AIRCRAFT-ACCIDENT- INVESTIGATION - TECHNIQUES -101

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FUELS, FUEL SYSTEMS, FUEL PUMPS, FUEL STARVATION, FUEL FIRES

AVIATION FUELS, come in several varieties:

Aviation Gasoline comes in several specialized octane ratings. These gasolines are designed for piston engines are color coded by individual octane rating. The individual aircraft handbook will specify which aviation fuels are preferred, and alternative if allowed. When an aircraft is fueled with the wrong gas the results range from inconsequential to disastrous. Mixing of avgas creates a different fuel rating from any commercially sold. This sometimes occurs when a tank is topped off with the wrong fuel.

JET FUELS, are Jp-4, Jp-5, Jp-6, Kerosene, Kerosene type A and military exotics. Some jet engines can burn Avgas as an undesirable substitute.

A piston engine airplane is very sensitive to being fueled with the proper fuel. For instance a load of jet fuel put in a prop will almost always spell disaster or at best an emergency.

When an accident occurs where fuel is thought to be the problem, fuel samples should be taken, and fuel should be analyzed at a lab. The fuel should be obtained from the crashed aircraft, from the truck, from the storage tank. Further other airplanes that were fueled from the same source should be sought out,

Too often I read in N.T.S.B. reports: ten other aircraft were fueled from the same source that morning. None of the ten aircraft reported problems...Case Closed. This is an incomplete investigation and meaningless. Until you investigate the amounts of fuel added to the ten aircraft, the approved gasoline options for the ten aircraft you have reported nothing of value. For instance I can put a gallon of diesel fuel, a can of Prist, a bottle of Vodka, and 19 gallons of fuel in my car and it will run fine. Put 19 gallons of diesel and one gallon of fuel and if I can get it started I am headed to an engine overhaul.

ENGINES MAY FAIL BECAUSE OF WRONG FUEL.

An investigators best proof of wrong fuel is the above mentioned lab test from the accident aircraft (when available). After that there are clues the investigator should look for:

1. Radio transmissions of lost or rough running engines.
2. Ground witnesses saying, smoking, backfiring, sputtering engines.
3. Survivors reporting bad engine performance and failure.
4. Engine at low power or failed.
5. Internal to the engine -signs of detonation
6. Internal to the engine - fouled spark plugs

CONTAMINATED FUEL

Fuels SYSTEMS may become contaminated with several common contaminants.

1. Water
2. Algae
3. Paraffin's
4. Metallic debris from pumps.
5. Foreign object material from maintenance.
6. Intentional sabotage.

Water is a common contaminant of fuels. Some water is always present in solution. Water can accumulate through condensation within partially empty tanks. A very small amount of water is harmless as it will simply be ingested and turned to steam. When it is sufficient to settle and form a slug of water the problems begin. In cold weather it may form ice in lines or on filters.

Algae are a real possibility in fuels and all aviation fuels have additives that fight its formation and growth. It is extremely unlikely that fuel from a reputable source will have such contaminants. Where it is sometimes found is from sources stored on ranches and warm third world countries with alternative gas supplies.

Paraffin's Aviation fuels are all simple carbon molecules and polymers. Gasoline's that are allowed to sit long periods of time may change in composition. Certain complex molecules seem to settle out of solution and form a waxy like paraffin substance. I don't know if this is a precipitation process as the aromatics and lighter portions of fuel evaporate over time. Regardless the remnant is dangerous.

METALLIC DEBRIS, Sometimes pumps that handle the fuel begin to deteriorate, and small metal debris are entered into the fuel through wear. These particles are supposed to be filtered out or be so small as to create no problem to the engine, the debris however may be indicative of a sick pump.

FOREIGN OBJECT MATERIAL, Sometimes materials are left by maintenance in the fuel tanks. I have seen an oil wiping rag and a Dzus key retrieved from a fuel tank. Also sometimes the rubber bladder material itself deteriorates. Tape, in particular, is sometimes found free in the tank.

SABOTAGE : The amateur's killer is sugar or sand.

Results of contaminants: Filter clogging, filter bypass conditions as a result of filter clogging, ice formation in the case of water, Fuel starvation at the engine as a result of fuel line blockage or reduced flow. Engine rough running, decreased power and engine failure.

FUEL STARVATION AT THE ENGINE: This condition may occur for the reasons described above as CONTAMINATION. In addition it may occur for the following reasons:

1. Pilot error in system management.
2. Design Induced Pilot Error in system management.
3. Ran out of fuel (pilot, controller, supervisory error)
4. Pump failure
5. Line failure (leakage)
6. Fuel injection failures, carb failures, fuel control failures
7. Carb icing.

Pilot error in systems management. A friend of mine was killed during Naval aviation training when he turned off the gas rather than reduced prop R.P.M. on climb out power reduction. The investigator said “If the S.O.B. did something that stupid, he deserved to die!”

There are many things that a pilot can do to mismanage fuel systems. It is the investigators task to see the switch and valve positions in a fuel system audit to ascertain the conditions asked for by the pilot. Often an investigator must determine if the switch position caused the engine failure, or if the switch position was intentionally placed to off by the pilot in preparation for a crash that was caused by an already failed engine.

DESIGN INDUCED PILOT ERROR: Some fuel systems are notorious in inducing pilot mistakes. In general aviation some fuel tank switching handles can be moved partially to a new tank. They appear and feel O.K. but in fact the switch has not been made totally. The result is fuel starvation with a full tank of fuel.

Some other aircraft had fuel shutoffs positioned adjacent to fuel control switches for an electronic fuel control unit. The switches are similar in size and movement. Moving one is routine, the other serious. The fix is to retrofit guards. Later production aircraft move one set of switches.

RAN OUT OF FUEL. This seems the obvious pilot error situation. However, an investigator must go further in his analysis. Were the gauges accurate? Was the aircraft a gas hog? Was the fuel load correct? Are there other factors? Was there a fuel leak or excessive burn?

AIRCRAFT PUMPS

GENERALLY speaking there are two varieties of pumps in aviation usage. They are considered “boost or transfer pumps" and "engine driven fuel pumps". Once an engine is started the aircraft should not need “boost pumps" to continue to operate.

Fuel system design is to be such that suction from the engine driven pump is sufficient to supply the engines power needs and requirements. Gravity in combination with engine driven fuel pump suction will supply the aircraft with its fuel needs.

Many general aviation aircraft require the fuel boost pump to start the engines. Often these pumps are powerful enough to supply fuel to the engine if the engine driven pump should fail.

It is common that the boost pump is "ON" for take offs and landings. It is used to try to restart an engine in flight, and in cruise it is normally "OFF". (To save wear and tear)

In jet aircraft the function of the boost pumps is to deliver pressurized fuel to the engine driven pump or to transfer fuel from tank to tank or to dump fuel overboard. A boost pump doesn't remotely supply enough fuel pressure to run a jet engine. The jet requires a working second stage engine driven pump.

Let's start with a look at a typical submerged fuel boost pump. You heard right...submerged pump. They are typically small ranging from beer can size to about the size of the large "FRUIT PUNCH " cans on your grocers shelf. If you have a swimming pool or a hot tub you may own an electric pump that you place in the pool and it pumps out water. This is similar. This electric pump is actually an electric motor and an impeller that is submerged totally within the fuel of the tank. Since it is submerged most of the time fire is not a concern. Only when a tank is run dry does heat and fire become a concern.

Boost pump failures occur because of contamination fouling the impeller. These are called loaded rotor failures. The pump feels the stoppage and draws too much amps and blows a breaker. If the breaker fails to work the case of the pump begins to heat and it shuts off electricity as an overheat fault.

Another failure that is common is motor bearing failure and bearing overheating or rubbing failures. In these situations the same safety devices should come into play and shut down the electric pump. In these failures the investigator should look to a pump teardown. The key will be rotor shaft overheat bluing. A boost pump will never be the sole cause of an engine failure.

Before leaving boost pumps, I must talk a little about fuel fires and fuel explosions in fuel tanks. A fire needs three things to occur…fuel, oxygen, and an ignition source. Within the tank there are usually only three possible ignition sources and these three are all fuel covered except at very low fuel conditions in the individual tank. Fuel tanks are routinely pumped dry in airline and military operations. The three possible ignition sources are:

1. Boost pump
2. Electric transfer valves
3. Electric fuel gauges.

Of the three the boost pump is most likely since the fuel gauge draws very little power, and the fuel valve is more deeply submerged. This means that the boost pump is exposed to dry run conditions and oxygen for the greatest amount of time.

In such fires and explosions there are external sources that can cause secondary explosions. Therefore it is a requisite to determine that the first fire started within the tank. All boost pumps now have an anti explosive cap and case, and theoretically a fire could be going internal to the pump and it should be contained and would not spread to the gas vapor

Some boost pumps are of such loose tolerances that they exhibit a side loading phenomena at the bearings. In these pumps the tolerances are such that the rotor moves minutely closer to one side of the stator due to magnetic attraction caused by the stator. This attraction in turn causes an unwanted and unplanned friction at the bearings in side load. The submerged boost pumps all use the fuel that they are pumping as lubrication. When the pump is no longer submerged it is no longer lubricated and is "DRY RUNNING" In this case the bearings may heat excessively.

Other boost pumps are a series of small pistons that pump the fuel. Some of this exhibit a deterioration called exfoliation. This is as a result of plating material peeling off. It is thought that this deterioration is exacerbated by newer approved fuels that have higher sulphur content than previous fuels. This variety of pump also will show distinctive deterioration in a very short time if it pumps highly water contaminated fuel.

In large jet engines it is typical to have a pump design with two stages. The first stage is low pressure and the second stage is high pressure. All such pumps require that the second stage portion of the pump be operable. Failure of that stage results in instant engine failure and no hope of recovery.

LINE FAILURE, Fuel Starvation comes about when a line fails totally, or a line fails partially. Line failure total will result in engine failure. Depending on where the failure is a fire airborne may result. Line failures come about because of maintenance failures. Lines back off and because of fatigue, wear and tear and vibrations. Some lines back off only a little and these result in either some fuel leakage and / or possible fire.

Fuel line failure on a suction line will allow air intrusion and the possibility of vapor lock or bubble formations.

Vapor Lock can occur in hot weather and with heated fuels. This occurs when the low vapor pressure of the fuel is exceeded. (Low pressure is attained and the fuel vaporizes. Desert Storm 747s returning fully loaded with desert temperature fuel were restricted to low altitudes so as to maintain pressure while the fuel cooled then climbs to cruise altitudes later.

Fuel injector Failures: Fuel injectors sense engine requirements for fuel based on Throttle position and other criteria. The injector distributes appropriate fuel to each individual cylinder. At the cylinder a nozzle sprays atomized fuel into the cylinder. Fuel air mixture occurs within the cylinder.

The same injector system determines the appropriate amount of air to be distributed to the intake of each cylinder. This is done through a series of pressure sensing bellows and dividers within the injector, and in the design of a series of dainty and high quality small tolerance valves. An investigator need be very familiar with the exact make and model of the specific injector before attempting an analysis. These injectors have been modified over the years by Bulletin, Letter and Airworthiness Directive.

An injector should be bench checked whenever possible before any dismantling. Before dismantling be sure you have a qualified man do it. A plumber will cause internal damage and spoil the evidence. Part of the reason for the teardown is to inventory the works to see if the current approved parts are installed within. This is secondary however, to determining if there were internal failures pre-existing the crash. I very complete inventory should be taken of the rubber bellows and the needle valve assembly that separates the chambers between the rubber bellows. Minute fuel or air leakage between the sides of the bellows will have a significant deleterious effect on its operation. There are very few qualified fuel injector experts around, there are lots of charlatans.

Some investigators don't have a clue. On two separate investigations they took the injector apart at the field ascertained that the rubber part was the current one. They mashed on the rubber then pulled it off the dainty needle valve and reported no fuel found on the air side. Once they screwed it together and released it for salvage it couldn't be meaningfully bench checked. Also there was little way of knowing whether the rip in the rubber caused the accident or was caused by the N.T.S.B. Knowing what I know, I suspect the N.T.S.B. spoiled some more evidence. The other case had lots of paraffin from sitting around a long time.

CARB FAILURES: these are usually easy for an investigator to find. Carbs are very simple devices that meter and spray fuel so as to mix with a certain amount of air and the combination fuel air mixture is delivered to a manifold from which it is sucked into an operating engine through intake valves. The usual carb failure is a linkage failure, or a failure of air heat either on or off. The investigator need only be able to differentiate pre existing failure from crash damage.

FUEL CONTROL FAILURES: If fuel injectors require a real expert the sophisticated fuel control units on jet engines require a wizard. These electronic devices use a computer to select appropriate fuel requirements and they adapt to temperature, density altitude, acceleration and deceleration parameters and
In military situations are tied partially to re heat considerations (afterburner). They are supposed to annunciate an internal failure and fail to manual safe operation. They may be deselected. They are attached to the auto flight, auto throttle parameters, and to say the least the range of sophistication is mind boggling.

Only the manufacturer and qualified maintenance shops are capable of bench testing these devices and few observers are qualified to observe such a test. When crash damage is great, and a tear down is performed the task is easier. Within the crushed device one will find witness marks that will allow an investigator to determine what the device was doing at impact.

CARB ICING: A carburetor is a device that has air sucked or forced through it. It sprays fuel into this rapidly moving airstream. The suction created by the engine accelerates the incoming air as does the carb itself through the Venturi effect of its internal design. Whenever air pressure is lowered so is the temperature. When you atomize and evaporate gasoline the temperature is also lowered, all these effects occur within a carburetor. When the fuel is contaminated with water or when the outside air was wet with precipitation or was very humid there is a possibility of carburetor ice formation. Such formation can cause engine failure. It can happen very quickly and in outside air temperatures as great as 65 degrees F. A general Aviation pilot should be knowledgeable about this phenomenon since if it occurs to engine failure there is little hope of re starting the failed engine. An investigator will almost never find the ice present at the wreck, and his only clue will be to discount all other possibilities for the engine failure, and have conditions correct for the occurrence.

Metal

Most airplanes are built of metals. Certainly all engines are metal and most airframes are too. Often airplane component parts fail causing the component to fail and this sometimes results in an accident or incident.

An aircraft investigator is sometimes in a potato field with a wreck scene a block long that looks like a landfill and somewhere there is a small piece of metal waiting to be found and eager to tell its story.

This chapter is not written in order to train anyone to be a metals expert or metallurgist. Instead it is written to educate a lawyer to the absolute need to hire a failure analyst expert or a metallurgist when trying to determine what metal part broke first and how and why it broke at all. Generally speaking metal parts break as a result of overload or fatigue.

OVERLOAD is a condition where a one time load exceeds the metals strength and it yields to the failure.

Fatigue is a localized change occurring in metals subjected to fluctuating loads which culminate in progressive cracking up until a point of failure.

Fatigue failures always propagate from areas of stress risers. These stress risers may be damaged areas, notches or sharp corners, corrosion areas, metal deficiency in heat treatment, or material imperfections.

Usually fatigue cracking is easily recognizing as radiating away from an area identifiable as the stress riser or original imperfection. Each cycle increases the crack propagation and the beginning and end of each cyclic tear is visible as striations. Whenever the fatigue failure is in a part that rubs another moving metal part there is always that chance (probability) that the cracks origin may be obliterated because of the parts rubbing against one another. This might be true in bearing failure and in gear failures.

The attorney is interested in why the fatigue failure occurred and who is at fault. Of course fatigue can occur as a result of defective design, defective manufacture, and defective maintenance, negligent choice of materials, improper inspection and material flaws not caught in Q.C. It can be said that aircraft design should be such that fatigue failures should not occur. The investigators job is to recognize it in the bent and tangled wreckage.

Overload failures are all the same to the extent that some load has been applied to a structure greater than that structure can withstand.

How the load is applied and where it is applied determines what variety of overload failure you will have. You may have tension failures, impact failures, compression failures or torque failures all as a result of overload forces.

Very, Very oversimplified the big fish that broke your line got away because of a tension failure---unless of course you tied a bad Knot like I am want to do. When you collapsed the legs on your child's lawn chair you created a compression overload failure. When you dropped a U joint as a teenager when you peeled out in your dad's car you created a Torque overload failure. When your drill bit hit a nail and seized you created a torque overload failure when the drill bit broke.

Suffice it to say that a metallurgist is required to determine the type and variety of failure and the fracture mechanics of the actual brakes. Suffice it also to say that metallurgists are often not at the wreckage scene. Therefore it is incumbent on the investigator to know enough failure analysis to determine what metal pieces need further examination. Logic plays a significant part in the Air Safety Investigators role in the investigation.

As an example an Air Safety investigator may see a fatigue crack propagating in an aircraft part that had nothing to do with the cause of this accident. That Air Safety Investigator should be equally as worried about that crack as he is determining the real cause of this accident. The Air Safety Investigator may alert the community to this fatigue problem as well as solve what caused this crash. The attorney's investigator is more focused on what caused this one so blame can be assessed. Thus the Attorney's investigator is looking for the first failure. As a practical matter he is only looking for failures material to causing or contributing to this accident.

Some materials used in aircraft manufacture are susceptible to Stress Corrosion and Hydrogen embitterment. When these are present, and it takes a metallurgist to determine their presence, the metal will break well below its expected strength characteristics. In some ways I think of stress corrosion as termite wood and Hydrogen embrittlement as plastic turning brittle after prolonged sun exposure. Landing gear collapses with aluminum alloys are an area where one might think of these phenomena before saying the pilot just landed too hard.

An air accident investigator has lots of clues to help him decide what happened even before he starts looking for the source of a metal failure. In certain varieties of cases he must suspect metal failure as one potential causative agent.

Cases that demand consideration of preimpact metal failures are known:

1. Engine failures
2. Transmission failures

3. Gear box failures
4. Rotor failures
5. Propeller failures
6. Airframe structural failures
7. Flight control failures
8. Gear failures

Metals used in aircraft structures are somewhat flexible. This is of course relative and some would say that it was stiff but not brittle. For the non metallurgist these terms suffice to describe what an investigator sees in the field. Ductility is similar to a plastic deformation in fact it is a tendency to deform. Now let's get really basic. When you pull Toffee you are deforming it. When you pull Toffee it narrows or necks down. Metals that are somewhat ductile Narrow or neck down when pulled in Tension to failure. Bolt failures in Tension will show this distinct trait. Strands of cable within a cable that has been overloaded will show this trait as a fingerprint. Control rod linkages that have been pulled apart will show this tendency.

Many structures that break in tension will show some deformation before the break. Remember that in mid air separations we look for structural bends in the direction of the break. An investigator when looking for the direction of break of a wing will examine first the main structural beam of the failed wing. This is usually the largest Aluminum "I" beam that runs spanwise away from the fuselage (Spaced about 30 percent aft of the wings leading edge.)

An investigator will usually find deformation of this spar in the direction of break. It is not unusual to see both an upward break and a rearward twist. Absent the fingerprints of fatigue this would be the first clue of a positive "G" overload failure. Since this part is an "I "beam that is attached at both the top and bottom we expect to see differing signatures on the top and bottom spar. If it was positive "g" at break then the bottom of the "I" beam was in tension and the top was in compression at the time of failure.

After the Main spar breaks the rear spar is sure to go and it will show the same variety of metal failure fingerprints. Since the wing is now departing the aircraft in an upwards ad rearward direction it will pull some cables and components with it, these cables under tension will break out of there pulleys and stretch. The stretched control cables may now saw through some wing and fuselage skin before breaking in tension. These cable saw marks are secondary evidence of the direction of wing breakage. In this example, since the wing broke up the metal skin of the airplane will be clean on the bottom, but there may be tearing of skin on the top. (This is secondary as well.) The wing that has broken off may exhibit upward deformation when looked at from tip to root. (Still more secondary information) The wings skin may show compression buckling on the top and tension stretching on the bottom. (This would elongate rivet holes)

Tail structures are the same as wing structures except smaller. The usually have a main spar and a rear spar just like the wing. Of course there are variations of this rule. Sometimes the structures show deformations in both directions and this show the investigator one of two things. The aircraft took enormous forces in both positive and negative direction before ultimate failure or the part being examined was not the first failure.

An investigator needs to get from the manufacturer the flutter analysis for certification when flutter fingerprints are suspected to be present. In one instance a group of flutter consultants failed a tail section of a well known general aviation aircraft in a wind tunnel. The resulting bends, breaks, creases were in places shown on that manufactures shake tests had predicted. The correlation was phenomenal.

NOW I DON'T PRETEND TO BE A FAILURE SPECIALIST OR A METALS MAN. However I am a pretty good junk yard dog and this is my method for overcoming my deficiency in this field. At this point in my career I have evaluated over 450 accidents. Whenever metals have been a consideration I have preserved pictures and testimony of experts as to the cause and failure modalities. In addition I have copied pages from Metals Handbook, 8th, vol 10 **"FAILURE ANALYSIS and PREVENTION"** as well as **" SOURCE BOOK in FAILURE ANALYSIS"** A.S.M., 1974. I have compiled a very large notebook as a "GO BOOK ", and I take it with me to every wreck sight. It is invaluable even when I am accompanied by an expert metallurgist. I recommend these two books and this method very highly. (I am sure there are updated versions of these pubs.)

Remember that somewhere out there in all that wreckage there is a piece of metal just waiting to tell a story.

ELECTRICAL SYSTEMS

Almost all aircraft electrical systems have one thing in common. Usually they all have a battery that will last at least 1/2 hour and run one communication radio and one set of navigation radios. This is usually designed in so that if everything else shoots craps a pilot can still get down in bad weather or night.

Often things do go wrong electrically and the airplane will lose some systems all the way to loss of the aircraft.

Types of failures that can occur.

1. over or under voltage.
2. over or under frequency
3. over or under excitation
4. Dead shorts
5. Wire chaffing
6. Sneak circuits
7. Insulation fires and flashovers
8. Generator speed control problems and surging
9. Generator failure
10. Transfer relay /load shed chattering
11. Load sharing faults in multiple generator aircraft
12. Transformer /rectifier failures
13. Fuse failure
14. Circuit breaker popping.
15. E.M.I.

Electrical systems of airplanes need electricity of a good quality and quantity to power sophisticated radio, navigation and weapons systems. Alternate current systems are usually 115 + or - 5 volts 400 cycle + or minus - 8, systems with generator excitation specified. So faults of varieties 1 to 3 are about the quality and quantity of electricity provided to and sensed at a load bus from a generator. The D.C system is usually 28 volt.

A dead short is simply a load carrying power supply wire or bus going to ground creating a severe short circuit and thereby pulling unlimited amps causing failures within the system. Suppose I short out a hair dryer at home. This does little harm to Austin Texas electricity. Suppose a crane gets into a power transmission line at the power plant. This causes havoc. Similarly there are severe shorts in an airplane and there are routine shorts as well.

Wire chaffing is a potential problem in airplanes. Take an F-16 that has 11 miles of wire bundles in its tiny airframe. Sharp screws, sharp edges, small radius turns, maintenance procedures, and flight vibrations may all cause unwanted chaffing. The fact bundles will chaff is known, when they will fail is not. Chaffing may cause interruption to a single system, failure of that system, short circuits and sometimes wire bundle fires.

Sneak Circuits. This is a very rare occurrence that was expected to be designed out. It is where an electrical signal designed to be transmitted solely in one set of circuits' sneaks to an adjacent circuit or by the proximity of one circuit to another, affects the adjacent circuit deleteriously.

Insulation Fires and Flash over There are generally three varieties of aviation acceptable wire insulation. It is a polymer rated at 150 degrees C and Kapton rated at 200 degrees C, and an irradiated Polymer with additives rated at 200 degrees C. All of these wires are supposed to not sustain burning absent a heat source. The temperature rating means that it is supposed to keep all its properties intact and insulate at the elevated temperature for at least 10, 000 hours of usage. The wires have been tested in excess of 300 degrees for 7 hours with no ill effect. Aircraft wiring in airliners is supposed to last 50, 000 hours. Remember that most aircraft parts are no where near the 200 degree C, which is about 392 degrees F. However all these wires under stress will exhibit phenomena known as flashover? An investigator will recognize it instantly for so long as he can find it in the remains of the wreckage. It is usually seen in airplanes that land safely and in the laboratory.

Generators Speed control. Generators are run by either fan belts or more likely from Constant Speed Drive mechanisms. These C.S.D. operate like the old Buick fluid drive automatic transmissions in cars of the 1950 era. When a C.S.D. gets low on fluid or the fluid is contaminated or when the fighter airplane pulls g's with a low c.s.d. fluid it drags. Generator speed is not held constant and the system surges and fluctuates. This can cause components that need good electricity to protect themselves by dropping off the line. If it is serious the entire generator may be taken off the line by its own protective devices thereby un-powering many subsystems.

GENERATOR FAILURE. Generator failures are caused by many things. Often it is the failure of a carbon block within the generator case. Regardless, when a generator self destructs all electrical capability is lost from that generator. Partial failures are unlikely although it is possible to only lose one phase of a three phase generator. If this occurs the generator will be tripped off the line and the net result is the same as total generator loss.

TRANSFER RELAY FAILURES AND CHATTERING Transfer Relay failures and auto shed failures occur when a switch designed to automatically switch positions because of a change in electrical availability fails to do its designed job. For instance in the old A model F-16 airplane when a main generator becomes unusable a series of 5 transfer relays are supposed too work automatically. The main relay is supposed to remove the first generator and install the backup generator. The others simply turns off 4 unneeded (non Essential) busses. Failures of these to perform will either deprive the airplane of a backup generator or keep busses on line that should have been turned of. Sometimes these auto shed devices can't seem to decide what they are supposed to do and they chatter. This is aviation description for switching back and forth. The failure and type of failure is easily recognized if the part can be recovered.

LOAD SHARING FAULTS Whenever a multiple generator airplane is attached to a common load buss, then each generator should supply the same amount of electricity. This is called sharing the load. Sometimes a single generator will provide errant amounts of electricity. When this occurs it forces the others to adjust. The generators end up fighting one another until the system decides to separate the generators to power their own designated busses. Sometimes when the disconnect has occurred the generators settle down and work satisfactorily separated.

TRANSFORMER /RECTIFIER FAULTS. These devices are devoid of moving parts and usually are flawless for the life of the airplane.

The transformer simply Changes 115 volt electricity into 28 volt electricity. The rectifier changes or straightens out the alternate current into direct current. Each such device is designed to carry a maximum load. Occasionally you will get an overload over heat failure and occasionally you will see a dead short across the device.

FUSE FAILURES are as a result of overheat and melting. A fuse is designed to carry so much amperage for a period of time. Once this limit is reached the circuit melts and the fuse is blown. When this occurs the electrical circuit can not be reinstated without changing the fuse. These are very easy for an investigator to detect.

CIRCUIT BREAKERS pop when to much current is passed through them. They may be reset by crewmember input.

E.M.I. Some electrical systems can be interfered with or operated by external interferences by Electronic Impulses. Electronic Flight control systems, Electronic fuel control conditions, CRT and other displays can all be affected. This is an area of great concern and, the investigations of this suspected interference is in its infancy.

INVESTIGATION FOR ELECTRICAL FAILURES

Electrical systems are sophisticated and usually have back up systems or redundancy for safety. A typical system might consist of two engines, two generators, and the back up battery. Either generator is capable of powering all the aircrafts essential electrical equipment. When working properly both generators will be tied to a common electrical bus so they can share the load.
When both generators are working they share the load and produce enough power to satisfy all needs (essential and non essential electrical equipment.)

Each generator will attach to a common bus and this buss will in turn power the primary AC essential bus this primary bus supplies AC power to a secondary AC non essential bus through the transfer relay (an auto shed device)(failure of one generator will be sensed and the transfer relay will turn off non essential).

Additionally, the primary AC essential bus will provide power to a T/R that will transform the electricity down to 28 volt and rectify it to DC. This DC electricity powers the primary DC essential electrical bus. It also provides DC electricity through another transfer relay (auto shed device) to the DC secondary non essential bus. Electricity from the essential DC bus is used to power the Battery charger and the hot battery bus.

When one generator fails the non essential busses are turned off by the transfer relays. When both generators fail the battery supplies 1/2 hour to the hot battery bus that has only a radio and one simple set of standby flight instruments.

Depending on design there are variants of this basic concept. For instance the B-737 has an additional generator called the auxiliary power unit that can be started and it will replace the loss of either generator. The F-16 has an instant on automatic starting Emergency power unit that senses the loss of the single generator (old models- new have two generators) and it will power all essential electrical systems within 2 seconds.
The B727 has three generators, aground only A.P.U. and a thirty minute battery.

Whenever a generator failure occurs, numerous individual components will be denied electrical power, and several warning and status lights will be illuminated.

Remember that some devices on an airplane require very good and constant quality of electricity to work properly. Examples are in your home, your home personal computer that has surge devices that protect the machine and the hard drive from errant electricity. Your T.V. needs good electricity or else the picture will go bananas. New housing codes require surge to short protectors around certain appliances so the they will turn off before electrocuting the user fatally. Not critical are the lights which will work dimmer or brighter before a failure.

Varieties of equipments in airplanes that require very good quality and quantity of electricity are: Inertial Navigation Devices, Flight Management

Computers, Electronic flight controls, A.D.I.'s, Heads Up displays, computers and gyro platforms.

These devices when they sense bad electricity disconnect themselves through protective devices, some internal, some with solenoid switches (powered on-spring loaded off) some with fuses, and some with circuit breakers. All other equipments although not as sensitive are provided overload protection through fuses and circuit breakers. You have these in your own home. The circuit breaker is reset, whereas, the burned out fuse must be replaced.

When an electric problem is suspected the investigator is faced with a monstrous problem. It is difficult enough in an intact aircraft. It is very difficult in a badly destroyed aircraft, and it is nearly impossible when one has been crashed and badly burned. The impossible takes a little longer!

The investigator must be very logical and thorough in this attempt to audit the electrical system. He must get a copy of the correct electrical diagrams and schematics for the airplane.

This is paramount for the next step is to determine what buss powers each and every component. Once this is learned then the investigator must determine the ratings and type of protective device (fuse, circuit breaker, solenoid, internal device) that protects the components.

Then the investigator should determine where the components, busses, fuses and circuit breakers were located within the aircraft. He should determine the wire bundles routing and make up.

Next he begins his audit by finding as much of the entire electrical system as he can recover.

1. Circuit breaker panels should be inventoried and condition of breakers recorded. These breakers should be systematically identified as to which component they were designed to protect. Popped breakers should be analyzed since they may be crash damage not electrical fault.

2. Fuses should be treated in similar manner to determine if they had melted as a result of overload.

4. Light bulb analysis should be conducted to ascertain that electricity was available to components that would be expected to be on. (AIRCRAFT NAVIGATION LIGHTS AND ROTATING BEACONS are on day and night) Cockpit lighting at night. Instrument panel lighting at night. Map lights at night. Passenger lights at night.

5. Light bulb analysis of component status lights and failure and warning lights should be conducted and inventoried.

6. Electrically powered components should be inventoried for operation; these devices only fail for lack of power or material component failure, or switch position.

7. Switch positions should be inventoried to electric components to help ascertain off or on condition. The investigator must be aware of wreck damage.

8. Electrical busses, transformer /rectifiers and Transfer Relays should be examined for status, operation, and short circuiting, arcing or overheat indications

9. Constant speed drives should be checked for fluid, condition and whether it had been disconnected.

10. The generators should be examined for rotation and condition. Sometimes the can be bench checked. They can be dismantled for indication of pre existing failure.

11. Wire bundles should be examined for flashover fire, overheated areas or obvious chaffing.

Any investigator who has read this will say “Sure you do" very sarcastically since severe wrecks are never amenable to such a complete inventory and audit. The point is that you attempt the discipline with what is available to you. The truth is that you will almost never get 100% reconstruction. The point is that you don't always need it to draw valid conclusions.

I always put a complete schematic on the wall of a conference room. Often a hotel room wall near the accident sight, as each piece of new data is captured I place it on the charts. Soon patterns begin to become discernible as to the status of the electrical system. The failure of multiple devices on a singular buss suggests a buss failure. Failure of all critical items on a bus with lights still available suggests that the buss was not getting good quality and quantity electricity and the components could not work while pumps and lights still worked. An electrical engineer familiar with aviation electrical system design and a metallurgist is helpful in this inventory.

Knowing the electrical system design, layout and function is a must before any determination of value can be made. A haphazard approach to the investigation of the electrical system will produce haphazard results and conclusions. The military does an excellent job in this respect. In my opinion the N.T. S. B. investigations range from good to non existent.

If an investigator completes a comprehensive investigation he will have determined everything that wasn't working, and from this he is more able to determine what failed and why. If he is extremely lucky, during this inventory, he will find tangible evidence of the actual failure, not just the results of the failure.

TRANSFER RELAY FAILURES AND CHATTERING Transfer Relay failures and auto shed failures occur when a switch designed to automatically switch positions because of a change in electrical availability fails to do its designed job. For instance in the old A model F-16 airplane when a main generator becomes unusable a series of 5 transfer relays are supposed too work automatically. The main relay is supposed to remove the first generator and install the backup generator. The others simply turns off 4 unneeded (non Essential) busses. Failures of these to perform will either deprive the airplane of a backup generator or keep busses on line that should have been turned of. Sometimes these auto shed devices can't seem to decide what they are supposed to do and they chatter. This is aviation description for switching back and forth. The failure and type of failure is easily recognized if the part can be recovered.

LOAD SHARING FAULTS Whenever a multiple generator airplane is attached to a common load buss, then each generator should supply the same amount of electricity. This is called sharing the load. Sometimes a single generator will provide errant amounts of electricity. When this occurs it forces the others to adjust. The generators end up fighting one another until the system decides to separate the generators to power their own designated busses. Sometimes when the disconnect has occurred the generators settle down and work satisfactorily separated.

TRANSFORMER /RECTIFIER FAULTS. These devices are devoid of moving parts and usually are flawless for the life of the airplane.
The transformer simply changes 115 volt electricity into 28 volt electricity. The rectifier changes or straightens out the alternate current into direct current. Each such device is designed to carry a maximum load. Occasionally you will get an overload over heat failure and occasionally you will see a dead short across the device.

FUSE FAILURES are as a result of overheat and melting. A fuse is designed to carry so much amperage for a period of time. Once this limit is reached the circuit melts and the fuse is blown. When this occurs the electrical circuit can not be reinstated without changing the fuse. These are very easy for an investigator to detect.

CIRCUIT BREAKERS pop when to much current is passed through them. They may be reset by crewmember input.

E.M.I. Some electrical systems can be interfered with or operated by external interferences by Electronic Impulses. Electronic Flight control systems, Electronic fuel control conditions, CRT and other displays can all be affected. This is an area of great concern and, the investigations of this suspected interference is in its infancy.

Instrument reconstructions

Instrument reconstructions and analysis is often very important in determining why an airplane may have crashed. The variety of accident will determine how important instrument condition may have been. Obviously a loss of control accident in instrument flying conditions makes it important to examine all flight instruments.

In these cases there are two very helpful clues that should be utilized initially:

a. A radar reconstruction- from this we can determine the aircraft flight path and airspeeds.

b. Radio communications with the F.A.A.

It is noteworthy that Federal Air Regulations require a pilot to announce lost instruments to the F.A.A. if that loss diminishes ability to comply with instrument flight capacity.

Thus it was in a General Aviation case I did near Bay Minette Alabama.

The pilot, a high time, instrument pilot radioed " *I'm in the clouds, my attitude indicator just tumbled"*

What a clue ! The attitude indicator is the primary instrument used for flying in clouds.

On wreckage review we recovered the indicator and had it torn down. Inside it there is a balance weight known as the trapeze. It was held in place with a screw and the screw was to be secured with a GLYPTOL no back glue. It appeared that there never was any glyptol, the screw had backed out and the trapeze was loose. Without the trapeze the attitude would fail or at least be incorrect.

Another real clue from which to compare instruments to is the aircrafts first impact with the ground. A lot can be learned from the wreckage and the hole in the ground. Steep or shallow dive the laws of physics remain the same. Wreckage scatter will continue in the direction of flight. Thus from the hole and a compass you may determine azimuth.

If the aircraft was other than level you may find wing gouges that tell you angle of bank at impact. The dimensions of the hole and destruction of aircraft structure gives a clue as to speed at impact. So does the length of a wreckage distribution path subsequent to the ground impact.

From the ground and scatter pattern we can approximate, angle of bank, yaw if any, dive angle, and speed.

A RULE: THE STEEPER THE DIVE, THE HIGHER THE SPEED, THE MORE LIKELY IMPACT MARKS ON AIRCRAFT COMPONENTS ARE GIVING VALID INDICATIONS OF WHAT THEY WERE DOING at impact… the converse is also true...The shallower the dive and the lower the speed the more likely that component parts may move and show erroneous or at least multiple impact marks or witness marks.

If a man jumps off the Empire State building and his watch crushes you have a good idea of the time of death.

The idea is that ground impact produces impact marks-called witness or capture marks by those in the business. Capture marks are those indentations made on a component such that the component is frozen and can not move from that position. Impact or witness marks are indentations made on components as a result of impact, but the component is not frozen and so they are indicative of a condition during impact or subsequent secondary impacts.

In a high speed steep dive it is likely that there is little subsequent motion and the impact marks are likely capture marks and therefore indicative of the condition at impact.

Since the most important flight instrument is the A.D.I. (Attitude and Direction Indicator) I will direct my discussion to the investigation of this instrument. This instrument gives the pilot his dive or climb indication as well as his wing roll condition.

The instrument is a movable globe or roll painted blue for sky and black for ground. On this globe every 10 degrees there are lines for dive or climb angles.

Stationery around the face of the instrument are gradations in 10 degree increments that depict roll angles of the wings.

A small airplane like device is held stationery in front of the globe. The globe is free (because of gimbals) to move in roll and pitch axis so the display that the pilot sees is his airplane relative to the movable horizon. All varieties of A.D.I. instruments are delicate watch like instruments. All varieties of A.D.I. instruments rely on high speed gyroscopic devices for alignment of the instrument's globe to the earth's horizon. You remember that a top is stable in space because of its high speed rotation. That is the gyroscopic principle.

As part of all mechanical gyros there are two rapidly spinning gyros aligned vertically and the other horizontally at start up. Once these gyros are started they will remain stationery relative to the original start up directions. This is made possible since they too have virtually friction free gimbals that allow three degrees of freedom.

An investigator then has three pieces of evidence to correlate. The indications derived from the hole in the ground and wreckage should be the same as the impact marks associated with the A.D.I. face and globe, and these in turn should be the same as the capture marks on the gyro system at the gimbals if all systems were working at impact. When the impact angles are shallow and there are multiple impacts it is incumbent for the investigator to determine which witness mark of the many was made first. This is analogous to determining the first break in the midair separation scenario.

There are a couple of rules for the A.D.I. globe that aid in this determination.

a. If the instrument is captured or frozen or damage is severe enough to have captured an intact instrument at some reading and there are other witness marks, THEN THE OTHER WITNESS MARKS HAD TO HAVE OCCURRED EARLIER. If those earlier witness marks are sequential toward the final capture mark then probably the farthest away is the valid first mark.

b. If a witness mark shows scraping or tailing that shows direction of movement then one should look upstream of this mark for an earlier mark, downstream occurs later

Let it be said that there are at least four general variants of the A.D.I. instruments that are in use commonly.

a. A vacuum driven self contained gyro instrument
b. An Electric driven self contained gyro instrument
c. An electric driven remote gyro instrument
d. An electric driven remote inertial gyro platform instrument

An A.D.I. instrument may be fully acrobatic or it may be incapable of such maneuvers. If it is non acrobatic and the airplane was tumbling it would be expected to have an erroneous
an indication at impact.

Before continuing let it be said that an investigator need have the appropriate manuals for the type and variety of instruments he is attempting to analyze. Further he must understand the workings of the instrument within the aircraft he is investigating.

Most electrical gyros have two separate failure flags that are supposed to come into view with failure modes. They are a "power flag" and an" OFF" flag. One displays if the signal has been lost to the instrument. The other displays when there has been a loss of electricity to power the instrument. Indications that either flag was in view at time of impact was a clue that there was a failure.

Clues an investigator should look for in any A.D.I. investigation

1. Flags in view
2. Capture position of the globe
3. Capture position of the gimbals and bearings
4. Witness marks of the aircraft symbol on the face of the globe
5. Glass shards imbedded in the globe
6. Identifiable witness marks from support frames of instrument to movable globe.
7. Human matter on face of globe. This occurred early in break up
8. Puncture marks in back of globe

9 other marks identifiably made from contact of the globe with the frame of instrument.

Clues an investigator looks for in the tear down of the gyro system if it is self contained, remote or an inertial navigational gyro platform.

A. capture marks of the gimbals' angles
B. capture of mechanical devices used to power the repeaters
C. rotational scoring between gimbals and rotating gyros
D. bluing of metal due to rotational friction
e. Torque breaks
f. Brake positions (support of gyro when not running-some models)

Note: on the very sophisticated gyros and inertial units the speed of rotation of the gyro is about 25, 000 R.P.M. Even though the gyros are small the edge of the gyro is moving at about 500 feet a second. This is very high energy. If the case for the gyro breaks on impact the delicate gimbals release and the gyro energy is freed uncontrolled. The container is literally exploded by the gyro trying to escape. It is the rule not the exception to find a gyro platform that has its case crushed spread all over the accident scene because of the release of the gyros. If this is not the case then you can assume that the gyro was not running at the time of impact. If the gyro wasn't running then the A.D.I. had necessarily failed pre impact.