AMERICAN BONANZA SOCIETY

The Mystique of Autopilot Accidents

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Aircraft avionics systems, especially autopilots, are a specialized area where most accident investigators need specialist help.

During the investigation of aircraft accidents where there is no easily recognizable evidence of the cause of the accident, the recognition and interpretation of the data that are available has led to considerable debate. This is especially true when there is concern about an autopilot's involvement. Considerable experience investigating a great number of accidents with autopilot involvement has led to an understanding of some of the misconceptions that permeate the investigation when an autopilot is involved.

The autopilot is a critical avionics component that significantly reduces pilot workload. Most pilots who rely on their autopilot exhibit a blind faith that it will keep them out of harm's way. Though this is generally true, there are failure modes of the general aviation autopilot that occur without warning to the pilot and can result in the aircraft entering a disorienting unusual attitude before the pilot can react.

For example, in position-based autopilot systems:

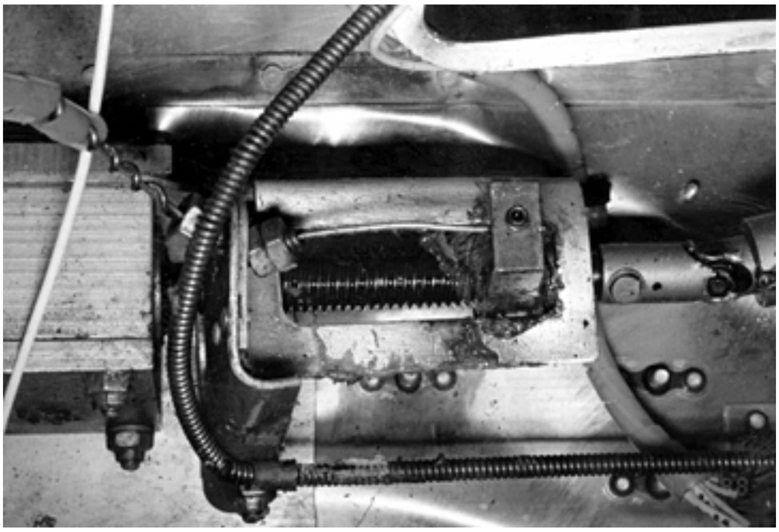
- The simple effect of the attitude gyro precessing, when the autopilot is engaged, can result in the aircraft following the gyro to an extreme, because the gyro is the source of the autopilot's attitude information.

- In the above scenario, with the heading hold engaged, the autopilot will attempt to hold heading even though it is receiving incorrect information from the attitude gyro.

- If the attitude gyro tumbles, the aircraft follows until the "g" disconnect activates in the resulting unusual attitude.

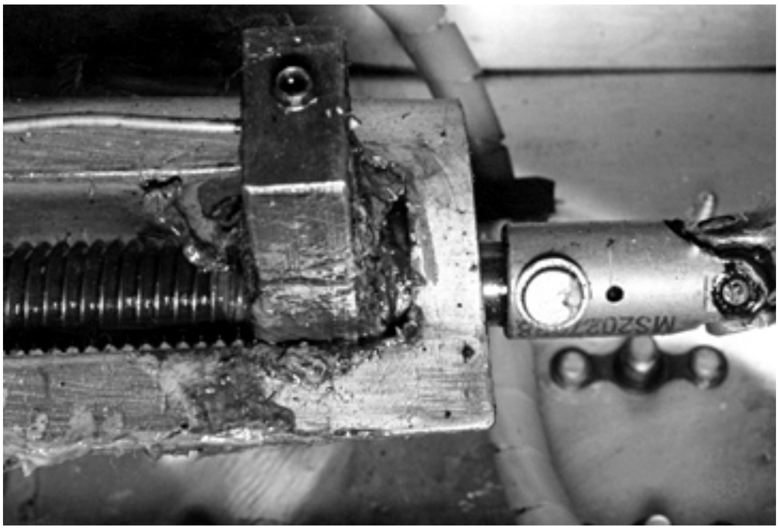
- If the auto trim system sends an undesirable up or down trim signal to the elevator trim while attitude or altitude hold is engaged, the pitch servo will offset the pitch trim servo until an attitude or altitude excursion is recognized by the pilot. The resulting disconnect of the autopilot by either the pilot or automatically can result in extreme stick forces most pilots have never experienced.

The pilot's intimate knowledge of his autopilot system and his response to an adverse situation is critical to accident avoidance.



An example of a Mooney pitch trim screw and nut in the full nose-down position.

The unit is located under the pitch trim wheel between the pilot seats in the cabin.



A close-up view of the full nose-down position.

The current variety of autopilot systems, both position-based and rate-based, is diverse; yet they all have similar operations, some of which can be deadly. The Bendix/King KFC-200 system can demonstrate the effect of improper response due to characteristics of the system. The autopilot system is tied into the aircraft control system by means of bridles attached to the roll, pitch and pitch trim servos. Three axis systems also contain a yaw servo in the yaw damper system. The servos each have individual clutch systems.

Engaging the autopilot sends an electrical signal to the engage solenoids in the roll and pitch servos, which activate the individual servo drive pinions to mesh the individual clutch drives. The pitch trim servo receives power to its engage solenoid when a trim signal is initiated from the autopilot computer or by the pilot actuating the manual electric trim switch on the control yoke.

The computer senses an out-of-trim condition via a torque signal from the pitch servo. Electric power is sent to the pitch trim servo to relieve the excessive torque on the pitch servo clutch. The autopilot computer, thus, reduces an excessive load on the pitch servo clutch by actuating the pitch trim system, thereby keeping the aircraft in a trimmed condition, just as a pilot would through the yoke trim switch. However, in systems with manual electric pitch trim, electric power is available to the pitch trim servo even with the autopilot in an off condition.

Another characteristic of this system is that the pitch servo will not mechanically disengage the clutch mechanism where there is a load on the interface between the pitch servo and the clutch. This is true even if the autopilot is disengaged electrically. The pilot will see the V-bar disappear on the attitude indicator and the autopilot annunciator lights go out and will believe the autopilot has disengaged.

However, if the pilot is applying back pressure on the yoke while the pitch servo is mechanically engaged, the pitch servo will automatically send a nose down trim signal to the pitch trim servo, which has power available and which functions as commanded. In this situation, the only way to obtain disengagement of the pitch servo and its erroneous trim signal to the pitch trim servo is to relax the yoke pressure and allow the pitch servo to mechanically disengage.

If this is not done, the pilot will have to overcome the clutch load and the aerodynamic stick force load. The combination of these loads can exceed the pilot's capabilities. The same mechanical lockup can occur with the aileron servo and clutch, which can increase the difficulty in recovering the aircraft.

Unexpected phenomena

These unexpected phenomena can be demonstrated during the normal preflight check of the autopilot system. With the autopilot engaged, place a small amount of yoke pressure on the ailerons and then disconnect the autopilot. The ailerons will be mechanically fixed by the physical engagement of the clutch until the pressure on the yoke is released.

Flight tests of a Beech B58 Baron at pattern airspeeds have revealed that the pitch servo clutch will slip when the pitch trim value is in the neighborhood of eight units of nose-down trim. Maximum nose down trim is 10 units.

To the unaware pilot, these autopilot anomalies can be catastrophic. For instance, an aircraft is at cruise airspeed in level flight and the autopilot auto-trim circuit is sending a nose-down trim signal to the pitch trim servo without the pilot's knowledge. While the trim is moving toward the nose-down condition, the pitch servo holds the nose attitude up so that the aircraft maintains altitude or attitude. As the load on the pitch servo clutch builds, the clutch will begin to slip and the aircraft will fail to hold the desired altitude or attitude. The pilot, detecting the excursion in altitude or attitude, may suspect a problem with the altitude hold or gyro and disengage the autopilot in a normal fashion. With near or full nose trim set on the elevator, the aircraft will pitch toward the new trimmed nose-down attitude with amazing speed and resultant negative "g" forces.

The pilot will most likely come out of his seat, straining against his seat belt, airspeed will rapidly build, and the stick force to level the aircraft will become extremely high. Flight tests by Beech have shown that these forces can exceed 100 pounds of force under certain approach conditions to maintain a level flight condition.

If the pilot is unaware of the aforementioned mechanical lock proclivity of the pitch servo and applies nose-up back pressure on the yoke before disengaging the autopilot, the pitch servo will not physically disengage and the pitch trim, if not full nose down, will continue to run toward a full nose-down condition, exacerbating the situation

Now recovery, with the pilot dislodged in his seat and passengers on the ceiling (if belts were loose) must be accomplished with full nose-down trim on the aircraft. The aerodynamic forces will be extreme and must be held until the aircraft is recovered and the trim is reset.

The trim on some aircraft may even mechanically lock and not be movable until on the ground even if the pitch servo lock condition is not in place. The forces required can easily exceed the pilot's capabilities. If this situation occurs on departure or arrival, the odds are that the aircraft will be in the ground before control of the aircraft can be reestablished.

Unrecognized gyro precession is subtler than gyro tumbling, but either failure mode can be catastrophic. In both situations, the first reaction is to right the aircraft by leveling the wings and applying yoke pressure and then releasing the autopilot. This is what pilots have been taught.

When this occurs, the pilot will have to fight the aileron and pitch servo clutch force while the pitch trim is running to full extreme. Control forces are building, and it is contrary to a pilot's natural reaction to push the yoke forward to release the pitch servo while the nose is already in a threatening nose-down condition or to roll the aircraft in the same direction of roll upset to release the aileron servo. The resulting crash may leave few clues to the originating causes.

The investigation of these accidents with an autopilot genesis is very difficult because telltale flight control trim position can change after the original upset as a result of pilot input or crash dynamics.

Mooney-type trim actuators, of the worm screw type, will lock and reflect setting at time of impact. Actual autopilot engagement at the time of breakup or impact may be clouded as removal of electrical power from the servo solenoids allows them to relax to the disengaged position.

We do know of an instance where the pitch servo and pitch trim servo were locked in the engaged position post impact. In fact, pitch trim settings have been found in the full nose-down position. There has been at least one full nose-up pitch trim position, which resulted in a stall/spin scenario at night.

Recorded radar data track and profile plots will provide the clues necessary to lead investigators to possible and probable autopilot involvement. The subject was covered in "Impact Reconstruction: Flight Path to Causation," published in the *ISASI Forum*, July/September 1997.

Investigator dilemma

To the investigator, the real dilemma comes after an accident when trying to substantiate pitch trim condition. As mentioned above, Mooney aircraft elevator trim is accomplished through jack screw/torque tube actuators that tilt the entire tail assembly around a hinge. A jack screw at both the aft and cockpit locations will remain frozen in place at impact providing a very reliable trim position determination. Some investigators report "no trim available" simply because they lack knowledge of the trim system installed in a particular aircraft, such as the Mooney, which has no trim tab. Any investigator who says the pitch trim condition is undetermined on the Mooney aircraft simply does not know the trim system.

Most other general aviation aircraft utilizes cables for pitch trim actuation. This is where the post impact controversy starts. A typical response is "cable pull" when the trim actuator is found in the near or full nose-down position post accident. Some investigators feel that the trim condition is undeterminable, regardless of the crash sequence. It does not matter if the aircraft is collapsed in a single pile within its own wing span or is spread across an acre. The type of aircraft seems to make no difference.

This frivolous approach (condition undeterminable) to the trim condition of an aircraft during an accident investigation is the result of the false assumption that the trim condition is unreliable in all accidents.

For example, the article "Before & After" in the July/September 1998 ISASI Forum has a great deal of sound engineering principles, however, one is led to the conclusion that the trim system findings in wreckage examination are questionable at best. This is simply not so when related to the rest of the factual data available.

To understand the base causes of an accident, the entire scenario must be looked at as a whole by relating all of the wreckage findings with aerodynamic factors leading to the impact.

Quite often it becomes obvious that it is impossible for a certificated aircraft to follow a radar profile unless the trim has been upset from a normal hands-off condition. The physical laws of aerodynamic stability state that following an upset, an aircraft will return to its trimmed state when controls are released. From a normal flight attitude – straight and level, climb or descent – a pilot just does not pull or push the yoke to the extreme stick forces that an aberrant pitch trim setting can develop. The worst thing an investigator can do is get tunnel vision during an investigation.

The so-called "cable pull" could also change the trim in the other direction, which could result in an investigator failing to consider an autopilot problem during inquiry. The radar profile will establish fixed data. The investigator has to consider aircraft aerodynamic forces and the pilot's ability to fly the aircraft manually when following the radar profile, along with the trim setting found in the wreckage.

Even though the trim may be opposite to that expected, either pilot input near the end of the flight or crash dynamics may have altered "the expected." Autopilot involvement cannot be ruled out as a causative factor and must be considered.

There have been accidents in which the pilot transmitted to ATC that the autopilot was not functioning properly or that it could not be disconnected. Aircraft with pitch trim set by cables were found in the full nose-down position during wreckage examination. Nobody brought up the "cable pull" theory. It does continue, however, to rear its head in other instances where elevator pitch trim was found in extreme positions.

Nose-down trim

There have been a number of Mooney aircraft found with full nose-down trim after the examination, and it is not really questioned by those who understand the Mooney trim system. If it is happening to Mooney autopilots, why isn't it happening on other aircraft? Or is it?

We have interviewed and read accounts by pilots who have experienced severe nose-down pitch forces during flight. In one case, the aircraft was at 6,000 feet on autopilot when the aircraft pitched violently nose down. The pilot pulled on the yoke and attempted to disconnect the autopilot but was unable to recover.

Upon remembering a discussion concerning the mechanical lock and the requirements to recover, the pilot applied forward pressure while plummeting toward Earth. The pitch servo released, and recovery was made below 2,000 feet. The aircraft was sold, and the pilot has not flown since.

Another general aviation aircraft, with two pilots aboard, experienced the pitch over and the recovery, and subsequent landing required the strength of both pilots on the yoke. A Malibu pilot continually experienced pitch problems with his aircraft even though the avionics shop changed out all of the autopilot components individually. Finally, the aircraft pitched over while on an ILS approach.

Having been briefed on the mechanical lock anomaly with his system, the pilot relaxed yoke pressure, disengaged the autopilot, and then recovered and landed. The complete autopilot and associated wiring in the aircraft were replaced, which finally solved the pitch problems.

Another pilot performed the preflight check of the autopilot just prior to takeoff. Following takeoff, the pilot engaged the autopilot. After climbing to cruise altitude and proceeding en route, the decision was made to disengage the autopilot and manually fly the descent and approach. Imagine the surprise when upon autopilot disengagement the aircraft violently pitched up. The pitch trim servo had failed shortly after takeoff and engagement of the autopilot.

The autopilot "flew" the aircraft totally "out of trim" with the pitch servo counteracting the extreme trim setting that, without pilot knowledge, had not been reset due to failure of the pitch trim servo. Suppose the autopilot had unknowingly trimmed the aircraft nose down and the pilot had elected to fly the approach with the autopilot. Disconnecting the autopilot at 200 feet above ground level or at decision height would have been catastrophic!

The pilot had conducted all of the prescribed preflight tests prior to departure and no trim lights were displayed during the flight. Remember, auto trim operates the pitch trim servo, setting the irreversible pitch trim tab without the pilot's knowledge.

These accident/incidents are happening year in and year out on a regular basis. There is a lack of information published to even define the problem, though it does appear occasionally. The autopilot and airframe manufacturers do not appear to recognize the problem. They merely caution that the manual fix after the pitch trim failure occurs is to securely hold the yoke when disconnecting the autopilot.

But remember, the pilot doesn't even know there has been a pitch trim failure or even realize what the effect of the failure will be. We have investigated a number of these accidents, which had the genesis of autopilot pitch trim involvement, and they were all listed in the federal data bank as pilot-error accidents.

This real safety-of-flight issue is being glossed over. The least that can be done is to let pilots know when the pitch trim motor is running. A simple light that comes on either when the motor runs or after a designated 2 or 3 second delay would let pilots know the pitch trim is changing. If the light, which would illuminate whenever the trim motor runs, remains lighted for more than 2 to 3 seconds, it would indicate a failure of the trim circuitry. The light, which would have a designated delay, would indicate the same condition immediately. Both conditions would require immediate action to remove the autopilot and electric trim from the aircraft control system.

It makes no difference if the direction of the trim is nose up or down – the disengagement of the autopilot and electric trim would occur long before the trim has reached an uncontrollable setting. The cost to implement such a system is minimal. Air carriers have such a system built in, so why should not general aviation?

Aircraft avionics systems, especially autopilots, are a specialized area where most accident investigators need specialist help. Without the proper help, investigators can easily be led astray and not even address the possibility of an autopilot involvement.

Such an assessment requires tying together the aerodynamic effect on the aircraft and the accident data available. Too often, it is much easier to assume the avionics are O.K. and proceed with the rest of the investigation.

We must change this mind-set in order to save lives. If the correct information does not go into the federal data bank, the real problem will never be defined.

Aircraft accidents that have been labeled "pilot error" and that had an autopilot with the autotrim capability should be reevaluated by a knowledgeable team of investigators. These autopilot anomalies have probably killed more people than we care to admit, because every one of the accidents could have been eliminated.

The investigator must remember that all systems do not always operate in the manner the manufacturer says they will. In any accident involving flight in which the pilot is killed, it is very easy to lay the blame on the person who cannot speak.

We must adopt the "show me" attitude to reflect the relationship between pilots, systems, accident data and wreckage artifacts. Perhaps by this approach, the investigator will not bypass potential failure modes and in so doing preclude future accidents and loss of life.

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