Active Control Transport Design Criteria

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Abstract

THE question of design criteria for active control aircraft is one of the key issues involved in the design effort. If sufficient benefits are to be realized, in terms of decreased weight, reduced fuel consumption, increased performance, etc., applicable design criteria must be established which take into consideration the design improvements derived from the presence of active control systems. In this synoptic we discuss briefly the definition and background of active control technology, and then cover some of the functions contemplated for active control systems. The various design criteria for each will be discussed, and the subject of government regulations affecting aircraft design will be touched upon briefly. This synoptic summarizes the work presented in Ref. 1.

Contents

Active Control Technology (ACT)

There is a question of just what constitutes an active control aircraft. Several designations for this type of aircraft have been used (fly-by-wire, CCV, etc.), but an aircraft utilizing active controls can, in general, be identified as one in which significant inputs (over and above those of the pilot) are transmitted to the control surfaces for the purpose of augmenting vehicle performance. These inputs, derived from various sensors and properly processed, can be utilized to provide reduced trim drag and tail area through stability augmentation, to reduce structural fatigue, to alleviate maneuvering loads, to suppress flutter, and to improve ride comfort. If applied in a meaningful manner early in the vehicle design, ACT can have a significant impact on vehicle weight and geometry, thus leading to the designation of a control configured vehicle (CCV). Most of the immediately available active control techniques have been well explored theoretically and, in fact, have been and are being demonstrated each day on a wide variety of experimental, commercial, and military aircraft. This demonstration experience is illustrated in Table 1.

The important conclusion to be drawn from this table is that when discussing active control technology, one is dealing with a technology which in some cases is well advanced, including operational experience on in-service aircraft. If one compares this to the introduction of jet engines on aircraft, one would conclude that the state of readiness of active controls approaches that of jet engines at the time they were introduced into commercial aircraft. It is important to note, however, the disparity between the status of various functions. For instance, the yaw damper has many thousands of transport flight hours behind it. On the other hand, flutter control is only in its infancy. This leads to the conclusion that one must approach active control technology not as an all-inclusive blanket addition to an aircraft, but in a step-by-step procedure with each new subsystem being carefully verified on the basis of cost effectiveness, need, and reliability.

Design Considerations and Regulations

Key elements in bringing ACT to the point of commercial application are 1) demonstration of benefits which justify ACT, 2) availability of proven design criteria, 3) availability of proven design practices to guide the combined application of ACT functions, and 4) limitations on ACT applications imposed by regulations. Design criteria are derived from many sources. Perhaps the most important are the manufacturer's experience and design philosophy. Studies performed or financed by NASA and DOD provide a large fund of suggested criteria and data which the designer uses in selecting his criteria for application.

The new generation of ACT functions will require more rigorous computation and demonstration of reliability (improbability of catastrophic failure) than those in use. There are systems on current aircraft which must not fail if controlled flight is to be maintained. These are designed such that complete loss of function in a short period of time is extremely unlikely. Further, these systems generally do not reduce structural capability under normal flight conditions. Some proposed ACT functions will, in effect, replace primary structure. This does not necessarily mean that these functions must be as reliable as the basic structure, however. An assessment of situation severity and a list of means available for reducing risks presented by failures in ACT functions are given in Table 2. There are three principal means of controlling the risk: control system redundancy, actuation and/or surface authority distribution, and reduced operating envelope.

While safety is often equated with reliability, there is another important aspect to this subject: dispatch reliability. A typical design goal for dispatch reliability is that, mechanically, the aircraft shall be capable of departure within 15 min of the scheduled time 99% of the time. This goal is very stringent and is currently being achieved consistently by only one transport aircraft, the DC-9. The design of this aircraft emphasized simplicity and reliability, whereas the design of later aircraft has emphasized performance, with a resulting increased complexity. As ACT systems are introduced that are dispatch critical, continued improvement of built-in test equipment (BITE) and trouble-shooting means will be required to quickly pinpoint and correct faulty system elements.

Design criteria for flight characteristics, or flying qualities, seem to be in good shape, judging by pilot acceptance of the wide body jet transports. However, it should be realized that most criteria in general use were derived 10 years ago or more. While most of the basic criteria are expressed in terms of conventional open-loop characteristics, many can be applied to ACT aircraft. Much more work has been done on pilot-model-in-the-loop criteria, which generally do not require such conventional modes of control and response.

Active control technology can change the external load levels and stiffnesses for which the structure is to be designed. Active controls will change the magnitude, distribution, and frequency of occurrence of the loads for which the structure is designed. Other areas affected include the selection of critical

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Table 1 ACT function application experience

ACT function	Aircraft	State of readiness	Payoff and trade data	System mechanized	Flight tested	Operational experience
Relaxed inherent stability augmentation	Military	—	—	—	—	→
	Experimental	—	—	—	→	
Center of gravity control	Military	—	—	—	—	→
	Commercial	—	—	—	—	→
Ride quality control	Military	—	—	—	→	
Yaw damper	Military	—	—	—	—	→
	Commercial transport	—	—	—	—	→
Maneuver load control	Military	—	—	—	→	
Gust load control	Military	—	—	—	→	
	Commercial transport	—	—	—	—	→
Fatigue damage control	Military	—	—	—	—	→
Flutter control	Military	—	—	—	→	
Envelope Limiting	Military	—	—	—	—	→
	Commercial transport	—	—	—	—	→

Table 2 Degraded situation severity and means available for modifying risks presented by failures

Function	Severity of situation with function degradation	Means available for modifying risks presented by failures
Relaxed inherent stability augmentation	Moderate–Very	Redundancy + Authority distribution Reduced operating envelope CG management
Load control		
Maneuver	Negligible–Moderate	Redundancy + Authority distribution Reduced operating envelope
Gust	Negligible–Moderate	Redundancy + Authority distribution Reduced operating envelope
Fatigue damage	Negligible	Reduced operating envelope
Flutter control	Very–Extreme	Redundancy + Authority distribution Reduced operating envelope
Ride quality control	Negligible–Moderate	Redundancy + Authority distribution Reduced operating envelope
Envelope limiting	Negligible–Moderate	Redundancy Reduced operating envelope
CG control	Negligible	Reduced operating envelope

conditions, calculation of external loads, both steady-state and dynamic, and flutter characteristics. However, it is likely that present structural design criteria can be applied largely unchanged to the next generation of aircraft. Most of the present maneuvers, load factors, gusts, safety factors, and flutter margins will be satisfied with the active systems operating.

The active control system will be demanding on control system components which are subject to wear. Because of the higher gains required by the active control system, control system components will have to meet tighter specifications, and remain within these specifications throughout the useful life of the control system. This may require new design criteria for components such as hydraulic valves and actuators whose phase and gain characteristics are affected by wear. It will also require tighter tolerances on control system bearings in order to prevent low-amplitude, fatigue causing, limit cycle oscillations. At the same time, the automatic controllers must handle out-of-tolerance conditions. These conditions can occur due to manufacturing tolerances, aging, wear, material failures, off-nominal power supplies, and dynamic characteristics caused by changes in environmental conditions. It is expected that digital implementation will improve the end-to-end tolerance problem significantly.

Conclusions

It is clear that a great deal of work remains to be done in the area of detail design criteria and design practice. It is also apparent that the overall improvement that can be achieved by going to active controls is, with but a few exceptions, not being held back by current regulations and basic design criteria. The area where the most work needs to be done is in the detail design criteria of the control system itself. The problems center on the derivation of reasonable criteria for the design of advanced flight controllers. Other problems are the achievement of the reliability goals and production of hardware which can be maintained and manufactured at costs comparable to the rest of the aircraft critical components. The determination of the relative magnitudes of inherent vs augmented qualities may then be the result of minimum operating cost trade studies. As this work progresses, more ACT functions will be proven both reliable and practical, and will be incorporated into advanced aircraft designs.

References

[1] Harris, R.B. and Rickard, W.W., "Active Control Transport Design Criteria," Douglas Aircraft Co., Long Beach, Calif., Douglas Paper 6663, April 1978.