PETER ROUSE

When the Lights Go Out

What you should know about aircraft electrical systems

> There is an old aviation maintenance joke regarding electrical systems:
>
> Q: What powers electrical boxes?
>
> A: Magic smoke.
>
> The explanation for the punch line is that once the magic smoke leaves the box, the box quits working. This joke is not to trivialize the importance of electrical systems on airplanes, but to humorously explain why there is a smell of charred insulation and a case of "interior IFR" when the "Whizbang 3000 integrated flight deck and food processor" decides to take a powder.

Where's the Plug?

Every powered airplane has an electrical system. Even the most basic powered airplane, the Piper *Cub*, for example, has an electrical system (its ignition system). There are wires, generators (magnetos), switches, and users of the electrical energy (spark plugs). This article addresses the electrical system that provides power for aircraft accessories, such as lights, avionics, motors, and actuators. Most of the airplanes we fly have at least an alternator or generator and a battery to provide power to the aircraft accessories.

The four primary components of an airplane's electrical system are:

- Aircraft bus
- Battery
- Alternator
- Voltage regulator

The aircraft bus serves as a central point to connect all of the electrical components. The bus is usually a simple bar of metal with holes drilled in it. The battery, which provides electrical power to the bus via electro-chemical reaction, is the primary power source when the engine is not running. The alternator provides electrical power to the bus by using the engine's power to spin a coil of wire on a rotor within another stationary coil of wire. The coil of wire on the rotor is referred to as the field; the stationary coil of wire is the stator. The rotor and field act as an electro-magnet and the spinning motion creates electricity within the stator.

The alternator is the primary source of power when the engine is running. The voltage regulator senses bus voltage and provides the proper amount of current to the field of the alternator to produce the desired amount of electricity in the stator.

Wiring Diagram

The three secondary components of an airplane's electrical system are:

- Wires
- Switches
- Circuit-protective devices (fuses or circuit breakers)

The wires are basic conductors, or pipes, that carry the electricity. The switches act as gates, or valves, that allow the flow of the electricity. The circuit-protective devices protect the wires from carrying too much electricity.

Why do we need switches? Switches control where the electricity is going, thus limiting the amount being used at any one time. Think of how high your electrical bill would be if every light in the house were always on. In the airplane, the electrical system is sized to provide all of the required power. However, every electrical component on the airplane does not have to operate continually. The switches also allow us to isolate the electrical components; we'll discuss why this is important later.

It pays to know what your electrical system looks like, how it functions, and what happens when it breaks.

Why do we need fuses or circuit breakers? When a wire carries electricity, a certain amount of heat is generated through the resistance of the wire. The more electricity a wire carries, the more heat is generated. Wires are sized based on the amount of electricity they have to carry. If a wire carries too much electricity, it can get hot and become a fire hazard. A fuse or circuit breaker is a switch that will open and prevent the flow of electricity when too much electricity flows through the wire.

The FAA released a Special Airworthiness Information Bulletin (SAIB) on circuit breakers: CE-10-11R1, Electrical: Fire Hazard in Resetting Circuit Breakers (C/Bs). I recommend that every pilot read this SAIB, which can be found at: www.faa.gov/aircraft/safety/alerts/SAIB/.

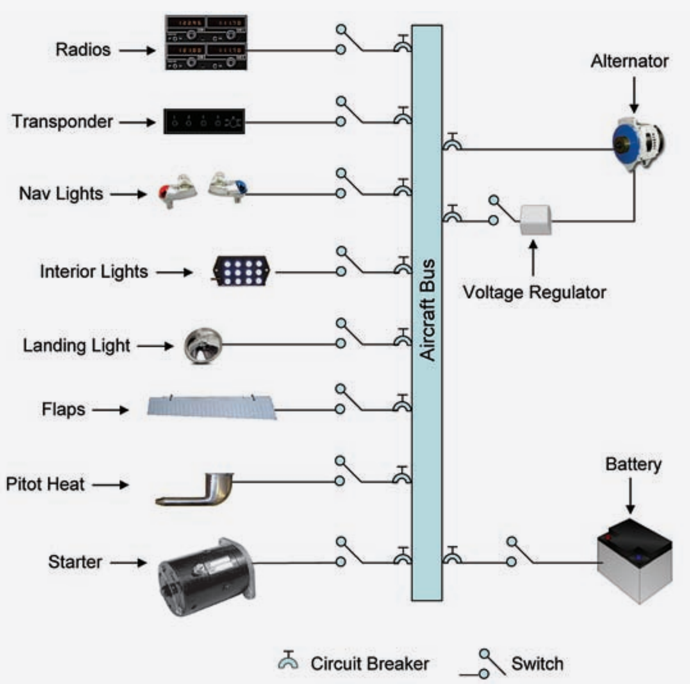

Fig. 1

A Simple Electrical System Problem on the Ground

Let's look at an electrical system in a typical GA airplane equipped with avionics, flaps, pitot heat, a starter, and lights, such as a Cessna 172. See Fig. 1 for a picture of a typically equipped Cessna 172 electrical system.

The basic procedure to bring the electrical system to life is:

- Master (battery and alternator) switch on
- Starter on until the engine is running
- Radios and transponder on
- Flaps, pitot heat, and lights as needed

If everything is operating properly, the pilot has little more to do than to operate the systems normally. It is when things are not operating properly that some thought and investigation are necessary.

The first indication a pilot will usually have that electrons have died and gone to electron heaven is that the engine won't start. The diagnosis is fairly straightforward: The battery is dead (most likely reason); the starter has failed (second most likely reason); the battery relay (or switch) is not working; the starter relay (switch) is not working; or the circuit breakers have popped open.

The lack of battery charge is simple to fix: Either get ground power for a jump-start or get a battery charger and let the battery charge for a while. Bringing the starter and relays back to life is more involved and requires getting an A&P mechanic involved.

The beauty of all these problems is that they occurred on the ground, leaving the pilot with a variety of options. Even so, the airplane has just talked to the pilot. All the pilot has to do is understand what the airplane is saying. For translation assistance, a conversation with your local A&P mechanic is a good idea.

What Happened to My Map?

While an inoperative landing light or flap failure can certainly add anxiety to your flight, a primary flight display (PFD) or multi-function display (MFD) screen that suddenly goes blank can be even more distressing. While these systems are much more reliable than the mechanical instruments they replace, as more aircraft migrate to glass-cockpit integration (some condensing nearly the entire instrument panel into a single display), pilots and mechanics will need to maintain a keen awareness of how to recognize and troubleshoot avionics component failures.

Photo by Susan Parson

Here is the good news. Today's display systems are designed to gracefully degrade when a failure occurs. If one display fails, the remaining display will revert to a mode that combines critical information from both displays on a single screen. This helps prevent the system from displaying hazardous or misleading information to the pilot. However, for mechanics to successfully troubleshoot these failures it is critical that they understand the system design as well as the role the individual components have in the overall system. For example, an air-data computer malfunction could result in the display's failure to present airspeed, altitude, vertical speed, outside air temperature, and true airspeed.

In some systems, a loss of information will be communicated to the pilot through a large red "X" over the inoperative indicator. In more advanced systems, a central maintenance system can provide detailed failure information that pinpoints the problem to a specific component or, in some cases, to an individual wiring problem. A component built-in test, known as "bite" capability, has become a highly reliable troubleshooting tool. However, don't let these advances fool you into thinking that avionics troubleshooting is now as simple as pushing a button. Knowledge of system operation and integration is essential, especially when there is a system problem and no associated component faults are found.

Because today's display systems are designed to eliminate hazardous or misleading information, some display problems may occur not as a result of a component failure, but because a system input is unavailable or invalid. For example, some systems may use valid GPS data as a critical input for the display of attitude, moving map, own-ship position, and heading. If the GPS input is not valid, the system will not display this information. Many situations external to the aircraft could cause the GPS signal to be invalid. These could range from planned GPS outages (typically covered by a NOTAM) to electromagnetic interference or sunspot activity.

Avionics display systems have evolved to provide more detailed information than ever, and much of it is crucial if we are to realize the improvements envisioned in the Next Generation Air Transportation System. Today's avionics mechanics have access to excellent troubleshooting tools that are integrated into the aircraft's avionics suite. This can provide quick and accurate problem identification. However futuristic and easy these systems are when they function properly, it is understanding the overall system operation, architecture, and integration that is the key to properly address advanced avionics problems.

— Tim Shaver

Tim Shaver is Avionics Maintenance Branch Manager in the FAA's Aircraft Maintenance Division. He is a commercial pilot and holds an A&P certificate.

A Simple Electrical System Problem in Flight

An electrical system problem in flight is indicated by either electrical accessories not working, or more seriously, an indication of electrical fire. An indication of an in-flight electrical fire will usually start with the smell of something burning or with visible smoke, which is caused by high current flow creating heat that melts wire insulation or other electrical components. An in-flight indication of an electrical fire is serious:

AIRPLANE + FIRE = BAD

The best course of action is to follow the manufacturer's emergency procedures immediately and get on the ground as soon as possible. The emergency procedures will generally start with using the master switch to turn off all electrical equipment. Next, the procedures may instruct you to turn off each piece of the electrical equipment, turn on the master switch, and then turn on individual pieces of equipment to isolate the failure. The switches allow us to isolate each of the electrical accessories (I told you we'd discuss why switches were important). Once you're on the ground, your local A&P mechanic can diagnose the problem while you're safely sitting in the FBO lobby sipping coffee.

The aircraft bus serves as a central point to connect all of the electrical components.

Luckily for us, electrical fires in flight are not that common. They happen, but the design of our aircraft electrical systems is intended to prevent electrical fires. The more common electrical-system problems in flight are individual component failures and supply-system (alternator and battery) failures.

Individual component failures are isolated and fairly easy to detect; you flip the switch and it doesn't work. The first place to look is to see if the circuit breaker associated with the component has popped. If so, the circuit breaker only requires resetting. However, as pointed out in the previously mentioned SAIB, resetting the breaker should be approached with caution and should only be done a limited number of times.

If there is an ammeter in the airplane, the ammeter should show an increase in output for the larger current-draw accessories, e.g., lights, pitot heat, and flaps, when they are selected. If there is no ammeter, or the component draws little current, then the failures may be a little harder to detect.

Photos by Susan Parson

One component malfunction that is hard to detect in flight is pitot heat failure. This is because there is no immediate feedback of failure. The indication that pitot heat has failed will be the loss of airspeed indication in the presence of icing, but this is not the preferred method of failure detection. The loss of the airspeed indicator will require you to fly using the attitude indicator (pitch), the tachometer (power), and altimeter and vertical speed indicator (performance). I have a performance card for my airplane that gives me the associated performance indications. This is also known as flying by the numbers.

Other Electrical Gremlins

Failures of the aircraft's lights are difficult to detect during the daylight hours, giving rise to the old joke that landing lights only fail at night. At night, light failures are easily detected as there is no immediate darkness abatement when the light switch is selected. I carry at least two flashlights and fresh replacement batteries. Flashlights stored in flight bags are known as convenient places in which to store dead batteries.

Radio failure is also easy to detect, because there is immediate feedback: You flip the switch, or press the push-to-talk switch, and it doesn't work. Radio failures manifest themselves by the loss of two-way communication and navigation. The *Aeronautical Information Manual*, chapter 6, section 4, Two-way Radio Communications Failures, covers the procedures for dealing with lost communication in flight. Navigation radio failures can be handled through the use of dead reckoning and pilotage. (Do you remember your student-pilot cross-country days?) I carry a portable GPS and communications radio as well as fresh replacement batteries.

Flap failures will likely be discovered during the landing phase of the flight. If your flaps fail to deploy, a no-flap landing is in your near future. Remember that your stall speed, approach speed, and landing distance will increase, so take a look at your Pilot's Operating Handbook (POH) to make sure you can get into your intended field with no flaps. A no-flap landing can easily be 30 percent longer than a normal landing with flaps.

Mind the Meter

One of the first indications that there is something amiss with the airplane's electrical supply system is an indication of a discharge on the ammeter. If the ammeter is not part of your regular cockpit scan, or there is no low-voltage annunciation in the cockpit, your first indication will most likely be blinking of the avionics and loss of the transponder when a demand is placed on the electrical system.

Earlier in my flying career, I experienced avionics blinking and transponder loss while flying in IMC. I was in a fairly new (to me) airplane that had a load meter instead of an ammeter, and there was no low-voltage annunciation in the cockpit. I first noticed a problem when I switched on pitot heat and the radios blinked.

There is an adage in flight test: If you touch something and it doesn't do what you intended, "un-touch" it. I un-touched the pitot heat and then ATC called me. It seems ATC had lost my transponder signal. I tried to respond and the radios blinked again when I pushed the push-to-talk switch.

I thought, "they're not supposed to do that and this is not good." I had time to receive one more call from ATC and acknowledge it before all of the electrons decided to take the afternoon off. Luckily, I had my portable GPS and I was able to get on the ground safely in VMC conditions.

It turns out that the cause of my electrical-system failure was that the generator brushes had fallen out of their holder (the generator was only 75 hours since overhaul) and the airplane had been running on battery alone. The load meter only shows a positive value, so there was no indication of battery discharge. When the battery was low enough, any additional demand on the electrical system resulted in an under-voltage on the bus and the blinking of the radios. The lesson learned: Have some way of checking the health of the electrical system, either a voltmeter or an ammeter, or preferably both. It also reinforced my belief in carrying portable navigation and communications radios. At the time of the failure, I did not have my portable communications radio; I have since taken care of that.

One of the first indications of something amiss with the airplane's electrical supply system is an indication of a discharge on the ammeter.

What Does This All Mean?

It pays to know what your electrical system looks like, how it functions, and what happens when it breaks. Doing a little homework will save you from getting a crash course in flight; no pun intended (actually, it was intended). Realistically, you do not want an in-flight electrical-system failure to be the first time you open your POH and read about the electrical system. Hit the books, get some dual instruction to blow the dust off of your emergency procedures, and get out and practice. Flying is easy when it goes right. But, it is when it doesn't go right, that your studies and training will pay off.

Peter Rouse is an aerospace engineer at FAA's Small Airplane Directorate in Kansas City, Mo. He is a 2,000-hour pilot and a certificated flight instructor. He has flown aerobatics in competition and is an active member of the International Aerobatic Club.