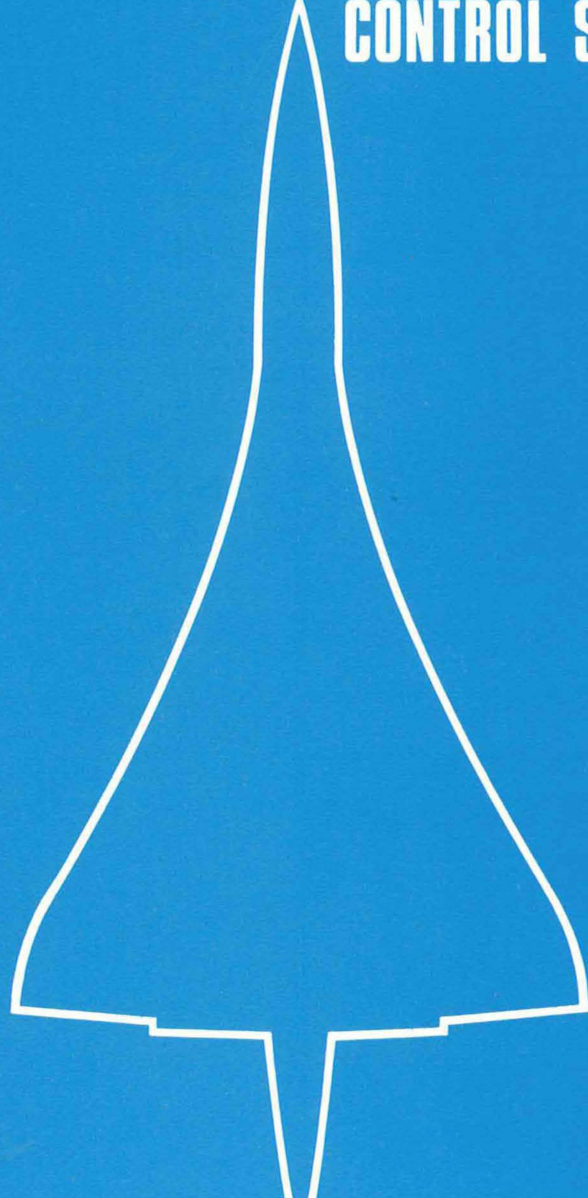
ELLIOTT
-SFENA

AFCS

AUTOMATIC FLIGHT CONTROL SYSTEM



FOR SST *Concorde*

www.rochesteravionicarchives.co.uk

The information contained in this brochure is based on the current design state of the Concorde pre-production AFCS equipment and may be subject to revision by the equipment or the aircraft manufacturer until the production equipment is certified.

27th MAY 1971

INTRODUCTION

The Automatic Flight Control System (AFCS) has been jointly developed by Elliott and SFENA for the production Concorde aircraft. Elliott carry overall design responsibility and the equipment will be supported in the field by both Elliott and SFENA.

The brochure provides a concise description of the AFCS so that aircraft operators can familiarise themselves with the system and formulate a maintenance and support plan.

The AFCS comprises the following sub systems:

- **AUTOPILOT and FLIGHT DIRECTOR**
- **THREE AXIS AUTOSTABILISATION**
- **AUTOTHROTTLE**
- **ELECTRIC TRIM**

Autopilot and Flight Director

The integrated Autopilot and Flight Director employs common computing and mode selection facilities. The autopilot function provides automatic control from initial climb, through cruise to automatic landing. Monitoring techniques ensure fail soft operation in all modes with automatic failure survival to a standby channel during final approach and automatic landing. Flight director commands enable the pilot to monitor autopilot demands against basic instruments and permit flight director control in all modes of cruise and approach flying. The system incorporates a landing display which consolidates the performance and system serviceability information needed by the pilot to assess the fitness of the AFCS to proceed under automatic control to touchdown. An automatic go-around facility is provided.

Three Axis Autostabilisation

The Three Axis Autostabilisation system provides augmentation of the natural handling qualities and improves passenger comfort. The system operates directly into the elevon and rudder control surfaces, without moving the pilots controls. This is achieved by electrically limited outputs into electrical signalling "fly-by-wire" amplifiers which are housed in the autostabilisation computer. Two channels are provided for each axis to meet the reliability requirements. The self monitoring of these channels also incorporates autochangeover to give smooth automatic failure survival.

Autothrottle

The Autothrottle system operates the pilots' throttle levers to control thrust according to Indicated Air Speed or Mach Number, self monitoring techniques and channel redundancy give automatic failure survival in approach and cruise flight cases.

Electric Trim

The Electric Trim system provides pilot operated pitch trim in manual flying. During automatic pilot control the auto trim facility reduces the aircraft transient on autopilot disengagement. In addition, open loop trim commands are utilised to augment static stability (e.g. Mach trim). Dual channel redundancy is provided with self monitoring to give automatic failure survival.

INTEGRATION WITH AIRCRAFT SYSTEMS

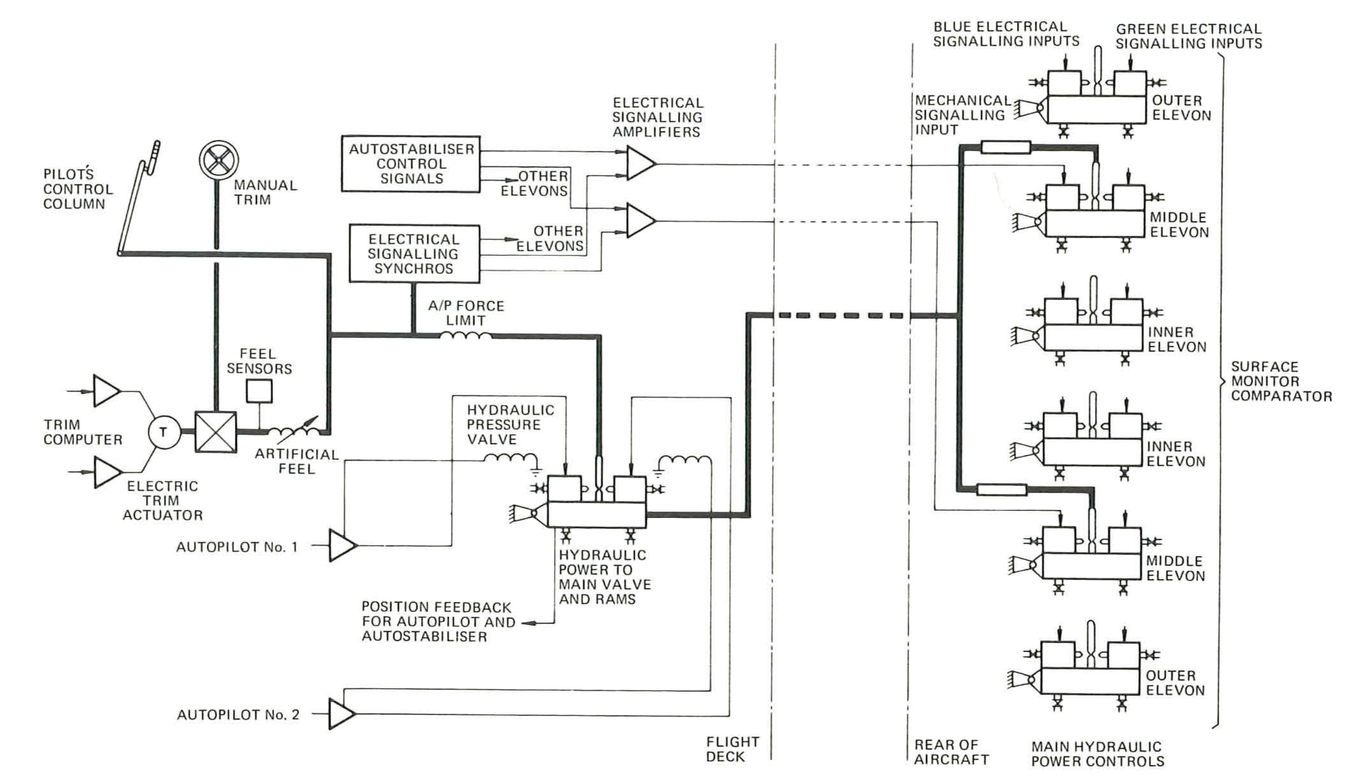
The four main sub-systems are integrated with the aircraft as illustrated. The general philosophy is that of duplicate systems. Each system is self monitored and the auto-stabilisation, autothrottle, electric trim, and low minima autopilot systems are provided with autochangeover giving automatic survival of a failure in the first channel.

The principal sensors are organised into two groups of self monitored signal sources. The sensors provide command and monitor outputs and an interlock to determine whether or not the signal is usable. A notable exception is the attitude reference sensor; in this case three inertial platforms are provided and the attitude reference signals are consolidated into two channels, each having command and monitor outputs, and an interlock signal.

be transferred to the "Green" electrical system or ultimately to the mechanical system. Failure of an electrical system is detected by the surface comparators which provide the appropriate switching of hydraulic supplies

(Note: The electrical signalling amplifiers are provided by the AFCS manufacturer, but the surface comparators and associated circuitry are not part of the AFCS initial fit or support commitment.)

When the pilot moves his controls he moves a mechanical linkage against the artificial feel. The datum of the feel is controlled by either the electrical or manual trim systems. It is significant to note that the pilot's control column, and hence the elevon, pitch trim position varies with flight case because there is no stabilising surface.



AFCS Integration with Aircraft Systems
(Pitch axis shown for simplicity together with only one lane of electrical signalling).

The aircraft primary flying controls are tandem hydraulic jacks. These are normally controlled from the pilot's column by one of two electrical signalling systems – "fly-by-wire". There is an additional mechanical linkage from the pilot's control to the main surface jacks and these mechanical controls are provided with a booster hydraulic jack. The normal method of manual flying is by the "Blue" electrical system. In the event of a failure of this system, control may

reduces the feel force datum to zero for a particular surface deflection and stick position.

The autostabilisation signals are introduced through the electrical signalling amplifiers. These signals do not therefore appear on the pilot's control column.

In the autopilot mode the hydraulic booster jack, provided for the reversionary mechanical signalling system, is used to drive the pilot's control column and move the control surfaces through the normal electrical signalling as follows:

When an autopilot is engaged the hydraulic pressure in the Moog valve stage of the booster jack locks the mechanical input lever to the jack body. The jack body then drives the pilot's control column, together with the mechanical control runs, to the position demanded by the autopilot.

The booster jack has two electrical (Moog valve) input stages. These provide separate actuation paths for the two autopilots and failure survival is achieved by switching the hydraulic pressurisation control valves.

When neither autopilot is engaged the mechanical input lever is no longer locked to the jack body and the booster jack fills its original role of slaving the control runs to the pilot's control column.

This form of integration is both convenient and accurate. It enables the artificial force to limit autopilot authority on the autopilot. Furthermore the hydraulic booster jack, artificial feel, pilot's control column and electrical signalling are all located in close proximity to the flight deck; this gives low backlash and therefore integration with improved aircraft and control column residual oscillation characteristics.

The autothrottle integration comprises an actuator driving the pilot's throttle levers. The aircraft linkage then operates the normal electrical signalling link to the engine control runs.

AUTOPILOT AND FLIGHT DIRECTOR

DESCRIPTION

The autopilot-flight director for Concorde includes additional facilities, over and above contemporary aircraft, which are considered worthwhile in a super sonic transport. They assist the pilot in his task of achieving the desired accuracy of control with minimum work load and fatigue. Great care has been taken to develop the AP and FD to optimise the trade-off between flexibility and complexity of operation. The need to provide automatic aids which do, in fact, ease pilot workload, and which are not too complicated to be used in practice has been the principal system design parameter.

The system is intended to meet the operational requirement of Cat III A operation, and Cat II operation after an en-route failure. The systems involved in low minima operation are all duplicated with automatic survival of a single failure. Although it is possible to undertake automatic landings with only a single system healthy, the systems have been designed to cover the operating procedures of those airlines who will require automatic failure survival after the minimum go-around altitude without pilot intervention.

The system is packaged with integrated autopilot-flight director computing. This is a natural economic development on an aircraft having centralised sensors for the autopilot and flight director. The integration of these functions allows a considerable economy in the cost per aircraft set and cost per flying hour, for a small penalty in increased common failure probability

A selection of the additional facilities of interest are:

- control from Localiser intercept to touchdown and runway guidance from a single controller selection.
- consolidated information on equipment low minima capability presented to pilot.
- glide path captures over a range of vertical speeds from above and below the beam.
- entirely automatic survival of the first failure in all systems for low minima operation.
- synchronised signal switching and control laws for improved flight director-autopilot compatibility.
- altitude acquire facility with provision for safety interlocks with autothrottle giving thrust compensation.
- datum adjust on all "hold" modes.
- facility of pre selecting approach speeds.
- optimum climb profile held without the need for frequent mode changing.
- reversionary approach coupling modes for low quality ILS beams.
- common selection of autopilot and flight director modes with clear annunciation to all crew members.
- either autopilot can be controlled (including heading and radio-nav references) by either pilot.
- Turbulence modes and provision for take-off direction.
- Altitude alert

MODES OF OPERATION

Autopilot

The modes of the autopilot functions are as follows:

Pitch Hold
Altitude Hold
IAS Hold
Mach Hold
Vertical Speed Hold
V_{mo} Hold
Vertical Navigation *(provision, alternative to V_{mo} mode)*
Altitude Pre selection and Acquire *(including automatic altitude change)*
Heading Hold
Heading/Track Select

Inertial Navigation
VOR/LOC
Glide Slope
Land
Turbulence

Flight Director

The modes of the flight director functions are:

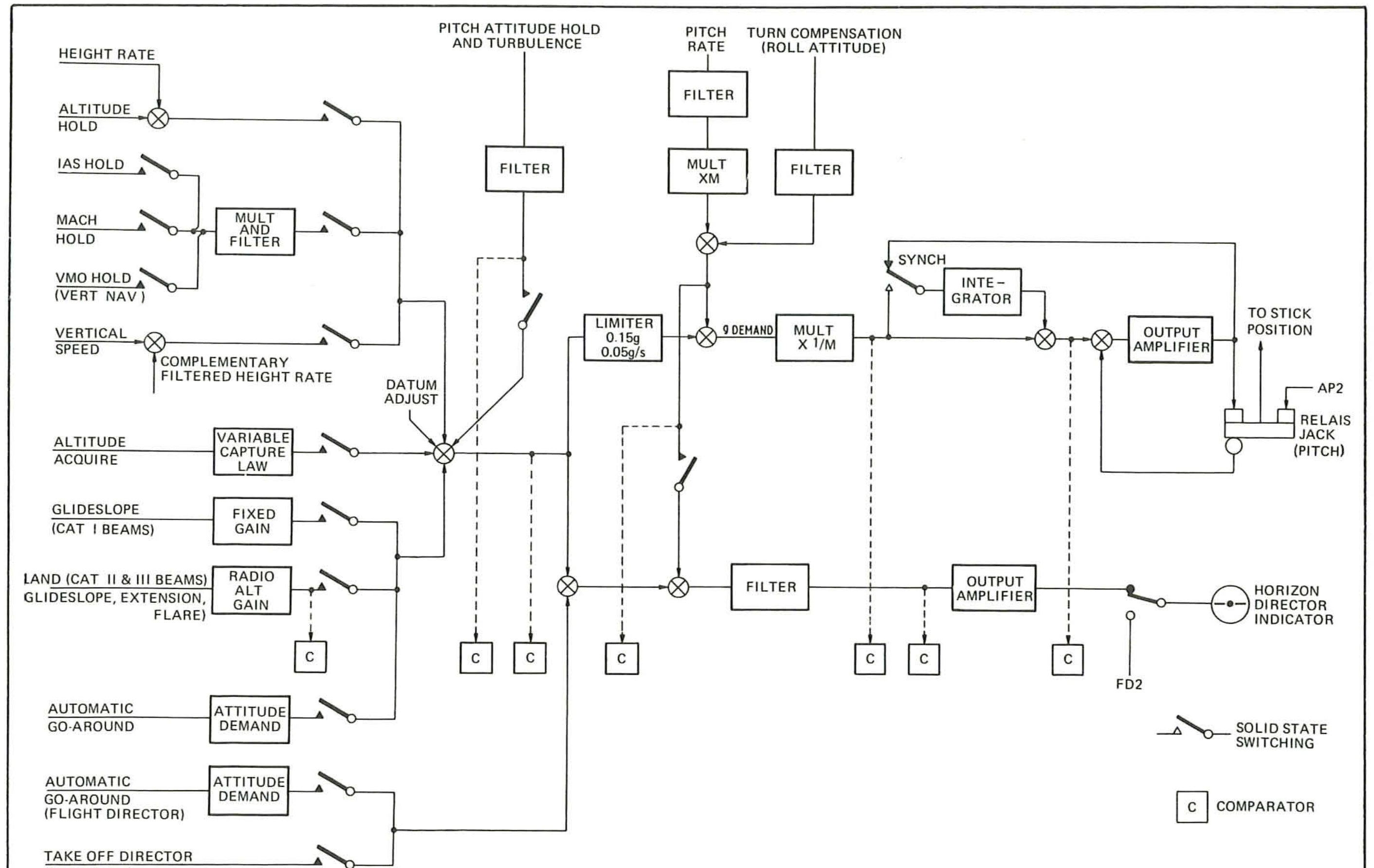
Pitch Hold
Altitude Hold
IAS Hold
Mach Hold
Vertical Speed Hold
Altitude Pre selection and Acquire.
V_{mo} Hold
Vertical Navigation *(alternative to V_{mo} mode)*
Heading/Track Select
Inertial Navigation
VOR/LOC
Glide Slope
Land
Back-Beam
TOD *(provision)*

Selection of modes for both autopilot and flight director, system 1 and 2, is by push buttons in conjunction with interlock circuits located within the autopilot/flight director computers Should both the autopilot and flight director functions be engaged at the same time, a single mode selection action will cause simultaneous selection of the appropriate mode (where compatible) in both autopilot and flight director channels. The successful selection of a mode is indicated by the illumination of the associated mode push button. Where an incompatible mode is already engaged the interlock will first reject the old mode and then engage the new mode. When the flight director is engaged prior to autopilot engagement, selection of an autopilot will re cycle the mode selection to pitch and heading hold to ensure transient free autopilot engagement and no unexpected changes in flight path.

Modes which are selected prior to automatic engagement are provided with "prime" indicators which show that the mode has been successfully armed. This prime indication changes to normal indication when the automatic capture takes place.

Pitch Hold and Heading Hold

These are the initial autopilot engagement modes whereby the aircraft is controlled to the pitch attitude and heading



Simplified Block Diagram of Pitch Autopilot/Flight Director
(Monitor computing not shown for simplicity).

existing at the time of engagement. Should the aircraft not be in a wings level condition at the time of engagement, a roll out synchronisation causes the aircraft to return to the wings level condition without a steady state heading error.

Changes in pitch attitude may be demanded by operation of the pitch datum adjust control. Due to the wide spread in the effect of attitude on flight paths, this control has been arranged to provide an approximately constant normal acceleration demand irrespective of flight case.

The nominal rates of normal acceleration shall be:

(a) fast ± 0.15g ± 20%
(b) slow ± 0.045g ± 20%

The maximum range of pitch attitude control is ± 20°.

Changes in aircraft heading may be demanded by operation of the turn control which will cause the aircraft to bank with a maximum roll rate of approximately 4° per second to a maximum value of 35°. The aircraft will maintain the heading existing when the turn control is returned to the centre detent. The bank angle limit under autopilot control is 25°.

The only flight director command provided when the mode is selected will be pitch attitude hold direction to assist the pilot in the slower response flight cases.

Altitude Hold

The aircraft is controlled to the barometric altitude existing at the time of engagement of the mode. By operation of the pitch datum adjust control it is possible to compensate for small engagement errors up to ± 600 ft. with the following nominal rates of adjustment:

(a) fast 60 ft/s
(b) slow 20 ft /s

IAS Hold

The aircraft is controlled by the IAS existing at the time of engagement of the mode. By operation of the pitch datum adjust control it is possible to compensate for engagement errors and small changes up to ± 22 knots with the following nominal rates of adjustment:

(a) fast 2.2 knots/s
(b) slow 0.7 knots/s

MACH Hold

The aircraft is controlled by the Mach number existing at the time of engagement of the mode. By operation of the pitch datum adjust control it is possible to change the Mach datum by up to ± 0.056M with the following rates of adjustment.

(a) fast 0.005M/s
(b) slow 0.002M/s

Vertical Speed

The aircraft vertical speed is controlled to the barometric speed datum existing at the time of engagement of the mode. This datum is given by the command "bug" on the vertical speed instrument. The datum "bug" may be adjusted after engagement by operation of the datum adjust control over a range of ± 7,000 ft /min.

V_{mo} Hold Mode

During the climb phase, this mode allows the pilot to avoid a number of conventional mode changes or datum changes by controlling the aircraft to the parameter V_{mo}, which is computed in the A D C and displayed on the airspeed indicator.

The mode may be engaged when the speed has stabilised and the altitude is not less than 5,000 ft.

Vertical Navigation *(alternative to V_{mo} hold)*

This facility enables the altitude hold, IAS hold, attitude, vertical speed, V_{mo} and Mach hold autopilot modes to be automatically engaged or sequenced from external logic command signals. This mode provides the basic capability for pre programming vertical flight path.

Altitude Acquire

In this mode the aircraft is caused to automatically capture without overshoot a preset barometric altitude. The pilot arranges the aircraft to follow a stable flight path towards the desired altitude. The capture initiation point is automatically varied as a function of height rate and during the capture manoeuvre the normal acceleration does not exceed a nominal 0.1g. Upon reaching the desired altitude the mode is automatically disconnected and altitude hold mode selected.

The maximum interception height rate in autopilot control is ± 8,000 ft /min. The maximum barometric height rate for flight director control is ± 10,000 ft /min.

The desired altitude, within the range 0 to 70,000 ft , is selected on the altitude select indicator incorporated within the AFCS control unit. The altitude select indicator has facilities for setting the barometric datum within the range 850 to 1050 millibars

Heading/Track

In this mode the aircraft will capture the reference which is set on the counter on the AFCS control panel and repeated on the VOR/NAV instrument. "Push-pull" movement of this control knob determines whether the reference is either TRK or HDG, and this is indicated by the HDG/TRK flag on the VOR/NAV instrument. In the event of a failure of the "drift" signal, switching action within the VOR/NAV instrument will automatically revert the signal to HDG. The selection of true or magnetic reference is by a switch on the pilot's instrument panel. For significant changes of direction the new heading will be captured at the autopilot bank angle limit.

Inertial Navigation

In this mode the aircraft will capture and maintain the track between two "way points" set in the inertial navigation system. The autopilot reduces the "steer" error to zero, within the normal autopilot manoeuvre limits.

VOR/LOC

(a) VOR

In this mode the aircraft will capture and maintain the VOR radial set on the VOR route reference on the AFCS control panel.

The intercept track/heading may be set manually on the HDG/TRK reference on the AFCS control unit.

The mode is capable of controlling the aircraft through the "cone of confusion" and on to the reciprocal radial without any further pilot action.

(b) LOC

When a localiser frequency has been selected the aircraft will capture and maintain the selected localiser beam.

The intercept track/heading may be set manually on the HDG/TRK reference on the AFCS control unit.

This mode is intended as a reversionary mode from Land, which is the normal approach coupling mode for Cat II and III beams. The LOC mode may also be suitable for poorer quality beams, and it does not require a serviceable radio altimeter for gain variation.

This mode can also be used if it is desired to follow the localiser without capturing the glide slope.

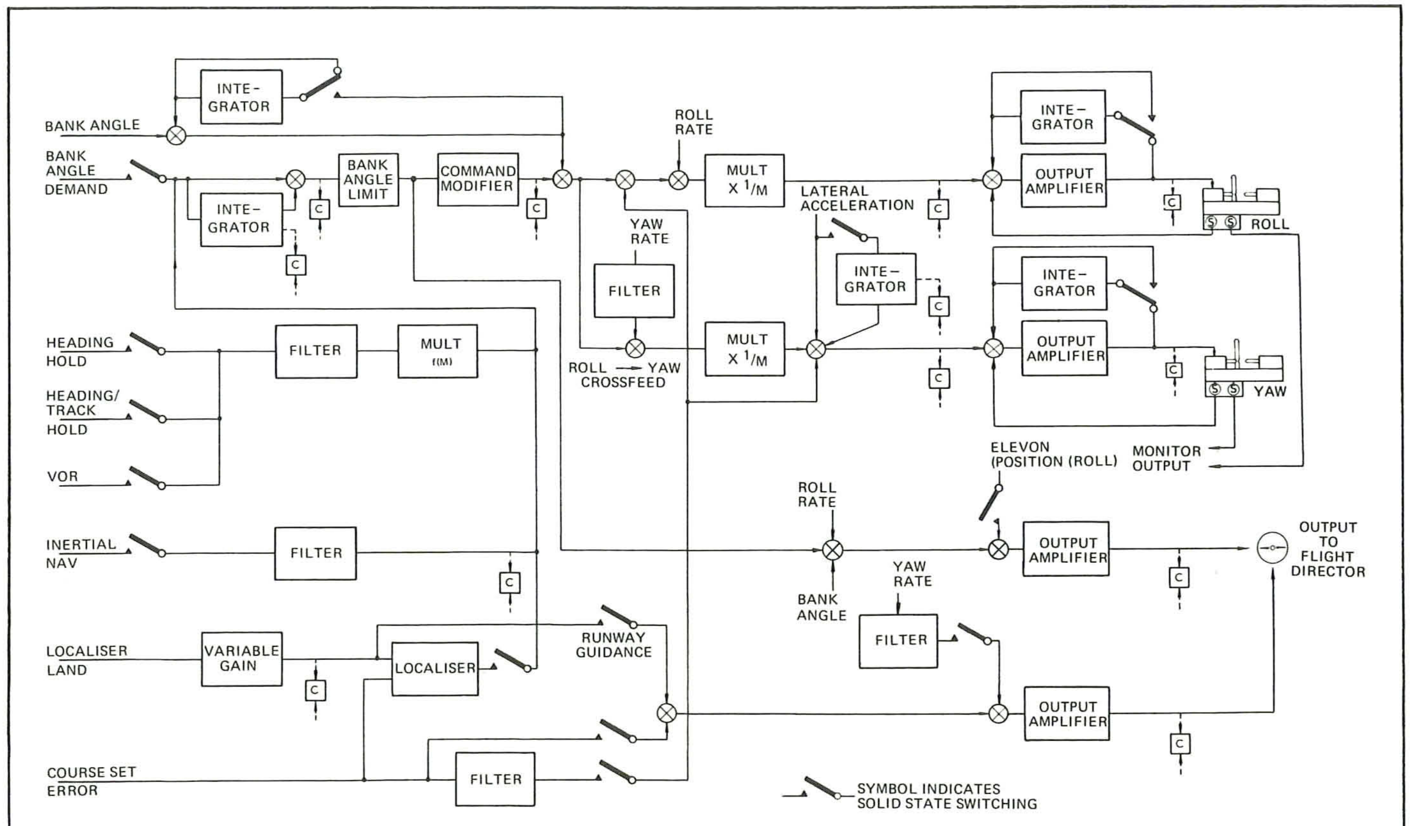
Glide Slope Mode

This is a reversionary mode from the normal approach mode, Land, and may be more suitable for poor quality beams. It does not require a serviceable radio altimeter for gain adjustment and is suitable for control to a minimum altitude of 200 ft.

Land Mode

This mode is the normal approach coupling mode for use on beams of good quality. The mode is capable of controlling the aircraft to touchdown.

The mode may be selected during the localiser intercept phase. In the azimuth plane the aircraft is caused to capture the localiser beam and track the beam centre line until the automatic runway alignment manoeuvre (de crab) commences at a fixed radio altitude. In the pitch plane the aircraft automatically captures the glide slope beam from above or below the beam at height rates between +500 ft/min and −1250 ft/min. After capture the



Simplified Block Diagram of Azimuth Autopilot/Flight Director

(Monitor computing not shown for simplicity)

aircraft will track the beam centre line to an altitude of 100 ft (30 m), after which the aircraft is controlled by inertially augmented vertical velocity until initiation of the automatic flare manoeuvre. The mode is fully monitored from the glide path capture and localiser track points and a failure of the active autopilot channel in either pitch or azimuth axis causes both axes to autochange to the standby channel.

Go-Around Facility

The automatic go around control and corresponding flight director commands can be engaged at any time on the approach (down to certification limits) by selecting two or more throttle levers to the maximum position. This action changes the control law in the computer and disconnects the autothrottle. The mode remains engaged, irrespective of further thrust changes until the pilot selects Pitch or Heading Hold mode or disengages the system.

The azimuth axis control law is the localiser track mode, provided the go-around is not due to a failure of the localiser receiver. In the latter case a flight director pre selected track mode is provided.

The pilot should disengage the go-around facility at a range not less than 500 m from the localiser transmitter by selection of another autopilot/flight director mode or manual disconnection of the system.

Warning and Landing Display

To reduce pilot workload in assessing the capability for low minima operation, the relevant information on system capability has been consolidated in one point on the flight deck. The warning and landing display tells the pilot whether:

(a) the ILS tracking performance is adequate to continue below the minimum go-around altitude.

(b) there is sufficient system serviceability to continue to 100 ft or touchdown in terms of automatic failure survival.

This unit does not of course replace any of the pilot decision making actions, it merely gathers together the relevant information as far as further reliance on automatic control is concerned.

Turbulence Mode

This mode is intended for use during cruise flying during severe turbulent conditions. The aircraft is "loosely" controlled to the pitch attitude and the heading existing at the time of engagement of the mode. Full provision for datum adjust is included.

Back Beam — Flight Director

In this mode director commands for localiser back beam flying are provided. The autopilot must be disengaged before selection of the mode can take place. This mode is intended to be used in approach on the back course sector of the localiser transmitter. It is a beam track control law and the pilot is required to disengage or disregard the mode at a range of less than 1000 m from the localiser transmitter.

Take Off Director *(Provision)*

This mode is intended to optimise the aircraft take-off and initial climb out performance.

If desirable, after prototype flight testing the control laws will be computed in a separate box.

THREE AXIS AUTOSTABILISATION

DESCRIPTION

The Three Axis Autostabilisation system is designed to increase the aircraft natural short period and dutch roll damping co-efficients over the normal and extreme flight envelopes, to improve the flying qualities and passenger comfort of the aircraft, and following an engine failure, reduce the resulting flight path disturbance, and minimise the effect of turbulence.

The aircraft installation comprises two separate channels for each axis of pitch roll and yaw. In normal operation, both channels of each axis are engaged with channel 1 having control authority. Following a failure or pilot disconnection of the active channel the affected axis will changeover automatically to the standby channel.

The principal sensors for the autostabiliser systems are rate gyros and stick position transmitters (used also for autopilot). Air data computer control terms are used for variation of gains and autothrottle limits. A lateral acceleration control term is used to reduce side slip angle in the case of an engine failure.

Authority limitation and self monitoring of each channel ensures that the safety requirements are achieved when in conjunction with the aircraft flying control monitoring system.

The Autostabilisation system consists of the following units:

Autostabiliser Computer (2 off)
Autostabiliser Engage Switch Unit
Rate Gyro (two per axis)
Lateral Accelerometer
Stick position sensors (common to the autopilot) mounted on the hydraulic booster jack.

Three rate gyros are required for each of the two channels. The six units are all physically interchangeable from a spares viewpoint. The gyros are of the mechanically sprung type having separate pick-offs for command and monitor computing lanes and a wheel speed monitor.

The autostabiliser demands actuate the power control units and move the aircraft flying control surfaces without movement of the pilot's controls.

There are two segregated electrical signalling systems (Blue and Green) of equal integrity for the aircraft flying controls. The amplifiers for the Blue system are located within the Channel 1 autostabiliser computer, whilst the amplifiers for the Green system are located within the channel 2 autostabiliser computer.

The monitoring circuits for the electrical signalling are not located in the autostabiliser computers.

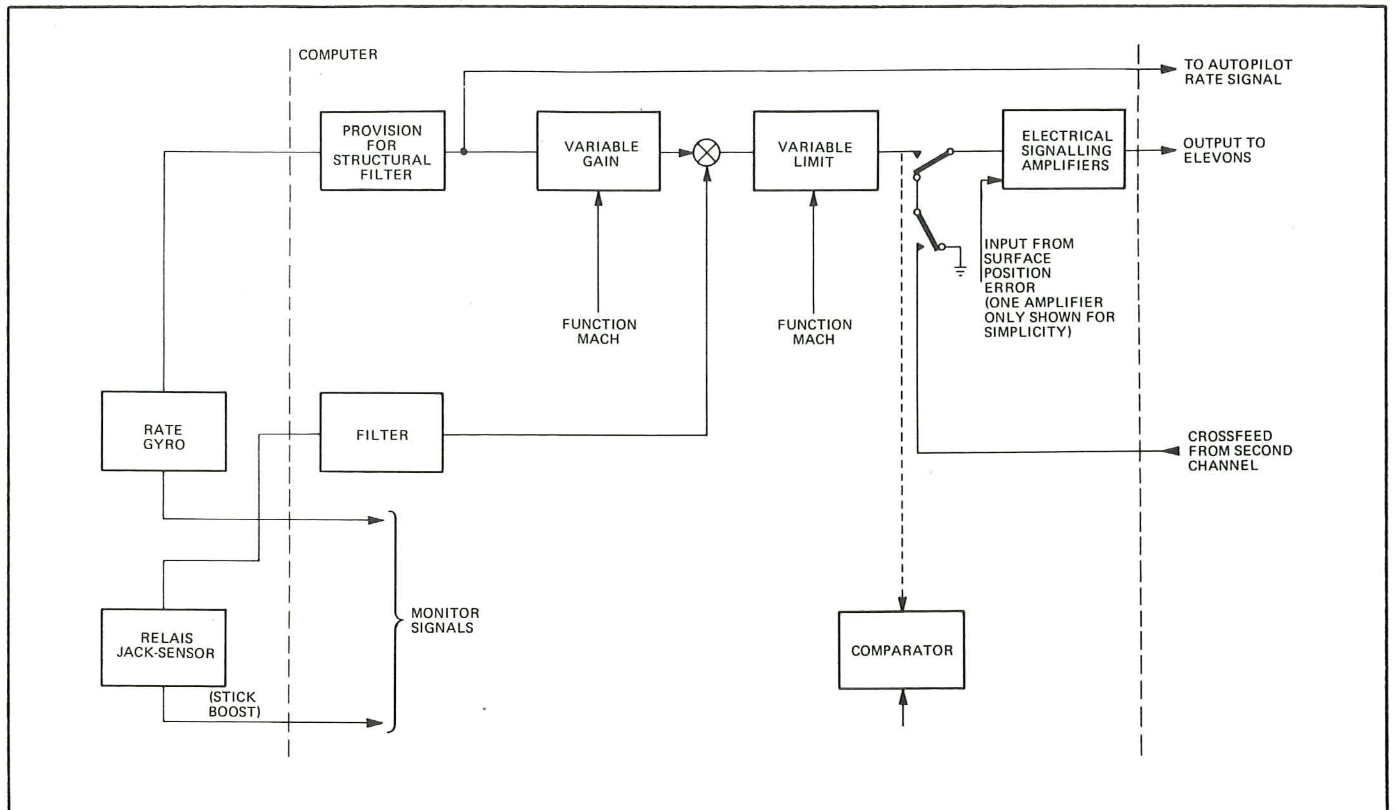
Should the aircraft flying control system revert to the mechanical mode, no control surface movement can be obtained from autostabiliser demands.

OPERATION

Each autostabiliser channel is engaged by a separate engage switch. During normal operation both channels are selected with channel 1 having control authority and channel 2 in a synchronised standby condition. In the event of channel 1 being disconnected for any reason, control is transfered to channel 2.

The engage switch for each channel is solenoid held in the engage position only when the associated channel of the autostabiliser, after selection, has satisfactorily engaged, as signalled by the various safety interlocks and monitoring devices. The position of the engage switches always indicates the engagement state of the system. When the autostabiliser is disconnected by any means the autostabiliser returns to the disengaged position.

It is possible however, by moving both engage switches to the disengage position to disconnect the autostabiliser system. In addition, it is possible for the pilot to physically force the switches to overcome possible jamming in the hold mechanism.



Simplified Block Diagram of Three Axis Autostabilisation System
(Roll axis only shown for simplicity)

AUTOTHROTTLE

DESCRIPTION

The Autothrottle system is designed to provide thrust control of indicated airspeed or Mach number for approach and cruise flying.

The system, which is duplicate monitored, is capable of automatically surviving a single failure both during an automatic landing manoeuvre and throughout the specified flight regime and comprises the following units:

- Autothrottle Computer
- Duplex Autothrottle Actuator
- Accelerometer

Control and engage facilities of the autothrottle system are integrated with the overall AFCS Control Unit.

A speed select facility is included by which the pilot, by moving a command counter on the control unit, may demand any desired airspeed up to 400 knots.

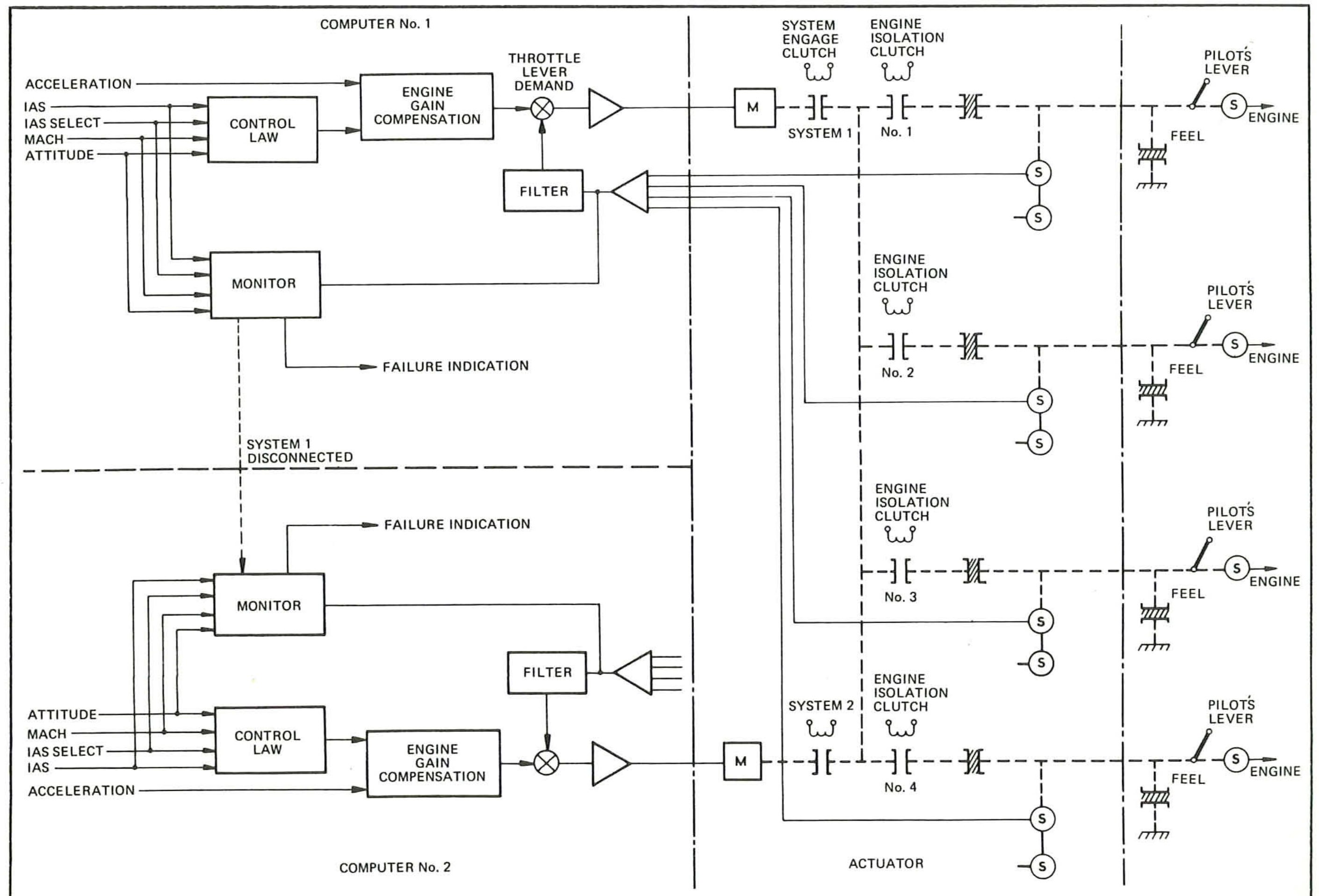
Two separate control channels are included, each operating segregated sections of the duplex actuator, which has a single mechanical output to each of the pilots four throttle levers.

Two pilot's instinctive disconnect switches are included, one on each of the outboard pilot's throttle levers. These disconnect switches are connected in the interlocks in such a manner that possible faults in the interlock circuitry do not inhibit the instinctive disconnect.

Separate engage switches for each autothrottle are located on the AFCS control unit. The selected system becomes operative when the switch is operated.

Four throttle isolation switches are provided to permit individual isolation of autothrottle demands to each throttle lever, for engine cut conditions.

The engine controls are electrically signalled via pick offs actuated by the pilot's levers. Artificial feel is presented to the pilot in the throttle lever mechanism. The autothrottle actuator may be over-ridden in an emergency by slipping the



Simplified Block Diagram of Autothrottle System

clutch in the actuator. This would result in an automatic disconnection by the autothrottle monitoring, so the normal pilot action would be to use the instinctive disconnect switches to avoid the need to over-ride.

The pilot can make changes to the relative position of the throttle levers without disconnecting the system as the monitoring is sensitive only to average position of all four levers.

OPERATION

IAS Acquire Mode

In this mode the aircraft will capture and maintain the indicated air speed set on the IAS select counter. It is possible to adjust the selected speed before or after engaging the speed select mode.

Range

IAS Hold and IAS Acquire 130 knots to 400 knots CAS.

Mach Hold for Cruise Configuration

(a) 25,000 ft to 40,000 ft 0.7 M to 0.95 M

(b) 50,000 ft to 60,000 ft 1.8 M to 2.2 M

IAS Hold Mode

In this mode the aircraft is controlled to the indicated air-speed existing at the time of engagement of the mode.

A datum adjust facility is provided which permits a change in the engaged IAS datum by $\pm$ 22 knots at the following nominal rates of adjustment:

(a) fast 2.2 knots/s
(b) slow 0.7 knots/s

MACH Hold Mode

In this mode the aircraft is controlled to the Mach number existing at the time of engagement of the mode.

A datum adjust facility is provided which permits a change in the engaged Mach datum by $\pm$ 0.056 M at the following nominal rates of adjustment:

(a) fast 0.005 M/s
(b) slow 0.002 M/s

ELECTRIC TRIM

DESCRIPTION

The Electric Trim system provides a pitch elevon trim facility throughout the complete flight regime by changing the neutral (or zero feel force) position of the pitch elevon control runs. The trim system does not move a separate stabilising surface, it merely alters the elevon and stick position for zero feel force.

Three modes of operation are provided:

Pilot Trim
Autotrim
Static Stability Augmentation

The system consists of two channels driving a single mechanical actuator with the standby channel engaged in a synchronising mode to give automatic failure survival following the first failure.

The Electric Trim system comprises the following units:

Electric Pitch Trim Computer (2)
Electric Pitch Trim Actuator
Electric Pitch Trim Switch Unit
Pitch Feel Sensor

The actuator includes two isolated electromechanical drive arrangements each with a separate engage clutch. A single splined shaft of the actuator moves the run force neutral point of the artificial feel system via an external gearbox. A mechanical slip clutch is incorporated in the output shaft to prevent seizure of the trim actuator causing a jam of the mechanical trim facility.

OPERATION

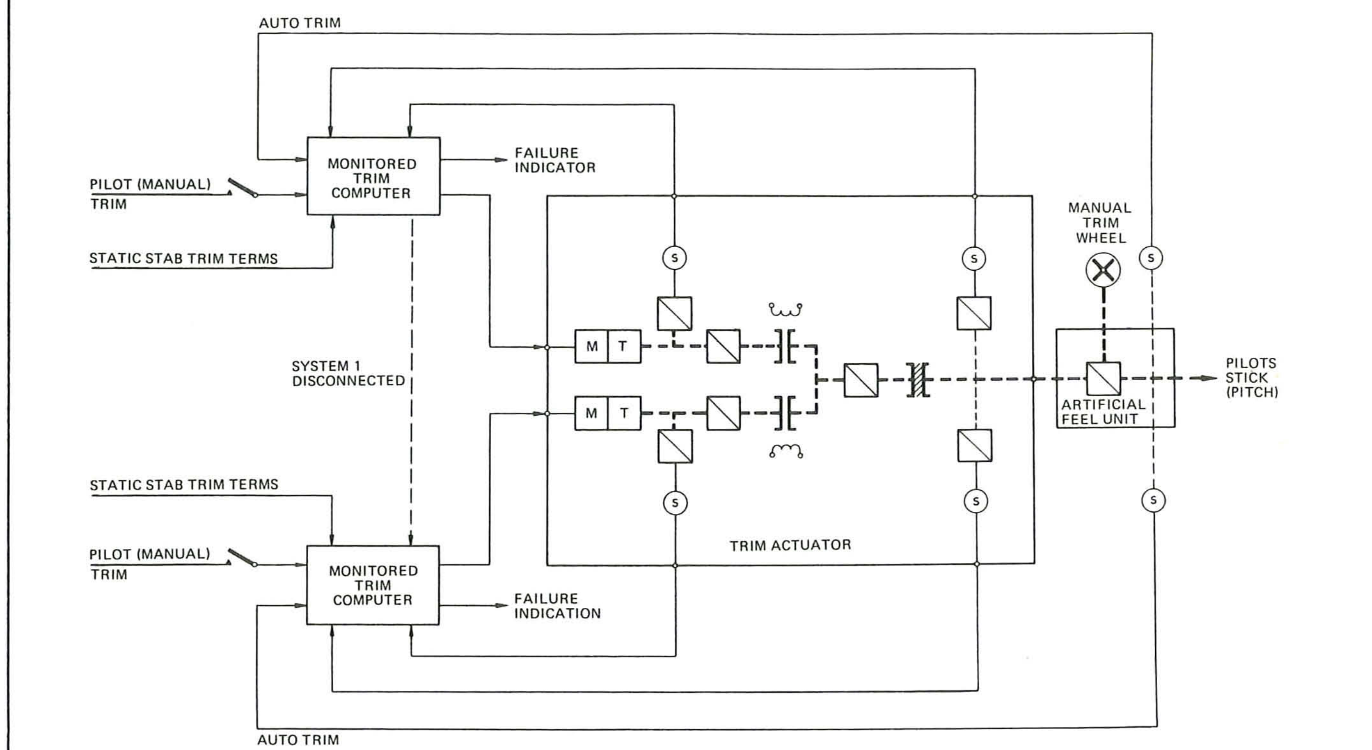
Each electric trim channel is engaged by a separate engage switch. During normal operation both channels are selected with channel 1 having control authority whilst channel 2 remains in a synchronised standby condition. In the event of channel 1 being disconnected for any reason, control will revert to channel 2.

The engage switch for each channel is solenoid held in the engage position only when the associated channel of the electric trim, after selection, has satisfactorily engaged, as signalled by the various safety interlocks and monitoring devices. The position of the engage switches always indicates the engagement state of the system. When the electric trim is disconnected by any means the engage switch returns to the disengaged position.

It is possible however, by moving both engage switches to the disengage position to disconnect the Electric Trim system. In addition, it is possible for the pilot to physically force the switches to overcome possible jamming in the hold mechanism.

Pilot Trim

The pilot trim is activated by manual operation of either trim switch mounted on the pilot's and co-pilot's control column and is inhibited when either autopilot channel is engaged.



Simplified Block Diagram of Electric Trim System

When demanded by pilot action the trim actuator output shaft moves at a constant velocity in the demanded direction, against the feel force of the artificial feel unit.

Autotrim

During autopilot operation only, the trim sub system reduces to zero any steady state feel force arising from pitch elevon autopilot demands, to minimise the out of trim condition when an autopilot is automatically or manually disconnected.

Static Stability Augmentation

This comprises the usual transonic mach trim and further terms, some of which are provisional to augment static stability in other flight cases.

Mach Trim

In the transonic region the trim sub system applys trim commands as a function of Mach Number to compensate for the de stabilising effect of the rear ward movement of the centre of pressure. Mach trim operates during both manual and autopilot controlled flight.

Incidence Trim

Trim command as a function of aircraft incidence, effective only in abnormally high incidence conditions.

Pilot operation of manual trim wheel results in the automatic disconnection of the Electric Trim sub system.

COMPUTING

Computing circuits and power packs which constitute the automatic flight control system are packed into six basic computers (2 off each) namely:

Autopilot and Flight Director Pitch Computer
Autopilot and Flight Director Azimuth Computer.
Autostabiliser Computer
Autothrottle Computer
Electric Pitch Trim Computer
Warning and Landing Display Computer

The computing circuits are split into modules which are arranged in stacks either side of the chassis assembly. These stacks are located together by plugs which also provide a means of inter connecting the individual modules and connecting the modules to a mother-board mounted on the chassis. These mother-boards are connected to the cableforms which run to the rear aircraft connectors and front test connectors.

The box is physically segregated into "command" and "monitor" computing areas to preclude common failures.

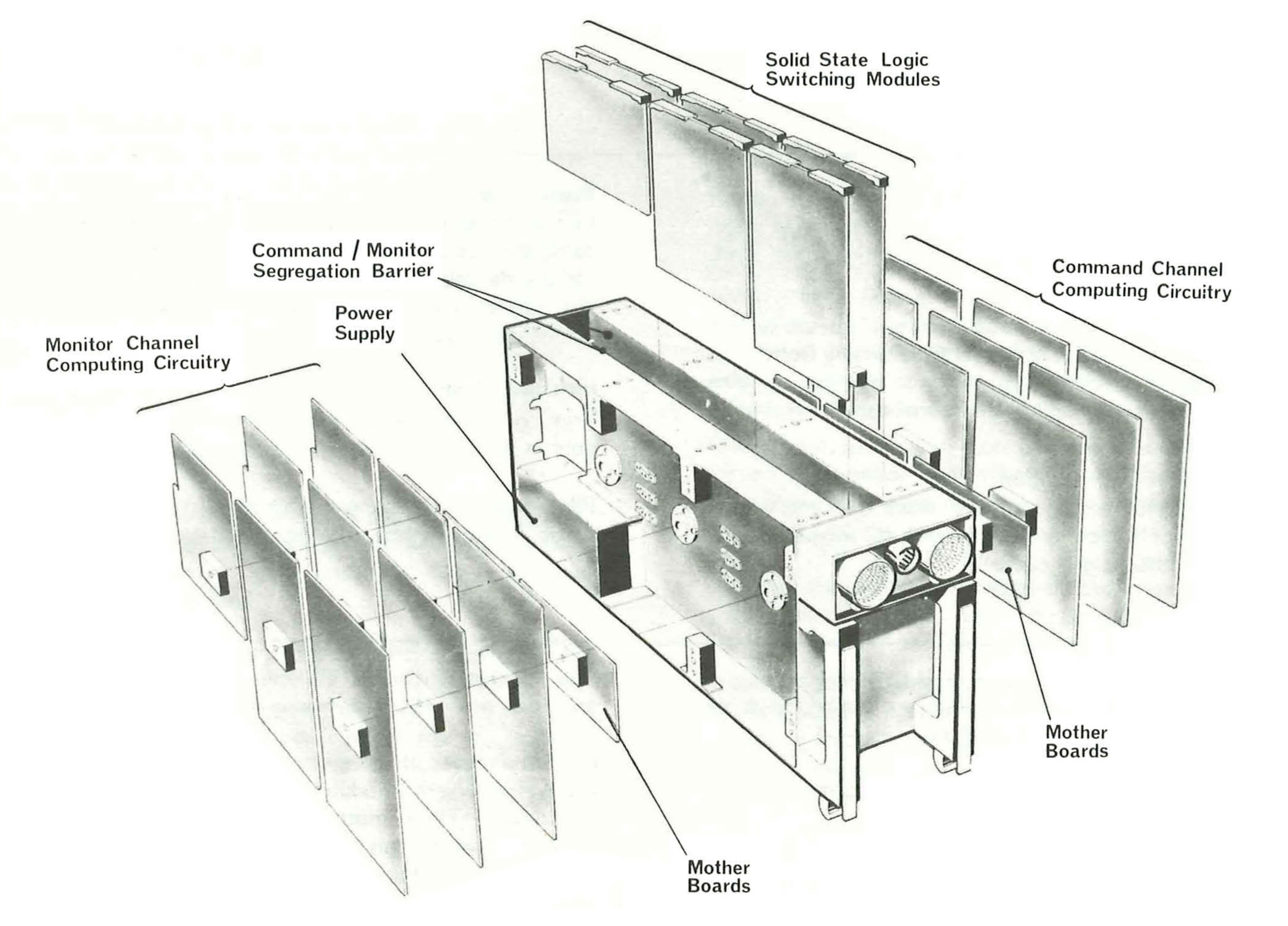
The solid state logic switching circuitry is incorporated in the centre segregation spline.

The electronic implementation is based on standardised micro electronic linear computing elements with external components to set gain and transfer functions. Electro-mechanical integrators have been eliminated and digital integration is used when long term storage of datums is required. All switching is solid state except where total electrical isolation or filament drivers are involved.

The computers include built-in test circuitry which is aimed at satisfying airworthiness requirements prior to take-off and fulfilling the first line maintenance objectives. The internal test facilities isolate the computers from the aircraft system and then test the relevant points of the comparators and control laws by injection of stimuli. The degree of built-in testing has been limited to approximately 15% degradation of the computer MTBF. The computer test facilities are sequenced by an external unit.

Additional test points are provided on the front of the computer to facilitate fault location to module level at the 'intermediate' servicing stage.

AP and FD Computer



AP and FD Computer Construction

CONTROLS

The control of the AFCS is divided into three natural groups:

(a) engagement of systems required throughout the flight.
(b) engagement and mode selection of pilot aids which are frequently switched in flight.
(c) autopilot manoeuvring controls.

The switches in group (a) have been located in the roof panel to reduce the risk of confusion with those in group (b). The controls in group (b) have been mounted on a panel in the centre of the flight deck immediately below the glare shield. This location provides ease of control for both pilots and a clear indication of the engagement and mode selection state of the autopilot to all members of the flight deck crew.

Pilot's Control Unit
Datum Adjust Unit
Engage Switch Panel

Pilot's Control Unit
The AFCS control unit is designed to enable both pilots to control the aircraft through either of the two autopilot/flight directors and autothrottles. The control unit contains the following:

SYSTEM ENGAGE SWITCHES

AT1 autothrottle engage switch channel 1.

AT2 autothrottle engage switch channel 2.

FD1 flight director engage switch channel 1, both pitch and azimuth axes.

FD2 flight director engage switch channel 2, both pitch and azimuth axes.

AP1 autopilot engage switch channel 1, both pitch and azimuth axes.

AP2 autopilot engage switch channel 2, both pitch and azimuth axes.

MODE SELECTION

Autopilot and flight director

PITCH HOLD Initial autopilot engagement mode, holds existing pitch attitude at selection.

IAS HOLD Indicated Air Speed hold.

MACH HOLD Mach Number hold.

ALT HOLD Barometric altitude hold.

VERT SPEED Barometric vertical hold and demand ± 7,000 ft/min

GLIDE SLOPE Automatic Glide Slope beam holding down to a minimum altitude of 200 ft.

HDG HOLD Initial engagement mode, hold heading at selection, independent of bank angle.

HDG TRK Aircraft track angle or heading, relative to magnetic or true north.

IN NAV Inertial navigation mode.

VOR LOC VOR and localiser navigation mode.

BACK BEAM Reciprocal localiser beacon approach mode (flight director only).

LAND Automatic approach down to and including touch-down.

ALT ACQ This mode primes the altitude acquire mode for capture.

VMO HOLD Holds maximum operating speed for climb.

TURB Attitude

Provisional Modes:

VERT NAV Alternative to V_{mo} Hold.

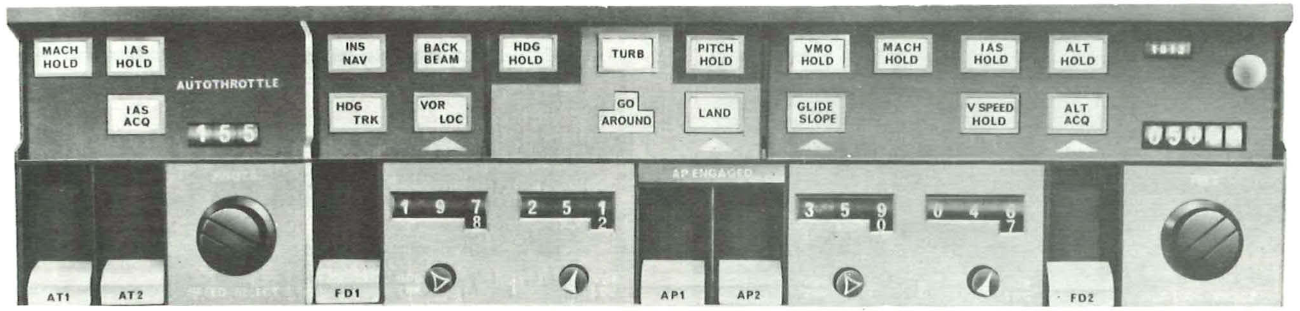
TOD Take-off mode – flight director only.

Autothrottle Modes:

IAS HOLD Indicated Air Speed Hold.

MACH HOLD Mach Number Hold.

IAS ACQ Capture speed set on select counter.



Pilot's Control Unit

Selectors – Autopilot and Flight Director

HDG/ TRK COUNTER These controls and digital read-outs enable either pilot to set the reference heading or track angle in either autopilot. The setting is repeated on the VOR/NAV instrument. Selection of either HDG or TRK is by a push/pull action on the knob and when HDG is selected a flag on the VOR/NAV instrument indicates the 'drift' servo is not functioning.

VOR/ LOC COUNTER These controls and digital read-outs enable either pilot to set the VOR radial or runway magnetic heading reference in either autopilot.

ALT SELECT COUNTER This control enables the pilot to set the desired altitude for the altitude acquire facility. The small secondary counter enables the barometric datum pressure to be set in millibars

Selectors – Autothrottle

IAS SELECT COUNTER This control enables the pilot to pre-set a desired IAS for autothrottle control. It is also the normal control for speed variation during local area and final approach flying.

Datum Adjust Unit

The Datum Adjust Unit comprises the control facilities used by the pilot to manoeuvre the aircraft through the autopilot and autothrottle. The unit has been located on the centre pedestal, remote from the AFCS control unit, to provide excellent ergonomics should the pilot require to control the aircraft through adjustment of the 'pitch hold' and 'heading hold' modes over long periods. This location also facilitates accurate setting of pitch attitude in turbulent conditions.

The unit contains the following controls:

(a) Autopilot/Flight Director Datum Adjust, which demands:

(i) changes in pitch attitude in the pitch attitude hold mode (including full provision for turbulence mode).

(ii) changes in the engaged datum of the manometric hold modes.

(iii) changes in the position of the VSI datum.

(b) Autopilot Turn Control provides a bank angle demand facility enabling changes of heading to be made at bank angles below the autopilot internal limit.

Datum Adjust Unit

Engage Switch Panel

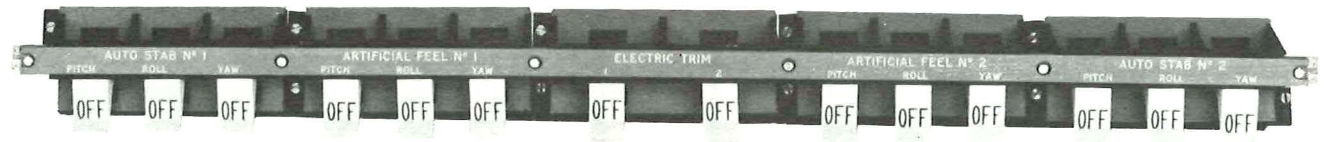
The Engage Switch Panel which houses the pilot operated engage switches associated with the autostabilisation, electric pitch trim and artificial feel systems is located within the cockpit roof panel.

The Engage Switch Panel comprises the following units -

Autostabiliser Engage Switch Unit
Electric Trim Engage Switch Unit
Artificial Feel Engage Switch Unit

These switches are engaged before take-off and, except in the event of a failure, require no further pilot action until after landing.

The switches are solenoid held and the pilot can detect the exact sub system failure by observing which switch has disengaged. The novel design of the switch handle and the bridge lighting can enable the pilot to readily identify the sub system which is in the abnormal condition.



Engage Switch Panel

COMPONENTS

Warning and Landing Display

This indicator consolidates the information required by the pilot to assess the system capability aspects of the decision to carry out a low minima approach or landing.

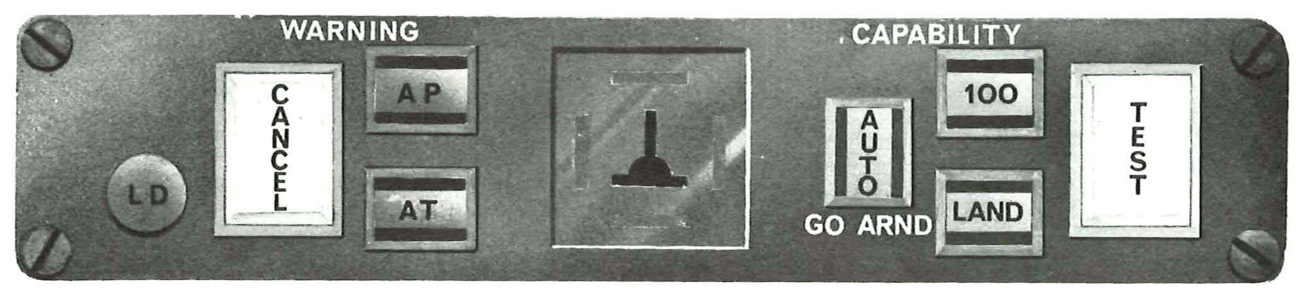
The information is of two types: performance and system serviceability. The performance indicator is a simple ILS "window".

If the aircraft is outside the window it can be assumed that there is a freak environment or performance condition which, provided the aircraft is within the operational limitation of wind and turbulence would mean that the probability of inadequate performance below the minima go-around height is unacceptable.

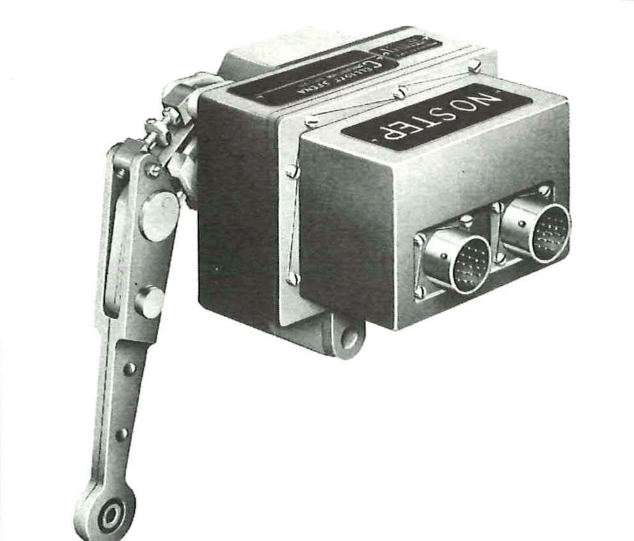
The system capability indication consists of bringing together in one indicator the serviceability of all redundant systems required for automatic failure survival between the minimum go-around altitude and touchdown. If all necessary redundancy is present the indicator shows the capability as "Land". If there is insufficient redundancy for automatic failure survival in all systems the indicator shows "100", as being the lowest altitude in which the system is safe without pilot intervention. (This does not preclude the pilot carrying on the land with only one system in clear weather provided he can take over after a failure; the indicator tells the pilot the system capability). If in addition to the loss of redundancy there is lack of a serviceable control law for low minima operation the indicator shows "200" as being the system limit.

During an approach, the indicator warns the pilot of any loss of system redundancy and should there be complete loss of a facility, e.g. autopilot or autothrottle, the pilot is given a prompt warning on a "take-over" lamp and the usual audio warning.

The display is provided with a confidence facility for use at the start of an approach and an alarm acceptance button.



Warning and Landing Display Indicator



Relais Jack Sensor

Relais Jack Sensors

The position transmitters on the flying control hydraulic booster jack are known as "relais" jack sensors. These produce two-wire synchro information on stick position for the autostabiliser and autopilot.

There is a separate unit for each axis of flying control movement i.e. pitch, roll and yaw.

Each unit carries the necessary synchros for channels 1 and 2 and command and monitor computing. The units therefore incorporate design techniques aimed at minimising the common failure probability.

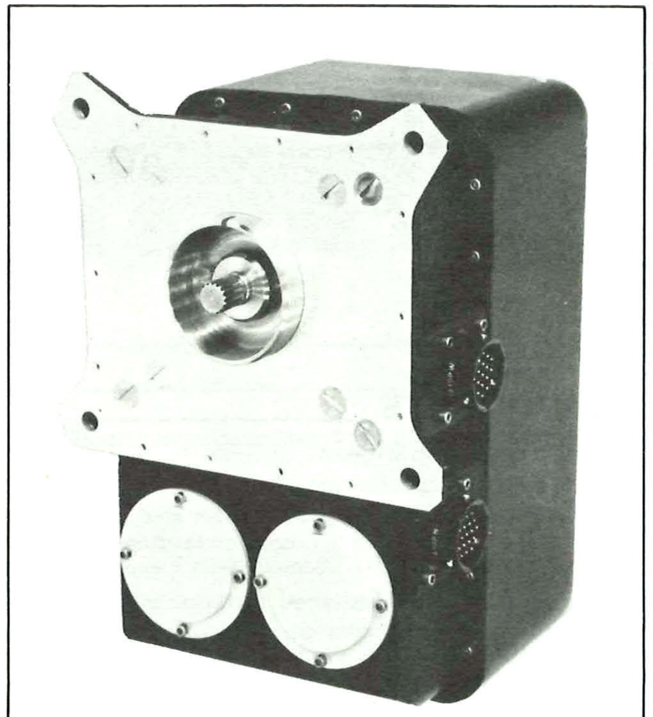
The units are mounted on the auxiliary hydraulic servo unit earth point and auxiliary servo extension is transmitted via a trailing link to the sensor input arm.

Accelerometer

Accelerometer

The Accelerometer is associated with the yaw axis autostabiliser. The unit is of the mechanically sprung type with two separate induction pick-offs for command and monitor computing lanes. A torque coil is also provided to displace the system during testing.

An identical unit provides longitudinal acceleration signals for the Autothrottle system.



Electric Trim Actuator

Electric Trim Actuator

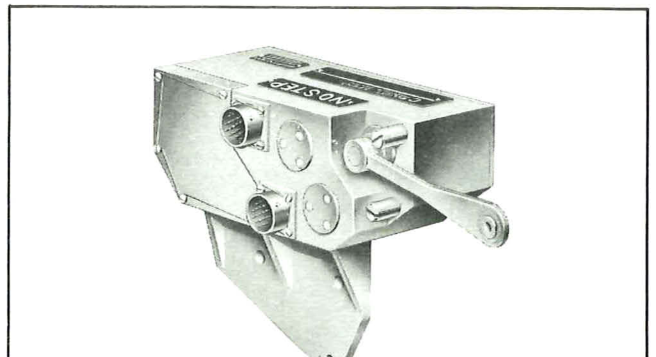
The Electric Trim Actuator is an electro-mechanical unit with a single mechanical output connected to the aircraft pitch elevon trim gearbox.

The Actuator comprises two separate drive mechanisms consisting of an electric motor, electric engage clutch and a reduction gear train driving a common splined output shaft which transmits the output drive via an internal friction clutch.

Feel Sensor

The Feel Sensor produces a two-wire synchro signal as a function of the feel displacement from the zero feel force position for use in the Autopilot and Electric Trim systems. The unit is mounted on the artificial feel chassis.

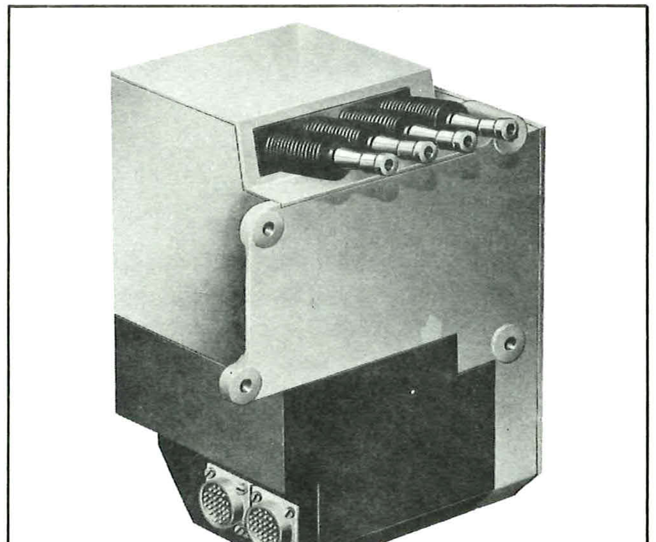
The sensor includes synchros for channels 1 and 2 command and monitor computing lanes. Specialised design techniques are used to minimise the common failure probability.



Feel Sensor

Autothrottle Actuator

The Autothrottle Actuator is an electro-mechanical unit which operates the pilot's throttle levers in response to electrical thrust demand signals from the autothrottle computers. The actuator assembly houses two segregated servo systems, each being connected to a final output drive mechanism via channel isolation clutches. The final drive mechanism incorporates a separate output isolation clutch, a final reduction gear, a slip clutch and position feedback sensors for each throttle lever. The actuator may be removed leaving the connection between the pilot's levers and the engine signalling system and feel undisturbed.



Autothrottle Actuator

Rate Gyro

The rate gyros are mechanically sprung with two separate inductive pick-offs one each for command and monitor computing lanes. A wheel speed monitor is also provided. A torque motor allows the gimbal to be displaced for system testing.

Rate Gyro

ELLIOTT

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