FUELS,
FUEL SYSTEMS, FUEL PUMPS, FUEL-STARVATION,
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AVIATION GASOLINE comes in several specialized octane ratings. These gasolines are designed for piston engines and are color coded by individual octane rating. The individual aircraft handbook will specify which aviation fuels are preferred, and an alternative if allowed. When an aircraft is fueled with the wrong avgas 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: Aircraft turbine fuels are made up of many different hydrocarbons. Therefore, these fuels are not identified by any chemical composition. Instead they are specified by their general property limits. The categories are Jp-4 or Jet B, JP-5 or JetA-1 and other exotic turbine fuels. There are instances when turbine engines can use aviation gasoline as an undesirable substitute for the kerosenes.

The turbine fuels consist of four types of compounds. These are paraffins, cyclo-paraffins, aromatics and olefins. The properties of each depend on the crude oil source and the refining process. Non hydrocarbon compounds may contain sulphur and nitrogen. These do little for fuel quality and may cause problems.
Aircraft fuels use additives for improving properties and overcoming certain problems. In particular formulations the additives are required and in other cases they are optional. 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 and samples drawn.

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 and 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 in nineteen 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. Paraffins.
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.
Paraffins. Aviation fuels are all simple carbon molecules and polymers. Gasolines 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 fuel tanks.
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 fuel starvation 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 select a new tank position. 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 were similar in size and movement.

RAN OUT OF FUEL. This appears as 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? Were there other factors? Was there a fuel leak or excessive burn? Was the fuel cap on correctly?

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. 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 current and blows a breaker. If the breaker fails to work the case of the pump begins to heat and it should shut off electricity as sensed thermocouple 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 four possible ignition sources and of these three are usually fuel covered except at very low fuel conditions in the individual tank. Fuel tanks are routinely pumped dry in airline and military operations. The four possible ignition sources are:

1. Electric boost pump.
2. Electric transfer valves.
3. Electric fuel gauges.
4. Static electricity.

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 such case the bearings may heat excessively.

Other boost pumps utilize a series of small pistons that pump the fuel. Some of these exhibit a deterioration called exfoliation. This is results in 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 fuel containing a high content of water.

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 vibration. Fuel line connector fittings may back off resulting 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 needle 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. A 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.

Most N.T.S.B. investigators don't have a clue. On two separate investigations they took the injector apart at the field. They 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 done they screwed it together and released it for salvage. After that treatment 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. I suspect the N.T.S.B. spoiled some more evidence.

TEAR DOWN ANALYSIS of FUEL COMPONENTS: Crucial evidence has been lost due to poor investigative teardown analysis of fuel component parts. Before tearing anything down the parts should be well photographed. The reason for a teardown must be decided in advance and standard protocols followed. A qualified technician must perform the task. Absolute control during such testing and disassembly is mandatory.

CARBURETOR 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 they are tied partially to re heat considerations (afterburner). They are supposed to annunciate an internal failure and fail to a safe operation. They may be manually 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 icing occurrence.