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PILOT INTERFACE WITH FLY BY WIRE CONTROL SYSTEMS

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ABSTRACT. Aircraft designers are rapidly moving toward full fly by wire control systems for transport aircraft. Aside from pilot interface considerations such as location of the control input device and its basic design such as side stick, there appears to be a desire to change the fundamental way in which a pilot applies manual control. A typical design would have the lowest order of manual control be a control wheel steering mode in which the pilot is controlling an autopilot. This deprives the pilot of the tactile sense of angle of attack which is inherent in present aircraft by virtue of certification requirements for static longitudinal stability whereby a pilot must either force the aircraft away from its trim angle of attack or trim to a new angle of attack. Whether or not an aircraft actually has positive stability, it can be made to feel to a pilot as though it does by artificial feel. Artificial feel systems which interpret pilot input as pitch rate or G rate with automatic trim have proven useful in certain military combat maneuvers, but their transposition to other more normal types of manual control may not be justified.

INTRODUCTION. The purpose of this paper is to describe what may be a problem of pilot interfacing with fly by wire control systems. To do so it is necessary to describe some diferences between manual and automatic control of aircraft which explains the evolution of the problem and why some would so easily accept a change in the basic way a pilot flies an airplane. This paper should not be construed as an argument against fly by wire. It isn't. Rather, it is an argument for a fly by wire control system that interfaces with the pilot in a manner similar to current airplanes with good flying characteristics.

MANUAL CONTROL. During the evolution of the modern airplane many examples of unstable aircraft have brought considerable grief to their pilots. Consequently, the FARs and MILSPECs specify stability requirements for aircraft which produce a consistency of feel that pilots have learned to depend upon.

Perkins and Haig (1) clearly identified the fact that "...the airplane's speed is determined by the value of the equilibrium lift coefficient, while its rate of climb or descent is regulated principally through the throttle control." for climbing and descending flight. Others (2-12) agree and have expanded upon the conclusion that net thrust over drag defines climb/descent angle while angle of attack defines airspeed except that small temporary changes in angle of attack are required to make temporary changes in lift required to change an aircraft's inertial trajectory.

With static longitudinal stablilty, a pilot knows his aircraft will not diverge far from its trimmed angle of attack without his input which provides an important tactile feedback of angle of attack. If a pilot tilts the lift vector by banking, he can depend upon the fact that he will need to increase the angle of attack to increase total lift so that the vertical component will equal weight. Lateral stability requires that a pilot hold an aircraft into a bank. Increasing angle of attack tilts the lift vector aft increasing induced drag which requires an increase in thrust to maintain equilibrium. When induced drag is a large percentage of total drag (low speed flight), then larger thrust increases are required. Although pilots in flight do not analyze these factors any more than birds do, the above characteristics are ones that pilots have learned to depend upon. They make up the feel of an aircraft which a pilot learns to balance much like a bicycle rider rides a bicycle. Pilots do not have to know anything about the forces that make up this feel any more than a bicycle rider has to know why he doesn't fall off when he goes around a corner.

It is very important to understand how pilots interface with current aircraft. Primarily we fly with visual feedback of our control inputs which is complemented with tactil feedback. An example of a similar task is that of steering a car. A driver has immediate visual feedback of control inputs which are complemented by a tactile feel of the steering wheel because it is self centering to the straight line condition.

An airplane is controlled by a pilot in a similar manner. He has instant visual sensing of control inputs with a self centering action to the wings level, trimmed angle of attack, condition which can be climbing or descending depending upon thrust.

Concerning static longitudinal stability, MIL-F-8785C states "For levels 1 and 2 there shall be no tendency for airspeed to diverge aperiodically when the airplane is disturbed from trim with the cockpit controls fixed and with them free." and "Alternatively, this requirement will be considered satisfied if stability with respect to speed is provided through the flight control system, even though the resulting pitch control force and deflection gradients may be zero." Moorhouse and Woodcock in discussing the above (13) say "...it should be noted that zero speed stability removes an airspeed cue that pilots sometimes find valuable, particularly at low speed; and that automatic trimming has been known to lead to an insidious slowdown of some aircraft to stall when the pilot holds a small back force."

Despite the above, there have been many attempts to change these basic characteristics. Sometimes the flying qualities have been bad. Instead of improving the flying qualities, attempts have been made to aid the pilot by relieving him of some perceived workload such as holding a desired pitch or bank angle, thus removing the pilot from the control loop. Pilots generally do not fly by attempting to hold a desired pitch, but autopilots do.

AUTOMATIC CONTROL. The issue of instrument flight brings into focus the differences between manual and automatic control. Under visual meterological conditions with manual control, the pilot feels the balance of his aircraft better than under any other circumstance. Under instrument conditions the pilot is hampered by inadequate displays which do not give him the intuitive assessment of aircraft trajectory and position that occurs with visual reference and some improved instrument displays.

If it can be accepted that pilots generally have no problem flying manual approaches to very good landings under visual conditions, the obvious question is why can't they perform equally well under instrument conditions? The equally obvious answer has to be the difference in information presented to the pilots and how they interpret it. The primary reference for instrument flight is a gyro horizon which displays airplane bank angle and pitch angle. Pitch does not tell a pilot where the airplane is going. Under visual conditions he not only perceives pitch, but trajectory. When this vital information is provided to him in a intuitively assessable manner he begins to perform under instrument conditions similar to visual conditions.

Approach couplers were designed to fly in the manner of their parent autopilots, i.e., they waved the elevator up and down at the glide slope, leaving airspeed control to the throttles. Pitch command on flight directors was designed to tell the pilot to do what the approach coupler was doing.

As pointed out by Perkins and Haig (1) and others (2-12), If an aircraft is descending too steeply but at the proper airspeed, its basic need to correct its descent path is an increase in thrust with a temporary increase in angle of attack to temporarily increase lift to redirect the inertial vector. Thereafter it will fly at its newly defined descent angle at its trimmed angle of attack. An approach coupler will not function in this manner, but will instead increase pitch to some precomputed value dependent upon its glideslope deviation. Then the airspeed will decrease and the pilot or autothrottle will attempt to restore the airspeed, except it will take more thrust than is necessary for the stable condition and a subsequent change will have to be made. Direct lift control was invented to help the autopilot fly in this manner.

Pilots at first had difficulty using flight directors and approach couplers but they soon learned to anticipate the thrust changes that accompany the pitch changes and so came to accomodate the manner in which an approach coupler flies and a flight director directs. Autothrottles were not satisfactory until they incorporated pitch anticipatory circuits which told them ahead of time that the pitch was being changed so begin a thrust change in anticipation of the new requirements. Thus the automatic system learned to coordinate its inputs just like the accomplished pilot had been doing. Nevertheless, pitch changes which are adequate for normal conditions are very inadequate for the adverse conditions of strong wind shear (14).

Instrument displays with flight path angle and flight path command instead of pitch command provide the pilot with intuitive assessment of his trajectory relative to a desired value, an instant recognition of his departure from a desired flight path and the proper command to return. With a properly designed system it is not possible to center the flight path command unless the aircraft is actually correcting to the desired flight path at the desired rate. Such is not the case with current flight directors in the presence of strong wind shear. In addition, the difference between pitch and flight path angle is geometric angle of attack which is a highly desirable performance parameter.

The practice of providing superior information to an automatic system and leaving the pilot to monitor the performance of the automatic system is undesirable as humans are very poor monitors of automatic systems. An important causal factor in a recent accident (15) was the pilots' over reliance upon an automatic system to perform its intended function. A contributing factor was the very high workload the pilots were faced with. Automatic systems intended to reduce pilot's workload do not necessarily perform this function especially when they remove the pilot from the control loop (16). Automatic systems have advanced toward a goal of total automatic control of the aircraft while little attention has been paid to the needs of pilots to enhance their performance under instrument conditions with manual control.

STABILITY AUGMENTATION SYSTEMS. Stability augmentation systems can be used on any aircraft and can be as simple as a yaw damper. However, recently they have been incorporated with fly by wire automatic systems to enhance stability of aircraft which are inherently unstable. The major use has been for military aircraft but they are now being considered for commercial aircraft. With a fly by wire system it would be possible to tailor the aircraft response to pilot inputs in a variety of ways. For instance the aircraft could be tailored to respond like an aircraft which perfectly complied to the certification regulations. It could fly a trimmed angle of attack with an appropriate stick force gradient for deviation. Phugoid dampening could be incorporated if desired or the phugoid could be left as in conventional aircraft for the pilot to dampen.

Aircraft simulators are in fact fly by wire systems which have been designed to duplicate a particular aircraft's flying qualities, bad as well as good, and sometimes not too accurately. However, with a fly by wire aircraft it should be possible to have the aircraft behave very much like conventional aircraft. Unfortunately the fly by wire systems are being designed by the same people who formerly designed autopilots and there is an indication they think pilots should fly and think like autopilots. In fact there is some indication of a desire not to let the pilot have an aircraft with synthetic stability like a conventional aircraft but instead to have him control the aircraft through an autopilot. The lowest order of control that will be possible will be a control wheel steering (CWS) mode which removes the pilot from the feel of the stability (real or synthetic) of his aircraft. CWS uses the normal controls of an aircraft to make inputs to an autopilot instead of using separate turn knobs and climb/descent wheels. In this mode the pilot does not have the tactile feedback of centering to the wings level position nor the feedback of trim stability, i.e., a tactile feel of angle of attack. Trim is done automatically by the autopilot. This could cause serious problems under adverse conditions as well as transition problems to and from other aircraft.

One reason for the above may be the fact that designers are tending toward side stick control for transport aircraft, the avowed purpose of which is to open up space on the instrument panel. The primary reason for a side stick in military aircraft is for pilot control in high G maneuvers. If space on the instrument panel is the primary incentive for transport aircraft, a center stick would accomplish this objective as well as the broilly handles used by Boeing in part of their SST development, both of which are controllable with either hand. The side stick will not be easily controllable with either hand. That could be one reason some designers want it to act as an autopilot controlling device instead of a conventional control system.

In certain combat maneuvers such as bombing, straffing, fighter tactics, etc., it has been found desirable for military aircraft to use a control mode where the aircraft automatically trims. In these maneuvers the pilot usually has a Heads Up Display (HUD) with flight path angle and some type of flight path command. Even with automatic trim the control system can still exhibit the other characteristics of a conventional aircraft or it can act as an autopilot with control wheel steering.

CONCLUSION. New aircraft are being designed which do not comply with the basic certification requirements regarding stability. Automatic systems are being designed to cause the aircraft to meet the stability requirements, but there appears to be little concern from regulatory authorities to require such systems to provide a pilot interface similar to that which is inherent with aircraft having natural stability. The manufacturers apparently desire to change the basic manner in which a pilot interfaces with the control system. This objective has not been validated with sufficient research to prove the desirability from a piloting standpoint. Problems may occur with pilots transitioning to and from other aircraft; pilots will probably not want to give up the tactile feel of angle of attack and wings level centering which is present with conventional control systems; and automatic trim could be dangerous in low speed flight.

Research should be done with a variety of systems which should include at least one which attempts to duplicate the best current conventional control systems incorporated with improved instrument displays expected to enhance a pilots performance with current control systems. Also the use of a side stick with a conventional system (not CWS) should be validated; and if fouund objectionable, alternate solutions should be implemented.

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