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When Pitch Trim Systems Turn Ugly

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From the AeroElectric-List on Matronics.com
At 11:00 PM 6/6/2007 -0600, you wrote:

A few days ago a Citation jet carrying a crew of two and 4 medical personnel including organ transplant doctors, went down in Lake Michigan just off shore from Milwaukee, WI shortly after takeoff. The pilot declared an emergency due to severe control problems and was cleared to return to MKE. No survivors. First my condolences to the families and friends. Next, preliminary reports are that the crash may have been due to "Runaway trim." Our RV-10s have electric trim. Should we or has anyone installed a trim power disconnect of some sort? I realize that the forces to overcome full trim on the 10 are not as great as a Citation, but would this be prudent? After Attending Bob Nuckolls seminar and hearing his reasons for not installing circuit breakers which I generally agree with, would this be a reason for a pullable breaker on this circuit? What do you guys and gals think? Mr. Nuckolls, how about your thoughts?

Lest we reduce this anecdote to a "dark and stormy night" story, let us ponder the simple-ideas behind managing and airplane with a malfunctioning trim system. I've been aware of (and sometimes investigated) a number of incidences of trim system failures. My first investigation of a stuck relay incident looked at a Baron some 30+ years ago where the outcome was a smoking hole.

Stories of these events demand attention. However, when they a not accompanied by a paper describing technical findings, the stories add no more value to our lives than standing on the street corner predicting, “The end of the world is at hand!”

The FIRST thing the OBAM aircraft owner should accomplish (preferably during the 25/40-hour flyoff) is discover the mechanical range of trim system motion needed to accommodate the full envelope of flight configurations for variations of CG, IAS and weight. If available trim motion is found ***generous*** for comfortable operation of the airplane then add ***positive mechanical stops*** to limit the range of motion.

Perhaps you say, “The designer of this kit has taken care of all that stuff.” Probably. But this is YOUR airplane. YOU should to do some simple experiments to validate or discount your faith in the designer. You may not agree with what he/she deems “acceptable”. Explore how hard it is to operate the airplane with the trim system stuck at either limit.

A trim system suffers from two kinds of failure (1) it might “***run away***” and drive to a limit or (2) ***fail*** to operate and leaving you trimmed for a flight configuration far removed from what you'd like to have for comfortable approach to landing and the flare.

I’ve flown aircraft with exceedingly weak trim systems where a mis-trimmed condition was no big deal. I’ve flown others where mis-trimmed conditions were difficult if not impossible to accommodate and still operate the airplane with confidence. Whether or not you opt for extraordinary design of controls for your electric trim system is up to you and nobody else.

My most recent experience with a trim failure involved sticking relays (note plural semantics here) in roll trim on a bizjet. In this case, with roll trim hard-over, flying the airplane is uncomfortable but manageable. Another case involved ***failure*** of an actuator to bring a stabilizer position out of Mach cruise configuration. This required something on the order of 180 pounds of pull on the yoke to put the airplane into an attitude conducive to orderly contact with the earth. Without going into a long dissertation of simple-ideas upon which these and other events were based, let's consider the situations unique to the airplane ***you*** intend to build and operate.

Once you have limited mechanical travel to practical and useful limits, explore the stick forces necessary to manage the aircraft with trim set to either extreme. This is the first step of a meaningful failure mode effects analysis (FMEA). Yeah, our brothers on the certified side are nowadays fond of Functional Hazard Assessments, MTBF studies, and reliability trees . . . big piles of paper.

I'll suggest that it is much more useful to ***assume*** that every component of the system is ***guaranteed to fail*** at some point in time. Evaluate the consequences of each failure possibility and craft a recovery plan. I find this approach easily supported by logical assessment of the simple-ideas and totally free of mathematical models where any assumptions are made beginning with a faith in the model's value. Each cause-effect-and-recovery plan is based upon repeatable experiments. Every potential failure can be generated for the purpose of investigating the validity of the recovery plan.

Assuming your airplane's out-of-trim handling qualities are more than YOU choose to deal with, I'll suggest you craft a ***Plan-B*** to deal a runaway malfunction. Let's consider words quoted from the accident investigation of one incident [1].

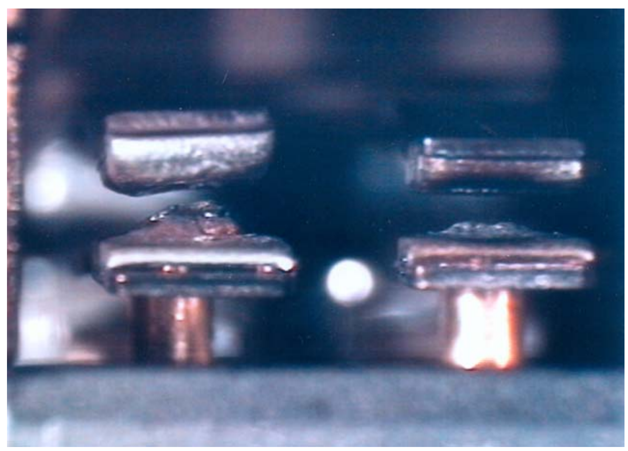
> *The Pitch Trim Printed Circuit Board, part number 6518351-5, serial number 0154, was examined and functionally tested at the Cessna Airplane facilities in Wichita, Kansas. Testing showed a repeatable fault in the operation of the K6 relay, resulting in the relay contacts remaining closed. This condition would be representative of the autopilot remaining engaged and a voltage (signal) present to drive continuous nose-down trim to the elevator servo.*

Hmmm . . . there may be more to this paragraph than was made available to us . . . but the idea that a single failure like one stuck relay is capable of producing unintended motion in the trim system is mystifying.

In virtually every system I've had the pleasure of designing, design goals included (1) no single failure within the product be capable of producing a runaway condition and (2) any single failure that marches off in the direction of potential runaway shall be monitored and annunciated. Cessna works out of the same Aircraft Certification Office that I do . . . if such a condition in fact made it to production, I'll suggest that somebody stubbed their toe here.

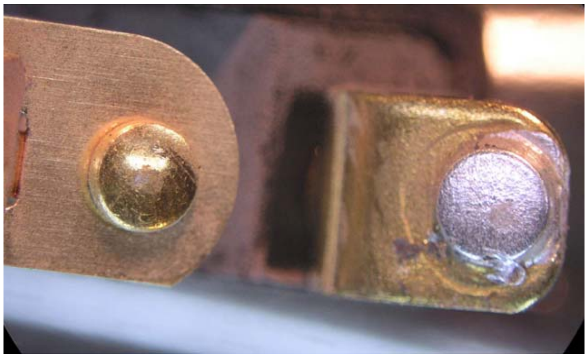
> *Examination of the relay, part number B46229, at Magnetech Struthers Dunn, Darlington, South Carolina, showed no evidence of electrical arcing or other damage. Wear was noted on the moving parts of the relay, and operation of the relay verified the condition found at Cessna. The designed operational life for this relay is 50,000 cycles. The number of cycles per flight is defined as the number of times that pitch trim is engaged/disengaged by the autopilot, and can vary depending on weather (turbulence) and other flight conditions.*

Let's examine the phrase ***"no evidence of electrical arcing or other damage***". This photo is of a set of contacts for a relay used in a bizjet trim system. These contacts were subjected to a standard test protocols for



reliability. Such testing is accomplished periodically on production parts to verify continued compliance with specifications. These contacts show severe metal transfer (due to arcing under rated load) but the relays were not sticking nor were they damaged in a way that prevented a relay from performing as advertised.

On the other hand, here are a pair of mating contacts that show only the tiniest hints of electrical stress after perhaps 2,000 cycles and they were ***failing*** to make connection! Visual inspection of these contacts did not reveal why an expected event didn't happen, yet the malfunctioning contacts were visually "perfect".



I offer these anecdotes to show that while many words offered in accident analysis are factual, they add no value when they fail to illuminate and then explain the significance of the observation. I've witnessed cases where well meaning but uninformed individuals banned particular manufacturers of devices use on their airplanes based on no better information than "Brand X relay sticks more often than Brand Y."

Decisions were made to purge the inventory of "Brand-X" relays and replace them with "better" and more expensive relays without ever having fixed root cause for the sticking. The importance of the paragraph I cited from the accident analysis is an inference that the relay in question was sticking closed from a mechanical failure and not an electrical failure . . . a notion worthy of some skepticism and further investigation.

> *ADDITIONAL INFORMATION*
>
> *The investigation revealed that the K6 relay failure would constitute a single-point type failure in the electric pitch trim system. Pulling the circuit breaker, which is called for by the checklist in the event of a trim runaway, would have arrested the trim movement provided the circuit breaker was opened prior to the trim reaching its stop. Further examination of the system revealed that the autopilot autopilot/trim disengage switch would not have disengaged the electric trim motor during the type of failure experienced in the accident airplane.*

This paragraph seems to confess existence of a single point failure that would produce a runaway. Further, the only way to halt effects of the failure was to pull the trim motor circuit breaker. Managers for every program I've worked have stated emphatically that, ***"Pulling a breaker is NOT an acceptable procedure to recover from an emergency condition "***. Breakers are not located, labeled and grouped for the purpose of quickly finding and operating them to bring impending emergency under control.

> *Personnel from the FAA Wichita Aircraft Certification Office reported that post accident simulator testing of the elevator flight control system revealed that full deflection of the trim tab (trailing edge up) would require extremely high control wheel forces to achieve level flight.*

Again, factual as far as it goes . . . but what is an "extremely high control wheel force"? The Beechjet was certified based on a demonstration that two pilots could safely land the airplane with the trim system stuck in full nose down (Mach cruise) condition. A number like 180 pounds of stick-force comes to mind. A couple of weight lifters in the front seats might call this "no-big-deal", you and I would certainly call it "extreme" but both terms are un-quantified and not useful for making an judgement as to the difficulty of the task or mitigating risk for an uncomfortable of not hazardous termination of flight.

I offer the foregoing words to illuminate the value (or lack thereof) in reading these reports and applying any real design or operational significance to them. So let's turn our thoughts back to the OBAM aviation world and evaluate ***your*** airplane's ability and likelihood of forcing a bad day in the cockpit.

Let us assume that you've accomplished out-of-trim flight experiments and decided that a trim system failure places a burden on you as pilot that you've considered unmanageable or sufficiently undesirable to do something about it. Let us further assume that you are willing to ***increase parts count and complexity*** in some way that reduces risk of having to endure the event.

The trim system runaway issue has been considered for decades. In fact, there's a long standing protocol for testing a proposed design that goes something like this. While in stabilized flight for the most critical condition (usually high speed cruise), the pilot puts his hands in his lap. The test engineer initiates a simulated runaway condition. The pilot cannot react to a perception of runaway onset for 3 seconds. After three seconds, he is directed to accomplish whatever recovery process has been offered in the aircraft flight manual. During recovery the airplane shall not depart level flight by more than xx degrees and shall not poke the edge of the envelope for safe operations.

The technique for passing this test in the early days was to simply slow the trim rates until the a 3-second reaction delay no longer poses a hazard for recovery from the failure condition. This worked pretty good except . . . trim rates appropriate to high-speed cruise were so slow that trimming operations during approach to landing were frustratingly slow.

I was privileged to craft what I believe was the first servo speed-controlled trim system first for the Lear 55 and ultimately as a retrofit to the fleet of 30-series Lears. The system offered a 4:1 range in trim speeds for high speed (flaps up) and low speed (flaps extended 10+ degrees) operations. Pilots loved it. Electronics for controlled the motor featured two, independently controlled, series switches for motor current. Both had to close to effect motor motion. Failure of either one to open after the command was relaxed caused a TRIM FAIL warning light to illuminate.

Additionally, pitch trim power was routed through what was call the “Wheel Master Disconnect” system . . . pushing this button caused power to be removed from every motor that was capable of driving a flight control surface.

Okay, what kinds of techniques might we consider for the installation of electrically powered trim systems such that probability of runaway is exceedingly low or zero?

First, consider a two-switch operation for trim systems. The first switch is the classic spring loaded, pitch-up, pitch-down operating switch. The second is a Trim Enable switch . . . also spring loaded that is normally open and wired in series with pitch trim motor power. This switch is perhaps built into the grip such that it must be squeezed to enable trim before the pitch-up, pitch-down switch will function. This is stone simple and offers the very solid, simple-idea that you’re not going to get simultaneous failures in two separate switches . . . while failure of any one switch is easily detected at pre-flight and probably noticed in flight as well.

Now, if you have a super-whippy autopilot, it’s likely that the electronics of the autopilot will want to “talk” to an already existing pitch trim actuator. This doesn’t change the considerations for manual pitch trim but does place some responsibility on the A/P designer to consider single points of failure along with an orderly plan for annunciating a failure and offering a Plan-B for recovery.

If you don’t want to go the **Press for Trim Enable** route, consider the equivalent of the **Wheel Master Disconnect** button. The schematic in Figure 1 describes one approach to a Master Disconnect system capable of handling any and all power paths to motor driven flight controls. The relay used needs one more pole than the number of systems being controlled. Alternatively, the relay can be a combination of 2 or more relays with the coils wired in parallel.

The goal is to provide a means by which operation of a single switch preferably on the control stick or wheel grip can be quickly operated at the first perception of a malfunctioning flight controls motor. The system is reset by a second button elsewhere . . . perhaps right next to the Master Disconnect warning light.

There are a variety of control and monitoring philosophies that offer interesting features but I can deduce nothing simpler and more direct than the technique cited.

Notes:

(1) http://www.ntsb.gov/ntsb/brief2.asp?ev_id=20030724X01192&ntsbno=SEA03FA147&akey=1

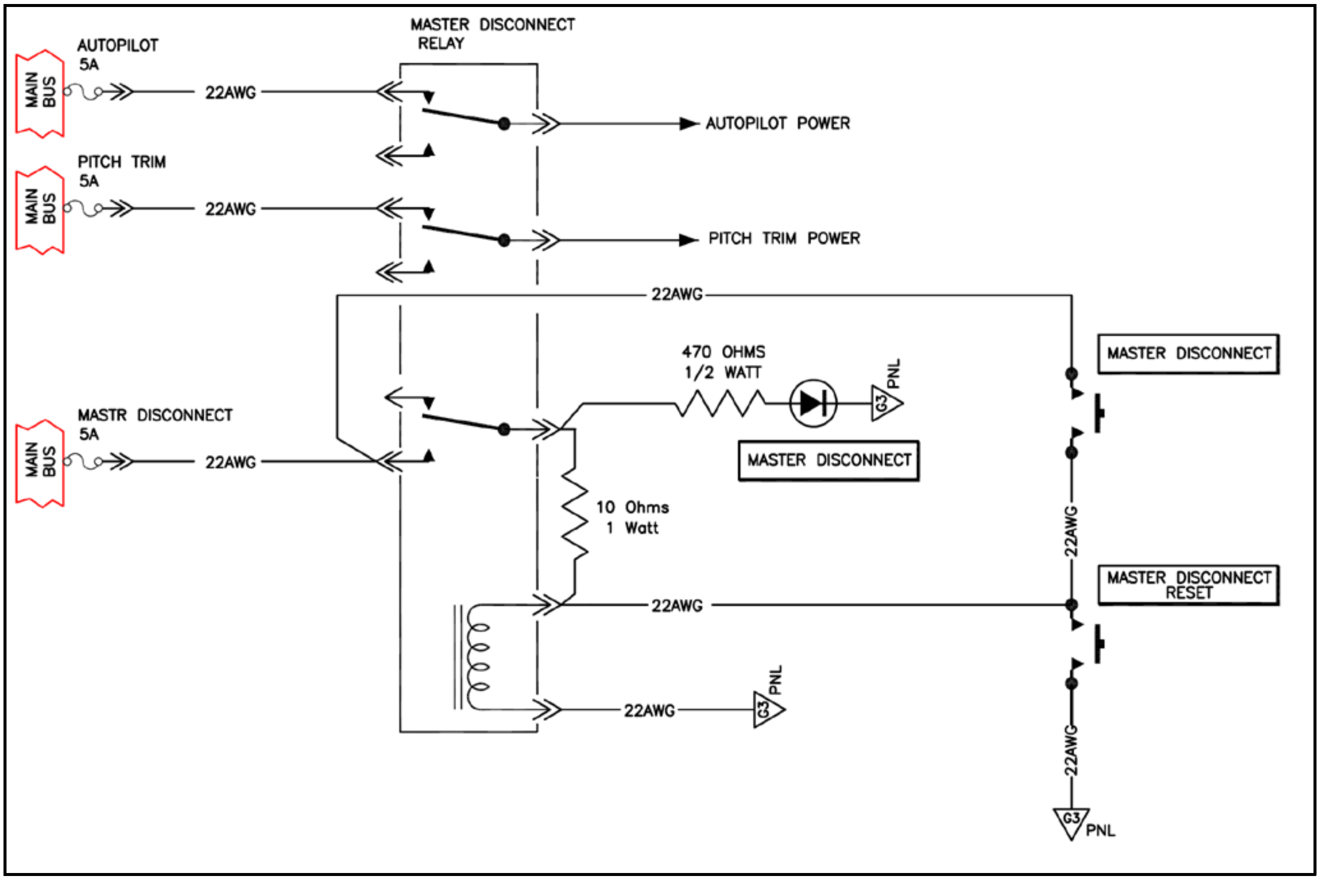


Figure 1. Master Flight Motors Disconnect System.