

AUTO CONTROL . . .

achievement of very high reliability in automatic systems. The main attack has been to use selective and integral redundancy and, when aircraft safety is continuously involved, to multiply the systems as well. Another way of achieving failure survival is to use alternative or dissimilar systems redundancy. The different systems forming the failure-survival combination may not be capable of the same performance, but the design criterion is fail-safety by failure survival and not necessarily the maintenance of full performance.

An interesting example of this technique in VTOL is lift unit failure-compensation. A number of current multiple-engine VTOL designs have lift units outboard in wing pods where a failure may induce a large rolling acceleration of the order of 0.5 rad/sec^2 , producing a bank angle of 20° in the order of $1\frac{1}{2}$ sec, and sideways slip as well. If such aircraft are to be operated in IMC weather

engine in the group. The actuator is series connected to the group throttle control runs and compares jet-pipe pressures of the individual engines. A thrust reduction in any one engine below a predetermined norm will initiate an increased thrust demand from the whole group by moving the throttle control runs. The actuator, one form of which is illustrated in Fig 13, can be made fail-safe in action, and is automatically locked out of operation until all engines are started. Preliminary discussions with engine designers indicate that the operating requirements can easily be met from pressure tapplings on lift units now being developed. This pneumatic device is completely independent of electrical and hydraulic supplies and can be made very reliable.

It is clear that in operation a GTC cannot completely compensate for all the moment and force unbalance resulting from a drastic engine failure, but it alone can make the pilot's correction task acceptable. For

ously described will give some assistance which may in many cases be adequate. But where high gains are necessary in terms of thrust change versus thrust lost, and where high response rates are required, either accelerometers alone, or accelerometers and thrust sensors on the engines themselves must be employed and the signals computed accordingly to give corrections via the automatic control system.

Acceleration inputs must normally be used in fairly low-gain control loops to avoid structural flexibility problems, but they are sometimes required for stabilization in high stiffness VTOL control systems, and also to alleviate the more severe gust disturbances, especially in the transition stages. Thrust sensors, on the other hand, can give very high-gain correction demands for lift-engine failure compensation as they can be made insensitive to vibration and flexibility problems. They can also allow immediate correction for any thrust asymmetry produced by hot gas ingestion or variable engine performance characteristics and so provide an equivalent, but much lighter and simpler solution to this problem than cross-connected hot-gas ducting. In fact a complementary combination of thrust and acceleration information can give a very high performance capability.

In the Elliott control system the thrust and acceleration sensors and vertical gyro (or inertial platform) outputs are fed to a force and moment computer, which applies appropriate balancing demands differentially to the aircraft automatic-control actuators. The thrust sensors are pressure capsule devices, which give error outputs from the instant at which the force and moment control system is engaged. Although the thrust sensors are temperature stable, long-term accuracy of thrust measurement is unnecessary.

During transition, aerodynamic forces and moments additional to those measured are allowed for by programming the gains of the various force and moment error signals. The Force and Moment Computer, engineered on exactly similar lines to the electrical signalling computer described before, is illustrated in Fig 14. Various combinations of Group Thrust Compensators, Force and Moment control systems and autostabilization can meet various reliability, safety and performance requirements. An example of a VTOL rate-demand control system with autostabilization, engine balancing and automatic engine failure compensation is considered below.

The layout of a hypothetical VTOL control axis having an aerodynamic surface, a group of engines which can accept thrust modulation and a bleed-air nozzle control is shown in Fig 15. It incorporates a realistic combination of the controls previously discussed, but does not represent any particular control axis of any known or projected aircraft.

In the manual control mode in wing-borne flight, lock A is disengaged and the control surface can be operated by the pilot through the mechanical linkage. Autostabilization can be added through the series actuator on the powered control, and its demand will not appear on the pilot's control, mainly because of the resistance of the artificial feel unit. Large-authority

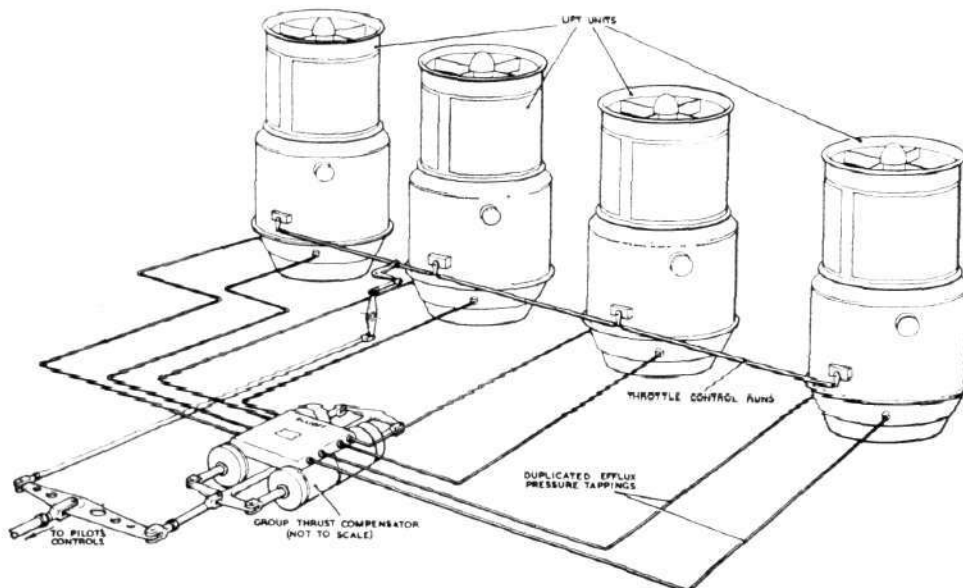


Fig 13 Installation of the Elliott Group Thrust Compensator

the pilot may find recovery difficult if not impossible. In fact, such aeroplanes will be expected to be as safe as conventional aircraft and no actions by the pilot should have to be more precise, rapid or complex.

The problem then is to design an automatic correction system which has adequate authority but will not by its own failure produce more than a small fraction of the effect of an engine failure. It has often been suggested that the solution to this engine failure problem is automatically to cut the symmetrically opposite engine, at the same time increasing the thrust of the remaining engines. This unfortunately means wasting the power of one good lift unit and involves a rather complex auto-control arrangement.

A much better solution (if there are adequate thrust margins), is Group Thrust Compensation (GTC), in which each group of lift units—where each unit has roughly the same roll-control moment arm—has a small pneumatic actuator to which are connected pressure tapplings from each

example, simulation has shown that an aircraft which reached 20° of bank in $1\frac{1}{2}$ sec following a standard pattern of engine failure, would roll only 3° in $1\frac{1}{2}$ sec or 20° in 6 sec with GTC. Adequate operation of such a device depends of course on there being sufficient reserve thrust and this is assumed to be an overall aircraft survival requirement. In certain cases GTC provides a very economical solution to the problem of unbalance following engine failure. It may obviate the need for large numbers of small lift units intended to make one failure insignificant, or avoid the use of high-powered correcting nozzles with excessive bleed-air requirements, ducting, larger engines and so on.

Force and Moment Control

Following the dissimilar redundancy technique, GTC can be supplemented by more complex dissimilar methods allowing automatic full balancing following an engine failure, namely, Force and Moment Control. The autostabilizer systems previ-