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ACTIVE CONTROL TECHNOLOGY AND THE USE OF MULTIPLE CONTROL SURFACES

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SUMMARY

Needed criteria for active control technology applications in commercial transports are lacking. Criteria for redundancy requirements, believed to be consistent with certification philosophy, are postulated to afford a discussion of the relative value of multiple control surfaces. The control power and frequency bandpass requirements of various active control technology applications are shown to be such that multiple control surfaces offer advantages in minimizing the hydraulic or auxiliary power for the control surface actuators.

INTRODUCTION

There is a dearth of criteria to aid in the design of flight control systems for commercial transport aircraft which include active control technology (ACT) applications. Such criteria are necessary, however, to permit an orderly design development without fear of costly redesign, as might result from special conditions imposed after the aircraft design was committed to take advantage of ACT. The Federal Air Regulation for transport aircraft, amendment 25-23, sets forth a number of failure tolerance requirements for flight control systems. Paragraph 25.671(C) states, "the airplane must be shown by analysis, test, or both, to be capable of continued safe flight and landing after any of the following failures or jamming in the flight control system and surfaces... 1) Any single failure, excluding jamming... 2) Any combination of failures not shown to be extremely improbable, excluding jamming... 3) Any jam...unless the jam is shown to be extremely improbable, or can be alleviated." Paragraph 25.672 says, "If the functioning of stability augmentation or other automatic... system is necessary to show compliance with the flight characteristics requirements of this Part, such systems must comply with...the following: a) A warning...must be provided for any failure...which could result in an unsafe condition if the pilot were not aware of the failure... b) The design...must permit initial counteraction of failures...by either deactivation of the system...or by overriding the failure by movement of the flight controls in the normal sense... c) It must be shown that after any single failure...the aircraft is safely controllable...at any speed or altitude within the approved operating limitations..."

These regulations, while not known to be written with active control technology applications in mind, may well cover the subject. Certainly, ACT applications will not have less demanding requirements. Considerations of operational, maintenance and cost aspects of potential system redundancy approaches, necessary to meet these failure tolerance requirements, leads to the conclusion that split surfaces offer unique advantages in mechanizing many ACT applications.

POSTULATED CRITERIA

In the absence of specific regulatory requirements, failure criteria which are believed to be consistent with certification philosophy are postulated and presented in table 1. For each ACT application function the failure requirements for the flight control system, under the heading of Redundancy, are given for several different aircraft designs graded according to the consequence of loss of the ACT function. The failure requirements for the several ACT functions are considered minimum in each case, and are based on the assumption that only that ACT function is involved. In reality, it is difficult to visualize an aircraft designed to utilize only one ACT function; where more than one function is involved it is obvious that the more stringent redundancy requirement would prevail. It should be noted that a failure warning is given to the pilot at each failure level to meet the FAR requirements. It is assumed, in at least some cases, that the operating envelope would be restricted to some defined level following each indicated failure.

An aircraft employing a pure fly-by-wire control system (which is not considered to be an ACT application per se) requires extremely high reliability in the entire flight control system. Such aircraft will likely have no less than two fail-operate redundancy and, as such, might profitably employ ACT applications with only relatively slight increases in the control system complexity. Once the commitment is made to inalterably depend upon the functioning of the sensors, computers, actuators and control surfaces, it makes little difference to safety as to how uncontrollable or structurally sound the aircraft is without the control functions. (In such cases, restricting the operating envelope may be moot.) However, it is in such cases that the full benefits of ACT, in terms of reduced direct operating cost and increased return on investment, will be realized.

CONSEQUENCES OF MULTIPLICITY

The multiplicity of flight control components, channels and power sources to achieve the operational reliability required does not come without its price. The price is in terms of equipment, but it is also in terms of pre-flight tests to establish that there are no latent failures and in maintenance action required by actual failures or false alarms. An STI report, "TFX Handling Quality and Flight Control System Study" (AD 447909L) published in August 1963, is recommended as an excellent reference which "facilitates tradeoffs between potential competing mechanizations" of redundancy in automatic flight control systems. Included in this paper is a matrix of practical redundant mechanizations versus major operational and maintenance qualities. From the data given it is evident, assuming a control surface pulse can be tolerated as the result of switching after a failure is detected, that an active/standby

TABLE 1

ACT Application	Aircraft design such that loss of function results in:	Redundancy
Relaxed Stability	Undesirable handling qualities	Fail Soft
	Unacceptable handling qualities	Fail op/Fail Soft
	Uncontrollable	Fail op/Fail op
Maneuver Load Control or Gust Load Alleviation	Dynamic and static loads less than limit loads	Fail Soft
	Dynamic and static loads less than ultimate loads	Fail op/Fail Soft
	Dynamic and static loads greater than ultimate loads	Fail op/Fail op
Flutter Mode Control	Flutter predicted above V_D/M_D	Fail Soft
	Flutter predicted above V_C/M_C	Fail op/Fail Soft
	Flutter predicted below V_C/M_C	Fail op/Fail op
Fatigue Life Improvement	Fatigue damage rate increase	Fail Soft or Fail op/Fail Soft
Ride Quality Control	Undesirable ride qualities	Fail Soft
	Unacceptable ride qualities	Fail op/Fail Soft

approach offers significant reductions in the probability of complete failure as compared to triple channel configurations. Even more impressive, the mean time between maintenance actions due to actual failures and false alarms is reduced by an order of magnitude (assuming the same mean time between failures for like components in each case).

The use of split surfaces with active/standby actuator redundancy for each offers an additional feature, namely that uninterrupted operation is assured after any single failure. After any second failure, uninterrupted operation is also assured but with a one in three chance (or less) that reduced performance (authority) will result. The eventuality of a possible lower authority after a second failure may be accommodated by selecting the original authorities above actual requirements, adjusting system parameters after the original or second fault or possibly by operational restrictions after the original or second fault.

MULTIPLE CONTROL SURFACES

The use of multiple control surfaces for individual axes of an aircraft has a long history. Trim controls that are separate from the primary maneuvering controls, for example, is a concept that has been used for many generations; more recently, split controls such as upper and lower rudders and inboard and outboard elevators are not uncommon. There are a variety of reasons why multiple control surfaces have been used including advantage from consideration of auxiliary power demands, operational safety, manufacturing costs (particularly on large aircraft), and flutter characteristics, in addition to accommodating the flight control failure tolerance requirements. When used for failure tolerance reasons, the multiple control surfaces in any axis must be sized such that the total authority exceeds the minimum requirement by some margin. Otherwise, the whole philosophy is fallacious, being analogous to a multi-engine aircraft in which the loss of any one engine results in an inability to continue to fly. This raises the question of what is the minimum authority required. A quantitative answer is strongly dependent upon the aircraft configuration and which, if any, ACT applications are involved. Some general-trend type observations can be made, however, which bear on the use of split surfaces for ACT.

Consider the auxiliary power required for a flight control surface servo or actuator. If it is assumed that a constant pressure hydraulic power source is used, the peak power supplied is simply proportional to the flow demand.

$$\text{Power supplied} = K\, P_S\, Q$$

where K is a constant, P_S is the supply pressure and Q is the flow rate. For a given stroke actuator, the area of the actuator is proportional to the maximum hinge moment (assuming the acceleration forces are small). Flow is the product of actuator area times rate, or proportional to actuator area times surface rate. Thus

$$\text{Power supplied} = K_1\, \dot{\delta}_{max}\, H\, M_{max}$$

where K_1 is a new constant, $\dot{\delta}_{max}$ is the maximum surface rate and HM_{max} is the maximum hinge moment. If ω is approximately the maximum frequency (in radians per second) at which the control surface in question must respond with some maximum deflection δ_{max}, the power supplied expression may be written as

$$K_1 \; \omega \; \delta_{max} \; HM_{max}$$

(Please note that HM_{max} and δ_{max} typically do not occur at the same flight condition.)

Qualitative values for the factors in this expression are presented in table 2 and have a number of implications. As a reference point, the "bandpass" frequency factor (ω) is shown as "low" and the maximum "control power" factor ($\delta_{max}HM_{max}$) is shown as "high" for the basic maneuvering of the aircraft. The corresponding hydraulic power (P) is the power required assuming no stability or control augmentation. Designing the aircraft with relaxed stability and restoring this stability with augmentation results in a higher required bandpass, although the authority required for the augmentation function may be somewhat lower than that required for the basic maneuverability. The peak hydraulic power for the augmentation function alone is higher than that for the actuation system to drive the baseline control surfaces. In many current aircraft, the control surfaces for these functions are one and the same, with the result that the peak hydraulic power is greater than the reference "P." In view of the power requirements (and compatability of bandpass requirements), it is not uncommon that relaxed stability, fatigue life improvement, and maneuver load control form a set of ACT functions which are considered together.

When ride quality control and gust load alleviation are considered,particularly where the higher frequency gusts are significant, the bandpass and peak hydraulic power requirements are considerably increased. These two ACT functions make another logical set. The bandpass requirements for flutter mode controls, except for isolated or specifically contrived cases, are relatively very high with the result that this ACT application stands alone. It is evident that gust load alleviation and ride quality control, and flutter mode control applications, are prime candidates for dedicated control surfaces. If a single control surface, with its high control power, were used for basic maneuvering and for an ACT function with a high or very high bandpass requirement, the peak hydraulic power demands for the actuators would be extremely high. As indicated by the control powers needed for the ACT functions in table 2, the use of smaller or partial control surface authorities can meet these needs, minimize the hydraulic power required, and minimize the effects of surface pulses or even a hard over, as might result in a failure or multiple failure condition.

One possible flight control design approach suggested by multiple control surface considerations would utilize a set of three-axis multiple control surfaces, with the possible addition of direct lift and side force controls, for maneuvering the aircraft either by the pilot or autopilot. Stability augmentation, maneuver load control and fatigue life improvement functions can conveniently use part of these multiple control surfaces. The servo actuators for those surfaces which are used for stability augmentation or fatigue life

TABLE 2

	Bandpass	Control Power	Auxiliary Power
Basic Maneuvering	Low	High	P
ACT Function			
Relaxed Stability	Medium	Medium	$>P$
Maneuver Load Control	Low	Medium	$<P$
Gust Load Alleviation	High	Medium	$\gg P$
Flutter Mode Control	Very High	Low	$\gg P$
Fatigue Life Improvement	Medium	Medium	$>P$
Ride Quality Control	High	Medium	$\gg P$

improvement require a higher bandpass than the maneuvering control surfaces actuators. But by using only a portion of the maneuvering controls for these purposes, the hydraulic power demands are significantly reduced compared to a non-multiple surface design.

If the ACT functions of ride quality control and gust load alleviation are added, they might also use portions of the basic maneuvering control surfaces but separate, "dedicated," surfaces located more optimumly would likely be desirable from a system weight and power demand standpoint. The desired location and required high-frequency response of control surfaces providing flutter mode control will, in all likelihood, necessitate separate dedicated surfaces for this ACT function. In any case, the possible use of any "dedicated" control surfaces as ultimate backups to the basic maneuvering controls is an attractive possibility.

The "fullness of time" for ACT applications has arrived. Improved aircraft efficiency in meaningful measures can be achieved and the use of multiple control surfaces can contribute significantly to this achievement without compromising safety or creating a "hanger queen."