AIRPLANE FLIGHT CONTROLS

Capt. M.P. “Pappy” Papadakis JD

The Primary Flight Controls

All airplanes are equipped with flight control devices that will aid the airplane in changing its direction of flight around three separate axis. The airplane may change its bank angle around the roll axis. The airplane may change its attitude about the pitch axis, and the airplane may change it's direction about the yaw axis.

To accomplish this aircraft are equipped with special devices known as flight controls. These controls connect the cockpit to movable devices on the wings and the tail and they are manipulated by pilot inputs from the cockpit.

To achieve nose up - nose down movement the pilot moves the control yoke forward or back in the cockpit. Forward is down, back is up. This causes devices on the tail to move into the slipstream creating the desired results. The normal situation is that the control movement moves a device attached to the rear of the horizontal tail known as an elevator. In other designs the entire tail is moved, and if this is the case the device is called a stabilator.

To achieve a wing up - wing down, bank angle control movements are made by the pilot to the yoke (steering wheel) or stick. Left is left wing down - right is right wing down. The movement in the cockpit moves devices hinged to the outboard rear of the wing tips known as ailerons. One goes up the other down. The one that goes up forces that wing to go down while the one that went down forces that wing up. Thus roll is achieved. Another device that is sometimes used to aid a turn is a device known as a flight spoiler. If a pilot wants to roll right he wants the right wing to drop and the left to elevate. A spoiler will extend on the wing depriving it of lift and that spoiled wing will drop creating the desired turn. Some airplanes use both ailerons and spoilers to achieve a bank angle.

To achieve the change of nose direction rudder pedals are connected to the rudder panel that is mounted (hinged) to the vertical tail. Stepping on a right rudder pedal will force the nose of the aircraft to yaw right. Stepping on the left rudder pedal will force the nose left. These controls are the primary flight controls, the secondary controls will be discussed later.

In the older simpler flight controls of smaller slower airplanes it was usual to move flight control panels directly by mechanical advantage through bell cranks, cables, pulleys, pushrods and the like. In the newer, higher powered, bigger, machines it was necessary to move the panels by hydraulic boosting and actuators. (power steering)

Depending on the variety of airplane, each system must either be failsafe or have a backup system if there is a possibility of failure more frequent than extremely remote. This is a requirement because if you lose the total flight control system in flight you will cause the loss of aircraft and / or the loss of life.

The civilian rules that govern design of transport category aircraft Engineering F.A.R. part 25 suggest that flight control design is very critical and all systems must have some back up or never be expected to fail.

The military follows the same flight control design philosophy in limited degrees since the mission of military aircraft differs so much. The concept is universal with flight controls. If its failure can cause loss of aircraft or life there must be redundancy. I quote MIL-f-9490d in paraphrase just to show how critical flight controls are. The current USAF flight control spec for 1975 says:

3.1.3 Flight Controls shall be as simple and foolproof as possible, while consistent with operational needs.(unless the failure is deemed extremely remote.) Contractor shall determine redundancy needs consistent with spec.
3.1.32 Within the flight envelope no single failure shall result in loss of aircraft before a pilot has time to take corrective actions.
3.1.33 A common mode failure of the Flight Control System is to be extremely remote. (5 x 10 to the 7th)
3.1.10 Means shall be provided to maintain, service and test [flight control components]
3.2.3.23 Pilot must be able to override hydraulic metering valve jams, unless redundant flight controls provide flight override authority.
3.2.3.2.4.4 Cable routing shall be accessible to inspection for its entire run.
3.2.3.1.1 Fasteners on critical flight control parts must have no back safety considerations.
4.1.1. There must have been a Flight Control Development Plan - approved.
4.1.1 a. Then the manufacturer must show compliance with the plan through analysis (must define assumptions and show conservative approach), inspection, and testing. (Includes requirement for procuring authority witness)

The contractor shall report a Safety analysis that shows all possible failure modes. The main point is that if a flight control goes, you don't simply park it on the shoulder and hitch a ride to town.

An air safety investigator is looking for several things when he conducts a flight control audit. The first consideration is that enough evidence can be ascertained from the wreckage to determine whether the control system had total integrity pre impact.

The investigator should attempt to determine the position of each flight control component at impact.

Finally, the investigator will determine if any flight control component was miss-positioned at impact, and he will determine if the component was operating normally at impact.

Flight control integrity pre impact is every bit as time consuming and difficult as an electrical audit when the wreck damage is severe or there has been a substantial fire. At other times it is relatively easy.

In the case where the system consists of simple cables, pulleys and flight controls, an investigator attempts to inventory all parts.

1. If components are intact then a simple pull on a cable may result in a movement of a flight control. If this is the case it was o.k.
2. Control cables that have failed in tension overload means that the cable was presumably intact and attached to something at either end.
3. Control rods that failed in tension overload usually mean they were O.K. and attached up to ground impact.
4. Control cables that have failed for, fatigue, corrosion, or electrical arcing are indicative of a pre - existing problem.
5. Pulleys that have their sides broken out in overload are indicative of a cable being in place during impact.
6. Pulleys dislodged from their brackets due to overload signify they were O.K. before impact and that a cable was in place at impact.
7. Pulleys that are lose because of fatigue failure, or corrosion is indicative of pre - existing failure.
8. All parts joined together by fasteners should be inventoried to determine that the fasteners were in place.
9. Tension overloaded damages at both extremities of a control system is some evidence that the system was intact during impact even though continuity can not be confirmed because of damage to the mid portions.

For each such inventory the investigator must rely upon the rigging control drawings or an identical aircraft as exemplar. When controls are the boosted variety then the inventory includes the condition of the hydraulic system, (see section on hydraulic analysis) its components and each flight control actuator.

Naturally, each inventory includes locating each and every flight control surface at the scene of the accident as well as all associated mass balance weights. (See section on midair separation and flutter) When the audit and inventory is complete on integrity of the flight control system and the component parts then an analysis may be attempted to ascertain the position of flight controls at impact. In practice these disciplines will be in progress simultaneously.

In aircraft where flight controls are moved by cables and bell cranks they are susceptible to movement upon impact, and determinations of what they were doing at impact comes about by discovering witness marks from the first impact.

When the controls are moved hydraulically there are better indications of flight control positioning at impact by determining actuator positions at impact. (see hydraulic section)

The investigator should check the cockpit indications to see that the system switches were in the hydraulic powered mode or in the emergency manual reversion mode. He should check for flight control status and warning lights by virtue of bulb analysis. (See light bulb analysis section)

Clues of positioning include:

a. If a control surface tore of in one direction it may have been off center in that direction at impact.
b. If a movable surface is trapped or wedged against an adjoining stationery part, the matching part may be some indication of the position at impact.
c. Stop deformation on one side of a movable control surface is some indication of position of control surface at impact.
d. If flight control cables show tension overload, then investigator should be aware that control surface may have be forced to move during impact and breakup. This phenomenon is cable pull through.
e. Sometimes there is bearing race deformation and witnessing that may help determine flight control position at impact.
f. In the hydraulic actuators, the amount of polished shaft exposed is indicative of position of flight control surfaces.
g. A single witness mark on the shaft external to the hydraulic actuator is indicative of flight control position at impact.
h. Multiple witness marks on the shaft of a hydraulic actuator is indicative of flight control surface position at impact as well as subsequent movement and impacts. The trick is to determine the first impact.
i. Internal to the actuator the moving piston may create witness marks to the first impact. Measurements will determine flight control position at impact.
j. Witness marks may be impressed on adjacent portions of flight control hinges at impact, and these may tail and otherwise abrade as the parts are forced to move during breakup sequence. Such marks are some evidence of position at impact and motion subsequent.
h. Paint smudging and abrasion may transfer between flight control parts and the adjacent stationery part.

TRIM SYSTEMS

Almost all airplanes utilize some device known as trim to relieve flight control pressures to zero for the flight condition encountered. An explanation:

For every regime of flight the forces on the flight control system are different. As the aircraft accelerates and goes faster the pilot must push forward on the stick to keep the airplane from climbing. Conversely if the pilot reduces power and the airplane slows down, the pilot must pull aft on the stick to keep it from losing altitude. In order that the pilot doesn't always have to hold some differing pressures on the stick for every flight conditions trim control is added to the system. The trim systems reposition a small flight tab or position the entire flight control system to a new trim neutral position. Once trimmed for the new flight condition, the pilot may let go of the flight controls and the airplane will continue the straight and level, or the trim for attitude.

Positioning the trim device accomplished electrically, sometimes hydraulically and sometimes manually. An investigator is always interested in determining the trim location at impact.

Most trim positions are normally close to neutral or zero. For instance several Boeing aircraft operate normally between about 6 degrees nose up and 1 degree nose up. Anything on extremes grater begs a question.

Uncommanded trim runaways have been known to be the cause of some aircraft losses. On some occasions when the primary system has been lost or jammed or restricted pilots have attempted to control the aircraft by trim alone.

In multi engine aircraft, a large rudder trim is indicative of control problems or loss of engine thrust on one side. Normally rudder trim is always zero.

The investigator is interested to determine trim position at impact since each pitch trim position, combined with weight and configuration is indicative of a trim neutral for a particular airspeed. If an investigator finds trim at its limits, he should be very concerned. The cockpit indication of trim position should equal that determined at the flight control.

SECONDARY FLIGHT CONTROLS

Secondary flight controls include flaps, spoiler / speed brakes, and leading edge devices.

FLAPS are devices that extend back and down from the trailing edge of a wing. They change the size and aerodynamic shape of the wing. The wing will produce more lift at a slower airspeed in this flap down configuration. The result is that the airplane will fly safely at slower airspeeds with flaps down. The flaps are used for takeoff and landing as well as approach speeds. Flaps should deploy symmetrically.
FLIGHT SPOILER/SPEEDBRAKES are incorporated on some aircraft to spoil lift on the top of wings and to create more drag. These panel when actuated as speed brakes come up symmetrically on the top of both wings. These devices are used to help an aircraft slow down from high speed and also to descend rapidly. They should always deploy symmetrically and they should never be used during takeoff, landing approach, or climb. (Only on descent and deceleration - go down, slow down)

LEADING EDGE DEVICES, FLAPS, SLATS are devices mounted along the wings leading edges. They deploy at the same time the flaps do and there function is comparable to the trailing edge flaps. These devices should deploy approximately symmetrically and they should deploy approximately simultaneously.

1. As part of the flight control audit the investigator should inventory all devices were at scene of accident. A loss of one or more of these devices can cause problems.
2. The investigator should attempt to determine and correlate cockpit handle position to flight control position indicators and warning lights.
3. The investigator should determine the position of each such device at the time of impact.

Clues as to position at impact:

a. Flaps are usually jackscrew devices and they remain where they were at impact.
b. Leading edge devices are usually actuators and so the shaft witness marks become important. Some are hydraulic motor driven and are jackscrew.
c. Spoilers are almost always deployed by actuators and the extension of shaft and witness marks on the shaft are indicative of position at impact.

LANDING GEAR

Landing gear makes it much easier for the pilot to taxi the airplane. In retractable gear aircraft accidents the investigator is often faced with whether the gear was up or down. The investigator looks at some very good indicators to determine this. The clues are:

a. In the cockpit he examines the gear handle for position.
b. He examines the gear indicator and associated lights.
c. He talks to witnesses.
d. He listens to tape to hear gear warning horn.
e. He looks at gear door locks, if broken they were up.
If they are not broken they were probably released.
f. He looks at gear up locks, if broken the gear was up.
If they are not broken they were probably released.
g If gear is in well they were up.

Flight Controls - Trim Tabs

An Investigator must not only determine trim tab or flight control trim mechanism position, he must know what it signifies.

If an aircraft always flew in the exact same speed, weight and configuration there would be no need for trim. This is not the case and with each change the airplane controls require the pilot to use differing exertion while applying control forces. For each change in flight condition, there will be a different force required on the controls to meet the dynamic changes.

THE FIRST RULE FOR AN INVESTIGATOR TO REMEMBER IS THAT ALL PILOTS ARE LAZY …and they do not like to do tiring work such as holding strenuous flight control positions. Luckily they don't have too since almost all airplanes are equipped with devices known as trim tabs or trim mechanisms. Regardless of what they are, and how they operate their purpose is to reduce the flight control pressures on the yoke so that the pilot can fly in a trimmed condition or "hands off ".

Trim systems come in a variety of designs that revolve around three basic concepts. Let us restrict ourselves to tail designs and pitch trim only. There are three common variants of design.

1. The most common is a fixed horizontal unmovable stabilizer, with a movable elevator and a trim tab that moves the elevator.
2. The next most common in general aviation is a flyable and movable horizontal stabilizer called a stabilator combined with a antiservo tab that is also a trim tab.
3. The last variety is a variant where the horizontal stabilizer is trimmable and the aircraft is equipped with regular elevators.

In each case, if the aircraft is equipped with hydraulic power boosting, the boosting aids the pilot manipulate the controls and not the trim. The trim is usually controlled manually or electrically.

When a system is sophisticated enough to incorporate an autopilot, the autopilot replaces the pilot in the flight control loop. For the sake of simplicity assume that the autopilot is a child flying the aircraft. Just like an adult the autopilot can fly the aircraft (manipulate the controls) and through the autopilots computer it can trim the aircraft as well. In either case the autopilot moves the same controls and same trim as the pilot would if he were flying.

All auto flight systems are designed such that they may be easily engaged and disengaged, and just as a pilot could overpower a child autopilots are supposed to be designed through clutch mechanisms so that they may be easily overpowered.

Most Trim actuators are of the variety that does not move during aircraft break up during ground impact. In some manner most are jackscrew design and therefore impervious to ground impact deformations. They usually remain where they were at impact and better yet they usually witness mark well. Therefore, most trim positions as found at impact are usually were commanded in flight.

Once weight, balance, power and configuration and altitude are known only one trim placement is correct for that condition. A finding of widely disparate pitch trim condition suggests an aircraft trim or autopilot problem in the pitch mode.

Disparate aileron trim may be indicative of stuck or failed spoilers or ailerons in the flight controls. In some aircraft it might mean unbalanced fuel or ordinance on the wings.

Excessive rudder trim may be indicative of engine failure, asymmetric thrust, yaw damper hard over, rudder hydraulic actuator hard over or engine reversal in multi engine aircraft. Aileron and rudder trim is always about neutral under normal conditions. Pitch trim is usually about zero at cruise speed, nose down at high speed and nose up for low speed flight.

Determining trim setting is a very important part of every investigation. The investigator must know how each system works and its normal rigging limits to derive full meaning from his findings. Flight test and simulator tests are very helpful in recreating the effect the trim would have on the aircraft.