ELLIOTT

THE CONCORDE
AUTOMATIC FLIGHT CONTROL SYSTEM

DOCUMENT No. 280TP 375.

THE CONCORDE AUTOMATIC FLIGHT CONTROL SYSTEM

by B. S. WOLFE
DEPUTY CHIEF ENGINEER

TRANSPORT AIRCRAFT CONTROLS DIVISION
ELLIOTT BROTHERS (LONDON) LTD
AIRPORT WORKS - ROCHESTER
KENT - ENGLAND

Telephone: MEDWAY 44400 - Telex: 96118

INDEX

LIST OF FIGURES

SUMMARY

This paper represents a review of the status of the automatic flight control systems at present being developed by the Consortium of Elliott, SFENA and Bendix. Elliotts were selected as prime contractor and have worked continuously with SUD Aviation and the British Aircraft Corporation. The present advanced development state of these systems is a tribute to the skill and determination of the combined Anglo-French-American project teams.

THE CONCORDE AUTOMATIC FLIGHT CONTROL SYSTEMS

1. Introduction

The Concorde Automatic Flight Control Systems (AFCS) have been developed over the period of the last three years from initial specifications prepared by SUD Aviation and B.A.C. Since that time a great deal of technical development has taken place both in England and in France resulting in certain modifications, but the basic system configuration has still been maintained.

The AFCS shown in figure 1 comprises the following main sub systems:

1. Autostabilisation (Three Axis)
2. Autopilot
3. Electric Trim (Pitch Axis only)
4. Autothrottle
5. Flight Director (Excluding Instruments)
6. Take Off Director (Excluding Display)

The whole AFCS is controlled from two control panels one being: the autopilot/flight director/autothrottle panel while the other is the autostabiliser/electric trim/feel system engage panel. The feel system engage switches were included in the latter panel in order to simplify the pilot operational problems even though the feel system is not part of the AFCS.

Looking back, three major specification requirements initially illustrated that the Concorde AFCS was taking the art of civil automatic flight control one step further ahead. The requirements were:

1. System MTBF
2. System Probability of Failure
3. The use of micro-electronics

There have been several revolutionary inovations since, but in my opinion the above three requirements have never before been specified so exactly in a civil application.

It was clear also that operational criteria such as weight, system reliability and minimum system maintainability costs, were likely to be extremely critical factors in the achievement of the Concorde operational requirements.

The achievement of minimum system weight is clearly desirable from a civil operator viewpoint since he will be able to carry more payload. System MTBF will also

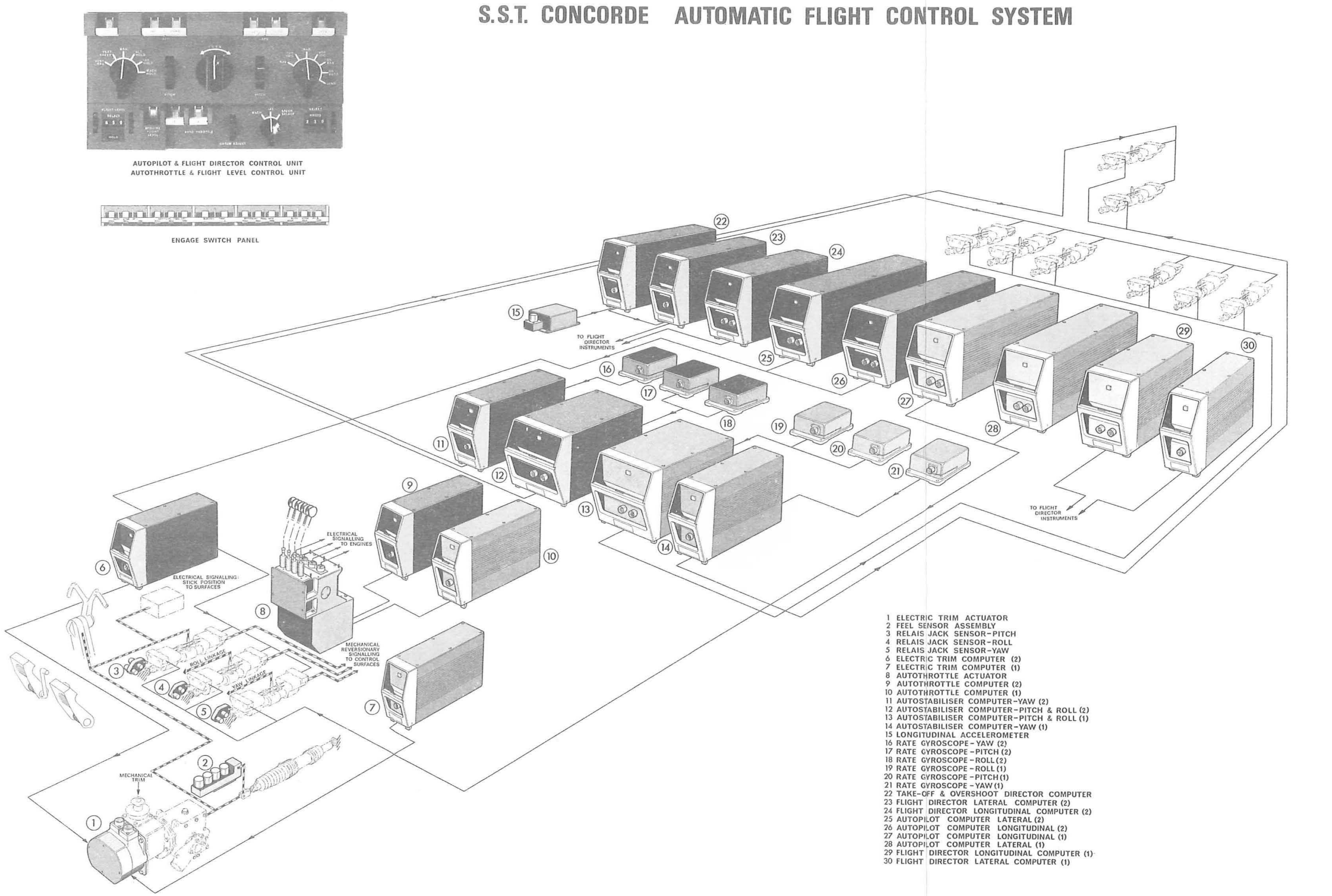


FIGURE 1
GENERAL LAYOUT OF THE AUTOMATIC FLIGHT CONTROL SYSTEMS (A.F.C.S.)

greatly affect the operator, since it is this parameter which fixes the spares holding and spares location requirement, the number of times a system is likely to cause unscheduled delays in service and thereby the maintainability cycle.

A system reliability requirement is specified in the case of the auto-stabiliser, autothrottle and electric trim systems over a critical time of 3 hours. The autopilot has also to meet the certification requirements over the last 30 seconds during an automatic landing.

Clearly these reliability targets in the case of the first three systems, are associated with aircraft handling qualities and to some extent safety, whereas the automatic landing requirement is a mandatory and internationally recognised safety requirement.

The present AFCS specification includes definite clauses related to system configuration, modes of operation, performance, monitoring, method of type approval testing and specified flight cases for theoretical studies. Relevant data for use during such studies is also specified.

Careful attention has also been paid to the attainment of the joint Anglo-French requirements regarding system performance and inspection as specified in the applicable T.S.S.Standards.

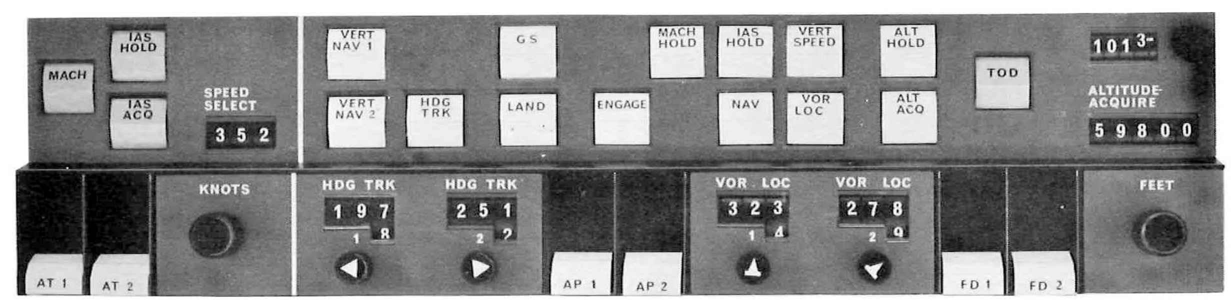


FIGURE 2
AUTOPILOT/FLIGHT DIRECTOR/AUTOTHROTTLE CONTROL PANEL
(PRE-PRODUCTION)

2. THE CONTROL PANELS - AUTOPILOT/FLIGHT DIRECTOR SYSTEM PHILOSOPHY

The Autopilot/Flight Director and Autothrottle panel is shown in Figure 2. This configuration represents the latest thinking of BAC, SUD, the potential airline operators and Elliotts. A great deal of discussion and thought has taken place and many of the operational considerations have come from pilot opinion. As many of us know pilots often are not unanimous in their opinions and add to this the opinions of 10 to 15 potential operators, we could have easily concluded our investigations with recommendations for a multitude of panels.

The present panel is the one most likely to be incorporated into the pre-production aircraft and it has taken into account many of the "operational work load" problems that have recently been studied.

For the prototype, the panel shown in Figure 3 has been manufactured and in its conception much thought was given to the problem of maintaining flexibility, in order to be able to evaluate all the potential autopilot modes of operation.

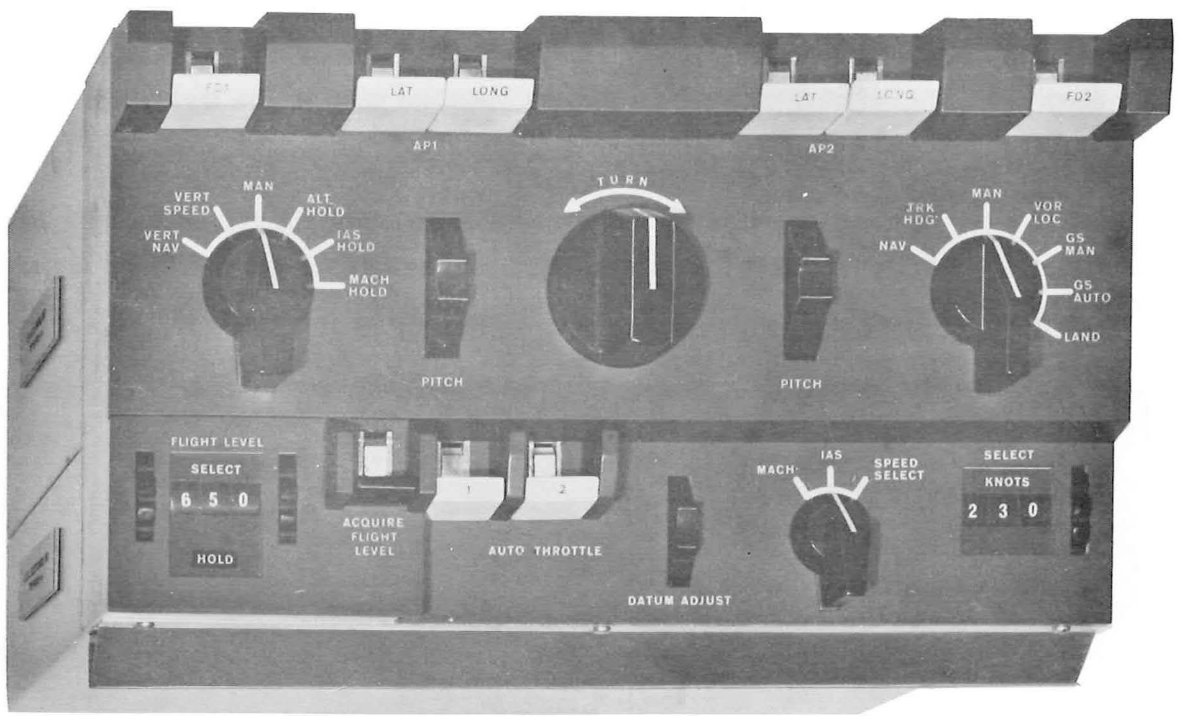


FIGURE 3
AUTOPILOT/FLIGHT DIRECTOR/AUTOTHROTTLE CONTROL PANEL
(PROTOTYPE)

The major difference between the two panels is the adoption of 'push-button' mode selection. This approach has been discarded on many occasions prior to the present day since it was considered that, for safety, it is mandatory to be able to mechanically disconnect a mode in the event of a failure. It is clear that a push button could easily 'jam' in the engaged position and thus preclude physical disengagement.

Additionally the turn and pitch manual controls have been resited separately on the pilots pedestal of the pre-production aircraft.

The adoption of integrated logic interlock circuitry has enabled the design of reliable "lock out" circuits which will disengage a failed mode even in the event of a mode selector jam. The subsequent engagement of the mode would also be precluded.

Both controllers have common autopilot/flight director mode selectors, the engagement of either the autopilot or flight director being made by separate solenoid held engage switches.

For the prototype, separate pitch and azimuth engagement of the autopilot and flight director was specified but it will be seen that this feature has been rejected for the pre-production aircraft.

Similarly the incorporation of a duplicated autopilot has also been confirmed for the pre-production aircraft whilst the necessity of two flight directors is still being discussed. One consideration that is greatly affecting the system configuration is whether to feed the flight director instruments from combined autopilot/flight director computers, thereby saving weight and improving maintainability. However, several operational problems have to be resolved, particularly those associated with the landing phase.

The autothrottle panel is included as a part of the autopilot/flight director control unit and engagement of both parts of the duplicated system is facilitated by solenoid held engage switches.

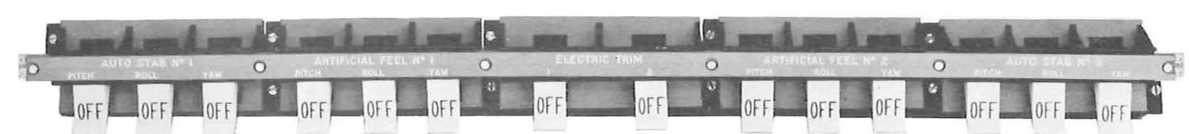


FIGURE 4
ENGAGE SWITCH PANEL

The combined autostabiliser, electric trim and feel system engage switch panel is shown in figure 4 and contains the 14 engage switches required for engagement of the above systems.

3. ELECTRONIC CIRCUITRY AND PACKAGING PHILOSOPHY

In adopting an electronic circuitry philosophy employing micro-circuits a new approach to the electronic circuitry had to be developed.

The approach at the outset was to analyse the various computing functions normally employed in an autopilot and attempt to procure micro-circuits from manufacturers interested enough to produce the new circuit functions.

It was considered that about ten circuit functions would be required, including a basic analogue computing amplifier, an analogue switch, a comparator, etc. but it soon became evident that the micro-circuit manufacturers were not interested in developing and manufacturing these custom built circuits in the comparative small quantities that were required. It became evident that the best approach was to select a number of basic circuit functions that were already being produced in large quantities at economic prices and use these circuits in developed configurations to suit the particular needs. Thus, a complete range of fundamental analogue circuits was developed using a Fairchild μA709 micro-circuit as the basic circuit element. In addition all logic circuitry was designed to employ Fairchild micro-logic in standard configurations.

Additionally one or two more complex circuit functions were developed such as a digital integrator having a time constant of up to 60 seconds and excellent storage capabilities.

The next problem was to develop a packaging approach which was compatible with the system requirements for facilitating optimum removable circuit blocks. The selection of the dividing lines between each part of the system had to be carefully assessed, based on minimum tolerance build up. Additionally the packaging had to allow easy access for circuit block removal and finally servicing at a component level i.e. the throwaway part was an individual electronic component.

The circuit blocks tended to contain a much larger number of parts performing a bigger electronic function than had been experienced previously. Up to 80 lead outs from a particular circuit became a requirement. Furthermore, printed circuits were to be employed for interconnection and mounting of the components.

The optimum board size approached 6" x 4" and it was evident that the printed circuit board connectors available would not meet the stringent operational requirements allied to reliability in the field. Also it was doubtful if a connector of the dimensions compatible with size of board would incorporate the required number of connections. Additionally

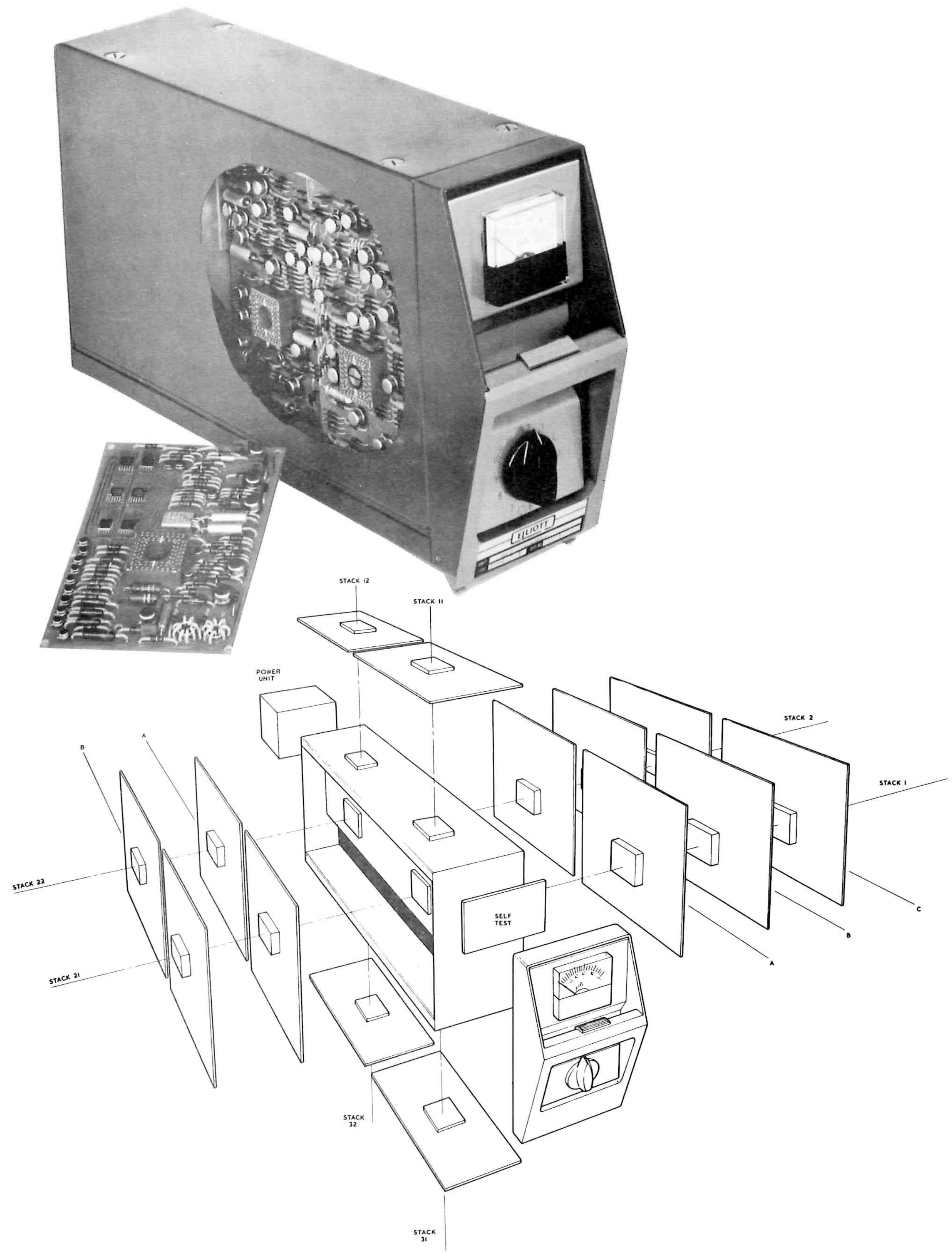


FIGURE 5
A.F.C.S. COMPUTER

it was evident that all connections could simply not be brought out from one side of the board.

Hence it was decided to employ a "centre connector" and this was mounted onto a board as shown in figure 5.

The packaging of a typical electronic box is also shown in figure 5. The box has been carefully designed and employs the novel feature of a central I-section which forms the main structural element of the box and maintains complete physical isolation between the command and monitor sections of the computer.

All of the AFCS boxes incorporate internal test circuitry which forms an interface between a central digital computing facility. It is intended eventually that all the avionics on the Concorde will be automatically checked out in order to minimise the "turn-around" times en-route. A target turn-around time of 35 minutes has been set.

4. SYSTEMS PHILOSOPHY

4.1 General Layout of Flying Controls

The general layout of the flying control system is shown in figure 6. The Autopilot, Autostabiliser and Electric Trim inputs are also shown.

4.2 Autostabilisation System

The Autostabilisation System is contained in four boxes.Two boxes contain the pitch/roll axis computing whilst the other two boxes contain the roll computing. The Autostabiliser boxes house the flying control electrical signalling amplifiers.

Each Autostabilisation Axis is fed from two rate gyros. The layout of one axis of autostabilisation is shown in figure 7.

Each channel is monitored by placing comparators at specific points and signal consolidation introduced to minimise the signal chain tolerances.

It may be seen that any failure in any part of the computing chain will be detected and cause a changeover from one part of the computing to the second redundant.

The probability of loss of one complete axis of the autostabiliser is less than 10^{-5} over 3 hours.

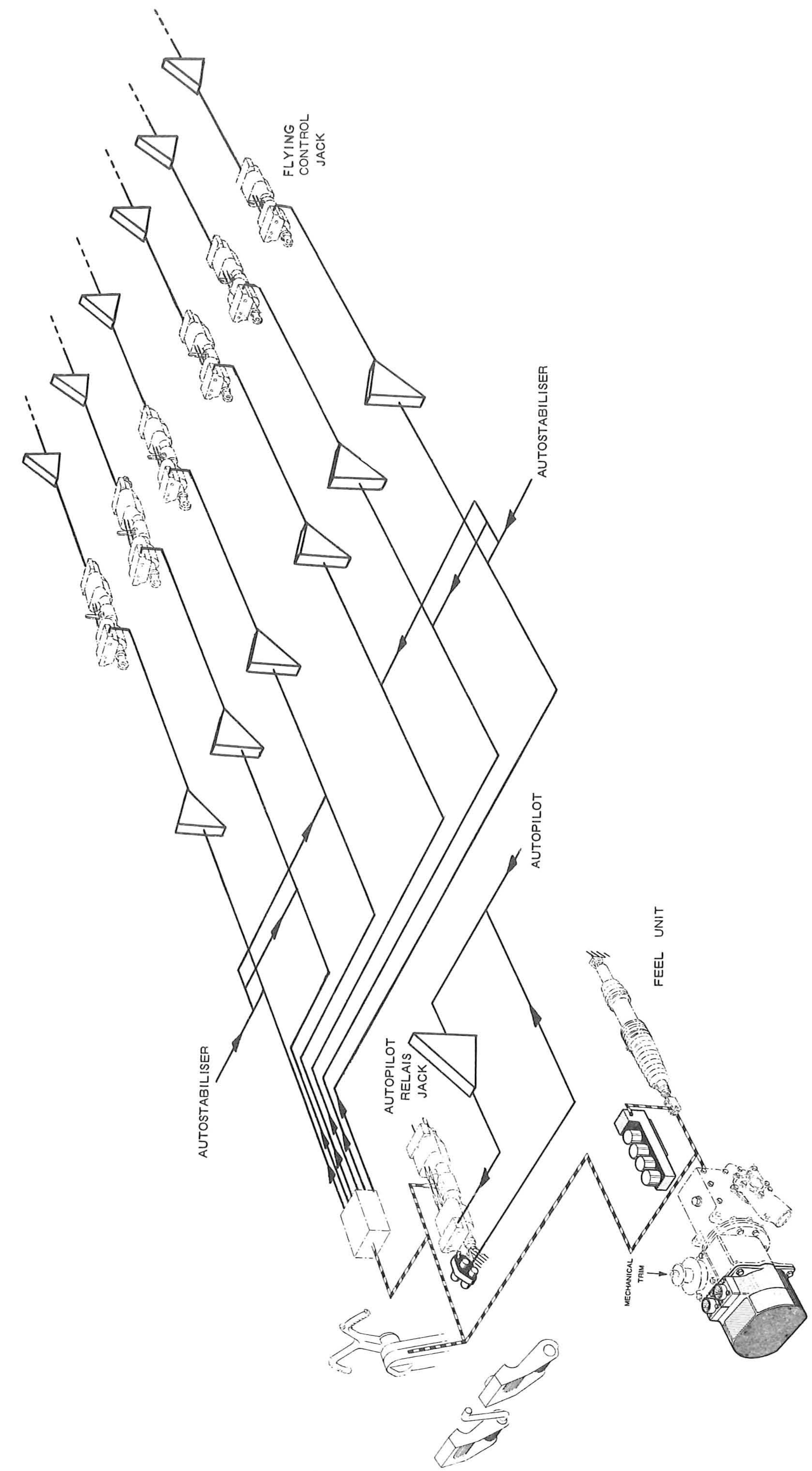
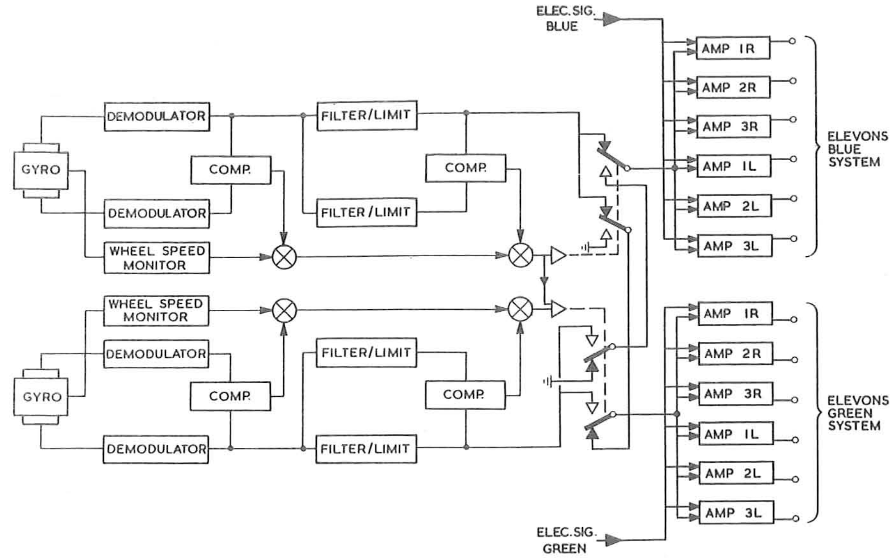


FIGURE 6
SIMPLIFIED DIAGRAM OF ELEVON (PITCH) FLYING CONTROL SYSTEM



REVISED FIG.7.
280 TP 375

BLOCK SCHEMATIC OF ONE AXIS OF THE CONCORDE AUTOSTABILISATION SYSTEM

4.3 The Autopilot

The block diagram of the autopilot is shown in figure 8. It will be noted that the azimuth channel (roll and yaw) is contained in one box and the pitch channel is another separate box.

All the sensor inputs are illustrated and it has been assumed in the system design that all sensors are self-monitored, i.e. capable of detecting a failure within themselves.

The autopilot modes can be interpreted by reviewing figure 2 and it may be seen that it is intended to employ the autopilot throughout the flight time. Certain modes such as height acquire may be preselected to enable the pilot to closely follow his flight plan or traffic control instructions.

The Autopilot is fully monitored in order to ensure maximum passenger comfort and safety. The Concorde will incorporate two autopilots in order to achieve maximum autopilot reliability under cruise conditions i.e. the probability of a pilot having to take off without a serviceable autopilot is very small. Additionally the presence of the two autopilots allows the attainment of the certification authorities requirements for use of automatics during landing. The autopilots will be used in a duplicate monitored configuration along the lines already established on the VC-10 aircraft. Some form of head down situation display has been envisaged but for the prototype this display has been limited to a sequence and serviceability state indicator. A dynamic display is being considered for the pre-production aircraft.

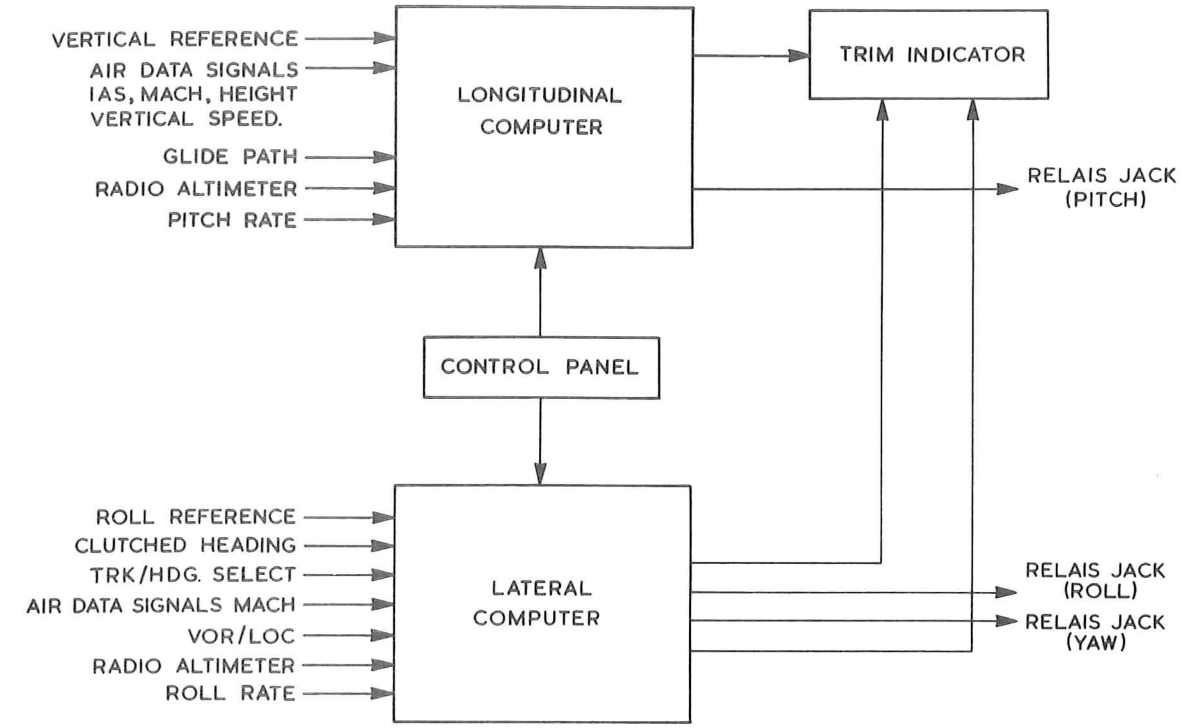


FIGURE 8
BLOCK DIAGRAM OF THE AUTOPILOT

4.4 Electric Trim System

The block diagram of the electric trim system is shown in figure 9. The system operates via an actuator to move the 'earth point' of the feel unit. Three modes are provided:

(a) Pilot trim - via a button on the control column
(b) Mach Trim
(c) Auto-trim - in autopilot only

The system is duplicated and is fully monitored and is contained in two boxes and an associated actuator.

The probability of loss of electric trim during a flight time of 3 hours is less than 10^{-5}.

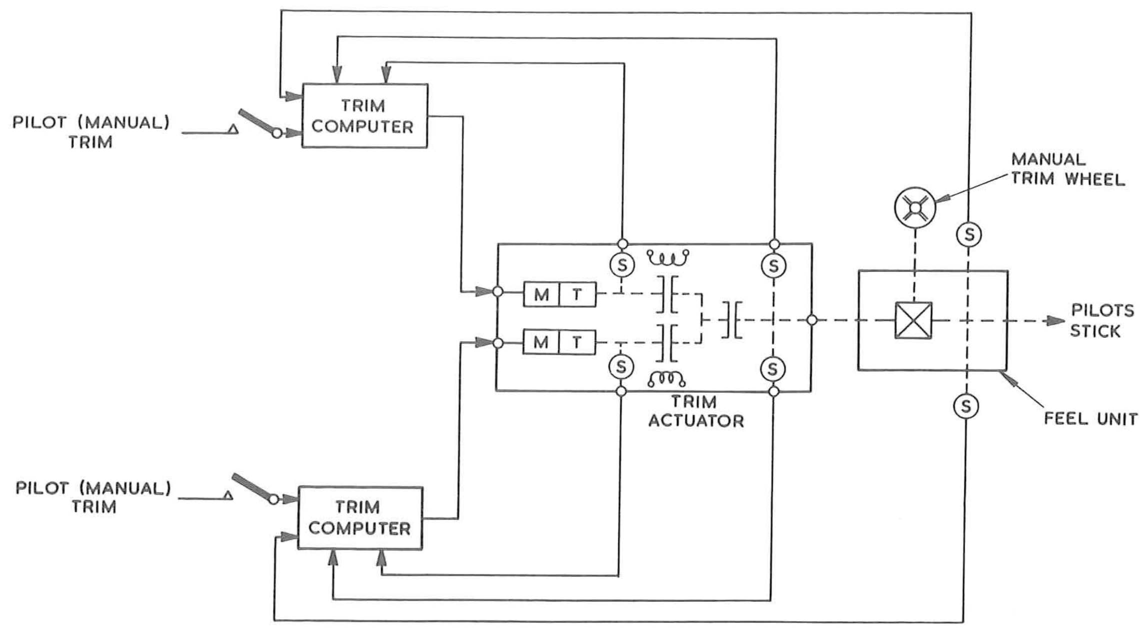


FIGURE 9

BLOCK DIAGRAM OF THE ELECTRIC TRIM SYSTEM

4.5 **The Autothrottle System**

The block diagram of the Autothrottle System is shown in figure 10.

The system operates via an actuator to move the pilots throttle levers. The power output requirements from the actuator are comparatively low since the throttles are "electrically" signalled and the actuator has only to move the throttle levers themselves. It should be noted that the electrical signalling synchros for the throttle system are fixed onto the autothrottle actuators. A pilot "feel" is built into the actuator in order to allow the pilot to push against a force when adjusting the throttles. Additionally the use of a non-reversible gear prevents the pilot from 'back driving' the autothrottle servos. Three modes are provided:

(a) IAS hold

(b) Mach hold

(c) IAS pre-selection

At present the IAS selector on the autothrottle controller (see figure 2) does not continuously slave to the ASI (Air Speed Indicator), the selector is used only for speed pre-selection.

The system is duplicated and fully monitored and achieves a system reliability of better than 10^{-5} over a flight time 3 hours.

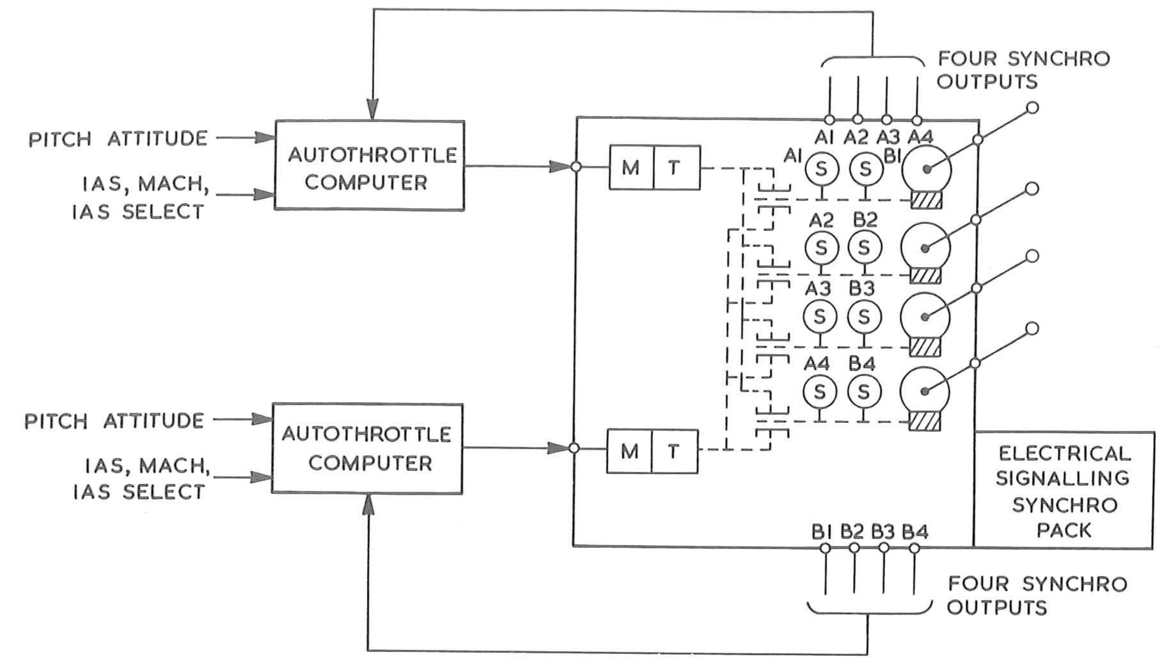


FIGURE 10

BLOCK DIAGRAM OF THE AUTOTHROTTLE SYSTEM

4.6 **Flight Director and Take Off Director**

The flight director and take off director computer configuration is shown in figure 11.

The flight director computers feed the pilots horizon director and navigation instruments. The flight director can be installed as a single or duplicate system.

All the modes of the autopilot with the exception of the manual modes are incorporated in flight director. The pitch flight director computer is monitored only in the flare mode whilst the azimuth computer is cross monitored against the second azimuth computer when two flight director computer systems are installed.

The Take Off Director Computer is fed to the horizon director instrument during take off and provides pitch commands to ensure optimum take offs in all conditions including engine out cases. The Take Off Director Computer is monitored and is pre-programmed to provide a given take off law based on pitch rate.

The possibility of employing a Head Up Display for take off has been studied following the work done by Elliotts in conjunction with RAE Bedford but no definite conclusions have been reached. Elliotts are currently reviewing the whole problem with BAC and SUD.

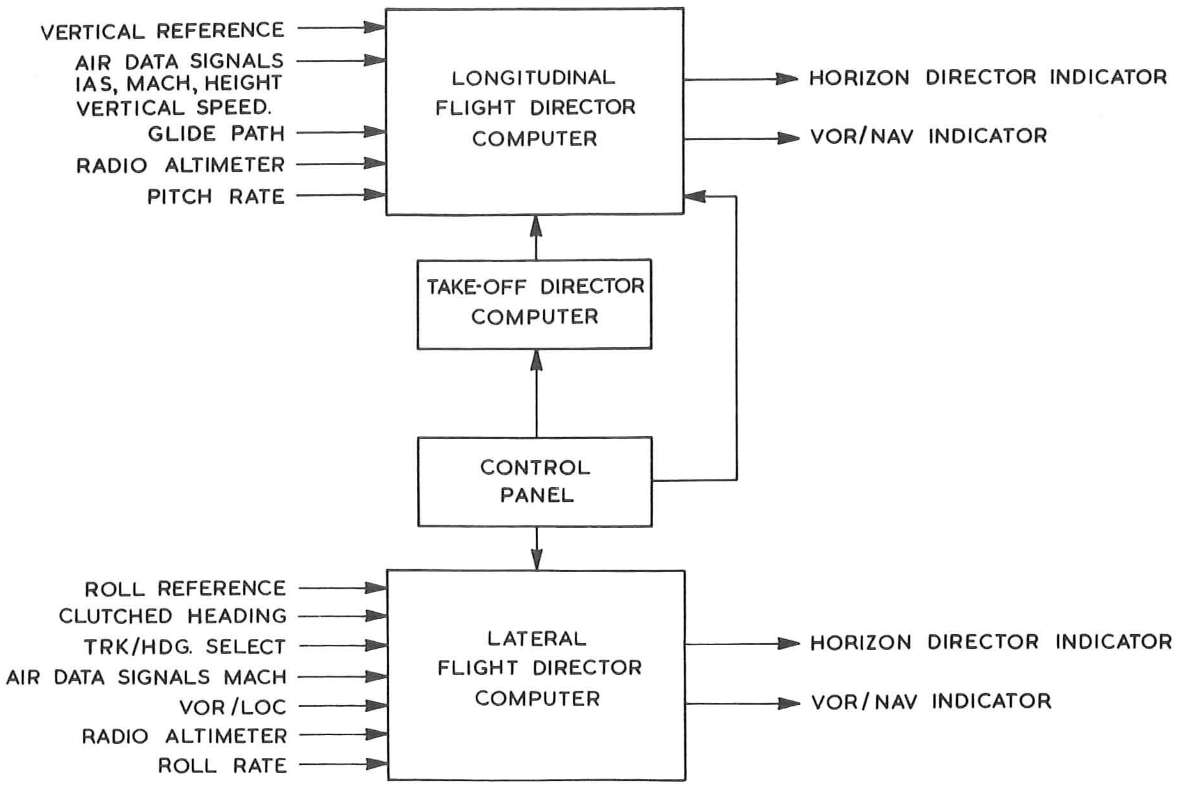


FIGURE 11

BLOCK DIAGRAM OF THE FLIGHT DIRECTOR AND TAKE OFF DIRECTOR COMPUTERS

5. CONCLUSIONS

It is hoped that in the limited time available the principles of the Concorde AFCS have been clarified. Furthermore it is evident that a great deal of work has still to be done and it is expected that the imminent phase of rig trials followed ultimately by flight trials will reveal even more of the complexities and the challenge of supersonic flight.

6. ACKNOWLEDGEMENTS

I would like to thank the management of SUD Aviation and the Directors of Elliott Flight Automation Ltd. for permission to publish this paper and to acknowledge the continued support of the combined project teams of Elliott, SFENA and Bendix.