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Build It Better

The Thinking Homebuilder

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Paul Dye retired as a Lead Flight Director for NASA's Human Space Flight program, with 40 years of aerospace experience on everything from Cubs to the space shuttle. An avid homebuilder, he began flying and working on airplanes as a teen, and has experience with a wide range of construction techniques and materials. He flies an RV-8 that he built in 2005, and an RV-3 that he built with his pilot wife. Currently, they are building a Xenos motorglider. A commercially licensed pilot, Paul has logged over 4800 hours in many different types of aircraft and is an EAA tech counselor, flight advisor, and member of the Homebuilder's Council. He consults and collaborates in aerospace operations and flight-testing projects across the country.

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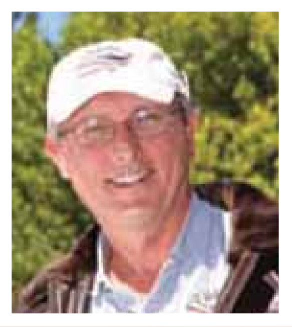


Flying is one of the most joyful experiences that one can have – yet it is also a horribly unforgiving activity for those who venture forth off the surface of our little planet. Whether you are flying a simple ultralight or a Space Shuttle, anytime you accelerate a human body beyond a reasonable speed and lift it above a certain height, the results can be catastrophic when things go wrong. Put plainly, our bodies simply aren't designed to take the impact of a fall from significant height, or a collision with a solid object. Therefore, careful attention must be paid to the design, construction, and operation of flying machines – no matter if they are built in a factory or a garage.

Homebuilt aircraft are no different than any other flying machine in this regard, but the responsibility for designing and building them lies mostly with the operator. We can't assume that every aspect of our craft have been through extensive engineering design reviews and certification – we have to find out for ourselves. When designing from scratch or making modifications to an existing design, we have to make good choices and exercise even better risk management. We have to ask questions, endless questions – and what's more difficult, we have to ask them of ourselves. Questioning one's own judgment is a skill that has to be developed and honed by experience.

Learning lessons from those who have gone before is a great way to shorten this process – and hopefully, it allows us to escape the bad experiences of others. Heavier than air, human flight has now been around for well over a century, and there are few excuses for repeating the fatal mistakes of others - mistakes that are well documented and are now part of the lore of aviation. It is our responsibility not only to learn and apply them – but to pass them on so that the future generation knows and heeds these hard-won lessons. And it is in the spirit of passing on these lessons that Build It Better was created.

The articles in this collection were first published in Kitplanes Magazine in 2012 and 2013, and are an attempt to capture lessons from aviation both big and small. You won't find directions for tightening a bolt, or safety wiring it properly. You won't find the design criteria for a wing spar, or the proper way to set a rivet. You won't even find a specific way to handle a gusty crosswind. What you will find is lessons that speak to the particular kinds of risk management required to live a long and productive life in aviation – no matter what speed or altitude you fly.

Build It Better began as a set of notes for a talk that I gave at Airventure in 2011 as a representative of NASA. At the time, I was nearing the end of my 34 year career in Human Spaceflight Operations, and felt that pulling together the many lessons learned from the thousands of people that had launched men and women into space and brought them back would be a good idea. Experimental aviation is experimental aviation – and the lessons learned in one area can always help inform those in another. The things that many consider routine knowledge in the space program might seem to be remarkable insights to the average homebuilder – and vice versa. It is amazing how many times people in the space arena were amazed at simple solutions to complex problems that were taken directly out of an experimental aviation background.

I was extremely privileged to be a part of NASA's Space Shuttle operational team from the first flight through the last, and served as a Lead Flight Director for almost twenty years. We flew many missions and built the International Space Station in that time. In those years, we saw many triumphs and experienced a few tragedies – and the best way to honor those we lost along the way is to take what we learned form those tragedies and make more triumphs. I have always believed that whether a person is lost in a high visibility program or a private flight accident, the results are just as tragic to the families and friends of those who didn't come back. SO it is just as important to practice good risk management in our personal flying as it is in an international space program.

While these articles contain a great many lessons learned and lots of good information, the real purpose of the series is to help people ask better questions, and figure out what it is that they do not know – for the purpose of helping them go out and find the right information to lower the risks of experimental aviation. I am always much more interested in good questions than I am in simply having good answers – for the process we use to get from one to the other makes us think outside the box and become better risk managers. Good questions lead to not only good answers but to more interesting questions – and remember, we license our airplanes built for the purpose of recreation and education!

So I hope that you enjoy reading these articles, brought together for the first time in one place. Remember, it is important to learn from the mistakes of others – because none of us will ever have enough time to learn them all on our own.

Paul Dye
Dayton, Nevada

THE CHOICES WE MAKE

The world of Experimental aviation is an interesting place. It includes people and organizations from the smallest garage tinkerer to the largest global corporations and world governments. The general public, when confronted with the term, will probably think of X-planes and rocket ships, while the general aviation pilot might think more in terms of homebuilt and unusual flivvers. Many have Experimental airplanes because that is the regulation under which we are allowed to build and maintain our own planes, but they have little interest in experimenting with new and untried technology. They simply want to own and operate an affordable airplane. Others are excited to tinker with new ideas and new technology, perhaps even with the goal of developing something for the market that could advance the science and even produce a few dollars.

Some Commonalities

What all of these various ideas have in common are the eventual attempts to go aloft in a new or untried aircraft. Because "normal" safety rules are often waived or not required to be observed, there is at least the perception of a heightened degree of risk when these aircraft are operated. Fortunately, through decades of hard (and often fatal) lessons learned by those who have gone before, we can look at history and make observations about the ways in which we can reduce the risks involved in Experimental aviation.

These risks are not only to life and limb; the risk of failure, and of spending great gobs of money for little return are all too common. I have been extremely fortunate to have been involved in the development and operation of high-technology aerospace vehicles for decades, and through this involvement, have collected a variety of observations, lessons learned and tips that can just as easily be applied to a multi-billion dollar flight-test program as to a one-off Light Sport homebuilt being put together in a basement.

One element marks all of the dedicated aerospace professionals I have worked with in my career—a commitment to learning from the lessons (and mistakes) of others to improve the safety record of the vehicles we know as flying machines. It is true that we still take risks, and we still lose people now and again. Hopefully, we learn and understand from each tragedy. Unfortunately, the records of the NTSB are filled with repeat lessons that have not been learned by some recreational pilots—or, to be fair, by many professionals as well. It is sad to lose someone to a unique event, but sadder still to see mistakes repeated that cost the lives of more than the unlucky initial victim.

In the flight-test organizations with which I have been involved, there are two key parameters that we strive to meet every day. We want to complete missions safely (everybody comes home), and we want to complete them successfully (all predefined objectives accomplished). Unless you are flying an unmanned, disposable drone, it is rare to have a successful mission if it is not also a safe one, but you can have a safe mission that is not fully successful. And that is OK—you can always re-fly a mission if you still have the vehicle and the people. It's hard to get a do-over if either one hasn't come back.

Safe and successful—two key words to remember as you contemplate the tips we will discuss through the course of this series.

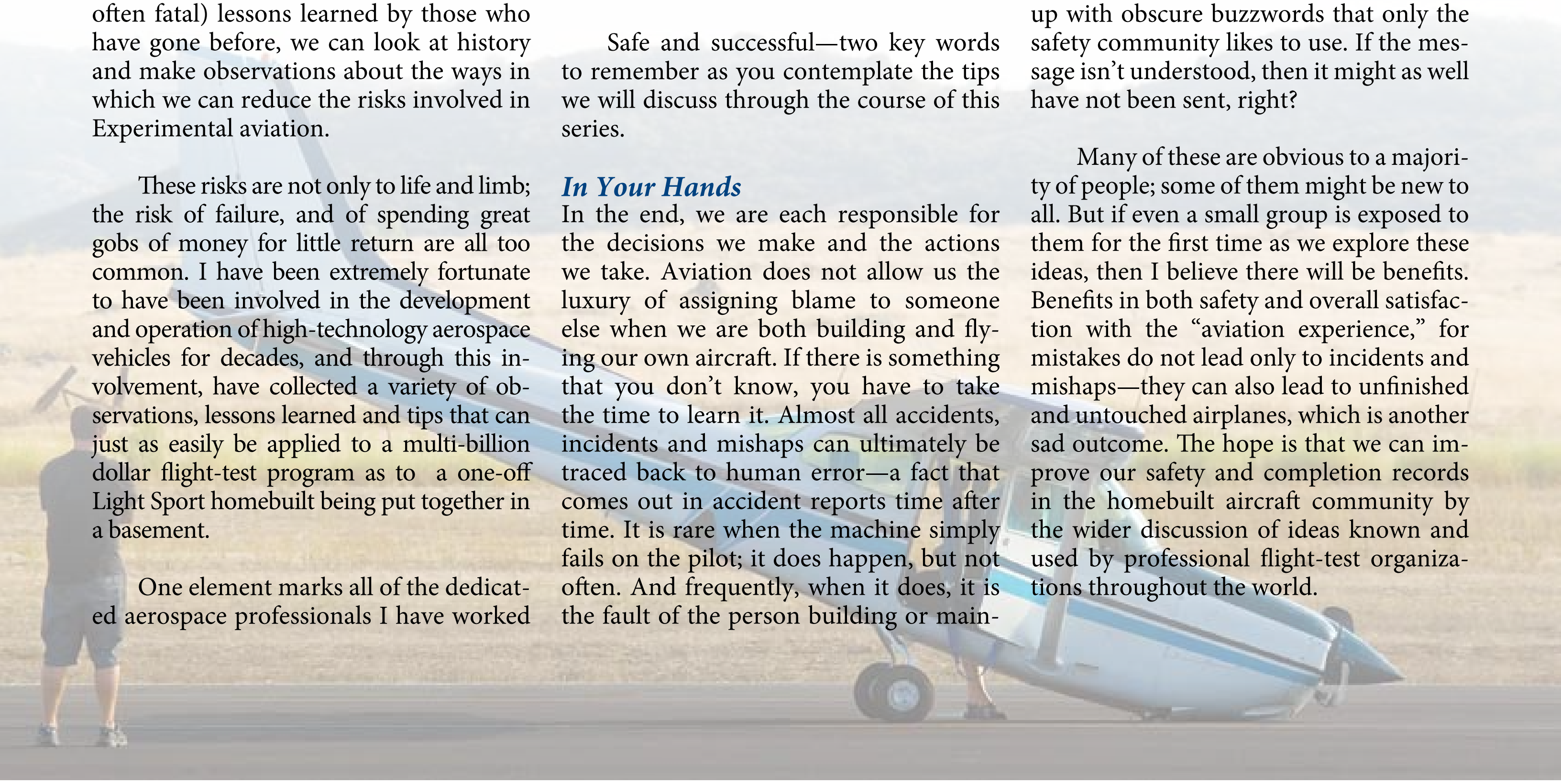
In Your Hands

In the end, we are each responsible for the decisions we make and the actions we take. Aviation does not allow us the luxury of assigning blame to someone else when we are both building and flying our own aircraft. If there is something that you don't know, you have to take the time to learn it. Almost all accidents, incidents and mishaps can ultimately be traced back to human error—a fact that comes out in accident reports time after time. It is rare when the machine simply fails on the pilot; it does happen, but not often. And frequently, when it does, it is the fault of the person building or maintaining the aircraft—something that the pilot of a certified aircraft might be able to pin on someone else, but those of us who chose to build and maintain our own must shoulder ourselves.

The most common human error is bad judgment. That judgment can come in the planning, building or flying parts of Experimental aviation. So we must think in terms of using good judgment whenever we step into the aviation arena. Whether you are drilling holes and pounding rivets, selecting equipment for your new airplane or pushing the throttle forward for your first flight, the requirement is just as valid: Good judgment is more important than pure building, design or flying skills. Good judgment comes from experience, which frequently comes from encountering your own moments of bad judgment. But it can also come by learning from other people's mistakes and their moments of bad judgment.

This series of articles will explore some of the tips that I have learned over a span of more than three decades in the aviation field. We'll talk about these tips in plain language that we can all relate to. I hate it when things get gobbledy-gooked up with obscure buzzwords that only the safety community likes to use. If the message isn't understood, then it might as well have not been sent, right?

Many of these are obvious to a majority of people; some of them might be new to all. But if even a small group is exposed to them for the first time as we explore these ideas, then I believe there will be benefits. Benefits in both safety and overall satisfaction with the "aviation experience," for mistakes do not lead only to incidents and mishaps—they can also lead to unfinished and untouched airplanes, which is another sad outcome. The hope is that we can improve our safety and completion records in the homebuilt aircraft community by the wider discussion of ideas known and used by professional flight-test organizations throughout the world.



UNDERSTANDING YOUR RISKS

One of my all-time favorite movie lines comes from the classic *Butch Cassidy and the Sundance Kid.* The two outlaws are standing on a high cliff above a raging river, pinned down by the law, with nowhere to go but down. Sundance, the young gunslinger, is clearly reluctant to make the leap. Butch Cassidy, the older, wiser one, is trying to convince him he has to go. Sundance keeps saying no, he can't jump, there has to be another way. Finally, Cassidy asks him why he won't jump, and Sundance blurts out, "I can't swim!" Cassidy pauses, then laughs. "Are you crazy? The fall will probably kill you!"

I like this exchange. It is such a classic setup, and tells us quite a bit about how we deal with risks. Aviation is full of risk. Anyone who tries to say that flying is as safe as sitting in your favorite rocking chair is trying to sell you something. But those risks aren't always what we think they are. For instance, anyone who carries at least a private pilot's license has spent countless hours looking for emergency landing sites and practicing poweroff approaches to fields, golf courses and roads in case the engine quits. This has to be the single greatest risk of flying in the minds of many: What if that single engine quits?

Well, it's true that engine failures happen. In years gone by, before the advent of our current crop of four- and six-cylinder aircooled engines, it happened a lot. But if you read the daily preliminary accident reports from the FAA, you get a better appreciation for what is really happening in the world of aircraft mishaps.

The truth? Bad landings. They happen every day: gear collapses, ground loops, and "failure to remain on the runway on rollout." Now these aren't anywhere as dramatic as an engine failure and off-field landing, but they happen often, and usually end up with some bent metal to go along with the pilot's bruised ego.

Identify, Appreciate

Understanding the real risks in flying is how we can eventually control them. And identifying those risks is the first step toward that understanding. We can spend a great deal of time practicing emergency landings, but if we play the odds, we should probably be spending much more time making routine landings, shooting touch and goes, and improving our ability to simply return the airplane safely to earth. By misidentifying and not understanding our real risks, we put our training emphasis in a place where we might not be doing the most good. (This reminds me of the years I spent in the Volunteer Fire Service. I was an officer and instructor for two decades, and remember well how hard we drilled our firefighters how to safely and effectively fight interior structure fires. This is dangerous work and we spent a lot of time training, figuring that if we could prevent firefighter injuries during this risky activity, we would have a great overall safety record. In fact, if you look at the statistics for on-the-job fatalities in the fire service, the number one killer is heart attacks. Number two is death in motor vehicle accidents while driving to the scene of the fire. Death by fire was a trivial few percent.)

Studying accident reports is the single best way to understand the real risks that we face in Experimental aviation. By knowing what causes accidents, we can better design, build and operate our aircraft to reduce or prevent them. Failure to understand the risks we are facing is like fighting an unknown enemy—a logical problem with no solution. It is not hard to identify a few common causes of accidents—most of them relate to poor decision-making on the part of the builder/pilot, or poor flying skills on the part of the pilot once the aircraft is flying.

We're Different

Pilots who fly certificated aircraft know that their airplanes have met minimum standard design criteria for safe operation. They have been designed to a common level of reliability and redundancy, and they have flight qualities that fall into some expected norm.

Experimental aviators, on the other hand, might be dealing with design issues that are non-standard and increase risk considerably. For instance, Experimental aircraft are not required to have docile handling qualities proven during certification testing. I have flown Experimental aircraft with remarkably harmonious controls that exhibited superb handling, while others were, to be kind, barely a step above the Wright Flyer (rated today by test pilots as "unflyable"). Aircraft with designs that exhibit quirky handling have a built-in increase in risk unless the pilot is aware of and trained to handle these quirks. Some modern, high-performance designs require faster takeoff and landing speeds, and consequently longer runways. These operational limitations must be taken into account, or risk is significantly increased. Other quirks might relate to stall or spin characteristics, inability to fly in rain without aerodynamic consequences, or stability and control variations with loading.

Design can influence risk in numerous ways. Unfortunately for experimenters, innovation generally is accompanied by increased risk. Fuel systems are a prime, if slightly overused, example. The fuel systems used in the vast majority of certified airplanes are similar and very simple. A tank (or two), fuel valve, auxiliary pump, gascolator, mechanical pump, and carburetor or fuel injector servo. Minimum parts, the fewer to fail. When designers start adding additional tanks, additional pumps, more valves, or unusual crossfeed configurations, the parts count goes up, adding more things that can fail, and, more importantly, the possibility of "unknown unknowns" increases.

It is clear from accident statistics that Experimental aircraft have a higher incidence of fuel-system-related engine failures (especially early in their test programs) than certified aircraft. Again, this is not the primary cause of accidents, so we shouldn't be necessarily frantic about it, but the fact that it is higher than in the certified world should get our attention. Something is wrong if we have a higher incidence of problems with our own unique designs, which begs the question of whether the potential gain is worth the risk. (But that is another topic altogether.)

A famous and overused case in point is the crash that killed entertainer John Denver. The builder of the aircraft (not Denver) had modified the fuel system to locate the fuel valve in a position that made it extremely difficult for a pilot inexperienced in that aircraft to switch tanks inflight. Was it a "bad" modification? Well, it certainly increased the risk on that particular flight. The point here is not to rant against fuel-system modifications, but rather to point out an increase in risk when you start changing proven designs.

Return to Ground

While I pointed out at the beginning of this article that the number one way to get yourself into the daily accident summary is to botch a landing, these accidents are rarely fatal—or even injury-inducing. Most of the time, they merely bend metal and the pilot's ego. In this respect, the risk to life and limb is fairly small. So what causes fatal accidents? For years we have all heard about VFR flight into IFR conditions and loss of control in IFR flight. These are still big killers in both certified and Experimental aircraft, and they need to be respected. Fortunately, there are significant measures you can take to lower the odds of adding your name to these reports. In-cockpit weather is probably the greatest single operational advance in cross-country safety. The ability for pilots to see all aspects of the weather without having to talk to someone on the ground and interpret what they are hearing cannot be underestimated when it comes to risk mitigation. This does not mean it allows pilots to fly through worse weather than before. It does mean they get an honest and accurate picture of what is going on around them, and can make better decisions.

Another way in which we can combat weather-related losses is through the use of modern instrumentation which is both more reliable and easier to read and interpret than IFR panels of old. EFIS equipped airplanes do a much better job of presenting data, and Experimental class autopilots do a remarkable job of reducing a pilot's workload by flying the airplane while the pilot thinks his or her way through the flight. And while this does not relieve the pilot of the responsibility to be able to hand fly any phase of the mission, failure rates of modern autopilots are extremely low, making the majority of the flights much safer. Designing features in the airplane that are appropriate for the mission of the plane is a great way to use the design and building phase as a means of reducing identified risks.

It is interesting to note that while pilots spend a great deal of time thinking about and preparing for "first flights" of their Experimental aircraft, a casual examination of the accident records does not show a preponderance of accidents on first flights, at least among aircraft that are built pretty much to plans. There are engine- and fuel-related issues during the early stages of flight testing, but these are frequently related to Experimental systems designs, Experimental powerplants or other such modifications. Which again, is not to discourage experimentation, but merely to point out that this is a risk elevator, and the pilot needs to be aware.

Powerplant, propeller and fuel mods should always be treated with great respect when it comes time to fly a new machine, and operational contingencies (emergency landing zones and the like) well thought out beforehand. Many pilots, myself included, worry about fire on first flights as we imagine fuel or oil lines working lose, but this has not proven to be the case in the real world—perhaps because we are so terrified of the idea that we take great pains to avoid the possibility.

It's About Airspeed

It is sadly true that a great many Experimental aviators come to grief in stall/ spin accidents in the traffic pattern. While I cannot say from personal study that the incidence is higher than for certified aircraft, I can say that many Experimentals do not have the stall warning systems that are invariably installed on certified aircraft. As annoying as those stall warning horns can be, they do get your attention. Coupled with the fact that many Experimental aircraft have fewer benign stall characteristics than certified aircraft are required to prove, it's just easier to get into a low-altitude stall while turning base to final. Good airmanship demands that we stay alert to this possibility and fly with margin above the stall, but many don't seem to be able to accomplish this task. Good stick-and-rudder skills help, but judgment, foreknowledge of the potential for an accident and situational awareness can help. If we could get rid of weather and low altitude stall/spin accidents, the Experimental aircraft safety record would be significantly improved.

One other real area of risk for the Experimental world is low-level acrobatics. It just seems like people who build their own hot-rod airplanes like to show them off. Here again is an area where risk must be managed entirely by the pilot, through self-discipline and respect for the laws of gravity and aerodynamics—as well as the laws of men. No one is as good as they think they are, and many have proven this by completing their acrobatic maneuvers 6 feet underground. Low-level aerobatics is a high-risk endeavor, easily identified, and almost always fatal if it goes wrong.

Final Notes

Can we make aviation—particularly Experimental aviation—safe? Well, safe is a relative term. I have heard that the only computer safe from viruses is the computer that is never turned on, which isn't very useful. The same applies to airplanes. The bottom line is that sometimes we simply have to accept some risks. We cannot guarantee that the engine is going to keep running when we are over hostile terrain. We can, however, significantly improve the odds through meticulous maintenance and honesty about its condition. By honestly assessing risks and identifying at least one way to minimize each one, we have made our flying safer.

Improvement is always good. One of my favorite questions to ask pilots preparing for first flight is: "What's your backup plan?" I want to know what they intend to do if the engine sputters on the takeoff roll, at 50 feet, 200 feet or in the traffic pattern. I want to know what they will do if they smell smoke. I want to know what they are going to do if they hear a loud buzzing or flapping noise. I am not so much interested in exact procedures for each case, but rather I want to know that the pilot has thought about the risk and come up with at least one idea of how to mitigate it. That is the sign of someone who is likely to survive in the world of aviation.

Thousands of textbooks have been written on the subject of identifying risk, accepting risk and mitigating risk. You can look them up, pile them on a table and read until you are too old to qualify for a medical. But that does not ensure that you won't have an accident. Simply put, real risks must be identified through study of the past. Reasonable precautions should be taken to prevent the failures of the past through careful design and construction. And pilots need to understand and accept the residual risk inherent in the airplane they are about to fly. You can't control what happens to the rest of the pilot population, but using this three-step process, you can significantly reduce your own chances of showing up in those daily accident reports.

WHAT'S YOUR BACKUP PLAN?

While the fancy Garmin GNS 430 might provide primary navigation, most glass cockpit displays have their own internal GPS that can be used in a pinch as a backup. It might not be IFR legal, but it will usually keep you alive.

If you are in aviation, by now you've heard the word "redundancy." Most everyone learns to fly, or has flown, an airplane with an internal-combustion engine. And almost all of those engines have dual ignition systems. If one fails— completely or partially—the other takes over and you can proceed to a safe landing. The engine has built-in redundancy.

The concept is simple: You have a Plan A and a Plan B. One is primary and the second is a backup (though in the case of ignition systems, they both operate all the time; one simply operates a little less efficiently if the other fails). And backup plans are what I really want to talk about. Redundancy theory can actually get a bit complex at times, and frankly, it has put a number of people to sleep. But the simple question: "What's your backup plan?" cuts through to the chase. Answer that, and you're golden.

How Golden?

Let's look at instrument flying. Generations of pilots have been taught to fly airplanes under IFR that were equipped with a vacuum pump and two vacuum gyro instruments. In addition, they had an electric turn-and-bank indicator that could be used with the compass, airspeed indicator and altimeter should the vacuum system (and its fancy gyros) decide to pack it in while the airplane was sniffing its way through inclement weather. Pilots were expected to demonstrate and maintain their skills flying the airplane partial panel, shooting approaches to minimums with the backup instruments and sweating buckets all the time—even in winter. It has been said that flying instruments is easy; the difficult part of the instrument rating was flying with the backups. Sadly, statistics point out that not only is this true, but many pilots could not maintain their skills at a level high enough to keep themselves alive.

When electronic instruments, now so prevalent in the homebuilding world, first began to appear, builders and pilots wisely elected to keep the old, proven mechanical instruments in the panel, "in case those electrons stop going 'round and 'round in all those fancy boxes." The good old needle and ball still appeared in the corner of the panel, along with the analog airspeed indicator and altimeter. The old paradigm was in full force—for a main instrument failure, you needed the old reliable backups.

Some people back up an EFIS with another EFIS from a different manufacturer to prevent bugs from taking everything out at once. Others prefer a simple set of "old-school" backups: airspeed, altitude and an attitude reference.

But then we started rethinking that strategy. The goal of the old-fashioned backups was not to be able to fly the airplane with ancient and arcane instruments the way Jimmy Doolittle did on that first-ever blind landing. It was to be able to safely fly the airplane with a failure of the primary systems. The turn-and-bank was the only available means to that end for many years, except for those pilots fortunate to have two vacuum systems and multiple gyros.

The New Paradigm

But what if you installed dual electronic flight instruments, and made sure that they had separate power supplies, independent of each other? Flying with primary flight instruments is much easier and safer than trying to line up ancient and arcane needles that bounce around in bad weather, or we'd all be using them, right?

The lesson in this story is that we don't necessarily need to have skills with needle, ball and airspeed (many newer airplanes don't even have them), but we do need to have a backup plan for at least one primary failure—be that a failure in the instrument, essential sensors or power source. If you have a viable plan, you are covered. If you can cover yourself for two failures, that is even better. Of course, those two failures need to be independent failures—not two things that can be taken out by a single, common cause. If all of your electronics, for instance, are connected to a single power bus, and that bus experiences a dead short to ground, then

Having two EFIS screens provides a backup in case one fails—as long as they aren't both rendered inoperative due to a common power loss. How you power expensive equipment is as important as having the equipment.

everything dies at once. Having a battery to back up the alternator in that case does no good— you can't get the electrons to the instruments if they decide to take a shortcut back to the source.

This all points out that having backups is not simply a matter of having more stuff. What we would like to have are smart backups, which are backups carefully considered to provide specific functions and therefore make the weight we put into our airplanes worthwhile. With today's electronic offerings, it is frequently both lighter and cheaper to install two different electronic attitude systems rather than build in an old-fashioned vacuum system and a backup. Plus, if one of them goes south, you won't need special skills to keep flying, you can fly the way you always do. No needle and ball to contend with.

It is important to keep your backup plans independent of your primary plan. By that I mean you want to make sure that if the primary equipment or process fails, it can't take out the backup as well. With the newer crop of all-electric instrumentation systems, that usually means you will need to have two separate sources of power (a battery and an alternator will do, so long as they can be isolated), and a bus structure that allows power to be supplied to your separate boxes if you experience a major short. This does not have to be terribly complicated— in fact, simpler is always better— but it needs to be considered.

A Non-Trivial Pursuit

I like to think of planning for backups as a question-and-answer game. I start by building a list of all the operations I might need to perform with an airplane. Control the aircraft, navigate, communicate, remain aloft, etc. Then I ask myself what equipment or operational technique I will use to ensure that those operations can be performed. Next comes the fun part, asking the crucial questions. What will I do if this equipment or operational technique fails? What will I use or do then? I always need an answer to that question, or my design is flawed.

Let's try an example. I need to be able to fly the airplane without visual reference with the ground. My primary method will be my whiz-bang, non-redundant EFIS, powered by the main and essential power buses. What do I do if the EFIS quits? I will use my backup attitude indicator, or maybe I'll use the autopilot to control the airplane, assuming that I have built the systems so that the autopilot is separate from the whiz-bang EFIS. What happens if the EFIS is fine, but that missing Cleco from my building days suddenly lodges itself between the main bus bar and the fuselage skin, creating the mother of all spark showers? Well, I will de-power the main bus, and power the EFIS from the essential bus. Of course, this is only after having carefully designed the electrical system to allow that option. Ahh…but your short fried the alternator? Not to worry, the battery can power the EFIS for an hour on the essential bus, right?

Un-Redundant

The big elephant in the room is that most homebuilt aircraft these days have a single engine. But even if the engine fails, you have a backup—you know how to land with an engine failure, because we all learned how to do that in primary training. If the engine is running partially, that gives you more options; if it quits entirely, then finding a safe place to land is imperative. Landing without power is a viable backup plan, unless you operationally put yourself in a situation where it is not possible—at night, in the mountains or in other inhospitable terrain. But the logic of backups applies. What happens if my engine fails? I make an engine-out landing. What if I am over water? Then I ditch and use my life raft and survival vest to save my life. Backup plans work.

Before we leave the topic of backups, there is one more thing I'd like to mention, and that is the issue of the Superior Pilot. (He's so important, I've capitalized his name.) We have all heard the old saw: "The Superior Pilot is one who uses his Superior Judgment to avoid having to demonstrate his Superior Skills."

Well, in the context of backup plans, if yours include the use of superior flying skill to get you out of a failure, it might be wise to think again. You may be having a bad day or may just not have brought your A game on the day you have a problem. And, quite frankly, most of us overrate our superior skills anyway. No, backup plans need to be realistic. Don't count on a miracle as a backup plan, they rarely happen on demand.

Backups are your friends, and they do not have to be complex. Powered airplanes are naturally backed up by their ability to serve as gliders. That natural capability should extend to all aspects of your flying needs and experiences, whether they be decisional, operational or related strictly to the equipment you need to stay airborne. Plan your airplane accordingly, and don't leave the ground without them.

WHEN 1 + 1 DOES NOT EQUAL 2

Previously I talked a lot about the concept of backup plans. Designing an aircraft—or aircraft operation—with failures in mind can seem like a daunting task to someone without an engineering or fault analysis background, but in reality it can be reduced to a simple set of questions. They are: If A happens, what will you do? If B happens, what will you do? If C happens, what will you do? And so on. As long as you have a viable answer that does not include the phrase "hope for a miracle," you have redundancy built in to your operation.

Operational redundancy does not mean that you have to have two of every essential item installed in the airplane—it means that you have multiple ways of accomplishing the essential functions required for safe operations. In fact, we are actually safer if the various methods of accomplishing these essential functions are different. In engineering terms this is known as "dissimilar redundancy," and it is better than "similar redundancy" because the two methods are not necessarily prone to the same exact failure. This time we'll talk about the concept of dissimilar redundancy and look at how to design redundancy into your operation in a smart and efficient fashion. In addition, we'll look at a few of the fallacies about redundancy—when redundant systems really, well, aren't!

Level Up

Let's start simple and talk about levels of redundancy and what they buy you. If a man has one watch, he knows the time to the accuracy of the watch, but only if the watch keeps running and he doesn't lose it. We assume that he wouldn't have bought the watch it if didn't at least keep reasonable time, but over some period it will drift, and the time it indicates may or may not be close to the real time on some master clock somewhere. In hopes of being able to tell time more accurately and more reliably, the man buys a second watch. But the second watch does not agree with the time on the first watch. This is an illustration of the age-old axiom: "A man with two watches never knows what time it is."

Photos: Richard VanderMeulen, BigStock Photo

Now there are certain things the second watch can help our poor man with. If one watch stops working altogether, we know that it has failed, and we could rely on the remaining functioning watch to at least give us the approximate time. If one watch is lost, the other watch—if it was agreeing with the lost watch before it disappeared—could be expected to tell time within reasonable accuracy for at least a short period of time. If it is daylight, the man can always consult the sun to see if the watch is still in the correct hemisphere.

Our man is becoming frustrated by the fact that he keeps missing lunch due to his inability to tell time and decides that avoiding starvation is worth buying a third watch. Now, my friends, we are getting somewhere. Assuming that all three watches were at least moderately well designed and working properly, they should all agree. If one watch starts to indicate a time different from the other two, we can assume that the two agreeing clocks are correct, and the one that is out on its own has suffered some sort of failure. As long as two watches are close, then we can average them to get a good approximation of time. If all three are close, we can do a three-way average, or take the one whose time is in the middle to get the statistically most accurate time. If two watches stop running, then you have no choice but to trust the third watch, and hope that it runs long enough to tell you what time the watch store closes so that you can return the obviously defective watches before they lock the doors. (By the way, choosing the middle time is referred to in redundancy engineering as "mid-value selecting," just in case you want to impress your friends while explaining the three airspeed indicators on your panel.)

Back to Airplanes...Phew!

It is rare to go beyond triple redundancy in aviation circles, but some noted aerospace vehicles have taken things to the fourth level. This can produce even more ambiguous results, commonly known as the "two-on-two split," wherein the four devices split into two camps and refuse to engage in peace negotiations or reconciliation talks. In this case, you need a tie-breaker such as a fifth device to side with one or the other, but by that point it makes little difference because your airplane is too heavy to leave the ground.

This lighthearted look at the concept of "like" redundancy might seem a little pedantic, and it probably is, but the point is that if you are thinking about using redundancy in instrumentation (a clock, for instance), then you really need to have three methods of measuring the quantity you are interested in—be it time, altitude, airspeed or whatever. Or you can rely on the fact that a failure in one of two items will be obvious. This might be easy to do with some instruments, but hard in the case of, let's say, a gyro panel.

But think about this: Unlike redundancy can help you out. If you have two attitude gyros, and one is showing a climb and the other a dive, how do you break the dilemma? Well, you could look at your altimeter or your airspeed indicator to see if they are following a nose-up or nose down condition. This is unlike redundancy—completely independent of spinning masses or other gyro-like methods, the altimeter by itself can tell you which of the two disagreeing partners to follow.

By the way, redundancy (or the need for redundancy) is highly dependent on the intended use of the aircraft that we are building or choosing to fly. For day/VFR operations, it is easy to back up almost all of the instruments with the good old eyeball. Guess what—you actually have triple redundancy in this case, because you have two of them (I hope). The elephant in the room, of course, is that most homebuilt aircraft have but a single engine. As we discussed in the section on backups, our redundancy in this case is in our wings and our ability to glide to a landing somewhere, hopefully somewhere from which we can walk away safely.

For IFR operations, we owe it to ourselves, our passengers and everyone else in the National Airspace System to have sufficient redundancy to return ourselves safely and predictably to the ground (preferably at an airport) without disrupting or colliding with anyone else. For heart-pounding aerobatics, it is nice to have redundant seat belts—just in case.

For a simple VFR machine, redundancy really isn't required. A single set of flight instruments (or a single EFIS) can be backed up by looking out the window.

If you really want redundancy for an IFR machine, consider two different brands of EFIS boxes, or a backup attitude source from a different company than your EFIS provider.

What's Not to Unlike?

Unlike redundancy becomes important in the avionics world when advanced electronics and software become involved. Old-fashioned steam-gauge hardware is easy to understand—gears, pointers, links, tubes and aneroids all working just fine until they fall apart or get some sort of debris in them to stop up the works. But electronics are more difficult, and far more complex. Hardware generally works or it doesn't. Even the space age, solidstate gyro platforms are usually accurate or go completely up in smoke. Computer based hardware failures are frequently found in the power supply part of the system—another "it works or it doesn't" situation. But gyros and accelerometers (the devices used to measure attitude and rate of travel) can drift and give inaccurate readings. And, worse, the complex software that does so many things for us can occasionally leave us high and dry if it wanders off into a corner that has never been fully tested.

Software is somewhat like a maze—a maze of little logical pathways through which the pointers run. Most of the time, the program pointers run through familiar passageways, measuring attitude and acceleration, putting out indications to the display processor, and keeping track of our airspeed and altitude, fuel and endurance, the temperature and pressures in and outside the engine—all that good stuff. Occasionally, we ask those pointers to run down a pathway we rarely, if ever, use, and if those pathways haven't been fully checked out (because they are rarely used), they might just have a trapdoor or a dead end around the next corner. Boom! Your fancy EFIS display or autopilot controller becomes a useless block of dead silicon. In the best case, we can reboot it by turning it off and on. If it is well-designed, it will come back up even keeping a record of its fault to send to the software designer so that the pilot can prove the EFIS was trying to kill him.

But if the pilot/designer/builder has a good head on his shoulders and a fairly respectable fear of death, he or she has probably installed some alternate method of keeping the airplane upright, or indicating its current attitude that uses different hardware and/ or software to accomplish the same end goal. This different method of achieving the same goal might come from a mechanical attitude indicator, an electronic attitude indicator from a different company (or the same company if it uses different software) or an autopilot that can keep the airplane upright if the main attitude system goes down because it has its own attitude reference built in. All of these are possible methods of achieving dissimilar redundancy for an attitude-control system. Altitude redundancy can be achieved with multiple air data computers or a combination of ADCs and an altimeter. Navigational redundancy can be achieved in a number of ways. You might have multiple GPSes, or a GPS and VHF nav capability. If you have reliable communications and are operating in a radar environment, you can even call the ground and have them help you navigate to someplace safe for landing. The key is to never put all your eggs in one basket—which, of course, means that you don't want all of these multiple redundant devices dependent on a single source of electrical power.

Juiced

Electrical power redundancy is not all that hard to achieve. The trick is to do it in a way that does not create additional probability of failure by increasing the complexity or count of failure-prone components. There are basically two things that can occur to preclude getting power to your end items: failure of the source of electrical power or the connections between the source and the device, or a short between the hot electrical system and ground, which means the electrons will take the shortcut past the device, will not pass go, and it will cost you considerably more than $200 by the time the smoke clears.

A short on an electrical bus can be handled only one way—removing power from the bus. Anything powered by that bus alone is now out of luck. To have redundant power, you need to have redundant busses. You then have to decide if you are going to feed all of the equipment from each bus through an isolation diode, or have your redundant equipment on different busses so that if one goes down, you have your functionality remaining. I like the diode isolation concept; it is simple in operation, as the pilot does nothing but turn off power to a shorted bus.

Redundant sources are equally simple. Most airplanes have both an alternator and a battery, so there are two sources right there. Unfortunately, being pilots and builders, we frequently neglect the fact that batteries are limited-life items. They age and lose their capacity to hold a charge. While they still start the engine, they might not provide sustaining power for as long as we like when (not if) the alternator quits. This is an argument for a standby alternator or redundant battery—or a religiously observed battery check and maintenance schedule.

One final thought that you might have caught in that last paragraph before we leave the topic of redundancy. Plan your system for when stuff is going to fail, not if it will fail. Forget reliability. Just assume that your stuff is going to break. Abandon all hope up front of the perfect system that will not let you down. Because they will all let you down eventually. Better get over the anger, denial, grief, etc. right now. Assume that you will be operating on your redundancy at some point, and make sure that you are comfortable with that. Build your redundancy and your backup plans knowing that you are going to use them. That should be incentive enough to make sure they are realistic— and that you won't be dependent on a miracle coming along just when you need it.

SIMPLICITY

You know you've achieved perfection in design, not when you have nothing more to add, but when you have nothing more to take away.

-Antoine de Saint-Exupéry

I first read this quote in a rock-climbing catalog when I was a young man studying aeronautical engineering. It was attached to a perfect piton—one with not an ounce of extra metal anywhere, designed so that you could carry more on the mountain, and have just exactly what you needed. While this excited me as a climber, it interested me just as much as a budding engineer, for the truth of the statement rang especially clear in the design of aircraft. Structurally, you want just enough material to meet the strength requirements, with no extra to add weight that will take away from performance.

But this idea extends beyond structure to systems design. The more complex we make something, the more difficult it is to build and understand. Additionally, the more components we have in a system, the more things there are to fail, making reliability a problem. In a world gone (sometimes) crazy with redundancy, it might seem counterintuitive that less can be more, but if good practices and sound components are used, that is most often the case.

Pounds Matter

Aircraft are different from cars, trucks or boats. Weight is important, as is size and wetted area. Smaller and lighter—these are worthy goals for any designer. Most of us in today's homebuilding world are not doing structural design—we are building from kits or plans where that work, for the most part, has already been done. We might add a lightening hole here or there, agonizing over the effects on strength that our obsessive behavior may have caused. But generally our structure is close to what the designers intended. (The best way to save 10 pounds in a finished single-engine homebuilt? Put the pilot on a diet!)

I won't talk much more about structure, but I will expound on simplicity when it comes to systems design. It seems that today's homebuilding web sites, magazines and catalogs are just brimming with new high-technology electronics and mechanisms for us to incorporate into our airplanes. From EFISes to power managers, we have at our hands—limited only by the size of our checking account balance—the capability of building an airplane that rivals the space shuttle in electronic capability. This is actually not hard to do, considering that the shuttle was designed in the 1970s, and the upgrades since then have always been well behind the generally available technological standards.

My own Van's RV-8 is no shuttle, but it has a two-screen EFIS, fully approach-coupled autopilot, four GPSes, three electrical busses, two batteries and two alternators. Yes, I like to have a very capable airplane. Yet I don't have anything that I can't justify as fulfilling a specific role in my primary mission requirements or backup plans. My electrical system sounds complex to some, but when it comes right down to it, I have far fewer components than many aircraft with similar redundant capabilities. I believe in old "Saint-Ex" and the more modern version of his statement: "Keep it simple, stupid" (the KISS principle).

Use this rule of thumb: If you can't explain how it works in a few simple sentences, it is probably more complex than it needs to be. If you can't explain how it works at all, it is more complex than you should be flying behind!

Switch-Hitter

It is quite an ego stroke to fly a complex airplane, one with lots of switches and devices that only we can understand. To have a checklist a mile long makes us feel like mighty astronauts or test pilots. Mere mortals are not fit to lift our flight bags, much less understand the complex litany of procedures and processes that we must go through simply to get our airplanes to the runway for takeoff. But complication for complication's sake is always counterproductive when it comes to completing the specific mission of an aircraft—unless the mission is to stroke the pilot's ego, of course.

I have seen some complex redundant electrical systems in recent years whose failure procedures sound like the litany of steps called out in the movie Apollo 13 as the astronauts worked with their failing fuel cells: "I've got a Main B bus under volt, amps on Main A and C are low and decreasing, oxygen pressure is zero, fuel cells 2 and 3 are reading zero, the entry batteries are discharging…." Wow. That sounds both frightening and pretty cool at the same time. Everything in that spacecraft had to be managed just about manually by throwing switches. Power had to be routed from source to destination by configuring the systems one step at a time. And if you got it wrong, you might end up with a shower of sparks. As they say in the movie, that's a bad way to fly.

Many Light Sport Aircraft designs are models of simplicity and low horsepower.

While the author is all for simplicity and lightness, this builder might have gone too far by eliminating both the covering and the wings.

Simplicity applies to tools as well. You could buy or borrow a powerful machine for big tasks, or you could just apply a lot of leverage.

Contrast that with the much simpler scheme available with today's electronics. A single box can be fed from two different power sources through solid-state diodes so that the box will draw from whichever source has voltage. Wire it to two or three busses, each with its own supply of electrons, and if a source goes down, the pilot need take no action at all—the good source picks up the load. Best of all, no moving parts! Not only is this simpler and more reliable, it is actually more in line with the design philosophies of modern jet cockpits: In an emergency, let the system take care of itself with no human interaction.

Fuelish Behavior

Have you ever seen the fuel valves on the Spirit of St. Louis? I doubt there were more than two guys alive who knew how to get all of the fuel in those many tanks to the engine (Lindbergh and the plumber who built it). Fuel systems are essential to continued flight, yet I see people adding complexity that provides no additional function and lowers reliability. Extra fuel is great, but if it takes a book of procedures to get it from the auxiliary tanks to the engine, is the system really workable and reliable? I have seen auxiliary tanks added to an airplane that require pumps to move the fuel to the mains. I have also seen the same amount of fuel added to the same type of aircraft in which the main and aux tanks were plumbed together at the wingroot, increasing the fuel capacity by the identical amount, without adding operational complexity at all. The tanks on each side were simply bigger than before. (I recognize that for structural and other reasons, such an option is not always viable.)

Complexity in design can have more than operational or safety affects—it can bring a project to its knees, or halt it altogether. I have seen projects abandoned in hangars and garages when a builder decided to make a gear retraction mechanism that was so complex that he simply forgot what he was building, or how it might work. In fact, the modern generation of "complex" personal aircraft, both commercial (Cirrus, Columbia) and Experimental (RV-10) are simply using superior aerodynamics to get the same speed and performance out of fixed gear as they could out of retractable gear, and avoiding the complexity altogether. That is simply thinking outside the box to get to a design goal: to make an airplane go a certain speed, not to make a retractable-gear airplane for its own sake.

Pen Mightier Than the S-IC

To sum up the concept of simplicity, I am reminded of a story from the heady days of the Apollo moon program. Everyone involved in technology in the United States wanted to be a part of it, including the makers of writing implements. A large company spent millions of dollars (its own money, not taxpayers') to design a ballpoint pen that would work in the absence of gravity. (We've all tried to write upside down with a Bic, right? Doesn't work very well.) They perfected this marvel of technological achievement for NASA's astronauts to use as they completed then-President Kennedy's goal of landing a man on the moon "before this decade is out." At the same time, the Russians were working on their own program, trying to maintain the thin lead they had built in the early 1960s, always one step ahead of the Americans during the Mercury and early Gemini missions. But they had little extra cash, and were masters of simplicity. Their solution to the zero-gravity writing problem? A pencil.

As always, we are free to choose how we equip and operate our homebuilt aircraft. We can choose to make them complex or simple—or have high performance or low performance. And those two design areas are not necessarily mutually dependent. We can chose to build a simple and elegant design with high performance that is easy to understand, or we can build a complex design that is heavy and difficult enough to operate that it is far less satisfying. Either way, it is important to know that we have a choice, and that we go into the design phase with our eyes open, guided by principles we understand. Personally, I stick with old Saint-Ex. When I have achieved my performance goals, I begin to search for ways to remove items and weight, further increasing performance and reliability. I look for that perfect design point where there is nothing left to be taken away.

DAR Mel Asberry checks the manual trim on his airplane. Manual flaps also serve his purposes and keep the systems simple.

WHERE'S YOUR MARGIN?

I am a strong believer in margin— that bit of extra space that you give yourself to make life a little more comfortable. What do I mean by comfortable? In an aviation context that means I am not sweating bullets or screaming silently because I am worried about the outcome of whatever it is I am doing. Margin is not always mental. It can be designed into airframe structure, systems, equipment and the way we operate all of the above. Margin is the extra strength built into your spar, that handheld radio you have in your flight bag or the extra fuel you keep in the tanks in case the headwind gets a little stronger.

When aircraft are designed and built, certain assumptions are made about the strength required, the capability of the systems, and the limits of endurance and range. Building and providing margin should be a goal of every aircraft designer and pilot because we never know when our assumptions about what the limits should be might just be wrong.

Structured Learning

Structural margin is usually represented as a factor of safety above the expected loads to be put on the structure. A very common design load factor is 1.4, meaning that the structure is capable of withstanding 40% more load than what it is rated for before bending or breaking. If the designer intends the airplane to be routinely operated up to 3.0 G for instance, and he is using a factor of safety of 1.4, then the structure shouldn't break until a G-load of 4.2 is exceeded.

The truth is that most (but not all) light airplanes are overbuilt in this regard. Because a designer's goal is to have a 1.4 factor of safety, he will shave more off structure if that margin is exceeded. Sometimes he will shave if the goal is to produce the lightest structure possible. If you are trying to build a world-record setting airplane where ultimate performance is important, then you will want to save weight wherever you can. In the aerospace world, weight is always detrimental when trying to get a vehicle into orbit, so margins are carefully controlled, and when they tell you that you have 1.4, you should never assume that you have 1.5.

Each pilot has a unique limit, and that limit may vary. Evaluating the aircraft condition, mission and weather determine how much margin is needed in a given situation.

There's a great magazine ad from the 1970s that shows a Mooney with a staggering number of employees standing and sitting on the wing, from tip to tip. By actual count, there are 30 on that wing, which makes me wonder how high they pumped up the tires. The point of the advertisement, of course, was to illustrate the strength in that wing—far more than any reasonable pilot would ask of the airplane during normal operations. When you consider that the airplane is not certified as aerobatic, what the manufacturer is telling you is that there is a great deal of margin in that structure.

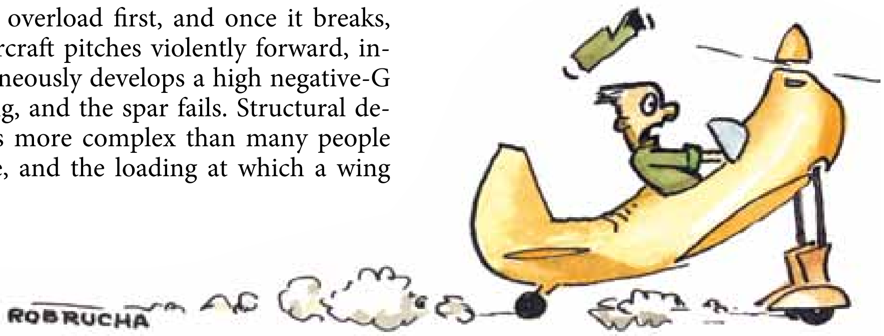
All aircraft have a breaking point; some far exceed others. Generally, the shorter the span, the stronger the structure is likely to be, because you will have less bending moment where the wing attaches to the fuselage. Most wings are built with the capability to sustain higher positive G than negative, frequently by a significant amount. But it is interesting to note that in most cases the wing is not going to be the first part of the airplane to fail.

More often than not, the tail fails under overload first, and once it breaks, the aircraft pitches violently forward, instantaneously develops a high negative-G loading, and the spar fails. Structural design is more complex than many people realize, and the loading at which a wing may fail depends not just on the straight G pulled with a pitch maneuver, but rolling moments as well. Without going into the details of V-G curves and charts, suffice it to say that when things get bumpy you should slow down below maneuvering speed and avoid high-G pulls while rolling. The point we want to get across with this discussion is that most aircraft have sufficient structural margin as long as the pilot operates within the specified limits.

Backup to the Backup

Systems design is the next area in which we find margin, and it is closely tied to discussions of backup plans, redundancy and even operational margin. (This is a subject near and dear to me, which is why it's woven into this series at several points.) We can add margin to our aircraft systems during the design phase, or we can incorporate it later on by adding equipment. It's important to know what you want your airplane to do, and also to know what it is honestly capable of doing. It is as unreasonable to use a short-range, two-place trainer for serious IFR cross-country work as it is to try and fly aerobatics in a four-place traveling machine.

Either one can probably be equipped to do those jobs, but that doesn't make them ideal (or necessarily safe) for that purpose. For want of a better word, the "criticality" of the mission often drives the amount of margin built into the systems. By criticality, I mean the importance of completing the particular mission on a given day. For instance, a fun flier whose sole purpose is to run around the local area to see the sights probably doesn't need to fly on any given day. If you go out to fly and something isn't working, you



might be disappointed, but it wouldn't be a disaster. At the other end of the spectrum, a medical airlift aircraft's mission may be extremely critical; if it doesn't fly now, then someone might well die.

Airliners are usually well enough equipped that they can complete their missions even with failed equipment. Down-checked (unavailable to fly) aircraft can wreak havoc with a complex flight schedule, so redundancy is built in, and minimum equipment lists are written to allow flight with known defects under certain conditions.

General-aviation homebuilts fall into categories depending upon how their owners and pilots think about them, but a generalization would be that rarely must a mission be completed or life and limb will be at risk. While our upcoming vacation in the Bahamas might be ruined if we can't fly, the risk to life and limb when we fly without specific equipment could be much greater. An honest assessment of the aircraft's suitability for "all-weather" operation needs to be made before spending tens of thousands of dollars to provide a capability that might be an illusion—or worse, a temptation to do something unwise.

Many Experimental airplanes today are better equipped than the light jets of a few years ago, and even better than some military and commercial aircraft. Highly integrated EFISes, WAAS GPSes, redundant power systems and sophisticated autopilots all make today's airplanes much more capable for IFR flying. Note, however, that I did not say all-weather flying. My own aircraft is superbly equipped for IFR flying in low-visibility situations thanks to precision approach capability, highway in the sky (HITS) guidance and fully coupled approach technology. Yet the basic airframe can't carry ice, and it certainly won't survive a thunderstorm.

Illustration: Robrucha

We all used to fly IFR with steam gauges and lots of needles that we had to mentally transpose into an image of where we were relative to the established navigation aids and surrounding terrain. Today's systems give us a margin by drawing a map, complete with a little airplane following a purple line. In fact, many airplanes have two such maps, so there is even more margin to help our saturated gray matter. An extra com radio makes the communication job easier, as does the ability to monitor more than one active frequency. Fuel totalizers make the management of this important commodity easier and more reliable.

The Margin Between Your Ears

While the designer and/or builder of an aircraft may provide structural and systems margins, the pilot provides the operational margin, which is that little extra pilots leave to stay inside what they understand to be the limits of the airplane. This might be a margin in airspeed above the stall, or below Vne. It might be the distance the pilot will stay away from weather. It may be found in the amount of fuel the pilot insists on having in the tanks upon landing—or once the decision is made that the destination weather isn't going to cooperate, and it is time to head to the alternate. Operational margin is usually the margin that has been exceeded when we read an accident report that includes running out of fuel, attempting to fly aerobatic maneuvers below ground level or continued VFR into IFR conditions.

Every pilot has limits. They are different for different people, and even different for the same person at different times. It is important to always evaluate current conditions of aircraft, pilot, mission and weather to decide how much margin one needs.

I'll share a few examples—not intended to be adopted by others, but merely to illustrate the concept—that I have used in the past. When I am flying IFR in a single-engine GA airplane, I like to leave myself a great deal of operational margin. In fact, I generally won't fly IFR in a "sensitive" aircraft without an operating autopilot. By sensitive I mean those designs, including many homebuilts, that have sprightly handling. The autopilot is for redundancy and to ease pilot workload under normal conditions.

I am also extremely paranoid about fuel. I constantly keep an eye on weather (using onboard satellite METARs, TAFs and NEXRAD radar) to make sure that at all times I have enough fuel to reach someplace with at least 1000- foot ceilings or better—and that I am sure will stay that way. Because ceilings and visibilities frequently take a nosedive at dusk, I generally won't trust forecasts that indicate marginal VFR at that time of day. Frankly, I won't fly IFR in a single at night because it just stacks one too many straws upon the camel's back.

As a general rule, if my destination is going to require an instrument approach, I want to always have two methods of completing an approach— or have the ability to retreat to a field where I can reasonably be assured of completing a landing. I will file for a destination that is predicted to require a precision approach, but only if I have an ironclad alternate. Those who know me know that I cancel flights when I don't feel good about them.

Margin, in all its forms, is a breath of fresh air in an activity that can sometimes be filled with tension. In fact, lack of margin is often directly related to that feeling you get in the pit of your stomach when you are out of options, and everything needs to go exactly right. An aircraft that always operates on the razor's edge can be exhausting to fly, and while at times that can be a thrill, operating at that point all the time is not the way to a long and enjoyable life. Look for ways to build margin into your airplane, your equipment and your operations, and know what that margin is and how it can be grown. Then relax a little, knowing that you have a cushion to protect you if the next worst thing happens.

SHOW ME THE DATA!

Powered, heavier-than-air aviation has been around now for a little more than a century, which still qualifies it as a fairly young human endeavor. Yet in those 100 years, quite a bit of information and data have been generated on how to build and operate flying machines. Much of this knowledge has been written down, and much more has been passed on orally from generation to generation—pilots telling pilots, mechanics telling mechanics and engineers telling anyone who would listen. Information that is passed on like this has a way of taking on a life of its own and often evolves as it goes, changing a little with each telling until occasionally it is unrecognizable from the original truth. Sometimes, this makes no difference—tall tales can be quite entertaining when the weather is low, and we sit around the lounge trying to best one another. But other times—those times when lives depend on the validity and veracity of the information—the truth and accuracy of what we pass on is vital. For those cases, I have a simple rule: Show me the data!

Whether we are building, maintaining or flying an airplane, we are bound to have questions and will need to find out how certain tasks are supposed to be done. Whenever I ask a question of someone or receive advice (solicited or otherwise), I have gotten into the habit of asking about the source of that data. I want to know if it is written down somewhere, or if the advice/answer giver is simply passing on what he was told by somebody else. It makes a difference, especially for technical issues and matters involving rules and regulations.

But in matters of safety, it is essential. And maybe nowhere in the aviation world is it more so than in the highspeed, high-energy world of human space travel. Things can go very wrong, very quickly when you are traveling at the speeds and with the explosive forces of spacecraft climbing into orbit. In the Mission Control Center in Houston, there is a room full of engineers who support the people running the missions. For many decades, engineers have walked into this room. Over the door hangs a simple sign—brief and to the point, just the way engineers like it. "In God we trust!" it reads. "All others must bring data!"

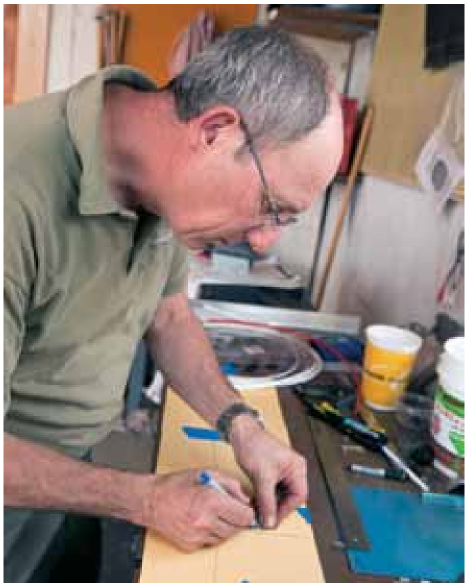
Speculation-Free Zone

There are no facts in mere speculation, and facts are what we want: Analysis, test results and good old physics govern everything. It's rare that gut-level instinct is trusted without some sort of data to back it up. Everything must have a traceable source, even things that are known to be good practices—they are documented somewhere.

The Apollo 1 crew was lost because they were encapsulated in a pure oxygen environment at 16 pounds per square inch (a virtual bomb waiting for a spark), and testing had always been done that way. No one questioned why, or how dangerous it could be. In 1986, the Space Shuttle Challenger was lost because there was no documented lower temperature limit for the booster rockets, and management felt that it would be OK—but they had no test data to back up that claim. (In fact, there was some data that proved the opposite; it simply wasn't documented well enough.) The space business is extremely unforgiving, as is the rest of aviation. Mistakes may lead to death whenever a human being is transported more than 10 feet above the ground, at more than running speed, and the system fails.

Down on Earth

Hearsay information exists in many different parts of the aviation world. Mechanics are constantly passing on tricks and tips they have been taught by other mechanics. Sometimes this information is correct, but many times it contradicts what is published in the bible of aviation maintenance, Advisory Circular 43.13 (Parts 1 & 2). When someone makes a recommendation but it sounds contrary to what I believe to be good practice, I ask the person to show me where it is written down. Is it really OK to substitute a pulled rivet for a solid rivet in a particular structural application? Well, you can look that up. Is it acceptable to inflate tires to the maximum pressure on the carcass for each and every airplane? Maybe you should check in the airplane-specific (and FAA-approved) maintenance or operation manuals. Do you really need to use AeroShell Grease 6 in your propeller hub? Why not consult what Hartzell has to say about this in its FAA-approved maintenance manual?



Measure twice, cut once...but be sure the measurement you're using is validated, current and appropriate.

This same caution applies in the operations world. Can you really fly an ILS without a marker beacon receiver but with a handheld GPS to identify the final approach fix? Better look that one up before you commit to it. (To save you the trouble, I'll give you the answer: You can't.) How does that downwind turn thing work again? Do you slow down as you turn away from the wind, and therefore stall because you're going slower? Dr. James H. Doolittle wrote his master's thesis on that subject in the 1920s, and the answer is no. Is it OK to enter a right-hand pattern at a field where there is no traffic on the radio, even if the airport has a standard, left-hand pattern? No, it's not, and you don't have the right to break the rules just because you're alone and it's more convenient. Besides, that student in the J-3 Cub doesn't have a radio, and you may have missed him turning left base because he was below you and painted green like the treetops.

Radio Daze

Let's take a common operating technique that has been debunked numerous times yet still seems to hang on. "Any traffic in the area, please advise," is heard many times on common traffic advisory frequencies every day, yet section 4-1-9(g) of the Aeronautical Information Manual clearly states that this phrase is not a recognized self-announce position or intention phrase and "should not be used under any condition." That's pretty straightforward, isn't it? It's about as stern as the government can get, and even though the AIM is said to be nonregulatory, failure to follow its recommendations can easily lead to a "careless and reckless" charge from the local flight standards district office.

This recommendation has been in the AIM for quite some time, yet some pilots persist in using the "Any traffic?" phrase. I began hearing it about 20 years ago, when commuter airliners started dropping into uncontrolled fields after being handed off from air-traffic control to the local frequency. They were on an approach and would be on top of the field almost immediately, and this was a fast way to "fish" for traffic because they hadn't been listening from a long way out like most general aviation pilots do (or are supposed to do) as they approach the field. I can't prove it, but I suspect this was either documented or taught by airline operating manuals at one time. Pilots in general aviation heard it and figured that's what the big boys do, so they picked it up. Again, I suspect, but can't prove, that this technique was promoted in some of the *ab initio* programs that produced certificated flight instructors headed for the regionals. They wanted to sound like pros, so they passed it on to their students.

The problem, of course, is that the phrase is ludicrously arrogant and meaningless. If you listen to the traffic at an airport for 2 minutes and everyone is self-announcing as they should, then you'll know where the traffic is. If you don't listen and simply barge in expecting everyone to respond to your request, you are inconsiderate and unlikely to get a response. Now I don't intend this to be a diatribe against the phrase, merely an example of the kind of thing that gets passed from pilot to plot as the thing to do, but it is not documented or even recommended by any written procedure. It provides a perfect opportunity for a person to ask, "I had never heard of doing that before. Is the procedure written down somewhere?"

The same can be said when it comes to the "beach ball" frequency—123.45 MHz. Many pilots use it for air-to-air communications because they have heard pilots arrange to meet there. Ever looked it up? International Civil Aviation Organization Annex 10 says, "123.45 MHz shall be designated for use as an air-to-air communications channel to enable aircraft engaged in flights over remote and oceanic areas, out of range of VHF ground stations, to exchange necessary operational information and to facilitate the resolution of operational problems." The continental U.S. is not considered out of range of VHF ground stations.

"In God we trust. All others bring data" is a clarion call, a challenge to everyone in aviation to be the best, the sharpest and the smartest they can be. It is a summons to excellence, and to precision. Some things aren't written down simply because they are still being discovered— after all, a century of flight is pretty short compared to the many centuries that humans have been building ships or constructing bridges (both of which can harm people if done improperly). The consequences of being wrong in aviation are sudden and often violent. We can't afford to take someone else's word for it. Whether you are building, flying, maintaining or simply talking in the lounge, know the source of information. Sometimes these sources are good enough, if the source is trusted and known to be thoughtful and knowledgeable. But accepting information that has simply been passed on without attribution is potentially dangerous. A good library is a great resource, as it offers the opportunity to verify what others say. Don't trust your life to rumors and assumptions. Go look it up!

TESTING, TESTING, ONE, TWO, THREE

I grew up playing with hardware, and as a boy, I was always underfunded when it came to my experiments. While I never tried to jump off a barn roof with an umbrella or bed-sheet parachute, I did try to build a free-wheeling cart out of a couple of 2x2s for axles, a thin sheet of plywood and baby-carriage wheels held on with nails. Needless to say, I didn't get very far with that contraption.

My mother predicted that outcome, and that's probably why she was confident in helping me carry my cart to the top of a hill. She knew intuitively that I wasn't going to go more than 6 inches "before the wheels came off." This early experiment in vehicle construction did, however, teach me a valuable lesson: No matter how good a machine might look on paper, you never really know what it can (or, in that case, can't) do until you test it.


It has been said that the Space Shuttle Columbia was almost worn out (from testing) before its first flight. In fact, over its lifetime, many more test hours were put on the vehicle than flight hours.

Old Lessons, New Relevance

I have carried that philosophy with me as I progressed from a teenage mechanic's helper to an aircraft restorer, a pilot and eventual aeronautical engineer. Being in the operations and testing area of aviation, I naturally tend toward the greasy hand part of machine verification and have always cast a sideways glance at a thing that hasn't proved itself in the real world—or at least a laboratory test rig. In days past, that is the only way machines and vehicles could be proved: You had to take them out and test them. Testing could be to one of various limits—operational, re-use or even ultimate conditions. In short, it was nice to know firsthand what you could do to something and still use it again—as well as where it was going to break!

With the advent of modern computer modeling, many engineering organizations have gotten away from the old testing techniques and are substituting analysis and modeling to predict when and how a piece of equipment (or an entire aircraft) is going to bend or break. They simply use the results of computer runs that say there is a certain amount of margin in the design, and since the models have been tested against real-world equivalents in the past, they trust that they will apply to the new hardware as well. While this approach frequently gets good results, and, if applied with caution, can save time and money while accurately verifying a design, it must be approached with caution and maybe even a little suspicion, especially in the world of homebuilt aircraft.

The reasons we have to be a little suspicious are twofold. First, the results of failures in the aircraft world can be very serious, and second, in the world of homebuilt, "custom" aircraft, the sample sizes (numbers of a particular aircraft or component) are small enough that statistical analysis might very well be inaccurate due to insufficient data points. Call me old fashioned—you can even call me a Luddite—but I am a believer in testing equipment and vehicles in the field to prove their capabilities.

Skin in the Game

In the early days of aviation, testing was the only way to prove an aircraft, and it involved a pilot strapping on the airplane and going flying. Proving the design was pretty much done by trying a few maneuvers. If the machine came back and the pilot survived, it was on to more rigorous testing, until the airplane proved capable of its designated mission. In those days, a design didn't last very long—it was superseded in months by something more advanced, stronger and better. The pace of development was just that fast. So if there was a problem, or an aircraft was lost, it wasn't as big of a deal as it is with modern development programs costing billions of dollars and consisting of only a very few airframes. Components are likewise costly to test because of each item's accumulated cost—hence the desire to prove them by analysis rather than test.

One of the reasons that the Apollo program was able to successfully land men on the moon in a short period of time was a philosophy that espoused testing. Cost was almost literally no object, and redundancy was not an option, due to weight and performance limitations. That meant that every part of the spacecraft had to be very reliable— it had to work, and the people flying had to know it would work.

Many components were sacrificed on the altar of destructive testing so that the operators would know exactly how far they could push the edge of the extremely thin envelope. Modern aerospace vehicles and programs are much more limited in resources, and therefore people are less inclined to destroy equipment in labs and on test stands; hence the need for computer modeling. But the kicker is that the models are only as good as the equations used to describe the physical reality of the devices being tested, and they can only be truly trusted if those models are verified by testing! That's why modeling techniques that might be acceptable for items and systems that will eventually be mass produced, yet those used for custom gear and situations have a built in fault—the lack of ability to prove them by testing.

Here on Earth

So what does all of this mean to the average kit or homebuilder? Well, it prompts a number of questions that you should ask about the designs you are considering for your next build. How has the design been tested? Has the structure been loaded to destruction? How much of the design has been accepted by computer modeling and

The Apollo spacecraft returned to earth via parachutes, and they were tested with boilerplate mockups many times before humans rode them home from space.

analysis versus test? A prospective builder can get an idea of the philosophy of the design team by looking at how many aircraft of that model that team has built. Is there only one in existence, or are there many built and flown? (That number is difficult to obtain. Just ask those who gather data for the KITPLANES® Buyer's Guides every year.)

This same philosophy can be used for aircraft components—engines, avionics and other equipment. I have an easy way to measure my confidence in an engine development program: I ask how many engines of this type they have built and how many thousands of hours of run time they have on a aircraft. In fact, I generally ask to see the development team's airframe—the one they use for testing. If they don't have one and are using potential customers' airframes instead, I have to wonder just how resource-limited they are, and this leads me to believe that the test program is probably a shoestring affair.

Engine components are in a class of equipment that is ripe for extensive, methodical testing. Heat, vibration and extreme stress can all be found in an engine compartment, and hours and hours of real-world run time has proved time and again to be the only way to build robust hardware. The lowly ignition magneto has proved itself over a century of aviation, but not without many development tests and millions of hours of time in service that lead to developments such as pressurization for high altitude flight. In the past two decades, electronic ignition systems have been developing with great success, but not without a lot of blood, sweat and tears on the part of the developers and testers. I can't think of a single one of those systems that worked perfectly from the start—rather, they have matured and gone through growing pains as weaknesses were discovered, components were beefed up and/or redesigned and more testing was performed to prove the upgrades. Several of those systems are now out there on the market and fairly reliable, but it has taken years to get them there— just as it took years for those magnetos to reach the point where we don't think much about their reliability.

Avionics testing today encompasses both hardware and software. There is nothing like a good old shaker table to discover flaws in electronics boxes intended for aircraft use. It is rare that an electrical component brings the system to a screeching halt; rather, it is a connection, an exterior fastener or a loose wire or solder joint that can only be found by testing. Electronics are almost always perfect when analyzed on paper—the real world discovers that hot spots appear in a box that can affect critical components in a way no one has predicted. Testing is the only way to find this out.

In the same way, software needs testing. Run time is important (how long does it keep going between resets and/or reboots?), but a well thought-out test program will also probe every logic path to see if the programs can be tripped up or brought to their knees. Bench testing is good, but in-flight beta testing is generally the only way to really find the faults. It is surprising to see just how many defects and errors are uncovered (and fixed) in even the most extensively designed software systems by actual field testing. It is often a simple case of the design team not being able to anticipate "field issues" until the software mixes with the hardware in the field.

Remember: If it hasn't been tested, you don't know that it will work!

New equipment, devices and components hit the market for Experimental builders almost every day. Some are from large manufacturing giants and others are turned out by homebuilders themselves in garage workshops, to be sold one at a time over the Internet. Some require little testing because their failure would have few consequences to safety or mission success. Others have a lot to do with the pilot's safe return to earth, and for this I would demand to see how well, how long and to what extent they had been tested. The old saying goes like this: If you want to know what the engineers think it will do, check the analysis. If you want to know what it will really do, test it!

Just because the equations say a piece of equipment or structure can withstand such and such a load before breaking doesn't mean as much as knowing that this has been proven true. Testing costs money—there is no doubt about it. But for critical components, testing is often the only way to be sure of where the limits really are. Whether you're going to the moon or simply across your home state, the confidence of knowing how much your equipment will take before letting you down is priceless.

KNOWING HOW IT WORKS

"You've got to know why a thing works on a starship."

- James T. Kirk, Star Trek II: The Wrath of Khan

I have watched the many and various incarnations of the Star Trek universe, and this line has stuck with me more than any other. Kirk is fighting a space battle against an old enemy who has hijacked another Federation starship, and while he knows how to fly and fight with it, he doesn't really understand it at the engineering level. He knows how to work it, but not how it works.

Kirk, on the other hand, the ultimate master of everything he does, knows that starships are controlled through computer commands and that the first part of every command is a code that designates if a command is "legal" for that particular vessel. This is to prevent an enemy (who does not know the code) from using captured weaponry. But in this case, it allows Kirk to send a command to the other ship, lowering its shields and making it vulnerable. He won the engagement because he knew more than his opponent - he knew how the systems worked.

Here on Earth

Forgive the lesson in fictional space travel—it is simply a way to introduce the topic of understanding your aircraft's systems. Many a pilot who has gone through the process of getting type rated on a complex aircraft has bemoaned the need to learn countless, apparently useless facts about every detail of the aircraft, items such as the nitrogen gas pressure in the nose strut, or how many quarts of oil the auxiliary power unit takes, or the allowable temperature of the fuel servo when it is not operating. It all appears to be some weird hazing ritual by those in the know, perpetrated upon those who would like to be members of the elite club. And to be truthful, many of these arcane pieces of trivia truly are useless, at least most of the time. The average pilot mostly wants to know how to get the engine started, how to tune the radios and what speed he needs to get the aircraft flying—forget all that mumbo-jumbo about how it is built. And many times you can get away with that level of knowledge.

Sometimes, however, knowing the details about how an aircraft system works can be a real lifesaver. Let's take a simple problem in a typical light homebuilt with an electronic engine monitor and EFIS. The airplane has fuel gauges, but it also has a fuel-flow transducer and the capability to account for fuel flow over time, thereby keeping track of how much fuel has actually been burned. As long as the pilot resets the counter when the tanks are filled, this can be (and generally is) far more accurate than the typical gauges in a GA airplane.

All of the fuel data is displayed on the pilot's EFIS—the data from the float gauges as well as the totalizer values. But what is this? The numbers don't agree! Wow, something must be off—the fuel gauges say I have 11 gallons in one tank and 15 in the other, but the totalizer says I have 34 gallons left. That's a difference of 8 gallons, which can be an hour of flight.

Which Is Correct? And Why Are They Different?

The undereducated pilot might spend a great deal of time brooding over the situation and make poor decisions based on a misunderstanding of it. But the pilot who knows the aircraft's systems will understand that the float gauges are there mostly for show—because of dihedral and the way the tanks are shaped, they say the tanks are full until several gallons have been burned away, and then they decrease in a non-linear fashion. The indicated amounts remaining do not accurately reflect the amount of fuel on board. The only time they are accurate, in fact, is when the tanks read zero.

The totalizer, on the other hand, is accurately reflecting fuel burned—with one exception. It actually shows slightly more fuel having been consumed than actually has been (giving the pilot an unknown, but positive, reserve). This is because the fuel-flow transducer reads high whenever the boost pump is active. The pilot knows this because he has seen the flow jump when the boost pump is on, even though the engine is putting out the same amount of power (and therefore burning the same amount of fuel). Knowing all of this, the educated pilot has a much better idea of just how much fuel is on board and can make better decisions. (I should point out that some engine monitors with fuel-level systems allow you to quantify a tank's dihedral effect or non-cube-ness to get much more accurate level readings. But they're still not likely to be as good, or repeatable, as a flow-based accounting system.)

They're Quirks, Your Quirks

While it is important for all pilots to understand their airplanes (and the quirks of behavior and instrumentation that can affect their operation), it is vitally important for those flying Experimental aircraft. Because homebuilt aircraft vary widely in their construction and systems, and because by their nature they are frequently proving grounds for new ideas, all sorts of different and unusual things might surprise an unsuspecting pilot. In a certified aircraft, the engineer designs and builds things a particular way. The test department proves the work and writes procedures that go into the checklists. The pilot merely has to operate the aircraft within the bounds of the documented procedures, and things should go well.

But in the Experimental world, the builder is working with unknowns, especially when he begins to modify designs or is designing from scratch. Naturally, the designer is well versed in the design's capabilities and its potential quirks, and it will be unlikely that he gets surprised by these behaviors in flight. But if a new pilot, unfamiliar with the design, comes along, and something odd should appear, all bets are off.

Experimental test flying is an art that combines engineering and aviating. The best test pilots are engineers, intimately acquainted with the new designs they are testing. Whether the envelope is being pushed in aerodynamics, propulsion or avionics, they have been part of the design process (or have learned as much as they can about the design goals and implementation), so that they can not only fairly evaluate the results of the experiments but also handle off-nominal situations or failures.

NASA's Dryden Flight Research Center lost an Experimental airplane, the X-31, a few years ago because the pitot tube froze up in thin, icy clouds. Like most accidents, the cause was a chain of events, not one single massive failure. It began with the design of the aircraft—a unique, fly-by-wire jet intended to fly with vectored thrust at extremely unusual angles of attack and conditions of sideslip. The pilot moved the stick, which told the computer what he wanted it to do, and the computer figured out what combination of control motions were required given the specific flight regime (altitude, airspeed, dynamic pressure, etc.) in which it found itself.

Airspeed was vitally important for the software to make the right control motions at a given time. Airspeed, of course, was taken from a pitot tube. Because this was a test airplane, it was never intended to operate in anything but clear VFR conditions. Even so, the original pitot probe was equipped with a heater, as are most air data probes for jets. Shortly before the final test flight, however, the probe was replaced with an experimental unit, one that did not have pitot heat—something that was not a requirement for the test program.

The day of the final test, a pilot newer to the program, one who was not familiar with the history of the pitot probe replacement, was flying. When he got into the thin ice clouds and sensed that there might be a problem with the software (because of an inaccurate airspeed value) he turned the pitot heat switch in the cockpit to ON. (It was still there, though it was not connected.) This did no good because the probe had no heater. The probe iced over, the computer lost its airspeed value, and the result was a loss of control. The pilot ejected, the aircraft was lost, but everyone survived (including, I believe, the engineer, who changed the probe without labeling the switch INOP). If the pilot had known that the pitot heat had been disabled, he might have tried harder to stay out of the ice clouds. His lack of knowledge of his aircraft systems was a contributing factor in the mishap.

Fuelish Choices

Engine and fuel systems are places where builders frequently experiment, and there is nothing wrong with that (it is how aviation advances) as long as they fully understand what the implications might be. This understanding must also be passed on to any pilot who will fly the machine, so that they are not operating on any false assumptions about how things will work. Many an aircraft has been lost due to fuel mismanagement, and a fair number of those incidents stemmed not from carelessness but from a lack of knowledge about how the aircraft was plumbed, where the fuel was and how to get it to the engine. When a builder does something new and unusual with flight-critical systems, he owes it to others to document the potential differences from the so-called norm.

The last topic in this vein is probably the fastest-growing segment of homebuilt- aviation technology: avionics. The pace of advancement and change in modern Experimental avionics is breathtaking— new models and even entirely new concepts come out every six months, and no two instrument panels are alike. For many years, any single-engine GA pilot could get into just about any single engine airplane for which he was rated and fly it with little difficulty, because the panels were much the same. Steam gauges and basic radios all worked the same way; it was easy to move from one airplane to the next. Enter today's world of Experimental EFISes and engine monitors. Not only does it take many hours to learn how to work the various modes and controls, but no two systems work exactly the same way. While displays are becoming more standardized through natural selection and survival of the best ideas—which are then copied by other manufacturers—the methods for pilot interaction are widely varied and numerous. It takes hours to master your systems at the operator level, and that is just the beginning.

EFIS technology has grown up with GPS navigation and moving maps. Some attitude reference systems rely on GPS to provide a good solution for "which way is up." Others rely on airspeed to do the same thing. And still others don't need external assistance, but they do need to be stationary when they are powered up. All systems have limitations that need to be observed to make them accurate and dependable. But rarely do the various systems operate all by themselves— they have to trade data back and forth. A typical GPS/EFIS/autopilot system may have three different manufacturers, and pass position and flight-plan data from the GPS to the EFIS and autopilot, or from the GPS through the EFIS to the autopilot, with the EFIS performing some modifications to the data before the autopilot receives it.

Moreover, the system might use flight-plan data derived in the EFIS instead of the GPS, so which one is the autopilot going to listen to? A builder who actually wired his own avionics will probably understand the data-flow paths well, whereas the builder who paid someone else to wire his system will only know it if he has taken the time to study it. I frequently help people set up their new EFISes (some software configuration is always required), and I see a broad spectrum of understanding. Some know every pin and wire combination, and which channel is connected to what. Others ask, "What's a channel?" Needless to say, when you're bumping along in the clouds on a stormy night and some of the lights go out, or the boxes disagree, that is not the time to suddenly wonder where the truth is and how the connection schemes could be failing.

Have You Heard the One About…

There is a new joke making the rounds about the three most common phrases heard in modern glass cockpits. The first is, "I didn't know it could do that!" The second is, "What do you think it's doing now?" And the third is, "What the heck do you think it's going to do next?"

None of those is good news when you're in the clag, especially while shooting an approach. This is why it is vitally important to the serious pilot to know not only how to work his equipment, but also how it works. Experimental avionics are not yet at the point where any good pilot can sit down and instantly understand how to use them. Likewise, builders need to spend time during the design process understanding how the various components are wired and how data flows from place to place. It is during this design phase that an understanding of the redundancy and backup plans is built up. Skipping the process by having someone else do it is acceptable if you have another way of obtaining this knowledge, but skipping it altogether is not a good idea when your life depends on the functionality you have in the airplane.

Captain Kirk knew what he was talking about when he said that you have to know how things work on a starship (and, I would add, an airplane). As another Star Trek character asked in yet another old movie: "Who am I to argue with the captain of the Enterprise?"

BUILDING TO REQUIREMENTS

In the good old days of homebuilt aircraft, back when people built from plans (or sketches) with materials cobbled together from various sources, before the Internet was even a gleam in someone's eye, and a kit meant several sheets of aluminum along with a few lengths of steel tube, it was common for projects to be abandoned because of the sheer effort it took to build. It was terribly difficult to figure out what you were doing, to find answers to questions you might have or simply to find someone who knew what he was doing to look at your work.

It is still common for kits to be abandoned, languishing in unused basements and workshops, or to eventually be sold to a second builder, but the reasons today are a bit more varied. Kit building is undoubtedly easier and more successful because of upgrades in materials, instructions and support available, but lack of time and resources (that generally means money) are major components in the demise of the dream.

Fork in the Road

While I will not assign a percentage value to the various reasons that kit progress grinds to a halt, I would like to talk about one that appears to be fairly common, yet remains somewhat mysterious. Call it a dream beyond reality, call it mission creep; sometimes a builder just bites off more than he can chew. What started out as a reasonable project grows with the passage of time into a complex and expensive assembly of parts never installed, systems never fully designed and a general lack of progress brought on by mental gridlock. The "simple weekend flier" the builder initially envisioned becomes bloated with IFR avionics, a monster engine, extra this and extra that.

There are all sorts of goodies and innovations that can ensnare us with their siren calls. A stunning all-color EFIS, extra fuel tanks, speed mods that promise a lot - these and more are the temptations we face as the project rolls along toward an uncertain end.

Discussions on message boards and hangar flying with friends are two seemingly innocent yet potentially dangerous ways to end a wonderful project. It is so easy to lose sight of our original goals, changing our plans with the wind of the day, wondering if we should go this way or that. And therein lies the problem: lack of a clear goal to which we can anchor ourselves when temptations surround us. What we have forgotten to do is to set forth a statement of requirements before writing a single check or entering a credit card number. Requirements—documented and analyzed— can save us from ourselves if they are properly derived and if we have the discipline to stick with them throughout the project.

Do You Need That?

In the aerospace world, we start every project with a set of requirements. Nothing gets started before they are determined, written down, hacked to pieces, rewritten, sold to management, sent back for rework, developed yet again, justified to all and finally agreed to in writing. Generating requirements is closely related to the problem-solving technique of clearly and completely stating the question. Frequently, when a person is having trouble with an answer to a perplexing problem, the reason is that he has not really fully developed the question—he hasn't asked it in enough detail. When the details of the question are fleshed out, the best answer becomes evident. So, too, with requirements in the world of airplanes.

You want to build an airplane? Well, what do you want it to do? No, strike that. What do you need it to do? Even though many (if not most) of us build airplanes because we want to, not because we need to, it is still important to clearly under-


Steve Wittman designed the Tailwind to be fast, not necessarily pretty. He followed his vision and came up with an airplane that did what he wanted, regardless of looks.

Photo: Paul Dye, Shutterstock

stand our needs and not just our wants. It is important if we want to actually finish, that is. No two people have the exact same mission for their airplane. Is it a weekend aerobatic machine? Does it need to be Light Sport compliant? Are we planning on 100% dispatch reliability in all foreseeable weather conditions to any place on the continent? (Good luck with that.) Whatever your requirements might be, you need to write them down someplace prominent.

Building an airplane is a long-term project. As the old saying goes, "When you are up to your ass in alligators, it is hard to remember that your original intention was simply to drain the swamp!" As we build, it is easy to lose sight of the final goal, to head off on tangents brought on by the latest developments.

Plan Slide

This tendency toward changing requirements throughout a project is often referred to in the aerospace industry as mission creep. It can be hard to get a new program approved—whether by the president, Congress or upper management— or even the spouse or significant other with whom you share a checkbook. Sometimes we ask for a little less than we know we want because we figure that getting started is the hard part, and adding features later will be simpler.

The problem is that this approach is dishonest, and it catches up with you over time. Before you know it, the project either gets bloated with contradictory goals and objectives, or it grinds to a halt due to lack of funding or simple gridlock; it can't move forward because you have lost track of where forward actually is! This is when that original set of requirements comes in handy. It pays to look at those requirements every day, or at least every time that you need to make a decision on purchasing equipment or parts for the project. Ask yourself: Does this serve the requirements?

Sometimes, with a project as long term as building an airplane, requirements change. We start out with a single-seater, and before we know it, the person of our dreams has become a part of our life. OK, we need two seats. Then along comes the answer to our prayers: We have a little one to share our life together, and the two-seater becomes a four-seater, and so it goes.

Boeing spends years determining its customers' requirements before cutting metal, and they charge customers when those requirements change. Maybe a personal penalty system would work for homebuilders who are trying to keep build times down.

The solution is either to be single-minded and ruthless about the project so that we don't have time for social activity, or to reevaluate our original requirements once in a while to make sure they still work. But be aware that changing requirements comes with a significant cost in dollars and time, so do it only when it becomes clear that sticking to the original will leave you with something completely unsuitable. Make requirement changes difficult in your own mind; they are the leading cause of cost and schedule overruns.

It is also important to remember the importance of a vision. Starting an airplane project without a clear-cut goal in mind, a vision of what you want it to be, is a great way to end up with a camel. We all know the story of the camel, right? It's a horse designed by a committee. If you have too many people involved in the decision-making process, without a single leader with a vision, you end up with a camel.

Fly It or Display It?

Builders sometimes talk about an award-winning airplane as a masterpiece. I like to understand the meaning of words, and "masterpiece" is interesting. Literally, it is the piece of work created by a journeyman ready to prove that he or she is now the master of a craft. This work of art proclaims that the creator is ready to join the ranks of masters and take on apprentices. I bring this up because, honestly, I have never seen a masterpiece designed by a committee. It requires the vision of an individual. Help can be sought and obtained, certainly. But the creative guidance comes from a single vision, or the piece fails to inspire.

Clearly stated goals, written requirements and a creative vision—these are all necessary if you wish to complete a project, no matter its size or scope. Many aerospace projects costing billions of dollars have failed because the vision was not clear, the requirements had flaws or obfuscating forces stepped in to sabotage the work. Likewise, unfinished kits lie abandoned in darkened workshops because the builder failed to keep the vision clearly in mind, or never had one in the first place. Establish your requirements and stick to them. If, along the way, you discover enough things that you want to change that the original vision is no longer viable, remember you can always save them for the next airplane you are going to build.

LEARNING FROM HISTORY

Even though you may be building with "modern" materials of composite or aluminum, much of what we know and use today came from the wood craftsmen of the past. Decades of aircraft construction have taught us how to use hardware properly.

It is often said that those who do not learn from history are doomed to repeat it. This pithy statement is closely related to another: "If you keep on doing what you have always done, you will continue to get what you have always got." (Not particularly good grammar, but it gets the point across.) In truth, both of these statements apply to virtually every aspect of aviation. Whether we're designing, building or flying, we need to understand the history behind the way airplanes are created and operated if we want to keep them in one piece and remain alive.

The history of aviation is, unfortunately, written in the blood of those who have gone before. Many things that we accept as given are done because someone perished in the past; the origins of simple standards that we don't even question are lost in the mists of time. For instance, there is the old rule that bolts should be installed with their heads up or forward so that if the nut comes off, the bolt has less chance of falling out of the hole. Most mechanics and builders know this rule, but have they ever really thought about how it came about? I wonder, sometimes, if some unlucky pilot looked down to see the bolt holding his wingstrut falling out of the hole, way back in the old days. It is a chilling image and not one I would want to experience without a parachute.

Going Back, Looking Forward

Because we are involved in the world of Experimental aviation, it is important to understand the history behind the designs and standard procedures that we employ. Pilots who accept a certified airplane for flight can be fairly certain that there are no hidden *gotchas* lurking in the design or construction, but those of us rolling our own need to understand all of the various ways in which we can come to experience a terrifying moment firsthand.

Even with certified aircraft, modifications to the original design are places where we need to learn from the past. I vividly remember getting my old Grumman Yankee out of the avionics shop after the installation of a particularly long and heavy HSI (horizontal situation indicator) unit. I taxied out to the runway and did my normal control checks—yoke full right, all the way forward, full left, all the way back, then back to center in both axes. All felt normal, so I initiated the takeoff. When I went to rotate, I pulled back—and the yoke came back halfway and stopped.

It turned out that the design of the yoke's push-pull tube had a bellcrank horn that stuck straight up to attach to the aileron linkage. The avionics shop had installed a cross-beam to support the weight of the new HSI, and it was just low enough to catch the arm of the yoke in the roll-neutral position. So when I "boxed" the controls, I missed the catch-point by essentially going around it. Ever since that day, I do a complete boxing of the controls, followed by an ailerons-neutral pitch cycle, just to make sure I have no hang-ups that will affect me during rota-

Illustration: Robrucha

Modern airplanes must be built with care and accuracy. Common reference manuals such as AC 43.13 are really the compilations of lessons learned by countless mechanics over a century of aviation.

tion. This little lesson could have cost me a great deal if I hadn't paid attention and aborted the takeoff when I did.

Circular Reasoning

I like to read through the various sections of AC 43.13, the bible of aircraft maintenance, repair and modification, and think about the various techniques and processes that quite frankly appear to be arbitrary, such as how to safety-wire bolts, or why an accessory mount needs to be stressed the way it is. I read these chapters and paragraphs thinking about what prompted that particular technique. How did we learn that you don't use a lead pencil to mark aluminum? Who had a structural component come apart because a line of rivets didn't have enough edge distance and unzipped under load? Who was the unfortunate individual who discovered that a fuel pump's overflow line needs to extend out the bottom of the cowl? Most of these techniques were not determined by a designer sitting at his or her desk— they came about from hard experience in the field and, frequently, the loss of an airplane and/or life.

Lessons from history are not confined to the building phase; they include everything having to do with operating an aircraft. I often visit databases provided by the FAA and NTSB; in fact, I check the preliminary report database several times each week. These reports are simple one-liners describing incidents that have just happened. Although the causes, at that point, are usually unknown— typically listed with the obtuse comment that the "aircraft crashed due to unknown circumstances"—you can get an idea that more aircraft are damaged due to gear collapses and failure to stay on the runway during landing than any other phase of flight. Fatal accidents have a small list of general causes. And a leading cause of airline "mishaps" are wingtip-to-wingtip collisions on crowded ramps. Preliminary reports give us an idea of what is happening right now in aviation safety and remind us that mishaps and accidents do occur every day.

Offering more detail are the final reports issued by the NTSB on the accidents that it investigates. We all know that the majority of aircraft mishaps are determined to have been caused by "pilot error," but it is rarely as simple as the pilot making a single major blunder. More often than not, the final action that caused the incident was precipitated by a chain of events, omissions or bad judgments that put the pilot and aircraft in position for that final act. We can learn so much from reading these reports because all it takes to prevent a similar accident is to break just one of the links in that chain. It still might result in an ugly day, but if the accident can be averted, we can learn from it and live to avoid those same mistakes the next time.

There is great benefit in learning from the mistakes of others, and I heartily endorse it. It doesn't matter what you're flying, the lessons learned the hard way by others in the past can help us complete every flight more safely. Studying the decisions that other pilots have made—or the successes and mistakes of other builders and designers—is a way to take advantage of other people's misfortunes and, in a way, honor the memories of those who have gone before. While I'd rather that no one experience the terror of losing a prop because they failed to safety the bolts the way it was spelled out in the manual, I am glad that we can all learn from the first person who was unfortunate enough to experience the results of such a mistake.

Aviation history is well documented and available to those willing to take the time to study it. A pilot or builder with a professional attitude will want to learn as much as possible from a hundred years (or so) of successes and failures and to vow never to make those same mistakes again. After all, we have plenty of time to make our own original mistakes—no need to repeat the lessons of the past.

Even a "simple" airplane demands respect—the thing about low-and slow machines is that they can just barely kill you.

Making good decisions is not always easy, especially when you are flying in adverse conditions, bumping along in an airplane where things aren't going exactly the way you planned. The problems might be caused by systems failures, bad weather, navigational errors…any number of things can distract us to the point of consternation. It's sometimes said that as soon as we leave the ground, our IQ drops 30 points—and for many, that is more than they can afford! Because of this, we spend a great deal of time learning the rules of aviation as part of our training. These rules come in many forms, from FARs to generally understood "rules of thumb," and they are enforced to various standards, from legal proceedings to the ultimate penalty—a fatal accident.

The Regs

The FARs govern a great deal of what we do in aviation, and frequently, we chafe and complain about certain rules and regulations. Military and commercial aviators live with a much thicker rule book, one stuffed full of standard operating procedures and checklists that *must* be obeyed every day, and on every flight. Variations are not accepted, and transgressions are punished. While some of the rules by which we all fly might seem arbitrary (we pass oncoming traffic by bearing to the right, etc.), others make sense if you think about them briefly (landing traffic has the right of way over departing traffic, because the departing traffic isn't in any danger as long they are sitting on the ground). These rules are applied by external entities, and, in general, they make sure that we don't put other people at risk.

The rules that govern Experimental aviation are, when you think about it, surprisingly lax. Those who enter our world from more regimented aviation environments (military and airline flying, for instance) are sometimes shocked that we are allowed to do what we do, both in building and operations. I have known many top-notch military aviators who find it hard to believe that we can simply take off and fly around without talking to anyone or completing a great deal of preflight paperwork and filing a flight plan. The rules governing the licensing and inspection of Experimental aircraft seem just as relaxed to many—and in fact, they are! When you consider that the average homebuilt is very similar to the average general aviation aircraft, yet builders (or even non-builder/owners) can do literally all maintenance activities on their own (whereas the certified aircraft requires a licensed mechanic), it really opens your eyes about just how liberal the FAA can be.

All of the above-mentioned rules are imposed on us by external forces. They are important and must be followed if we are going to continue to exercise our rights to aviate. But that's not what I really want to talk about. What I want to discuss are rules that we impose upon ourselves—the rules that help us to continue to exercise our right to keep *breathing* while we aviate, the ones that we create and enforce ourselves because they make sense.

An Era of No Rules

During the early days of the manned space program, there were no "rules" per se. Putting people in the nose cone of a rocket and blasting them off the planet was an entirely new and novel idea, with little precedence in engineering legend or fact. The people involved in this somewhat risky and untried world knew that they were going to have to create everything from scratch, including the rules governing this dangerous activity. While the rockets and spacecraft were developed using fairly standard techniques of construction and assembly from the aviation world, the techniques used to operate these unique craft had to be developed essentially from scratch.

Illustration: Robrucha

The operations engineers and pilots preparing to fly these spacecraft had backgrounds in Experimental aviation and knew the value of training and rehearsing for the operations to come. They did their best to develop training methods for the operations they believed they would encounter during increasingly long flights off the planet. Training teams developed scripts testing the capabilities of the pilots and flight controllers to deal with what they called "off-nominal scenarios." When they began these exercises, they had few rules by which to operate; they had to make them up as they went. While basic tenets applied ("Always have at least one method to bring the men home; when you are down to a single method, with no further redundancy, then you bring them home NOW"), they had to create rules based on the lessons they learned in training sessions.

In essence, they tried stuff and then documented the results. If the spacecraft developed a leak during the launch, they had the opportunity to fire the escape rocket and abort the mission, plopping the men back in to the ocean, but with a breathable atmosphere. If they didn't abort, and the leak was bad enough, they would strand them in orbit without enough atmosphere to survive until they could get them home. The abort had its own dangers, so you didn't want to take that course unless you had no choice—so they tried different-sized leaks in training and saw how the scenarios turned out.

Sometimes, the simulators said that the men lived, and sometimes they said that it was a "bad day." From

these experiences, the teams wrote their rules: "For a leak at a rate equivalent to that through a quarter-inch hole that occurs during the first 2 minutes of ascent, you will declare an abort. After the 2 minutes, you will continue to orbit. If the leak is less than eighth-inch equivalent, you can stay on orbit for up to a day." This and hundreds of other rules (lessons learned, really) were written down and put in a book: *The Book of Flight Rules*. It was then followed and expanded as the years went by. Unlike the violation of an FAR, which can lead to enforcement action, a violation of a flight rule from this book can lead to a much more tragic end.

Homebuilt Variations

So how does this apply to what we do with our Experimental homebuilt airplanes? Well, we are not so different from those early rocket scientists. We have new aircraft that are different in many ways from the certified airplane world. While we need to follow the FARs, the choice of how to operate our aircraft is left largely up to us, and it pays to think about the rules we will follow before the time that we will need them. It pays to not only build our own rules, but to follow them—or the exercise is wasted.

For instance, my RV-8 is well equipped for IFR flying, with dual- and triple-redundant EFIS, GPS and power systems. My Operations Limitations (as issued by my DAR) allow instrument flight when I am properly equipped per the FARs, and once I am done with my Phase I testing. Theoretically, that meant that as soon as I was out of Phase I, I could file and fly IFR. But I knew that my systems were complex and integrated in a fashion new to both me and to the aviation world. These were Experimental avionics that needed testing and checkout in benign conditions. So I set a rule that I would not fly IFR until I had a certain number of hours of experience in simulated conditions, with a safety pilot, to both check out and write procedures for the complex systems. Furthermore, once I was satisfied that both the systems worked and I knew how to use them, I raised my IFR minimums considerably for another specified number of hours (and other experience criteria) to make sure that I left myself some "outs" in case things didn't work the way I expected.

Once I had set these rules, I took the next step: I wrote them down. Writing your rules down is important because it tends to focus you on what they really mean, and in a way, it forces you to acknowledge and follow them. If the rules are unwritten, they don't really exist.

Sharing your rules with others is another way of helping you to follow them: Peer pressure is a force not to be underestimated, and most pilots want to be known as people who obey "the book"—even if they wrote it. Following the rules that we set for ourselves requires self-discipline, and—like having a buddy to help us do our daily exercise routine (and not skip it for a trip to the donut shop)—it keeps us on the straight and narrow.

The rules under which we fly are set by others, based on the experience of many generations of pilots. Those that reduce the risk we pose to other people are required for civilized aviation to work; they generally don't address the risk we accept for ourselves. That risk is addressed by the rules we create and apply on our own. Developing, documenting and following a good set of personal operational rules sets us on a higher level of safety and is the mark of professionalism in the aviation world. You don't have to be paid to qualify as a professional—professionalism is a matter of attitude. Some of the most professional pilots I have ever known have never earned a dime in the cockpit, but they lived long and interesting lives, passing on their own personal rules to keep the next generation alive as well.

Illustrations: Robrucha

FOR WANT OF A NAIL

For want of a nail, the shoe was lost; for want of a shoe, the horse was lost; for the failure of battle the kindgom was lost - all for the want of a horseshoe nail.

—14th Century Proverb

So goes the proverb, which instructs us about the importance of details. This little poem, which ends with the loss of the kingdom no less, goes back centuries in the English literary tradition and reminds us that we need to be careful of dismissing the "little things" that might seem trivial, but in the end prove to be serious. I can think of few areas of human endeavor where this is more true than aviation—a field where speeds and altitudes mean that small problems can become big ones (with fatal consequences) in the blink of an eye.

Those who have wandered the hallowed ground of Oshkosh on any given July afternoon have doubtless seen airplanes bordering on perfection. Grand Champions are remarkable to examine, because every rivet is perfect, every line exquisite. It is clear that such a craft is the product of thousands of hours of work by an individual dedicated to leaving no detail to chance. Yet even these airplanes have their flaws, little spots here and there, usually known only to the builder. Perfection is a goal, not an end, but it is a goal that we must strive for when thinking about the details—those items that can lead to failures with greater consequence than simply losing the Gold Lindy.

Details in the engine compartment mean padding the mount tubes with rubber or silicone tape if you need to attach a wire tie.

Airplanes are the sum of thousands of parts, and it is hard to pick those that are unimportant. The very nature of airplane design is such that if it is not essential, it will probably not make the final cut, because weight is performance and performance is everything. This leads us to realize that if the designer has done his or her job properly, there is little in the initial design that can be omitted, or that is not essential. Every nut, every bolt has its purpose. In today's airplanes, where electronics have become more important, we have to extend that thought to the hardware and software that help us navigate our aircraft or might even keep the spark going to the engine's cylinders.

I know of no "fly-by-wire" homebuilt kits out there today, but the way we tend to embrace new technology, it is only a matter of time. Just think about this: An average small computer probably contains at least a million words of software. Each word is made up of maybe eight individual bits, which can either be a one or a zero. And at the front of each of those words is a "sign" bit, signifying whether the word (or number, more correctly) is positive or negative. If you get one sign bit backward, you go down, instead of up, left instead of right. With those millions of bits in the computer, if just one sign bit is wrong, the whole thing can fail. This is different from being slightly low or high with an analog torque value on a nut somewhere. There is no tolerance when it comes to binary software; it is either right, or it is wrong.

It's a pretty fuel-line installation, but it wasn't quite right. The tube had to be remade because it was rubbing on the large bracket. All it took was a slight kink to make it better.

Details Matter

Whether it is in how accurately we locate

Wiring to an electronic ignition can vibrate over time, leading to failure. Adding Adel clamps will increase reliability.

All it takes to cause a crack in acrylic is a single rivet hole with a burr or microcrack. Take the time to polish edges and holes correctly.

fastener holes, or how we crimp wire terminations, the details make a difference. For example, the rear spar attach points on most RV aircraft are drilled to hold the angle of incidence that is carefully adjusted when installing the wings. This is a pretty important pair of bolts (one for each wing) that not only sets this critical angle, but keeps the wing from twisting off under load. Edge distance on both the spar stub and the fuselage center section is of paramount importance in order to leave enough material around both holes to avoid this bolt "pulling through" under design loads. There is not a lot of tolerance for these bolt positions because there isn't much excess material in the components, so it pays to measure, measure, and measure again to make sure that the bolts are in the right place and all limitations are observed. These two holes are among a couple of thousand that must be drilled in the assembly of an RV, some of which matter less, but few of which matter more. The builder either needs to be very educated on the structural design of the airplane, or treat all of these holes with equal respect. The details that matter will then take care of themselves.

Wire crimps? How could they be a problem? My simple airplane will fly just fine without any electricity at all! Well, sure, but do you have an engine with a magneto system? Does it vibrate? Remember that the P-leads that connect the magnetos to the ignition switch are used to ground the mags to keep them from firing. If one of those leads comes off, then the engine is "hot" when just sitting there—all it takes is a pull on the prop with just the right combination of fuel fumes to let it fire. Have you ever done maintenance around your prop with the cowling on when you can't see if the P-leads are still connected? Do your friends or children visit your hangar and walk near the prop? You get the point—P-lead connections are vitally important for safety, so their crimped terminations need to be secure.

I have had acrylic windows crack suddenly due to residual stress from poor fitting combined with micro-cracks at their edges. It will surprise the heck out of you when it happens next to your ear! If the window had been fitted properly, and the edge polished with care, this probably wouldn't have happened. I have seen wire ties pulled so tight around a cable bundle that the insulation started to "flow" and squeeze out away from the conductor—it takes time, but given enough years of service, this can lead to a bundle short. I have seen the rubber tubing on a battery-case drain become brittle and crack, spilling battery acid inside the tail cone of an aluminum airplane. When neglected long enough, it renders the fuselage a piece of junk—or a candidate for expensive repair.

Details count in so many other ways as well. When you approach an airfield and give a position report "Pearland Regional Traffic, RV 188PD 5 miles to the south," are you really 5 miles out, or is it 4, 6 or 7? Are you truly south, or is it more like southwest? It makes a difference, because once you tell people where you are, that is where they will be looking. If you are actually somewhere else, they will miss you entirely and, worse, stop looking for other traffic where it should be.

Years ago, at the beginning of the space age, people who had made their living designing and building airplanes started to build rockets. They used the same techniques, materials and methods, but soon discovered that the new vehicles were horribly unforgiving—errors simply couldn't be tolerated, because when something went wrong, the rocket just blew up, and there was little left to even evaluate, much less rebuild. Most of the spectacular mishaps that you see in visual retrospectives of the early days of the space program were caused by details—rags left in an engine compartment, a tiny amount of contamination in a liquid oxygen line, or a single pin in a large plug that was recessed a millimeter below the height of its neighbors.

One famous aborted launch was caused by just that—a single connector that came apart a millisecond before it should have and prompted the engine to shut down. Unfortunately, the rest of the rocket thought it was still going, and went through all of its programmed events, including firing the escape rocket and deploying the parachutes. The only problem was that it was still sitting on the launch pad. It was a spooky day for the men in the nearby bunker, because the fully fueled rocket was now sitting on its tail with nothing holding it down—and a parachute at the top, wafting in the wind. All of this occurred because one small pin wasn't fully inserted in its connector. Details.

While any reasonable person knows that perfection is unattainable, it is still important when building or flying aircraft especially Experimental/Amateur-Built aircraft—to make sure that we think about the details and try to get them right. While we rarely worry about horseshoe nails in these modern times, we still don't want to lose our riders—especially when we are leaving the safe, firm earth to go hurtling through the magnificent blue sky.

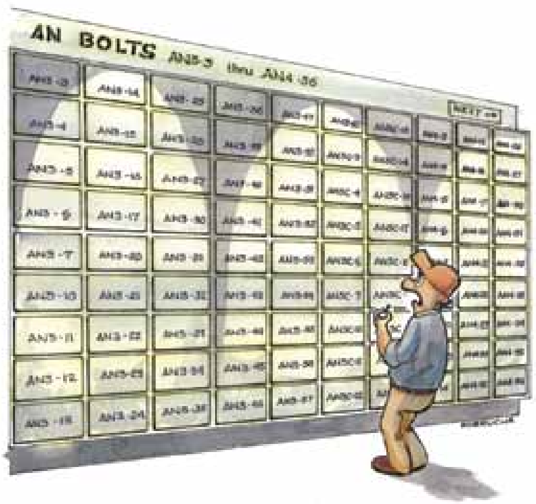


Illustration: Robrucha

A good team is invaluable when it comes to a flight-test program. More eyes mean more chances to catch problems.

Experimental test flying used to be a solitary game. A lone pilot walked out to a new machine and gave it a workout, *mano-a-mano*. No copilot, no flight-test engineer, no ground or support time— just the pilot, the wing and the wind. The pilot looked the airplane over and, assuming he didn't see anything immediately fatal, mounted the machine and called for the mechanics to crank it up. First flights and test flights were whatever the pilot decided to do, and when he came back, it was thumbs up or thumbs down. It was all very simple, really—but not particularly rigorous or safe, as early aviation statistics prove.

Likewise, airplane design and building in the early days was often a solitary affair. I have often heard the Piper Cub referred to as "farm equipment," because it was designed and built by men who grew up in early 20th-century America, men who frequently came of age building and tinkering in the farm workshop. The "aerospace industrial complex" had yet to develop, and even outstanding aircraft could frequently trace their lineage back to a single man whose inspired design created a masterpiece.

Farm Team

The early days of Experimental homebuilding harken back to these times. Individuals with the idea of building their own flying machines toiled away in isolated garages and basement workshops, building light, simple planes to try new things, save money or just to prove that they could (with their own hands) make something that would fly. The Experimental Aircraft Association eventually bound these people together into an organization that created the homebuilding movement that we know today—but still, the creation of these machines involved lots of solitary nights spent cutting aluminum, welding steel and gluing wood. When not engaged in actual fabrication, builders might spend hours trying to find a source for parts and ideas, sending away for updated catalogs from companies that they found out about on airport bulletin boards, pilot lounges or that venerable yellow publication we all know and love.

When the airplane was ready to fly, the pilot would recruit a few friends to help haul it to the airport, or get it ready in the hangar, for a flight that (ideally) proved the machine would indeed fly— and then head back to the hangar or workshop to fix the minor cracks, delaminations, bumps and bruises from the experience. Usually conducted out at the edges of the field in the early morning or late evening, these significant events frequently went unnoticed because people building their own airplanes were out on the fringes themselves.

The Mystery Revealed

I knew a few of these folks in the early days of my own involvement with aviation. Hanging around a local FBO as a "hangar rat," helping to rebuild and recover old Cubs and Tri-Pacers, I was aware of these folks in the hangar down at the end of the row who kept to themselves or their small group of friends. There were rumors that airplanes existed in those shady places, but all I ever saw were bits and pieces of materials and an occasional vertical stabilizer. Yes, I was aware that homebuilt airplanes did fly now and then, but it was definitely not the mainstream of aviation. These were lonely people engaged in their lonely pursuits, enjoying their solitude.

And then came the Internet! The explosion of information available to the average homebuilder is simply mind boggling in its vast nature and complexity. Before the Internet took hold, the EAA grew up and provided much greater presence and support for those who decided to venture into the brave new world of homebuilding. While Oshkosh has become Mecca for builders who make the trek to meet others and examine aircraft, the In-

Illustration: Robrucha

Sometimes it takes a team just to have enough hands to get the job done!

ternet is where they go on a daily basis to communicate, get questions answered and look for examples of how things can (or should) be done. The fact that builders frequently ask, “How did people build these things before the Internet came along?” is telling—it has quickly become ingrained in how we produce homebuilt aircraft.

The Value of Collaboration

What homebuilders have discovered is something that the aerospace industry discovered decades ago: Teamwork works. When aircraft and their development programs became complex and costly enough, designing and producing them became a team effort. Likewise, the early Pietenpols and Breezys have given way to faster transportation machines with complexities that almost require us to interact with other builders on a daily basis. The price of doing something wrong is too high to ignore the lessons of others. We need to learn from their mistakes, as well as their successes.

Teamwork is not only a matter of getting and giving information, it is also a social experience. Many homebuilders discover that while they started to build an airplane, what they ended up with was a new social circle with whom they interact on a daily basis (or at least on weekends for “hundred-dollar hamburgers”). Homebuilding has built groups of people on the local, national and international level, who first meet by communicating on the ’net, and then stay in touch with finished airplanes when the dream of easy travel is realized. Aviation circles used to be small and local, the group that gathered for coffee in the airport lounge; now they are vast networks of folks helping each other and enjoying what goes on in each other’s lives.

There is still nothing wrong with toiling away in isolation while bonding with one’s airplanes. Many people simply don’t enjoy a high degree of social interaction; they are not wired that way. Yet it is nice to know that there are people out there who can help, answer questions, give a hand, lend a tool. Teamwork does work, whether you are building a multibillion-dollar fighter plane or a puddlejumper to fly on lazy summer evenings. Sharing our work and time enhances the experience in many ways, not the least of which is to make it safer, mechanically and operationally. The EAA designates volunteer technical counselors and flight advisors to help people get their questions answered in the name of safety and success, and if you have no one else on your team, they can be quite an asset.

Use Your Resources

While many builders and pilots have mixed emotions about the massive organization known as the EAA these days, it is hard to deny that local EAA chapters can be incredibly useful sources of information and help. As mentioned above, getting a good technical counselor on your team early in a build will benefit you all the way through. Don’t think of calling a technical counselor as a one-time inspection. Get to know him (or her), invite him back, call with questions and make him a part of your building project. The same thing should be considered with flight advisors and, in fact, with other local builders you meet. Our hangar is often visited by other builders and pilots on the weekend (it’s the reason I leave the doors open), and I am happy to be on the support teams of other builders. Not only do I continue to learn myself, but it is a way to give back to the aviation community after what I have been given by so many others.

I love doing things by myself. But I have learned over the years how rewarding it can be to interact with others who share a common interest and similar goals. The Homebuilding Team is large, vast and diverse. It is spread across the globe and available to all, from the local coffee klatch to the global reach of the Internet. I encourage everyone with a building project or a flying airplane to be part of the team. The rewards are great, and the whole is greater than the sum of its parts.

The author enjoys building alone, but sometimes (like when you’re hanging an engine) having help does make things easier.

HOPE IS NOT A PLAN

Have you ever had these thoughts in flight?

"I hope this thing flies."
"I hope I will be able to handle this thing when I get it off the ground."
"I hope I'll be able to land it."
Have you ever had these thoughts run through your mind while getting ready to fly an airplane?
"I hope that fog bank doesn't roll in before I get there."
"I hope that I can find a hole in these clouds."
"I hope those thunderstorms don't get any worse."
I see the heads nodding out there, at least among the long-time pilots.

The truth is that everyone involved in aviation has had, at one time, a fleeting hope that things would turn out all right. It is human nature to get into something just a little beyond our comfort level, just a little beyond our experience, and hope that things will be OK.

Well folks, let's be honest: Safe aviating begins with a plan; good aviating entails following that plan. And the truth is, hope is not a plan. We've all heard the saying, "It is far better to be on the ground, wishing that you were in the air, than to be in the air, wishing you were on the ground." Anytime you start a flight hoping that things will turn out, you are probably about to experience that "wishing you were on the ground" part.

Flight Planning

Planning a flight (or a build, or a flight test program) is a way to figure out if you have all of your ducks in a row. Do you know that you have all the information that you need to complete the flight safely? Do you know that you have the necessary skills required to come back down in one piece? Do you know that the airplane is sound and sturdy—ready to accomplish whatever mission you have set for the day? During the planning process, we walk through every step of the flight, before leaving the ground, to make sure there are no holes into which we might fall.

I remember a local Saturday morning flight in my old Grumman, many years ago. I was still enjoying the glow of first airplane ownership and was new to the fact that I didn't have an FBO's mechanic taking care of the rental airplane (that I was about to fly) to give me some confidence that it was airworthy. Going through my preflight, I noticed a ding in the prop leading edge. Not big, just enough to snag my finger as I slid my hand down the blade. Of course, I knew all about props and preflights—you check them to make sure that there aren't any dings that could grow in to cracks. But no prop is ever perfect; there are always tiny imperfections that we accept. What is "good?" What is "bad?" The ding was small, probably a chip from some gravel. The prop blade was pretty big and beefy; this looked OK to me— at least, I hoped it was. I really didn't have any money for a prop repair, so it must be OK, right?

I finished my preflight and started the engine. I noticed no vibration. As I taxied out to the runway, I kept thinking about that little ding. What does it take to propagate a crack? How much centrifugal force is pulling on that blade? Is there a crack forming? I reached the end of the runway and ran the engine up. I noticed nothing out of the ordinary and pushed that little worry deep into the recesses of my mind. I hoped— I was sure—it would be OK for a little local flight. I taxied onto the runway and added takeoff power. And then I thought about what would happen if the prop blade failed. I thought about the engine coming off due to the severe imbalance and vibration. I pictured the uncontrollable flutter of the airframe as it descended without that big chunk of Lycoming. And as I passed through 40 mph, I decided that hope was just not a good plan, pulled the throttle back and aborted the takeoff.

As I taxied back to the hangar, I noticed a local mechanic working at his shop. After shutting down the engine, I walked over and asked if he'd have a look at the prop. He was happy to do it, and sure enough, he said, "Oh, that little ding? No problem. But let me grab a file and dress it out, just so it doesn't bother you or grow into anything later." He was very nice about it, understood my concern, and didn't charge me a dime; I bought him a Coke and we called it even. It was a nice day to fly, and I only lost a half hour of it. I had hoped it was going to be OK, but the mechanic knew it would have been OK. I was worried, and he was confident—but he understood I needed that same confidence, a confidence brought on by knowledge.

Know What You Don't Know

In Experimental aviation, we rely, to a great extent, on our own mechanical ability to assemble and assess our aircraft and systems. Especially during the flight test phase, our airplane is unfamiliar, as are its random noises and characteristics. Is that vibration normal? Should the cockpit really sound like this? These are questions that we can address by asking others with similar experience, or by being very ready for problems if they arise. Modern kit designs are pretty good when it comes to the "big stuff"— generally the wings and engine will stay attached, and the pointy end will want to continue heading forward. But what about that special oil system that you designed? Or the modifications you made to the fuel system? Are those surplus circuit breakers that you got at the fly-mart really going to trip if there is an overload, or do they just look cool? These and a thousand other questions might go through your mind when flying your new homebuilt, and it is important to be honest with yourself about the difference between knowledge and hope.

Aviation is full of unknowns. We are never going to know exactly what the weather is going to do, for instance. But we can use our knowledge of trends to give us an idea of what it might do, and then build a plan to deal with it if it stays nice, or if it turns ugly. It is one thing to say, "I hope the weather stays nice," and another to say, "I have a plan if the weather doesn't stay nice."

Reduce the unknowns to a small handful, and have a plan to deal with them if they don't go our way. Plans need to be realistic, and we need to be honest with ourselves about what we don't know and about our own skills. When you taxi up to the hold-short line, ask yourself, "Am I relying on hope today?" If the answer is yes, then maybe it's time to turn around. The odds are rarely in our favor when we rely on hope to get us through. That's just gambling, and in the end, the house always wins.

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