, it is designed as a covered switch. Thus the pilot must remove the cover -then move the switch to disarm the lights.

Most fighter airplanes are equipped with some sort of covered or two step master armament switch, so as to preclude inadvertent ordinance drops. Place a pilot into a complex machine and to be effective you must maximize an interface between the man and the machine to best achieve the goal of safe flight and mission accomplishment. To do this there must be a simple and efficient way to transfer and display information from the machine to the man, and for the man to enter needed control inputs into the system.

In the simplest of control systems the pilot is directly in the man machine interface control loop. The pilot is the brains and he is the functional force applying the control and correction inputs.

Get only slightly more complex and add "power steering" and now the pilot is reacting to unreal tactile feedback from the machine and is in control of a hydraulic system that is actually driving the flight controls.

Go to auto pilot flight and the pilot is beginning to become a systems manager. He is still in the information loop (the aircraft provides information) and he has taken a supervisory roll while the autopilot is attached to the control loop.

Go to the even more modern Flight Management / Inertial Navigation /auto flight systems and the aircraft still provides informational data and the pilots have become system monitors in the grandest sense. Sometimes in such systems the pilot is lulled into a false sense of reliance and security, because it serves so well when it works.

I have noticed (while flying International Airline Routes with airplanes equipped with this sophistication) that most pilots turn it off and hand fly it during takeoff, climb, descent and landing. When questioned why they don't rely on it more there are two standard answers,

> *“Hell on these long legs I want some flight time. I could forget how to do it"*
>
> *Or*
>
> *“Hey Iron Mike the autopilot is great when it works, but who has got to do it when the S.O.B. fails"*

Another major transition is occurring in the industry at this time and that is the radical departure from a pilot being a pilot to becoming a computer operator. The flight management, computerized flight control system forces the older pilots through a learning process that is a little intimidating and confusing.

One major rule in designing these equipments with man machine interface in mind is:

If the machines are mass produced, and there are many similar models as well, it makes good sense to standardize the man machine interface, so to make transition and training costs minimal, while maintaining error free operation. Imagine the chaos if someone invented a far superior typewriter key board, and then introduced it to the world of secretaries! They would adapt, but not without a lot of complaint and lost time due to the training curve.

Some rules that apply to the standardization of switches in aircraft cockpit design are:

1. Forward is on, aft is off.

2. Up is on, down is off
3. Rotating clockwise gets you to the big numbers.
4. Rotating clock wise is on.
5. When possible switches should be mounted near the systems instrumentation and warning feedback panel that they operate. (Imagine a car having a radio tuning switch totally remote from the radio frequency panel)
6. Certain cockpit handles are designed to look like the device they work.
7. Critical switches are placed accessible.

What the designer is attempting to create is a functional, easy to operate work environment for the pilot. The aircrafts mission and tasks must be understood and all missions for the airplane must be designed to be operated from the same seat.

1. The first function is safe operation in all modes
2. The second function is mission optimization
3. The third function is ease of operations in as many modes as possible.
4. Throughout this information must be prioritized and displayed as needed.

When a Jet airplane is covering the ground at 600 Kts, he is doing 1,000 feet a second or three football fields in one second. Even at approach speeds he is covering a football field in one an 1/2 seconds. The display of information is critical. It must be accurate, easily understood, timely and prioritized. This is a very formidable task as the aircraft move from pointers and dials to computer generated C.R.T. displays in glass cockpits.

In line with safe engineering practice several engineering principals are followed in aviation when it comes to warnings and warning devices. Within the design of an airplane itself there are certain design criteria as how warnings are to be conveyed.

The principals to be followed in aircraft lights are;

1. The color red is reserved to convey an emergency of a Cat I. nature.

2. The color amber is reserved for abnormal situations, conveying the need to react.

3. The color blue is reserved for a satisfactory status analysis.

4. The color green is reserved for a safe situation status.

In cockpit design of warning devices several principles have evolved, they include:

a. In cockpit design it is recognized that a distinct audible noise is the best attention grabber to reflect an emergency or warning (bell, clacker, siren, whistle etc.)

b. In cockpit design it is recognized that an illuminated light that is flashing intermittently is the next best attention grabber

c. It is recognized that a steady light is next best.

d. It is recognized that a warning label is least desirable

e. For a light to be effective it must be placed in the pilots directed line of sight. (A thirty degree cone)

f. For a critical emergency it is usual to combine an audible with a red light

g. Since cockpit dashboard space is limited it is recognized that all warning lights can't be placed in the pilots directed line of sight. Thus a master caution will be provided to attract his attention to other lights not so well situated.

Military Manuals and some civilian manuals utilize standard in flight manuals.

Warnings are highlighted in Red block and use the word WARNING in all capital letters. The word is reserved for data that if ignored could cause loss of aircraft or life.

Caution is a word in all capitals that means a failure to take corrective action may result in mission or system loss.

Note is used when a failure to comply will result in some adverse but routine situation that can be avoided.

Whenever possible cockpit design criteria require that a warning light is placed adjacent to the switch that needs to be moved in order to correct the situation. The same holds true for warning and informational labeling.