Electrical System Reliability

Everyone with an electrically endowed aircraft wants a "reliable" electrical system. How is this accomplished? Does certification have any benefits toward electrical system reliability? Having worked in the aerospace industry for 38+ years, I can attest to industry's quest for the holy grail embodied by the world's most "reliable" electrical system. Given the efforts of industry and government for the past 50 years, how are we doing?

The following article was shamelessly purloined from the pages of AOPA Pilot Magazine for March of 1999. There was no particular reason to pick this story - it was simply the most recent one I could recall. It's one example of perhaps hundreds of similar stories appearing in aviation journals for decades. I didn't want to interrupt the flow of the story so you'll find only footnote tags [ ] tying points in the story to later analysis. AOPA Pilot Magazine and other journals publish "Never Again" style articles with a stated goal of, "Enhanced safety by providing a forum for pilots to learn from the experiences of others." So, read carefully and observe. Afterward, we'll talk about what this story reveals.

Sparks in the Dark

As an Air-LifeLine pilot, I thoroughly enjoy flying patients to and from places for medical care. On one such trip I took a 4-year-old patient and her father to the Cincinnati Municipal Lunken Field from my home base at the Manassas (Virginia) Regional Airport. Our return trip was to be a three-hour flight in a rented Cessna 172RG. The weather was 3,000 feet overcast at Lunken, dropping to about 1,000 feet at Manassas.

We left Lunken in the late afternoon, and it soon became dark. I adjusted the cockpit lights accordingly As I tweaked the elevator trim wheel on one occasion, I noticed that the instrument lights got brighter for a second or two. I assumed that the brightening was caused by a loose wire's being jostled by the motion of the trim wheel. Since the cockpit light rheostats are close to the trim wheel, I ignored it.

The undercast was slowly rising to meet us, so I asked for a higher altitude. As I adjusted the rudder trim after the climb, I again saw the lights get brighter briefly and again wrote it off to a loose wire.

During my last several trips I had been regularly updating what I called my escape route - where I would land if I had an emergency. I would open the Jeppesen book to the selected airport and tune in its ATIS. On this flight, I added a new twist to my planning - a handheld GPS. By keeping the cursor on the selected airport, I always knew its bearing and range. The airplane was also equipped with an IFR-capable GPS.

At the time of the electrical hiccups, the chosen airport was the Beneduni Airport in Clarksburg, West Virginia, which was well above minimums for ILS and GPS approaches. About 30 minutes after I first saw the lights brighten, they got bright and stayed that way. I looked down at the ammeter, which was pegged at a full charge. I turned the alternator on and off several times, hoping to clear the problem [1].

On the third cycle, a puff of smoke and a shower of sparks erupted from behind the panel. I turned toward Clarksburg, now about 20 miles away, started a descent, and called approach.

"Mayday, mayday, mayday, Lifeguard Cessna Four-Eight-Five-Seven-Victor. We have an electrical fire; we'll need a descent into Clarksburg."

The controller cleared me to 5,000 feet and asked if my ILS receiver was working. I intended to keep my transmissions to a minimum. After all, I might not be able to land at Clarksburg, and I wanted to keep the battery charged to power the ILS receiver [2]. He vectored me toward Clarksburg.

Just before we entered the clouds, another shower of sparks erupted from behind the panel, so I turned off the master switch and utilized the small flashlight hanging from a chain around my neck. I kept the airplane on a northerly heading using rudder only, because my hands were busy with the flashlight and setting up the radios for the ILS [3].

By the time I got Clarksburg set in the handheld GPS we were in the clouds, and I was wandering 30 degrees on either side of my assigned heading. Suddenly, I remembered my passenger, gave him another flashlight, and asked him to shine it on the panel. This freed up one of my hands and allowed me to use my smaller flashlight to read the approach chart. Occasionally during the descent, I turned the battery back on to get a new heading from the controller. On one occasion, the controller told me that a departing aircraft had reported the ceiling at about 1,000 feet AGL. He suggested a visual approach. I'd been planning on an ILS, but I wasn't flying too precisely, so a visual approach had some appeal.

Once I reached 2,500 feet, I again turned on the battery and called the controller. He asked repeatedly if I had ground contact beneath me, and I repeatedly told him that I did not. Four miles from the field, I conducted a prelanding checklist and was able to lower the gear with battery power.

When I broke out of the clouds I saw bright lights at 11 o'clock, where the controller and the GPS said the airport should be. I wasn't sure that it was the airport I was looking at, seeing no runway lights, rotating beacon, or approach lights. I descended slowly to 500 feet AGL without positively identifying the field. Eventually, the GPS confirmed that the airport was behind me, as did the controller. Once I surrendered the navigation task to the controller, I had allowed myself to lose situational awareness - despite having two GPS receivers. I turned to the right and saw the runway lights.

On short final, I thanked the controller for his help and made a normal landing.

There are some important lessons that I took away from this flight.

Land first, fix it later [4]. At the first sign of an electrical malfunction, I should have landed. Waiting for the smoke and sparks to make the decision for me was stupid. I had a stable situation until I started troubleshooting it. As I learned later, the voltage regulator had failed, sending too much charge to the battery-which was indicated by the pegged ammeter [5]. Coincidentally, the alternator circuit breaker did not trip to protect the rest of the electrical system [6].

Fly the airplane. While fiddling with the avionics, I allowed my heading and altitude to wander.

Navigate. Once I had allowed the controller to vector me, I essentially stopped navigating. Had I lost communications at that point, I would have spent several precious seconds flying around at night, in clouds, over mountains, while determining my position.

It pays to be prepared. I would have been more scared had I not carried two flashlights, extra batteries, and a handheld GPS receiver. It pays to play "what if" scenarios through your mind during those hours of boredom.

Get help wherever you can. The Clarksburg Approach controller made a great copilot. He took over navigation and terrain clearance, though probably more than I should have allowed him to. Your passengers can help, too; they can pump the gear, hold a flashlight, fold a chart, and more.

Martin Gomez, AOPA 830204, an engineer from Fairfax, Virginia, is a 675-hour commercial pilot.

I congratulate pilot and author Gomez for his resourcefulness and skill in bringing this event to a happy ending. Further, I appreciate his willingness to publish his experience for our benefit. Critical review like that which follows is not intended to demean the author or diminish his stature in the community of aviators. One purpose of this chapter is to demonstrate how Mr. Gomez and our fellow aviators have been trapped by circumstances which need not have happened. I will suggest design and operational philosophies that will allow us to fly for the next fifty years "never again" having to experience this kind of problem. Let's look at some data points in the article:

> [1] ***I looked down at the ammeter, which was pegged at a full charge. I turned the alternator on and off several times, hoping to clear the problem.***

This is a clear indication of either regulator failure or a shorted cell in the ship's battery. If the airplane had a voltmeter, momentarily setting the alternator field switch at OFF would confirm the diagnosis. If bus voltage falls to 12.0 volts or above, the battery is okay and the regulator is failed. If the bus voltage falls to a bit above 10 volts, then the battery is shorted. Battery shorts are very rare compared to all other battery failures so it's most likely that the regulator has failed. What happened to the ship's overvoltage protection system?

> [2] ***After all, I might not be able to land at Clarksburg, and I wanted to keep the battery charged to power the ILS receiver. He vectored me toward Clarksburg.***

Our hero's first concern after taking the alternator off line is keeping needed avionics running. Since he was in a rented airplane it's a sure bet he didn't know what the ship's battery capacity was. This lack of knowledge forced him to shut down essential systems until the final minutes of the flight.

> [3] ***I kept the airplane on a northerly heading using rudder only, because my hands were busy with the flashlight and setting up the radios for the ILS.***

The C-172 has overhead flood lighting that draws just under 200 milliamps. Much preferable to holding a flashlight in the teeth. None-the-less, with the master switch OFF, it was unavailable to him.

> [4] ***Land first, fix it later. At the first sign of an electrical malfunction, I should have landed. I Waiting for the smoke and sparks to make the decision for me was stupid. I had a stable situation until I started troubleshooting it.***

Throughout my writings and conversations with builders, I've encouraged pilots to leave their toolbox closed until safely on the ground. Unfortunately, the electrical system architecture and operating limitations built into most certified aircraft make it tempting to do in-flight diagnosis and repairs. It's distracting to an already busy pilot and may make the problem worse.

> [5] ***As I learned later, the voltage regulator had failed, sending too much charge to the battery- which was indicated by the pegged ammeter.***

Correct . . . but his mechanic said nothing about (or worse yet) didn't know about ADDITIONAL problems with the airplane. Where did the sparks come from? Something behind the panel was exposed and faulting to ground. What happened to the overvoltage protection? Was this built into the voltage regulator and fixed with a new regulator. OV protection might have been a separate and overlooked component, still in a FAILED condition and waiting to ignore the next regulator failure?

> [6] ***Coincidentally, the alternator circuit breaker did not trip to protect the rest of the electrical system.***

A very common misconception about circuit breakers. The alternator's main output breaker almost never trips in an OV condition. Alternators are current limited devices meaning that while the bus VOLTAGE is climbing, output CURRENT from the alternator is only a few percent above the alternator's rated output which should NOT open the breaker.

The alternator's field circuit breaker is expected to open during overvoltage IF the airplane is fitted with a crowbar overvoltage protection device . . . I'm reasonably certain this airplane was not so equipped.

As I suggested earlier, this article is not unlike many, many others we've all read for decades. I think you'll agree that they all end the same way. "Sure glad I did this . . . next time I'll do that . . . boy! I'll never do this again." Have you ever read an article where the author questions either the manufacturers or regulators of airplanes as to what might be done to reduce if not eliminate the probability of a reoccurrence? We're schooled as pilots and mechanics that somebody knows a lot more about airplane design and safety than we do. We're taught further that once these bastions of knowledge and public interest pronounce aviation products fit for sale to the public, the notion of making any changes for the better are overwhelmed by bureaucratic roadblocks and ignorance.

What are we really looking for when using words and phrases like "reliability" and "failure rate"? For the majority of designers, manufacturers and users in the aerospace industry, these words bring up mental images of individual components carefully designed, tested, procured, installed, maintained and used in accordance with thousands of words of documentation.

Many of the documents are specifications, regulations or rules which (if not dutifully complied with) can be the basis for punishment of individual(s) who do not faithfully follow the words irrespective of motivation. How about Mr. Gomez's C-172RG? How much of the script for his harrowing experience was written by industry and government authors?

Mr. Gomez's story has ratcheted up the worries of perhaps thousands of pilots. References [5] and [6] highlight omissions and misconceptions in the story. These can also contribute to uncertainty on the part of folks who don't do this for a living yet are obligated accept the airplane as-is-where-is. Manufacturers might have an interest in upgrading their products but regulators often make this an expensive and time consuming task. Further, when a product is so highly regulated, manufacturers tend to relax . . . after submitting their product to the will of government, it must surely represent perfection! This is the biggest reason why aviation lags decades behind virtually every other industry.

That leaves it up to our hero to do whatever he can within his limited understanding of the system to plan his own actions for the time when he may expect to encounter this problem again.

Aviation journals appreciate these stories too . . . they get a reader's attention and in some small way, publishing them may indeed improve some pilot's chances of dealing with a similar situation. This lends some validity to the publisher's stated mission of improving on aviation safety.

The very same issue of AOPA Pilot carried an advertisement from a company that takes money from pilots to prepare them for these events. A testimonial from a former student congratulated himself for having taken the training course. The pilot said something like, "Only weeks after having completed this course, my efforts were rewarded when I successfully handled total electrical system failure in my airplane." The author of these words is justifiably proud of the success he experienced by training for a very stressful airborne situation. Ignorance is a strong pacifier and fear is a still stronger motivator. A combination of fear and ignorance is useful when it comes to extracting money from people with the feel-good mission of making a pilot more confident and capable of dealing with airborne adversity. The sad facts are that contemporary electrical systems are so untrustworthy that such training courses are valuable.

Aviation in the US deals with system inadequacy by striving for failure reduction, an increasingly expensive task as the numbers and kinds of failures become more random and rare. When system shortcomings are noted, they're more likely to be treated by add-on hardware, new regulation and/or additional pilot training rather than to fix the root problem.

The most elegant solution yet is totally unheard of in contemporary certificated aviation . . . design systems so that most failures of the nature described by Mr. Gomez don't matter. Failure tolerant design is much easier, lighter and less expensive to build than contemporary certificated designs.

For years, I've been working with amateur airplane builders who have chosen NOT to be ignorant. None-the-less, they bear heavy baggage brought with them for having read pilot's journals and listening to hangar tales of nail-biting escapes. Unlike the folk who swing wrenches on certificated aircraft, the amateur builder is encouraged to think outside the box and free to consider the value of doing something because analysis shows the action to have beneficial effect.

I wonder how Mr. Gomez might have summed up his experience if he knew that for $15 in parts, a few hours work on the airplane and NO new training or preparation, his story would have been so ho-hum that it wasn't worth publishing?

How would you describe a reliable flight system? May I suggest this:

"System reliability is optimal when I can suffer any of the most common failures and still put the wheels on the ground, at my intended destination, without breaking a sweat."

I present forums and weekend seminars around the country on the topic of aircraft electrical systems. One of my favorite questions of an audience is to rank components of the flight system with respect to the need for absolute reliability. I get some interesting comments from the crowd but here's my personal list of reliability priorities:

I. Airframe

1. Surfaces
2. Structure
3. Flight Controls

II Pilot

1. Skills
2. Training
3. Physical Condition

III Power Plant:

1. Engine
2. Propeller
3. Fuel System
4. Controls

IV. Systems

1. Electrical

    (a) Panel Lighting
    (b) Primary Nav Radio
    (c) Transponder
    (d) Turn Coordinator
    (e) Fuel Pump/Transfer
    (f) Engine Support

2. Landing Gear

etc.
etc.

The airframe and other things that make the airplane flyable are at the top of the list. Most people are surprised when I put the pilot as number II on the list. Consider that if the airplane is hanging together, the pilot is skilled and in good physical condition, the chances of living through the

circumstances of any given flight are greatly improved. Of course, if everything lower on the list is kaput, the pilot has few options. However, assuming the engine is delivering enough power to hold altitude, only then do the options begin to include choices for WHERE you will land and HOW you're going to get there. Note that I've ranked electrical system goodies a distant fourth place.

Let us consider life's little benefits that provide the maximum reduction of sweat. I put lighting first on the list. Recall that our hero's most immediate problem upon loss of the electrical system was being able to see. I mentioned earlier that the overhead flood light in the airplane has a very small electrical energy budget . . . but given the way most certificated airplanes are wired, the flood lights are DARK any time the master switch is OFF.

Second on my list is the primary navigation radio . . . VOR, GPS, Loran . . . etc. One solid state radio receiver draws about 0.2 amperes . . . not much energy needed here either.

Third is a turn coordinator . . . generally the only electric flight instrument on the panel and it will save your buns if you are practiced in its use (remember item II. 1 - Pilot Skills?).

Forth comes the transponder. If you've got a situation placing a graceful return to earth at risk, then a 7700 squawk will go a long way toward getting airspace in front of you cleared of other aircraft with no other taxation of your time and attention than to set a few knobs.

Obviously, that list can and should be modified to accommodate your personal flight habits. If you NEVER fly at night, panel lighting isn't an item high on your list. If you NEVER get close to clouds, then perhaps you don't need to worry about the turn coordinator. Further, if your engine is electrically dependent, then perhaps fuel management, ignition and other controls would move to #1 on your list. If you share my fondest dream where vacuum systems are used only for carpet cleaning, your electrical system's architecture for reliable flight will have to accommodate the additional tasks.

Some omissions from my list brought quite a few questions from the audience . . . how about the Comm radio? Engine instruments? Autopilot? Consider this when deciding what goes on your ME^{2}L (Minimum Electrical Equipment List): In order to keep an electrical system condition from becoming an emergency, we need to make a list of those things which are most useful in keeping you airborne with enough electrical assistance to maximize probability of comfortable termination of flight.

If we're dealing with an alternator out situation, then the goal is to run just those goodies that help us fly and navigate while minimizing loads on the battery. When you take off, there is one critical commodity on board that puts an absolute limit on time aloft . . . FUEL. Since that limit already exists, let's try not to impose any new limits on endurance. Let us see if we can design and maintain the system so that critical electrical system endurance is equal to or greater than fuel endurance.

Getting back to the Comm radio . . . how much help is the guy on the ground? Assuming you are skilled enough to use the equipment on your ME^{2}L, do you really NEED ground based assistance? Wouldn't it be a good idea to assume that it's not going to be available? Besides, when you're busy doing your job in the cockpit and doing it right, I'll suggest that the guy on the ground can become more of a distraction than a help. Recall some of Mr. Gomez's comments about how much of his own duties he turned over to the guy on the ground and how it caused our hero to overshoot the airport and descend too low . . . .

Does this mean that the Comm radio shouldn't be on the essential bus? No, but it does suggest that while you're in a minimum power consumption mode, it may serve your mission best to have the radio OFF. Tell the guy on the ground what's happening, what you're going to do and let him know that you'll be back in touch at some waypoint close to your intended destination and only after your safe arrival is assured.

Which brings up another point . . . the essential bus need not be LIMITED to the critical items on your ME^{2}L . . . however except for devices that you want to have running under every condition, any E-bus powered device should have its own ON-OFF switch . . . most avionics do.

Autopilot? If you have one, especially a low current wing leveler, you might have it on the essential bus . . . but while you're boring holes in the sky between waypoints, you might improve your electrical power condition by hand flying the airplane except when you have to deal with maps and/or nav radios. Engine instruments? When was the last time you heard of an engine stopping because you didn't know what the oil pressure was? If you're in cruising flight and every engine instrument goes down, how does that impact the probably outcome of your flight? Engine instruments don't help keep an airplane airborne.

Many airplanes are being constructed with electronic ignition and/or electronic controlled fuel injection. These must become a part of your ME^{2}L and essential bus planning. Planning is pretty easy and you do it like this: