Integrated Flight Instrument and Control System for HIGH PERFORMANCE AIRCRAFT

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★ *The October, 1957, issue of AIR CLUES included an article on "A Plan for new Flight Instruments". The article indicated why it had proved necessary to reappraise the conventional display and control information available to a pilot, summarised the requirements arising from the appraisal and described the development work proceeding at R.A.E. and in industry to meet these requirements. Since that time interim versions of the equipment have been flown extensively in Sea Vixens, Scimitars and Lightning Mk. 1 aircraft and development flying has proceeded at C.F.E. The purpose of this article is to describe the installation and facilities now available for high performance aircraft. Some design, performance and functional parameters are mentioned, but these may vary with different installations.*

The basic conception of the new system has been to provide the pilot with a working environment which physically and psychologically will enable him to fully utilise the tactical potential offered by the aircraft. In the Weapons Systems Concept, the Integrated Flight Instrument and Control Section must be viewed as a sub-system in the overall control loop of the aircraft. The pilot is an integral part of this loop and he must be provided with knowledge of and ability to control the flight path. He can act as both sensor and computor but is required to exercise the minimum scanning and collation of these quantities such as attitude, altitude, speed and power which govern the flight path.

The single purpose instruments of the 1936 Blind Flying Panel are therefore replaced where possible by multi-purpose instruments. The "what is happening" presentations are supplemented by "what to do" presentations covering the control parameters dictated by the aircraft flight profile envisaged in Fig. 1. The system is concerned not only with the presentation of, say, heading or bank angle, or height or speed, as quantities to the pilot, but also to use such quantities for computing quickest possible time to height, for computing and satisfying control surface demands in a predetermined auto-manœuvre or in normal autopilot modes. The radar and weapons may utilise similar information and I.L.S., U.H.F. and TACAN positional aids can be combined with such quantities to ease the task of the pilot.

To ensure the success of the operational sortie from take-off to landing, application of a systems engineering philosophy has been essential during development. All developments do not run at the same rate, and while the errors of, say, a vertical gyro may be quite acceptable for attitude presentation, the tolerance required on elevation and bank signals may be much tighter for other systems in the aircraft.

Dynamic and aerodynamic information is presented and used in conjunction with the Flight Control System so that the pilot may operate the aircraft:

(a) Manually; or
(b) Manually through the Flight Director; or
(c) Automatically and monitored by the Flight Director.

Conventional types of capsule-operated instruments and separate gyro units are nearly all replaced by electro-mechanical displays in which the pilot presentation of aircraft attitude, position, bearing, etc., is integrated to a greater extent than has been achieved in earlier displays. The two central sources of flight data are the Master Reference Gyro supplying signal information relative to the aircraft attitude and azimuth position, and the Air Data System supplying signal information relative to Height, Mach No., Vertical Speed and I.A.S. Conventional but miniaturised Artificial Horizon, Directional Gyro and Altimeter are fitted as a stand-by.

For discussion and explanatory purposes it is convenient to consider the system as comprising:

(a) The Dynamic Reference System dealing with the source, presentation and application of quantitative data concerning aircraft attitude, heading, bearing;

(b) the Aerodynamic System dealing with the source, presentation and application of quantitative data which is dependent on the condition of the air surrounding the aircraft and on the motion of the aircraft relative to the air;

(c) the Flight Control System which utilises data derived from Dynamic and Aerodynamic sources to present steering instructions on the appropriate display and to provide automatic control of the aircraft during certain phases of flight.

DYNAMIC REFERENCE SYSTEM.

This measures and presents continuous bank, elevation and heading information during all attitudes of flight, and presents Flight Director steering instructions during certain phases of flight.

Master Reference Gyro. The M.R.G. consists basically of a servo-operated gyro-stabilised platform, carrying a vertical and an azimuth gyro each having its own gimbal system. The platform is in two parts, the inner being pivoted about the athwartships (elevation) axis and carrying the two gyros and being itself carried by the outer platform which is pivoted about the fore and aft (bank) axis. The vertical gyro is used solely as a means of maintaining the inner platform in its vertical reference position, conventional mercury switches being used to define the vertical. The azimuth gyro which on pilot choice is monitored by the flux gate detector, provides a reference from which angular movement of the aircraft in azimuth can be measured. There are four special advantages derived from the M.R.G.:

(a) The gimbal system is stable at all aircraft attitudes.

(b) A continuous and accurate output of elevation signals throughout 360° of pitching can be obtained, and the vertical gyro is free from toppling forces within the pitch and roll envelope of the aircraft.

(c) The azimuth gyro as fitted on the inner platform is stabilised by the vertical gyro and is therefore free from gimballing errors.

(d) bank, elevation, and heading information can be supplied to all users from one central source.

Movement of the aircraft of $\frac{1}{4}$° from a steady state heading, bank or elevation angle will initiate servo response, and relative movement of the platform gear train and data transmitters. The time lag to display this is of the order of $\frac{1}{20}$ second.

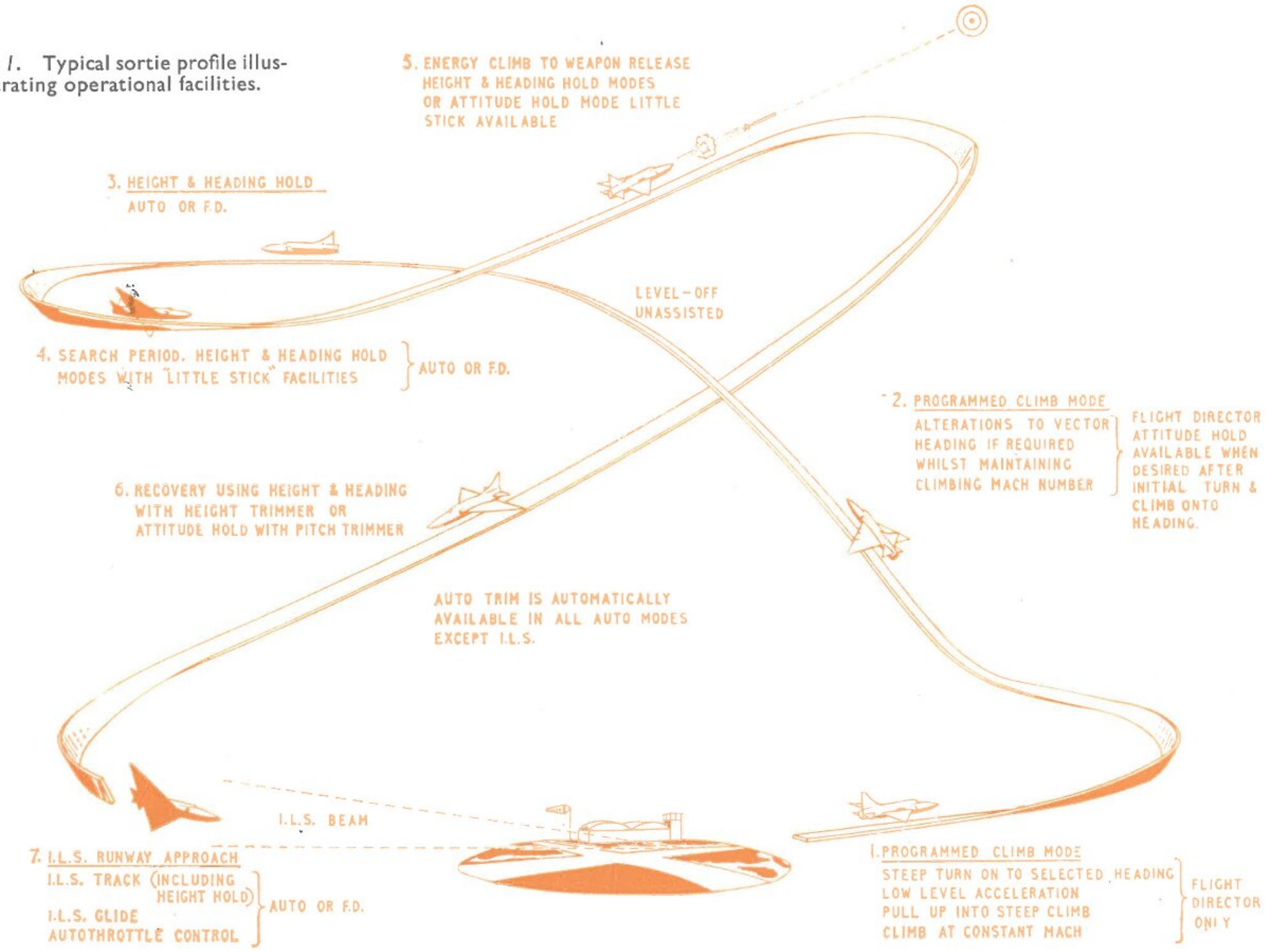
The M.R.G. is controlled by an Instrument Master Switch and the gyros should be running at effective speed and dependent displays at readiness within 20 seconds of switch "ON". After 20 seconds the power failure warning on the Attitude Indicator should clear, indicating the end of the M.R.G. starting cycle. The azimuth gyro is monitored by amplified signals from the sensing elements of the compass detector unit which is located in the wing. The compass card is slaved to the gyro to display aircraft magnetic heading, and whenever precession is occurring a cross or dot is shown in the annunciator window of the Navigation Display. The compass detector unit is conventional embodying a pendulous floating raft, the North sensing accuracy of which is adversely affected by flight acceleration and centrifugal forces. Therefore detection devices in the M.R.G. cut monitoring whenever horizontal linear acceleration is in excess of $\frac{1}{12}$ g, whenever the elevation angle is in excess of ±20°, and whenever the angle of bank is in excess of ±10°.

Attitude Indicator

(a) This displays aircraft attitude in bank and elevation and demanded steering instructions on a fly-to type of Flight Director Bead. Slip or skid is shown on an integral ball-in-tube slip indicator. Bank and elevation are simultaneously displayed on a roller blind divided laterally into two sections, one grey representing sky the other black representing earth, with the junction between the two sections representing the horizon. The blind carriage has freedom to rotate through 360° of roll, and pitching movement is denoted by the blind moving up or down to the ±90° elevation position. At high angles of climb or dive a zenith or nadir star respectively is visible on the blind and for any pitching manœuvre of 90° from straight and level the blind will display all grey or all black with the appropriate star in the middle of the display. The tail of the star points to the horizon whenever the latter is not visible on the display.

Straight and level flight is indicated when the division between the grey and black portions of the blind is coincident with the small centre circle on the bezel glass and the bank indicator pointer is coincident with the central reference of the bank angle scale which is marked around the lower half of the dial circumference. A loop through the

Fig. 1. Typical sortie profile illustrating operational facilities.



zenith results in a rapid rotation of the blind through 180° as zenith is passed and a similar rotation will occur through the nadir point.

This rotation is automatically achieved and is accompanied by equivalent rotation of the compass card.

Concentric circles and small arcuate marks marked on the bezel glass provide a reference for measuring elevation angle by displacement of the horizon or stars from the centre mark. A pointer on the blind carriage provides a reference to read bank angles against fixed references on the face of the indicator.

(b) The Flight Director index takes the form of a small black and white ring which is actuated by rectilinear crosswires attached to carriages which enable the ring to be moved laterally and vertically behind the bezel glass. A central fixed index on the glass represents the nose of the aircraft and pitch and roll demand information is fed to the ring marker from the Flight Control Computor. The Flight Director is of the fly-to type so that demands are in the natural sense, *i.e.*, if the bead moves up the pilot raises the nose of the aircraft to follow it, and if the bead moves right the pilot banks the aircraft to starboard. The bead can be parked in the top right-hand corner of the Attitude Indicator by placing the central column engage switch to "OFF".

(c) A Power Failure Warning in the form of an orange and white striped disc appears on all production instruments should there be any interruption in the a.c./d.c. supply from the M.R.G. distribution box.

Navigational Display

(a) General

The navigation display is a composite instrument continuously presenting heading and selected heading information and in addition either TACAN homing or I.L.S. information may be displayed by appropriate selection. A servo operated compass card driven by the M.R.G., is used to display heading information. Behind, but within the circumference of the card, a blind mechanism displays Localiser information in the I.L.S. mode and TACAN range and bearing in the TAC mode. I.L.S. glide slope displacement is displayed by a separate servo driven index between the blind and the glass. Provision is also made for homing to a chosen point offset from the TACAN beacon rather than to the beacon itself.

(b) Compass Mode

Operation in this mode is conventional. Immediately after M.R.G. start up the flag in the annunciator window assumes a central position, and the compass card will indicate a random heading. Some 20 seconds after switch-ON the compass card will be locked to the azimuth gyro and monitoring will commence at 2–3 degrees per minute. This is indicated by dot or cross appearing in the anunciator window. If the heading displayed is substantially different from the aircraft heading then more rapid synchronisation can be affected by turning the SYN knob – clockwise if a cross is showing and anticlockwise when the dot is in view. The Syn. knob mechanism embodies a ratchet device so that it will slip if turned in the wrong direction, thus avoiding the possibility of synchronising on a reciprocal.

Slow oscillation between cross and dot indicates that the compass card, azimuth gyro and detector unit are synchronised. The desired heading knob may be PUSHED IN and the Select Heading Pointer turned to any desired point on the compass card and when the knob is released the pointer and its reciprocal will then rotate with the card. Should the power failure warning appear on the attitude indicator the compass card must be treated as suspect and will not continue to synchronise automatically, but a magnetic heading can be obtained by turning the SYN knob manually.

(c) I.L.S. Mode

When standard I.L.S. receivers are carried in the aircraft the display presentation comes into view when the mode selector switch is set to I.L.S. With I.L.S. receivers switched on their outputs are channelled *via* a distribution box to both the Navigational Display and the Flight Control Computor. In the latter these signals are used for auto-approach computation and to feed demands to the Flight Director. The I.L.S. mode is therefore available as a manual, Flight Director, or Auto facility, and additionally the auto mode is monitored by the Flight Director.

Turning to Fig. 2 the display provides the pilot with a plan-view of the runway and the position of the aircraft relative

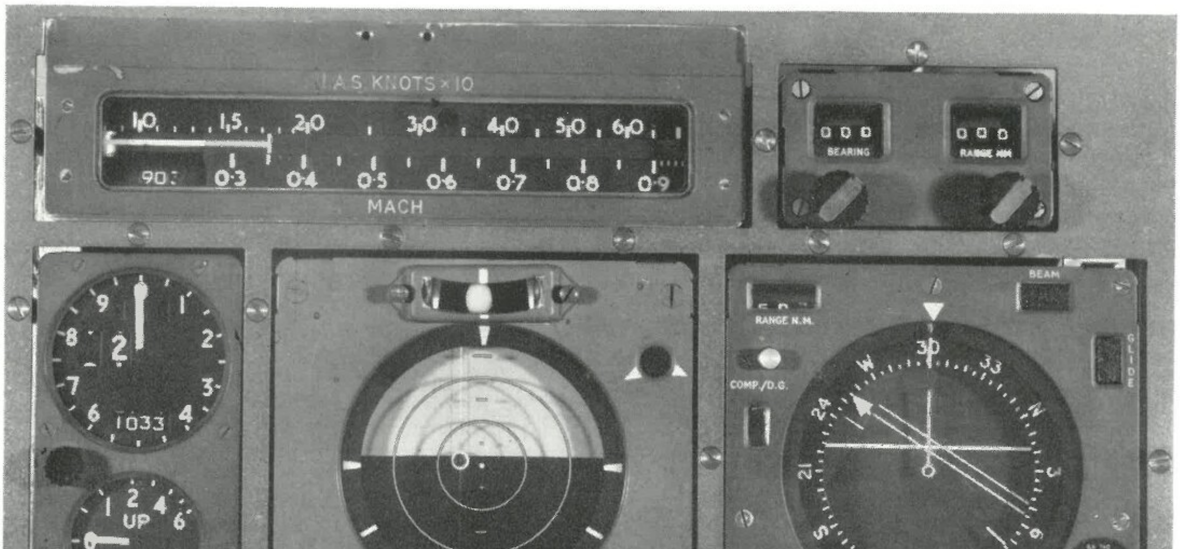


Fig. 2. The flight data presentation.

to the runway. A single-bar glidepath indicator is superimposed horizontally across the roller blind display which appears as a two bar localiser indicator. The glidepath bar is carried on a rack mechanism positioned by the output of the glidepath receiver. The bar is always horizontal and moves up or down relative to the central index on the dial.

The servo operated roller blind carrying the localiser bars moves transversely across the display in response to signals from the localiser receiver or rotationally as bank angle is applied. A reference mark on the blind carriage can be seen through a transparent portion of the roller blind and represents the centre of the localiser beam. Deviation of the aircraft from the centre of the beam is therefore shown by displacement of the localiser to either side of the mark. The index mark is set to runway heading by PULLING OUT and turning the HDG knob. There are two windows at the top right of the instrument which indicate when localiser and glide path input signals are at operating level. The flags in these windows will show black when the signals are acceptable and OFF when they are not acceptable. The marker beacon lamp at the bottom centre shows a flashing blue light when the aircraft is passing over the outer and inner beacon transmitters.

In the example shown at Fig. 2 the I.L.S. display shows the select heading pointer set to 255° M. This represents runway heading plus 10° drift correction. The localiser index mark is set to the Q.D.M. of the runway. Some pilots prefer to align the localiser "runway bars" on Q.D.M. (D) so that when flying the beam centre line the bars remain vertical on the indicator. The double bar localiser indicator shows that the aircraft is displaced to the left of the beam and the heading lubber line shows the course being flown as 300° M., *i.e.*, approaching the beam centre at an angle of 45°. The BEAM and GLIDE "OFF" flags have cleared showing that both functions are operational and the glide path indicator shows the approach being made under the glidepath beam. The attitude indicator shows zero bank with the aircraft very slightly nose down, whilst the Flight Director is demanding slight nose up and turn to port to put the aircraft on the correct angle of closure to the runway.

During development flying the I.L.S. display and its operation in the different modes have been well received by pilots at R.A.E., A. & A.E.E. and C.F.E. as an improved operational aid. The simultaneous display of heading information and beam displacements on the same instrument enable the pilot to be constantly aware of his position relative to the beam. With the conventional type of I.L.S. indicator, cross reference is necessary between compass

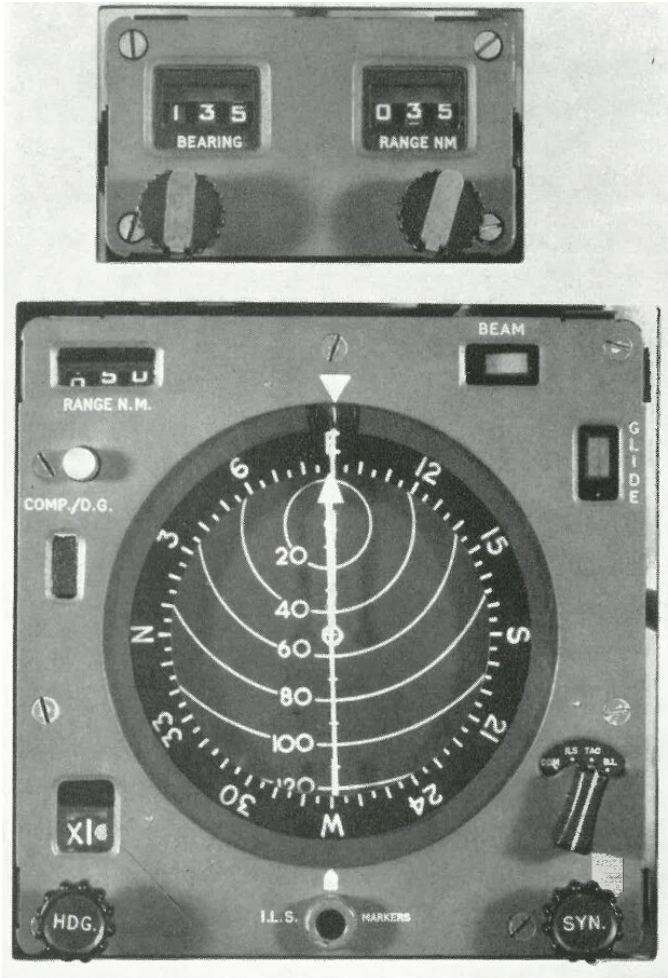
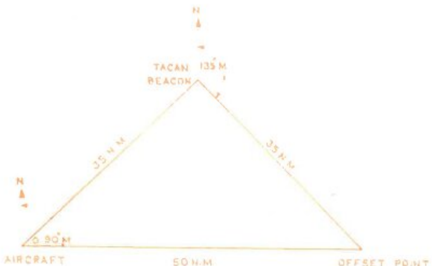


Fig. 3(a). Navigation display in offset TACAN mode, and shown below *Fig. 3(b)*, is the offset homing point.



and indicator before demand signals can be satisfied. Additionally, the glide bar is natural and can be likened to an artificial horizon.

(d) Tacan Mode

This mode is available either as straightforward TACAN facility giving range and bearing from a chosen beacon, or at any stage of flight within TACAN range the range and bearing of a chosen point offset from the beacon can be wound into the Offset Computor.

Fig. 3 (a) illustrates the Navigation Display in the TACAN mode. With the mode selector switch set to TAC the roller blind display is seen as a series of concentric arcs centred on the homing point each one representing a unit of 20 n.m. distance of aircraft from homing point. A line bisecting these arcs indicates the bearing when read against the compass card and is marked between each arc to indicate 10 n.m. intervals. Range is read using the bezel glass central index mark as a reference. The homing point will not be visible at ranges in excess of about 80 n.m. but the bearing index and the distance arcs show in which direction it lies. The distance of the aircraft from the homing point is also shown in nautical miles in numerals by a veeder counter at the top left of the instrument.

In Fig. 3 (a) the aircraft is shown on the computed course 090° M. at a range of approx. 50 miles from the offset point illustrated in Fig. 3 (b). If the offset computor is set to zero range and bearing then the display will present the range and bearing of the beacon from the aircraft. To enable the range and bearing information to be utilised should the M.R.G. go unserviceable, a M.R.G. isolation switch is provided in the aircraft so that in such circumstances the compass card can be locked to provide a heading reference.

(e) U.H.F. Homing

As a supplementary feature to the basic rendezvous aids of air to air TACAN for range information and U.H.F./D.F. homings, the pilot can select and display U.H.F. Homer displacement information on the I.L.S. localiser bars of the Navigation Display. The localiser index mark is then aligned with aircraft heading so that the tramlines are vertical, and can be related to heading. The picture presented is positional, *i.e.*, left or right of required heading for rendezvous.

AERODYNAMIC REFERENCE SYSTEM. This system measures the basic aerodynamic quantities of pitot and static pressure and computes corrected values of barometric height, vertical speed, indicated air speed and Mach number. The corrected values of I.A.S. and Mach No. are not used for display purposes when a conventional A.S.I. and Machmeter is fitted. The system comprises a power supply unit, pitot static and static transducers, the Air Data Computor and a height display giving barometric height and vertical speed indications.

The two transducers are sited as close to the pitot head as possible. They convert static pressure and pitot/static pressure difference into electrical signals. The pressures are detected by means of metallic capsules each being so designed that its displacement is approximately proportional to the logarithm of the pressure difference across it. Log S and log (P–S) voltages are fed from the transducers to amplifiers in the Air Data Computor. Position error is computed in the A.D.C., and height correction is fed back to the static transducer from which corrected height synchro transmission signals are supplied to drive the servo operated altimeter in the height display unit which always reads barometric altitude.

Another synchro in the static transducer transmits to two servo-gearboxes in the Air Data Computor. One gearbox feeds barometric pressure information and height lock switching to the automatic system and the other provides a voltage for the vertical speed indicator. The transducer outputs are also processed in the Air Data Computor to transmit true Mach No. information and Mach Lock switching to the Flight Control System.

Height and Vertical Speed Indicator. Two dials contained within the same instrument present altitude and rate of change of height (*they can be seen in Fig. 2*). The altimeter has one pointer which rotates around the scale once per thousand feet. The circumferential scale is marked 0 to 9 in 100 feet steps and further subdivided at 50 feet intervals. A digital display appears in a counter window to indicate thousands of feet and tens of thousands of feet up to 99,000 feet.

The counters gain or lose a 1,000 feet when the pointer is between 950 feet and zero, and development flying has shown a need to remove the possible misinterpretation around the zero. A modification which provides a third counter indicating hundreds of feet is now being embodied in production instruments. A knob below the altimeter is provided for setting ground pressure in millibars.

The vertical speed indicator has one pointer indicating climb or dive and the rates are marked from one to six thousand feet per minute. During development flying, pilots have experienced much difficulty in using the V.S.I. to maintain height in turns and in recovery from climb and dive. The response rate of the servo operated V.S.I. is much quicker than the conventional type, with the result that the tendency indications of the latter around zero were not available. The time constant of the rate of climb channel in the A.D.C. was therefore increased around zero to provide an output equivalent to height change and not rate of change of height. The rate term takes command outside the zero region, and the combined characteristics give trend and response similar to the conventional V.S.I. This does not affect V.S.I. signals fed to the Flight Control Computor for Auto modes where accurate response rates are advantageous.

An amber power failure warning disc appears in a window on the altimeter in the event of a failure in electrical supply to the instrument.

Air Speed Indicator and Machmeter. These can be conventional capsule operated instruments or the tape Speed Display shown in Fig. 3. It has an I.A.S. tape moving left to right and read against a fixed I.A.S. scale. The Mach scale at the bottom also moves and is read against the I.A.S. index, allowance being provided for the I.A.S./Mach differential.

STANDBY INSTRUMENTS. A Mk. 6 Artificial Horizon, Directional Indicator Type B and Mk. 24 Altimeter will normally be installed to serve as a "get you home" standby in the event of failure of the M.R.G. or the servo-operated altimeter. The Artificial Horizon and the Directional Indicator are operated from a 115 volt 3 phase a.c. system, and should this fail then the system automatically uses 28 volt d.c. as power supply for a static inverter which supplies single phase a.c. to keep the gyros running. Should main d.c. fail then an emergency switch is provided to keep the Horizon running from the 24 volt service battery.

FLIGHT CONTROL SYSTEM. The Flight Control System provides three-axis autostabilization, auto-tailplane trim, a programmed climb, height and heading holds, attitude hold in pitch and bank, and I.L.S. coupling.

With the system finally developed it is intended that the pilot should have the option of engaging Flight Director or Auto in all modes, except the initial part of the Programme Climb, which is F.D. only, and Attitude hold which is Auto only. All applicable Auto modes can be visually monitored by the Flight Director. The I.L.S. approach also makes provision for auto throttle control. The auto-system is essentially a control surface position demand system of limited authority, the maximum permitted aileron, rudder and tailplane deflections remaining constant throughout the flight profile except for the tailplane actuator whose maximum permitted stroke may be increased in the Auto I.L.S. mode and in any other mode above say 30,000 feet. There are normally no rudder demands except for autostabilisation.

The Flight Control Computor (F.C.C.) is the functional control and computing centre of the Flight Control System and accepts pitch and bank information signals from the M.R.G., heading error signals from the navigation display, Log Mach No., pressure height corrected for P.E., and rate of change of height signals from the Air Data Computor. I.L.S. angular displacement from localiser and glide path beams is fed to the F.C.C. from the I.L.S. receivers as also are autostabilisation signals from the rate gyros. Control signals from the F.C.C. are transmitted according to whether F.D. or Auto is selected, to the Flight Director display on the attitude indicator, and to the primary flying controls *via* the autostabiliser actuators. In the I.L.S. mode I.A.S. and pitch control signals are also fed to the engine throttles *via* the throttle servo.

Flight Director information displayed during auto modes serves as a monitor, but should normally give a null indication. A *g* switch is fitted as a safety device to protect the aircraft from autopilot tailplane runaways, and will detect accelerations outside the values 0 to +3 *g* absolute (*i.e.*, −1 or +2 from normal). Whenever such outside values exist or in the event of a.c. or d.c. failure the *g* switch initiates action to switch off power supplies to the Flight Control System, and reversion to manual takes place.

In the event of a faulty *g* switch or circuit causing a "nuisance disconnect" then a double switching action is necessary to restore the system to normal *i.e.*, disengage auto – auto-stab. OFF – master OFF – master ON – Auto-stab. ON – Engage Auto.

PILOT'S CONTROLS. The **Engage Switch** is designed to be mounted on the control column handle and has three marked positions F.D. (up) – OFF – Auto (down). In either the F.D. or Auto positions, the switch channels outputs of the Flight Control Computor according to the mode preselected on the pilot's controller, to either the

Flight Director alone or in the Auto position to both Flight Director and the control surface servos. A magnetic indicator on the Pilot's Controller indicates "OFF" or "F.D." or "Auto", and remote indications may also be provided.

The **Pilot's Controller** seen in Fig. 4 incorporates mode selector keys, toggle switches, magnetic indicators and a "little stick" control knob. The "Master" switch completes a.c. and d.c. supplies, as indicated by the OFF or all black position of the doll's eye indicator. Raising the "STAB" switch completes the three axes auto stab. signal circuits. The mode selector keys are rocker type keys which lock in the forward position, and the Height and Heading Hold keys are interlocked as they are used together.

Once a mode is selected then selection of a new mode cancels the existing mode except when selecting I.L.S. Glide with I.L.S. track already selected or Heading Hold with Height Hold selected. I.L.S. glide can only be selected when I.L.S. track is selected and engaged. The control column engage switch must be switched OFF whenever a change of mode is made except when operating the Heading Hold key or when selecting I.L.S. track from Height and Heading Holds.

The "little stick" control is an over-ride control to permit datum adjustments to Bank Angle and Vertical Speed when the Auto modes of Attitude Hold or Height, or Height and Heading Hold are engaged. In Height Hold turning the vertical speed control (V.S.C.) will demand a desired vertical speed up to 6,000 feet/min. and the aircraft will relock at any new height when the knob is returned to centre. The V.S.C. is not spring centred, but to prevent inadvertent engagement with the control off centre an interlock is provided so that attitude hold can only be engaged after the V.S.C. has been returned to the centre position. In the attitude hold mode the control has a range of $\pm 6°$.

The little stick bank angle control (B.A.C.) is spring loaded to centre when the autopilot is engaged in programme climb, attitude hold, or height hold mode with heading hold selected out. Turning the knob to left or right banks the aircraft to port or starboard. In the heading hold mode the knob provides a range of $\pm 15°$ of bank angle in 5° click stop positions over the 50° the F.C.C. demands in a turn whenever the heading error exceeds 15°. When aircraft heading is within 15° of the new desired heading the knob is spring loaded to its centre position. In the Attitude Hold mode the B.A.C. has a range of $\pm 30°$ and is spring loaded to centre over this range.

The **Heading Selector Knob** on the Navigation Display is pushed IN and rotated to enable desired heading

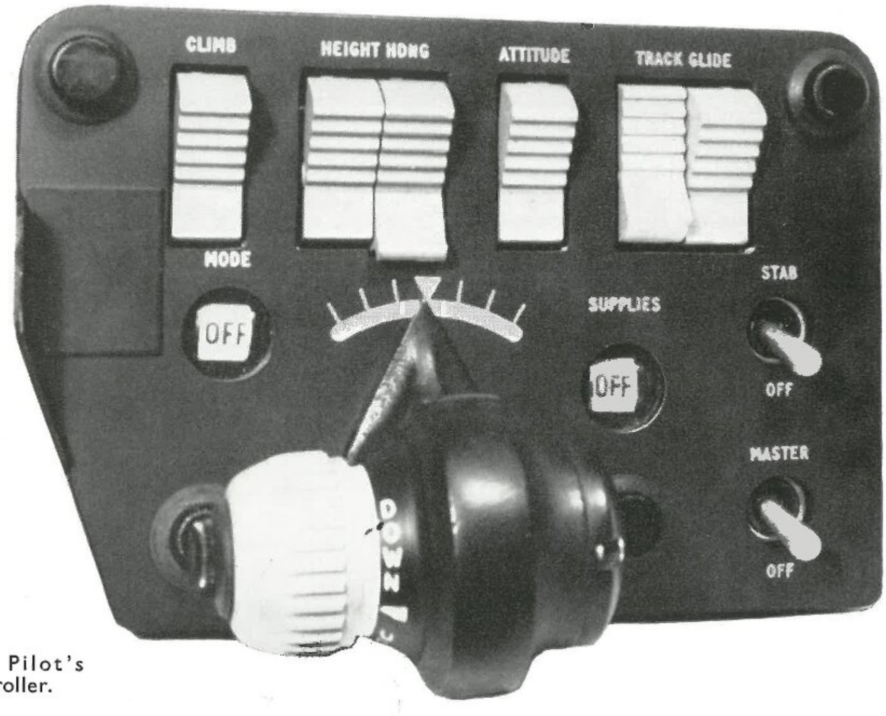


Fig. 4. Pilot's controller.

information to be fed to the F.C.C. for Flight Director or Autopilot manœuvres. The heading error signal transmitted to the F.C.C. is translated into a demand for port or starboard bank towards the new heading. When the knob is pulled OUT and rotated it enables the I.L.S. localiser index to be set to any desired heading.

Automatic Throttle Control is provided to control airspeed during the I.L.S. approach and in Height Hold below 300 knots during the Pre-track Phase. The throttle servo is operative whenever I.L.S. Track is selected on the pilot's controller and the throttle servo clutch control is set to ENGAGED. Amplified electrical signals from the F.C.C. are fed to an electrically operated actuator which is coupled into the throttle control run *via* the clutch mechanism. The actuator maintains the predetermined aircraft I.L.S. Track speed set by the pilot, and small manual adjustments of the throttles can be made with clutch engaged.

In the GLIDE phase the throttle servo control adjusts r.p.m. automatically to maintain the predetermined speed at the new aircraft pitch attitude. In emergency the pilot can override the servo control by direct movement of the throttle levers, a maximum force of about 18 lb. being required.

MODES OF OPERATION

Fig. 1 shows a typical sortie profile in which an aircraft is required to take-off, turn on to selected heading, climb to intercept a target and return to base. It provides a quick reference to the facilities available throughout such a flight.

Three axis autostabilisation. This is selected STAB or OFF by the switch on the Pilot's Controller. Autostabilisation control is provided by three rate gyros to increase the aircraft's short period damping, *i.e.*, to stabilise short period oscillation and transient changes of attitude. It is available under all flight conditions and is a prerequisite to use of any autopilot mode.

To provide optimum stability throughout the flight envelope it is necessary for aerodynamic reasons to alter the auto-stab. gearings, *i.e.*, the ratio of demanded control surface angle to aircraft rate. These gearing changes in pitch and yaw channels are introduced at high altitudes, and are effected by relays in the F.C.C. which are operated by Mach and I.A.S. switches in the Air Data System.

Autotrim is not operative in the I.L.S. mode but is operative in other modes when Auto is selected on the control column engage switch. Autopilot demands on the tailplane greater than 0.5° are transferred automatically to the tailplane trim actuator, thus ensuring that the autostabiliser actuator is maintained within the central region of its authority. The system therefore enables the application of large tailplane angles to counter substantial changes of aircraft trim without enlarging the restricted authority of the tailplane actuator.

An autopilot trim indicator shows any out of trim held by the autopilot actuator. The trim indicator is therefore a visual monitor of the auto-trim facility when engaged, and prior to engagement the pilot must check and trim for zero stick force. Before disengaging the autopilot any trim demand shown on the trim indicator must be removed to avoid pitch disturbance to the aircraft.

Programme climb. This mode provides signals for the acceleration after take-off, the turn on to a selected heading and the transition into and maintenance of the optimum climbing condition. The initial part of the climb can only be performed manually using flight director guidance and is not available in Auto. The mode ends with disengagement of the F.D. followed by a push over judged and executed by the pilot.

With CLIMB selected on the P.C., selected heading set on the Navigation Display, F.D. is selected on the control column engage switch. The A.D.C. supplies the F.C.C. with a d.c. signal proportional to aircraft rate of climb. The F.C.C. compares actual with desired rate of climb and displaces the F.D. bead in proportion to the error. The Flight Director moves upwards to indicate the nose-up attitude required to climb and accelerate under full climbing power and on reaching, say, 300 knots, the bead will slowly deflect UP and to left or right to indicate the port or starboard angle of bank required. Satisfying the demands will null the Flight Director bead and result in an accelerated climbing turn manœuvre on to selected heading. This manœuvre is computed by the F.C.C. using pitch and bank signals from the M.R.G., Rate of Climb from the A.D.C. and heading error from the Nav. Display.

The F.C.C. limits the heading error signals to a maximum equivalent to 45° bank, and as the aircraft rolls the M.R.G. bank signal backs off the heading demand. As bank angle demand is progressively reduced the bead returns to centre and is central when aircraft bank angle proportional to the heading demand has been established. Tailplane demands are fed to the bead to counter loss of lift during the turn on to heading, and to increase the rate of climb according to heading error in order to reduce aircraft acceleration.

As the desired heading is approached and with the pilot following the bead the aircraft continues to accelerate in a gradual climb up to a pre-determined Mach No. At this Mach No. the transition stage from accelerated climb to constant Mach climb occurs. The F.C.C. open circuits the Rate of Climb error signal substitutes a Mach No. error signal and compares rate of change of Mach with desired Mach. When Mach No. exceeds this figure, the F.D. bead moves up and the demand is satisfied by the pilot until acceleration is reduced to zero and the climbing Mach No. stabilises. Optimum climb at constant Mach follows to any required height, deviations from datum being shown as pitch signal demands on the Director bead which are nulled by the pilot.

The initial climb and turn on to heading is not available in Auto for safety reasons and auto application to the constant Mach climb is not at present considered by Air Ministry to be a mandatory requirement. However, the autopilot using Attitude Hold may be engaged at any time after transition providing the aircraft is in trim, and alterations to heading made by using the heading selector on the Navigation Display (push) or "little stick" for temporary heading changes.

The level off at height is not programmed and the control column engage switch should be placed "OFF" and a manual bunt out performed. After trimming to straight and level flight, height hold or height and heading hold may be engaged or, alternatively, the aircraft may be flown into a desired attitude and attitude hold engaged.

Height hold is selected by pressing the Height Key (control column engage switch must first be OFF and V.S.C. at centre) trimming the aircraft and after a few seconds delay switching to F.D. – ON or A.P. – ON. The datum is then maintained to that existing at engagement either by Auto demands on the tailplane or by Flight Director pitch signal demands for pilot correcting movements.

V.S.C. Up or Down will cause variation of the datum at a vertical speed, up to 6,000 feet/min. in either direction. This is effected by offsetting the vertical speed knob from its centre position and when the knob is returned to centre the aircraft will be held at the new datum. V.S.C. varies the height datum by applying a voltage to drive the height servo in the F.C.C. at a rate proportional to the amount the knob is rotated. This in turn causes a F.D. demand or tailplane angle in the appropriate sense to satisfy the vertical speed demand.

Use of the B.A.C. to change heading will create a tendency for the aircraft to lose height as it turns owing to reduction in vertical lift component. The control equation therefore introduces Bank Angle Crossfeed and counters any loss of lift by an automatic demand for tailplane up. The M.R.G. bank angle error signal is fed to the F.C.C. tailplane channel and the circuit ensures that the signal applied to the autopilot tailplane actuator is always tailplane up, regardless of direction of bank angle. The equation calls for reduced demanded tailplane angle with increase in Mach and therefore the bank angle crossfeed current into the F.C.C., and then the tailplane channel is reduced as a function of increased Mach No. The pitch rate gyro provides a further signal into this channel to maintain short term stability of the aircraft in pitch.

Height and heading hold may be engaged in either the flight director or autopilot mode. Height will be held as described in the previous paragraph and any aircraft heading error from the desired heading selected on the navigation display will demand aileron movement until the desired heading is restored.

Heading hold is not available as a separate mode and can only be engaged concurrently with height hold but it is possible to disengage heading lock independently by using the mode selector key while Height Hold remains engaged. In the auto mode with heading lock engaged then manual movement of the select heading knob on the navigation display will bank and turn the aircraft on to the new heading. In this mode bank angle up to a limit of ±50° above 300 knots and ±30° below 300 knots is applied proportional to

Fatigue and Forethought

When there is a need for aircrew fatigue to be considered by a Board of Inquiry as a possible contributory cause of an accident, the problem is always difficult to resolve.

It is almost impossible to define operating conditions which will result in the crew being too tired to be efficient at the end of the sortie – a 12-hours trip may be normal to a Shackleton crew. Some loss of efficiency may be expected at the end of the period of operation but whether this loss is dangerous or not largely depends on the rest and food which the crew achieve in the hours before flight.

This is to a large extent a matter of self discipline but there are still instances of bad programme planning which produce unacceptably long working hours. Such cases where the remedy lies in "the system" rather than the individual must be eliminated wherever they are found. They are immediately apparent to a Board of Inquiry but by then it is too late; such things as manning shortages (for whatever reason) and secondary duties, need careful study to ensure that crews are fully fit to complete their flying tasks efficiently. Flying is, after all, the crews' primary function in any flying appointment in the Service.

heading error and is progressively reduced as desired heading is reached.

In auto with heading lock disengaged a new desired heading may be preselected on the navigation display and the turn initiated when required by re-engaging heading hold. The bank angle can be adjusted by rotating the B.A.C., thereby altering the rate of turn. The control equations provide tailplane co-ordination during turns.

Attitude hold maintains the aircraft in any attitude initially achieved under pilot control. After selection on the pilot's controller, the aircraft must be trimmed and after a 3–4 seconds' delay Auto is selected on the engage switch. The datum pitch and bank signals from the M.R.G. are then stored in the F.C.C., and any error from datum thereafter induces a demand for corrective control surface movements.

Little stick control is available in both pitch and bank. The V.S.C. can be used to modify the elevation angle by $\pm 6^\circ$ and the controller will remain in the position selected. The attitude hold mode cannot be engaged unless the V.S.C. is initially at centre. The B.A.C. can be used to modify the bank angle by $\pm 30^\circ$, but in this case the controller is spring loaded to centre.

I.L.S. mode. This mode enables the aircraft to be flown manually using the Nav. Display I.L.S. presentation, or on Flight Director, or automatically into the approach path as defined by the two radio beams of a standard I.L.S. ground installation. It is necessary to disengage the Flight Director and Auto modes at break-off height and complete the landing manually. In a typical Auto-I.L.S. approach the aircraft will possibly be flown using TACAN OFF-SET and Height Hold to an area within the localiser signal when the BEAM OFF flag will clear. The Nav. Display localiser bar index is set to Q.D.M., select heading pointer to Q.D.M. (D), altitude reduced to about 2,000 feet using V.S.C., airspeed reduced, throttle servo engaged, B.A.C. used as necessary. The aircraft should be trimmed to zero any tailplane out of trim indicated on the autopilot trim indicator.

When "Track" is selected the autopilot commences to turn the aircraft into the I.L.S. localiser beam and holds course towards runway heading. The aircraft remains at constant height and airspeed. When the glidepath bars come down to the central index, GLIDE is selected. This removes Height Hold and the aircraft is automatically held to the glidepath in the vertical plane.

The use of Attitude and Air Data information and their integration with the aerodynamic requirement including thrust presents some complex technical considerations to the flight control system which is required to provide full azimuth and longitudinal stability during track and glide phases. In azimuth a satisfactory flight path cannot be achieved by localiser demands alone, and a stabilising term is obtained by comparing the localiser demand signal with a relative heading demand derived from a heading potentiometer, the initial output of which is determined by the pilot in setting the Select Heading Pointer of the Navigation Display. The output of this potentiometer is not linear with heading error but is so shaped that it promotes rapid closure towards the beam centre while angular displacement is large. When localiser and relative heading error signals are equal in value and of opposite polarity, the algebraic sum is zero, demand is zero, and there is net demand for bank. In the Track phase bank angle is limited to $\pm 30^\circ$ and reduced to $\pm 15^\circ$ in the Glide phase.

To effect longitudinal control in the Track phase the Flight Control Computor stores the height from the A.D.C. in a locked condition (the datum of Height Hold engagement), but the elevation angle store has the time constant of follow up increased so that it is virtually locked for transient changes of pitch attitude and these are not corrected.

Bank angle crossfeed is achieved in the same way as in Attitude, Height, and Height and Heading modes. When "Glide" is selected the height error signal stored in the F.C.C. is replaced by the glidepath error signal received from the I.L.S. Glidepath Receiver. This error signal should be zero when the Glidepath Bar on the Navigation display is at the centre of the display. In the Manual mode the bar would then move downwards creating a demand for pilot correcting movement.

To pitch the aircraft into the Glide beam the F.C.C. arranges for the M.R.G. elevation angle signal to be compared with a false elevation reference which is 3° less than actual. This difference creates an apparent 3° pitch up, which is satisfied by an autopilot demand for a 3° nose down into the glidepath. As this occurs the M.R.G. vertical gyro detects the change in aircraft attitude and reduces the elevation angle error signal from the F.C.C. to the tailplane actuator to zero when the aircraft is 3° nose down. The system then stabilises giving only that tailplane required to maintain the aircraft at the required angle of the Glide beam. Automatic thrust compensation for changes in pitch angle is provided throughout the Track and Glide phases. The onset of a change in air speed can be detected by either the Air Data System or the elevation angle error signal. In the Track phase the latter is used to create a change of thrust demand, so that the demand is simultaneous with the aircraft pitching and in advance of a change of airspeed instead of after it. On Glide selection the airspeed datum is, however, automatically reduced, to cancel the demand for increased thrust arising from the apparent pitch up, and to reduce engine thrust and prevent an increase in air speed as the aircraft pitches into the glidepath. This anticipation provides much better accuracy than adjusting thrust after a change in airspeed has been detected.

The approach may also be made manually following the I.L.S. presentations on the Navigation Display, or on Flight Director with or without autothrottle. The latter, however, assists in achieving a high degree of stability of airspeed and as would be expected pilots generally consider height and glide beam holding in Auto to be superior to Flight Director, and the latter to give a better performance than manual.

SUMMARY

The difficulties of achieving accurate control in high performance aircraft were outlined in the October, 1957, issue of AIR CLUES, in which Group Captain J. C. T. Downey established the corner posts for the new Flight Instrument System as CLEARER PRESENTATION, FLIGHT PATH DISPLAY, WHAT TO DO INFORMATION, and AUTOMATIC CONTROL. This description of the system has tried to show how these corner posts have effectively been translated into hardware.

The description is far from comprehensive but may be sufficient to stimulate the interest of aircrew and ground personnel who hope to fly the aircraft of the near future or maintain them. Some 2,000 hours' development and proving flying have shown how difficult it is to reconcile all pilot opinion on display presentation and use of the various operational facilities.

The apparent complexity of the system may give rise to some doubts, but must be considered in relation to the results obtained, and the penalty of obtaining equivalent capability without an integrated system.

The aim has been to make the pilot's impossible task possible, but the servicing task must also be possible and integration and complexity do of course necessitate a "Systems" outlook from servicing personnel. With this in view Air Ministry are introducing Diagnostic Systems Technicians, and have also initiated action to evaluate the possible advantages of using Automatic Test equipment on aircraft. The attainment of satisfactory reliability is a continuing process and the electromechanical reliability of the equipment and the attainment of repetitive performance within specification limits has merited intensive development effort. ■