THIRD EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

Paper No. 36

CONTROL AND MISSION PLANNING FOR THE REMOTELY PILOTED HELICOPTER

G.L. HODGE and J. BARTOVSKY

WESTLAND HELICOPTERS LIMITED, ENGLAND

September 7-9, 1977

AIX-EN-PROVENCE, FRANCE

ASSOCIATION AERONAUTIQUE ET ASTRONAUTIQUE DE FRANCE

SUMMARY

The design of remotely piloted helicopters poses rather different problems in control to those of conventional manned machines. The absence of the pilot from the aircraft imposes upon the designer the need to determine the requirements of not only the aircraft but also of a ground-based control station, which will include the navigation and control systems, the command signal and data transmission links and, not least, the definition of procedures which govern the performance and operation of the overall system.

Some of the problems which arise in the design and operation of the system are discussed with reference to the method of control and the planning of the aircraft mission. It is shown that flight of the aircraft can be considered as consisting of three different phases, each of which will have differing requirements in terms of authority and rate of application of pilot control demands.

The design of control systems which can fulfil these requirements is discussed, highlighting the possible division of flight control system elements between the aircraft and the ground station.

NOTATION

$\emptyset_0$	(rads)	blade collective pitch angle
$\emptyset_s$	(rads)	longitudinal cyclic pitch angle
$\emptyset_c$	(rads)	lateral cyclic pitch angle
$\emptyset_d$	(rads)	differential collective pitch angle
θ, Ψ	(rads)	pitch attitude, yaw orientation of aircraft
Q,R	(rad/s)	pitch, yaw angular rates of aircraft
K		control system gains

Subscript

D	pilot demanded input

1. INTRODUCTION

The potential ability of unmanned aircraft to carry out a wide range of tasks more cheaply, safely and efficiently than conventional manned aircraft has for long appeared attractive to both the military user and the designer.

Small, lightweight, relatively inexpensive yet reliable, electronic components and communication systems are becoming increasingly available. These have enabled the concept of a system in which a small unmanned aircraft and its equipment may be continuously controlled by a ground based operator, even while out of sight, to become a practical proposition. This is the truly remotely piloted vehicle (rpv).

Westland Helicopters Ltd. (WHL) have had an interest since 1968 in systems for battlefield surveillance and target acquisition based on the helicopter rpv equipped with 'real time' surveillance sensors. Feasibility studies have shown that its ability to hover and to take-off and land, virtually at will, from small, unprepared sites, together with the degree of control, manoeuvreability and speed suited to the mission, make the remotely piloted helicopter (rph) the best choice for this role.

The configuration adopted by WHL is that of a craft having twin coaxial rotors and a fuselage shape symmetrical about the rotor shaft: the plan-symmetric helicopter. The main advantages of this arrangement in the rph role over that of the conventional single main rotor/tail rotor layout,are offered by the improved flight handling, simplified control, reduced detectability and the possible simplification in realising the communication links between the rph and the ground control station.

A basic, experimental rph, Mote, was built by WHL in 1975. Use was made of readily available aeromodelling components, producing an aircraft with an all-up-mass of 15kg. This successfully demonstrated the feasibility of the plan symmetric configuration. This has been followed by Wisp, a machine of 30kg all-up-mass embodying the same basic concepts as Mote but having rotor system components re-designed to a higher standard. With a maximum cruise speed of about 30 m/s and hover endurance of 20 minutes, the aircraft is designed to carry a tv camera and to have a limited operational capability. Since the first flight in 1976, a successful series of flight tests within sight of the pilot has been conducted. The payload and performance, however, are such as to allow for a limited out-of-sight capability.

Prominent amongst current and future projects is a complete surveillance system, able to operate at considerable distance from a ground station, which is being produced in collaboration with Marconi-Elliott Avionic Systems Ltd. Wideye®, the helicopter on which the system is based, has evolved from the design principles demonstrated in Wisp, although it is larger, heavier and will carry a bigger payload.

2. THE WESTLAND PLAN SYMMETRIC RPH

The concept of the plan-symmetric helicopter may be readily appreciated by reference to Fig. 1, which illustrates the configuration adopted in one WHL design proposal. This comprises a twin coaxial rotor system and a fuselage which is symmetrical about the rotor shaft axis (hence, plan-symmetric).

The fuselage is characterised by its 'bluff' profile and the absence of a tail. The two rotors are contra-rotating, which means that provided that equal power is consumed by each rotor, there will be no torque reaction to cause rotation of the fuselage. Thus, the tailcone and anti-torque tail rotor of the conventional helicopter may be dispensed with.

2.1. The Effects of the Rotor System and Fuselage Shape on Control

Some aspects of control of the plan-symmetric rph demonstrate features which are very different from those of conventionally configured helicopters. Most of these are inherent in the coaxial rotor configuration, the others arise from the size of the vehicle and the unorthodox shape of the fuselage.

With a conventional helicopter it is not possible to realise a pure pitching motion by a simple fore or aft movement of the cyclic pitch control. Variation of the rotor azimuth phase lag angle with forward speed means that the rotor will produce an uncoupled response to a control input at only one forward speed condition. At any other speed a longitudinal control input will produce some lateral rotor disc tilt in addition to the desired longitudinal disc tilt.

With the co-axial rotor system the piloting task is eased because the lateral and longitudinal control inputs are uncoupled. The lateral disc tilts produced on each rotor are in opposite directions and thus the net rolling moment about the centre of mass is effectively zero.

The task of controlling the vehicle in yaw is accomplished by varying the collective pitch settings on each rotor differentially so that a net torque is produced to yaw the aircraft.

The decision to pursue a plan-symmetric approach necessitates the use of an aerodynamically 'bluff' fuselage shape. Such shapes display very different aerodynamic characteristics from conventional helicopter fuselage shapes, having large drag coefficients and sometimes demonstrating unsteady flow effects.

The large drag forces cause the aircraft to assume relatively large angles of tilt in forward flight, compared with more orthodox configurations. The appearance of significant lift and pitching moment effects (at these large tilt angles) can affect the aircraft trim and could cause complications in the definition of laws for the Flight Control System. However, careful aerodynamic design can ensure that any undesirable effects are kept to a minimum.

It is obvious that the plan-symmetric helicopter has, by virtue of its symmetry, no preferred direction of flight. There are two main consequences of this fact. Firstly, since the fuselage characteristics which normally endow helicopters with a preferred direction of flight (notably, tailcones and tail fins) are missing, there are correspondingly less ways for gust disturbance to influence the motion of the aircraft. At the same time, however, the aerodynamic damping present in yaw will be almost negligible.

Secondly, the lack of a preferred direction of flight, when taken together with the absence of control coupling, offers the possibility of dispensing with the 'twist and steer' methods of control necessary with conventional tailed aircraft, in favour of a 'cartesian' method of control. In other words, independent longitudinal and lateral demands may be made to direct the rph as if on a grid, there being no necessity to steer the aircraft so that its nose points into wind.

3. PHILOSOPHY OF CONTROL IN FLIGHT

3.1. Definition of the Task

The philosophy of control in flight has been developed from considerations of ease of control by the ground operator so that the rph may be adequately and safely controlled by personnel who may not be pilot-trained.

The type of mission which the rph could be expected to undertake might typically comprise the phases of

- take off
- cruise or high speed flight out of sight of the operator
- hover and low speed flight over an area to carry out tasks such as surveillance or target acquisition, marking and fire control
- high speed return flight
- landing

For the purposes of defining the general control requirements in these various phases of flight, the concept of three basic control modes is instituted.

3.2. Control Modes

The three basic control modes necessary to satisfactory operation of the rph are considered to be a hover mode, a navigational mode and a remote hover mode.

The hover mode embraces take-off, landing, hover and low speed flight within visual range of the operator.

The navigational mode covers flight between specific waypoints and small, controllable deviations from the planned flight path, beyond the visual range of the operator.

The remote hover mode consists of station holding and small deviations from a ground referenced hover, the aircraft again being out of sight of the operator.

When considering the requirements for control in each of these modes it must be remembered that the remote operator will not be subject to many of the flight cues available to the pilot of a manned helicopter. Although translational motion and angular attitudes of the aircraft will be observable to some degree whilst within sight of the ground station, a 'seat-of-pants' feel cannot be present in any mode of flight.

If the rph is carrying a tv sensor then the 'real-time' video picture relayed to the ground station will provide the operator with some flight cues, though these will have limited usefulness for control of the aircraft. For example, when manoeuvering in low speed flight around the hover, the result of angular body motions on the view of the ground, obtained from a sensor fixed in the fuselage, could effectively make the translational motion of the rph appear to be in a direction opposite to that which is taking place. However, with a sensor which is stabilised in attitude, a correct sense of the translational motion will always be obtained, but no indication of the fuselage angular attitude and rates will be apparent.

In order to maintain stability of the aircraft and ensure that it remains within its design envelope, it is evident that some limiting of the operators' demands will be required.

Taking these points into consideration and bearing in mind the tasks to be undertaken by the rph, WHL have postulated control requirements for each of the three modes.

In the hover mode, for the purposes of take-off, landing and low speed flight within sight of a ground station, the operator will be given manual body attitude demand for translational control, and collective pitch control for positioning in height.

In the navigational mode the operator will be permitted the full range of attitude control, but the rate of change of control demands will be limited such that the rph design envelope may not be exceeded. Height will be under the command of an automatic system.

In the remote hover mode, for out of sight ground-referenced hover or low speed flight, the operators demands will be restricted to a limited amount of the available range of control but sufficient response will be present to enable the rph to contend with the prevailing wind conditions. Again, height will be automatically controlled.

3.3. Division of the Flight Control System

With a remotely piloted vehicle, the ground system will embrace both the aircraft and the ground station, the control elements available to the remote operator being an extension, on the ground, of the aircraft flight control system.

Fig. 2 shows a possible division of the flight control system for an rph. For translational control, WHL have adopted an attitude control system by which it is possible firstly to stabilise the naturally unstable motions of the helicopter about its pitch and roll axes, and secondly, to provide the operator with a means of demanding changes in airspeed via the trim relationship between body attitude and forward speed.

The pitch and roll demands made by the operator are limited at the ground station, in authority or rate of application, according to the mode of flight selected, and then transmitted to the aircraft as inputs to the onboard pitch and roll autostabilisation systems. Because of the absence of control cross coupling, these systems are mutually independent.

Most of the height control system is contained within the aircraft. The manual collective pitch setting, the demanded altitude and an enabling signal are transmitted from the ground station. In the manual mode, the collective pitch demand drives the collective actuator. In the automatic mode, collective pitch is adjusted by the height hold loop to maintain the aircraft altitude at the value demanded.

The yaw hold system is, again, situated in the aircraft. In the system shown, the rph is to be orientated in azimuth to a fixed compass bearing, which is selected at the ground station. The yaw demand signal is input to the yaw control system in the aircraft, which drives the differential collective actuator until the aircraft takes up the demanded orientation.

4. AIRCRAFT FLIGHT CONTROL SYSTEM

4.1. Pitch, Roll and Yaw Stabilisation

The plan-symmetric helicopter shares the inherent instability characteristics of all rotorcraft. These normally comprise oscillatory deviations of attitude and velocity at low speeds which are modified to a pure attitude divergence at higher speeds. The instabilities are, in addition, influenced by the effects of scale so that a reduction in size of the aircraft results in a shortening of the time constants associated with the helicopter's response. This effect, coupled with the fact that the remote operator will be unable to experience the attitude and velocity cues available to the manned helicopter pilot, leads to the conclusion that some means of automatic stabilisation is essential for the rph.

At the same time, however, it is desirable to simplify the piloting task of the remote operator.

The two requirements can be effectively met by the introduction of a combined autostabilisation-command system. With this scheme a body attitude is demanded and the stabilisation system applies cyclic pitch proportional to the difference between the demanded attitude and the attitude of the aircraft as measured by a gyro mounted in the fuselage. In the steady state the translational velocity of the aircraft is approximately proportional to the fuselage angle of tilt in the direction of flight, thus the body attitude demand control can be considered as, effectively, a speed demand control.

For the pitch axis the cyclic pitch inputs are scheduled by the following control law. A block diagram of the system is shown in Fig. 4.

$$\phi_S = K(\theta_D - \theta) - K_Q Q + K_T \theta_D$$

The second term is a rate feedback term commonly used in ASE systems, to reduce transient oscillations. In this case it is purposely made small because the rotor provides a large angular damping contribution. The third quantity of the equation is a feed forward trim term.

Lateral motions of the helicopter may be stabilised by a roll control law of a similar form to that used in pitch.

It is pertinent at this point to consider the axis system to which reference of pitch and roll attitude is to be made. From the standpoint of stability and control, the wind axes are of greatest importance. These are axes which are attached to the aircraft, with the longitudinal axis aligned with the direction of flight and pitch motion being about the lateral axis. For fixed wing aircraft, which fly nose-into-wind, there is no problem, the wind axes remaining fixed within the aircraft for any flight state. Thus, flight control laws will refer to a particular set of fixed aircraft axes. Consequently, the output of any attitude or rate gyros fixed within the aircraft may be fed directly into the ASE.

The plan-symmetric helicopter, however, does not have any preferred direction of flight and it is not intended that it should fly with a particular axis continually pointed into wind. The control laws in this case will have to be referred to axes which will rotate about the rotor shaft axis, depending upon the direction of flight.

There exists, therefore, a fundamental problem of 'indexing' these control laws and the outputs of gyros which are fixed in the aircraft, so that they may refer to the appropriate wind axes. There are ways in which a solution could be found but they would undoubtedly be somewhat complex in realisation. Fortunately, it has been found that the use of identical control laws in fixed aircraft axes, giving the same laws and gains in wind axes, will provide a satisfactory solution, and avoid the need for indexing. This has been successfully demonstrated with Mote and Wisp.

Control of yaw orientation is achieved by a control law of similar form to those for pitch and roll (see Fig. 3).

$$\phi_d = K_\Psi(\Psi_D - \Psi) - K_R R$$

Differential collective control is applied proportional to the difference between the demanded orientation and the actual aircraft orientation. The additional rate term is most important because of the almost negligible aerodynamic damping provided by the fuselage. To provide this signal a yaw rate gyro will be required. In addition, a gyro compass is required for reference if the orientation of the aircraft is to be held constant with respect to a fixed compass bearing.

4.2. Height Control

The need for an automatic height control system in all phases of flight except landing and take-off, is obvious. The piloting task will be considerably eased if the operator is restricted to simple demands for speed and direction of flight.

The realisation of a system to perform this task however is not as evident as the need. The primary requirement of the system is a suitable height sensor for the control loop. The various types which are available fall into the categories of those which measure the height above local ground level (radio or laser types), and those devices which measure only pressure altitude (barometric). The direct, or active, measurement devices whilst being potentially more accurate than the barometric devices are often limited in range.

Having found a suitable height sensor, the problem of devising a practical height hold loop remains. The design of this obviously depends upon the dynamic behaviour of the aircraft. The rotor has a steady state thrust limit which is governed by retreating blade stall conditions.
. This limit can be reached by 'overpitching' of the rotor such that collective pitch control is applied more rapidly than the rotor inflow can build up and reduce the flow angle of attack at the blades. This can result either in rotor blade stall and consequent vibration or in a slowing down of the rotor, either effect being undesirable.

Having examined some features of the rotor upper thrust boundaries it is necessary to explain the limitations of the rotor at lower thrust settings. It must be pointed out that, unlike most other helicopter configurations, the plan-symmetric helicopter is incapable of autorotation, since yaw control is achieved by differential variations of torque between the rotors. It necessarily follows that a loss of rotor torque implies a loss of control. It is obviously of paramount importance that collective pitch is never reduced to such an extent or so rapidly that autorotative conditions can occur.

Investigations of height control systems undertaken at WHL have been based on the assumption that a conventional collective pitch type control will be used during the take-off and landing phases of the mission. In this case the system must be designed such that the changeover between manual collective control and the height hold mode can be achieved simply and without any step discontinuities of collective pitch demand.

Possibly the simplest way in which these problems might be overcome is illustrated in Fig. 5. The height control system shown is a simple feedback loop which applies collective pitch in proportion to the error between the demanded altitude and the actual altitude of the aircraft. The control signal so derived is summed with the manual collective pitch input before being transmitted to the collective pitch actuator. When the height hold mode is switched out the system operates as a simple manual collective pitch demand system. When the height hold mode is selected the collective pitch input is 'frozen' to provide a '1g' hover collective pitch datum. The height hold loop provides small changes in collective pitch which are added to the datum collective setting to enable the aircraft to maintain its altitude or to change it as required.

The amount of control authority allocated to the height control loop must be a compromise. The control power must not be so great that the aircraft may trespass outside the maximum thrust and autorotation limits previously mentioned. At the same time however, sufficient authority must be available to accommodate the variations of collective pitch requirement which occur due to changes of forward speed, changes of aircraft all-up mass as fuel is consumed, and variations of air density as the aircraft changes altitude.

5. GROUND STATION FLIGHT CONTROL SYSTEM

In previous sections the WHL philosophy of control has been explained and a division of the flight control system elements between aircraft and ground station introduced. In the preceeding section the main features of the aircraft FCS were described. These consist basically of control loops for pitch, roll and yaw stabilisation and for height hold. The control demands for each of these loops will emanate from the ground, being produced by the ground station fcs.

5.1. Attitude Demand

Translational control of the WHL rph is obtained through an attitude demand system. The operator, wishing to position the aircraft or to direct it on to a particular course, depending on the mode of flight, will input commands through some control device to the ground station FCS. This will limit the commands according to the control mode selected and transmit them to the aircraft as pitch and roll demand inputs to the onboard ASE.

The three modes of control and their requirements have already been introduced. In the hover mode the operator is to be permitted the full range of control. The most suitable control device for this mode is likely to be a small, self-centring two axis joystick, in which the output of each axis represents the full range of fuselage attitude demand. The operator will need a control to provide relatively large control demands from relatively small stick movements. Simulation studies have shown that an isotonic (constant force) type of device will be suitable for the task. The miniature aero-modeller types of device have been used successfully for the control of the Mote and Wisp aircraft.

Whilst controlling the rph within sight of the ground station, the joystick controller must be aligned with the aircraft fixed control axes. In this way movements of the stick will correspond sensibly to movement of the aircraft. For example, movement of the stick away from the operator will command the vehicle to move away from the ground station. Because of the nature of the 'cartesian' system of control and the plan-symmetric configuration, the aircraft does not turn into wind but will continue to fly in the commanded direction. Thus, there will be no pilot orientation problems as may be found with, say, conventional model aircraft.

If the fixed aircraft axes are considered to be constantly aligned relative to North, then the positioning of the joystick controller must take into account the orientation of the ground station. This could be achieved by mechanical means. Alternatively, if directional communication links are being employed, requiring the aircraft fixed axes to be constantly aligned with the ground station, then it will be necessary to continuously resolve the joystick signals according to the bearing between the aircraft and the ground. This is best accomplished by electrical means and may be included as a function of the ground station fcs.

In the navigational mode of flight the operator is to be permitted the full range of control, but control demands are to be limited in rate of application. This rate limiting is to be included as a function of the ground station fcs. As this mode of flight is to cover translation between specific waypoints, the operator will need a velocity demand control. However, rather than permitting direct longitudinal and lateral control inputs as with the hover mode, it would seem more appropriate to provide a velocity and heading control, such that an appropriate speed and direction of flight may be demanded.

Ergonomic studies have shown that the two functions of the navigational controls may best be realised in two separate devices: a linear slider or single axis joystick for velocity demand and a rotary control for heading demand. A visual appreciation of the demanded aircraft heading can be obtained by displaying the rotary control output on a suitably selected compass-marked dial.

Taking a computed course to fly, an appropriate airspeed would be selected and the heading-control rotated to match the heading demand with the bearing required to reach the desired waypoint.

The two axis joystick recommended for the hover mode could, of course, be used for navigational control. However, the need in this mode for control stick movements to be made slowly and held constant for long periods would require the inclusion of a friction clamping device, which would be engaged during navigational flight to overcome the self-centring springing essential to hover mode control. In addition, the mechanical range of movement required for velocity demand in the navigational mode might well be greater than that which is acceptable for a hover mode joystick. It would, doubtless, be desirable, in the interests of economy of controls and ease of changing between modes, if the same attitude control device could suffice for all modes. It is clear, though, that it would be necessary to strike a careful balance between the differing requirements of the various phases of flight if this were to be achieved. However, it is considered that there are strong psychological advantages to be gained from providing an operator with different sorts of controls for distinctly different modes of control.

The exact form of rate limiting functions for velocity and heading will need to be determined by simulation studies and validated by flight testing. A possible solution which, by its simplicity, appears attractive, is to limit the linear and rotational accelerations of the aircraft by setting a fixed limit for rate of change of velocity demand and a limit for rate of change of heading demand, which is inversely proportional to the current velocity demand. This can be readily obtained from hardwired analogue circuitry and can also be achieved through digital computation.

Another simple system which has been considered is based on a recursive digital filter. In addition to undertaking the basic function of rate limiting, this system would also offer the facility for eliminating pilot induced low amplitude, high frequency control inputs by reducing the bandwidth of signals being passed from the ground station fcs to the aircraft.

The third mode of control is that of remote hover. The attitude control requirements in this mode are the same as those for hover in sight of the ground station, excepting that the range of control is to be reduced. The same two axis joystick recommended for the hover mode may be used. It will be necessary, if control is to be referenced to a video sensor view of the ground to ensure alignment of the joystick such that control inputs correspond sensibly to movement of the picture. This can be achieved by suitable transformation of the joystick signals.

An important requirement for control in the remote hover mode is the ability of the control system to enable the operator to accurately hold station. The degree of success which can be obtained in the execution of this task will depend not only upon the sensitivity and authority of the controls but also on the video camera field of view and the aircraft altitude. Setting aside any possible degradation of performance which might be introduced through picture imperfections, the size of sensor 'footprint' will influence the position and motion cues available to the operator due to the apparent size of objects of reference on the ground and relative picture crossing rates. These factors must, of course, be taken into account when determining a permissible range of control which will have sufficient authority to overcome the local wind conditions whilst providing an adequate position holding ability.

Design studies which are currently being undertaken at WHL are taking all of these aspects into consideration. Considerable use is being made of real time computing techniques to investigate the effects of parametric variations. The WHL simulation facility, which is based on a PDP 11/55 minicomputer, includes a vector graphics screen and has been configured to drive a simple closed circuit television system to produce a moving video picture. Both these display devices are being used to assess the low speed flight controllability and position holding accuracy in the remote hover mode.

Fig. 6 shows the layout of the simulation facility. The computer software includes the dynamics and aerodynamics of the rph and is able to move the vehicle image around the screen, in real time, according to the computed motion of the aircraft.

In one series of studies operators are being tasked with maintaining a schematic plan view of a vehicle on the ground, as might be viewed from an rph, beneath cross wires in the centre of the graphics screen. Results obtained so far have tended to justify the proposition that the range of control will have to be reduced in the remote hover mode.

5.2. Yaw Demand

Maintenance of the aircraft orientation in azimuth, as mentioned earlier, will be undertaken by a yaw hold system on board the aircraft which employs a gyro compass as a direction seeking reference. The required orientation with respect to North is to be selected within the ground station and transmitted to the aircraft.

If a directional communication link is to be used, requiring the aircraft axes to be constantly aligned with a ground-based antenna then it will be necessary to continuously update the required orientation reference as the bearing of the aircraft from the ground station changes. Thus the aircraft must be continuously tracked in bearing. This bearing will then constitute the yaw demand and will be transmitted to the aircraft as the required input to the yaw hold system.

5.3. Height Demand

Control of the rph in height may be manual, through collective pitch demand or automatic, through a height hold system onboard the aircraft. Whichever mode is selected, the appropriate demands will emanate from the ground.

From experience gained with Mote and Wisp it is expected that a slider or quadrant type device will prove to be adequate for the provision of manual collective pitch demands.

In the automatic mode, which will be essential throughout all phases of flight except landing and take off, the type of height hold system which has been discussed previously will require a height demand together with a collective demand to provide a '1g' thrust setting. The demanded height will be 'keyed in' to the ground station fcs. As a new height is selected in flight it may be necessary to arrange for some 'shaping' of the demand height change to take place on the ground so that the aircraft design envelope may not be exceeded. To eliminate this risk, scheduling of changes in height demand might need to be provided as a function of the ground station fcs.

5.4. Mode Changing

With three distinct modes of control, it is essential to ensure that the transition from one mode to another will be as smooth as possible and that the operator may not inadvertently cause a catastrophic upset of the aircraft whilst effecting the change. Remembering that movement of the hover attitude demand stick must correspond sensibly to movement of the aircraft as seen by the operator, or as apparent through a tv picture of the ground when out of sight, and that a different set of controls may be provided for navigational flight, it will be seen that the control signals will have to undergo axis transformations which will be different for each mode. This will, of course, complicate the task of the designer in realising a suitable mode changing system.

The sequence of mode selection envisaged for any mission will always involve changing between the hover and navigational mode controls. The simplest solution might be to first adjust the set of controls which are next going to assume command until parity of signals is obtained and indicated by, say, the illumination of some warning lamps and then to throw a switch to simultaneously switch in one set of controls and switch out the other. It is considered, however, that changing modes of control in this fashion would prove to be somewhat pedestrian if a safe change-over were to be ensured.

Various schemes have been considered which make use of trim signals to maintain continuity of demand through these mode transitions. So far, no mention has been made of arrangements for trimming out the controls in flight, but it is envisaged that separate trim control devices will be provided. It is considered that the most important function of any trim system will be to take out the mean wind in the hover modes, giving the operator a 'hands off' capability and freeing the available control stick range to cope with wind gusts and to control low speed flight around the hover.

A suitable arrangement may be found in the type of system which will have separate trim controls for each mode. These trim signals will be constantly applied, being summed with the output from whichever set of attitude controls is currently selected. Figure 3 shows an example of this type of system. Two sets of pitch and roll trim wheels are provided: one for the hover mode and one for the remote hover mode. These are resolved into the correct axis system for each mode before being summed.

These axis transformations are the same as those to be applied to the hover attitude joystick demands in the two hover modes. Therefore the output from the hover joystick is summed with the trim signals appropriate to whichever hover mode is selected before undergoing the necessary axis transformation.

When navigational mode control is selected, the rate limited demands are fed forward and summed with the trim signals. No separate trims are provided in this mode, but the hover trims which will be set up whilst the aircraft is in the hover mode are continuously applied through navigational flight, providing the continuity of control demand between the modes.

6. OVERALL CONTROL THROUGHOUT THE MISSION

For successful control of the rph throughout a mission the ground control station will need to offer the following facilities:

- Suitable control devices with which to make the appropriate control demands, switch between modes and enter and select co-ordinates of waypoints.
- A system which will perform the appropriate shaping and transforming of control demands to be transmitted to the aircraft, facilitate switching between modes, store waypoint co-ordinates and output suitable navigation information.
- Displays which will indicate the position of the aircraft, assist in point to point navigation and in bringing the aircraft to a hover at a desired location.
- A system to monitor the health and fuel state of the aircraft
- A system to assist in pre-flight and in-flight mission planning.

The various control function requirements have previously been discussed at some length. When these are taken together with the requirements of systems to undertake route planning, navigation and management of the aircraft health and fuel state, it may be seen that there could be a need for the flexibility and capacity of a digital computer within the ground station.

6.1. Route Planning

The initial step in planning the route will involve the selection of a series of waypoints appropriate to the locations to be visited. From a knowledge of the take-off fuel state and the wind conditions prevailing in the area of operation, the permissible time on station can be computed. It will be necessary to update these fuel calculations throughout the mission to take account of deviations from the flight plan and variations of wind intensity and direction.

The operator must also take into consideration the question of altitude. Not only must the aircraft be prevented from making contact with the ground whilst being flown beyond the visual range of the operator, but also, clear radio line of sight must be ensured for the maintenance of the communications links.

To fulfill this requirement the operator will need information in addition to that obtainable from conventional relief maps. This problem is illustrated in Fig. 7.

The rph operator will need to plan the route with reference to a 'line of sight' map to ensure that the aircraft does not trespass into 'shadow' areas where radio communication would be lost. Unfortunately, for any given area an infinite number of line of sight maps exist, a different map resulting from every possible position of the ground station within that area. It is obvious that the operator would be considerably restricted by reliance upon pre-prepared line of sight maps. The operator will find it necessary to produce a new map when the ground station has been fixed at the beginning of each mission.

It may well be sensible to use the computational capacity of a digital computer in the ground station before commencing the sortie to generate the necessary mission altitude profile. With the aid of the height control system installed in the aircraft it will be possible to delegate the task of altitude monitoring to the computer so that the necessary altitude changes may be scheduled automatically.

6.2. Navigation and In-Flight Monitoring

It is entirely possible that a digital computer in the ground station could perform the calculations necessary for navigation of the aircraft.

It is assumed that the aircraft must be continuously tracked during its mission by some active or transponded radar system such that its range and bearing from the ground station is available at all times.

The operator may insert the required waypoints into the computer, selecting the co-ordinates currently desired. From the tracker information provided, the computer will calculate the necessary course to fly and present this to the operator in the form of a range and heading to fly from the current position of the aircraft to the desired location. The heading to fly can be displayed together with the heading demand from the navigational mode controls as previously described in Section 5. The piloting task in navigational flight then reduces to one of matching the indicated heading demand with the required heading to fly.

By continuously computing the course to fly the control demands may be updated so that drift effects due to wind can be minimised.

Simulation studies undertaken at WHL have shown this to be a satisfactory method by which point to point navigation may be undertaken. As might be expected, however, the computed heading to fly becomes degraded and increasingly unreliable as the desired waypoint is closely approached. Work has shown that suitably selected range and aircraft velocity displays can be extremely useful in successfully bringing the aircraft from navigational flight to the hover at the required location. It should be possible to arrange for a 'dead beat' system such that, if speed and heading demands are correctly scheduled, the range to fly and aircraft velocity as displayed, say, on a pair of bar indicators, will reduce in unison until the rph is brought to rest.

This system is attractive in its simplicity and also because the majority of the equipment can be situated on the ground. An alternative solution to navigation of the rph, relying on equipment carried by the aircraft, could be based on the use of an onboard Inertial Navigation System (INS). This might appear attractive, as an INS could provide the necessary attitude and rate signals for the pitch, roll and yaw autostabilisation, besides giving an accurate indication of the inertial position of the aircraft. To utilise an INS as an 'active' navigator would require the co-ordinate waypoint information to be transmitted to and stored in the aircraft. More significantly, it would be necessary to undertake control authority and rate limiting onboard the rph if full use was to be made of the inertial navigator, particularly in the event of a loss of the communication link.

Inertial Navigation systems offer distinct possibilities for future applications, but at present the weight and cost preclude them from use in the rph field, where it seems politic to simplify the aircraft avionics as much as possible.

Additional assistance in navigation can be derived from a real-time video picture if the rph is to carry a tv camera. Recognition of significant topographical features will provide, from time to time, a check on position when compared with the available maps. However, it is considered that the contributory effects of local cloud cover, ambient light levels and passage over featureless terrain would prevent a video sensor picture from being used for continuous navigation of the aircraft.

A further facet of the overall control of an rph throughout the mission will be the background task of in-flight housekeeping. In addition to undertaking route planning and navigation calculation duties before and throughout the sortie, digital computation can be employed to undertake the functions of a performance monitoring and advisory system. Such a system might run a continuous check on the fuel state and the various parameters indicating the performance and health of the power plant, avionics and surveillance sensor which would be relayed to the ground from the aircraft. The operator could then be advised of any rescheduling or curtailment of the flight which might be necessitated by, say, excessive expenditure of fuel or the occurrence of system malfunctions.

7. CONCLUSIONS

It has been demonstrated that the concepts of control for remotely piloted helicopters pose problems somewhat different to those of conventional manned helicopters. The designer is presented with the task of defining a flight control system, which will exist both in the aircraft and on the ground, embracing the performance and operation of the overall system and tempered by the remoteness of the pilot.

As acceptance of and confidence in rph surveillance systems grows with continuing development, so does the challenge to the designer. It can be seen that scope for innovative design in the solution of control system problems may be provided by the increasing application of digital computation techniques both on the ground and within the aircraft.

REFERENCES

1. A.J. Faulkner, Control Aspects of the Plan-Symmetric Remotely Piloted Helicopter, AGARD Symposium, Avionics, Guidance and Control for Remotely Piloted Vehicles, Paper No. 55, October 1976.

2. I.A. Simons, The Concept of the Remotely Piloted Surveillance Helicopter, 33rd Annual National Forum, American Helicopter Society, Paper No. 16, May 1977.

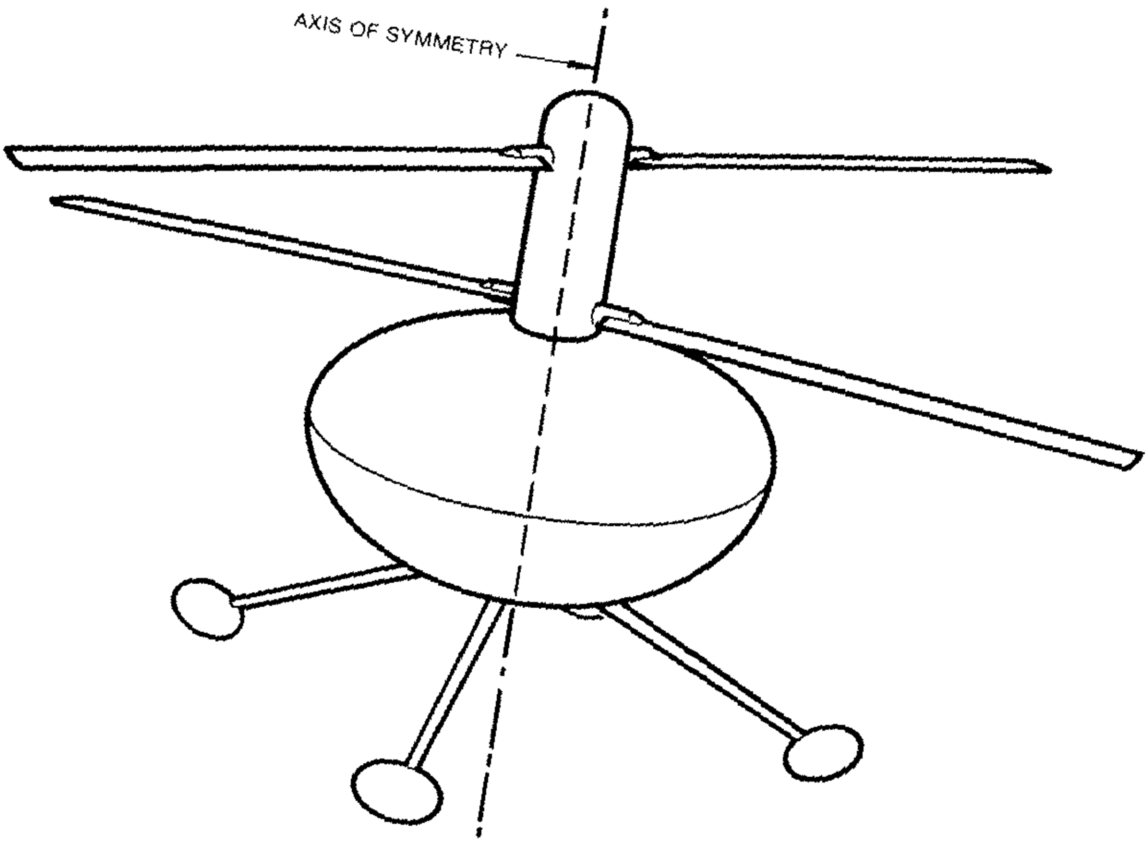

FIGURE 1. A PLAN - SYMMETRIC HELICOPTER

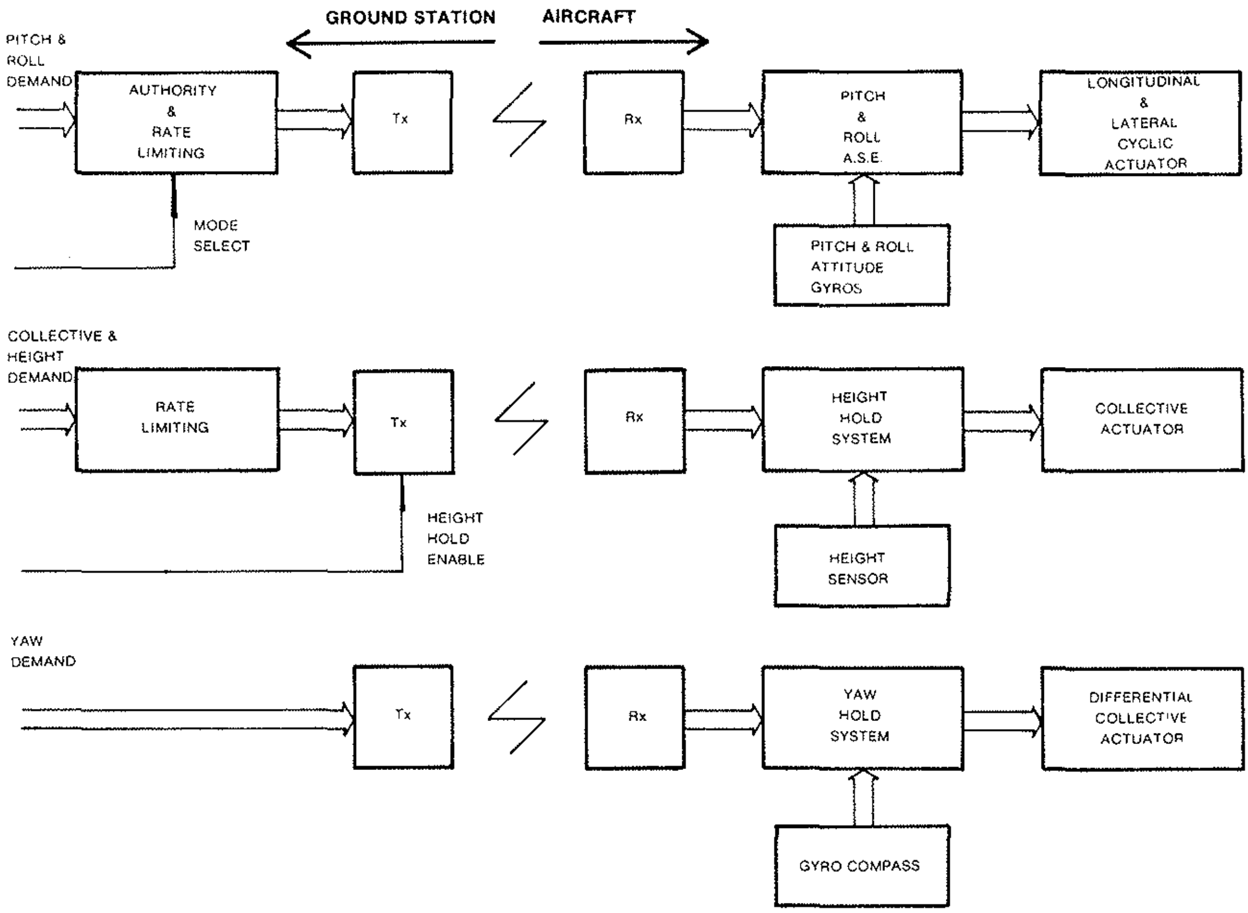

FIG.2 DIVISION OF THE FLIGHT CONTROL SYSTEM

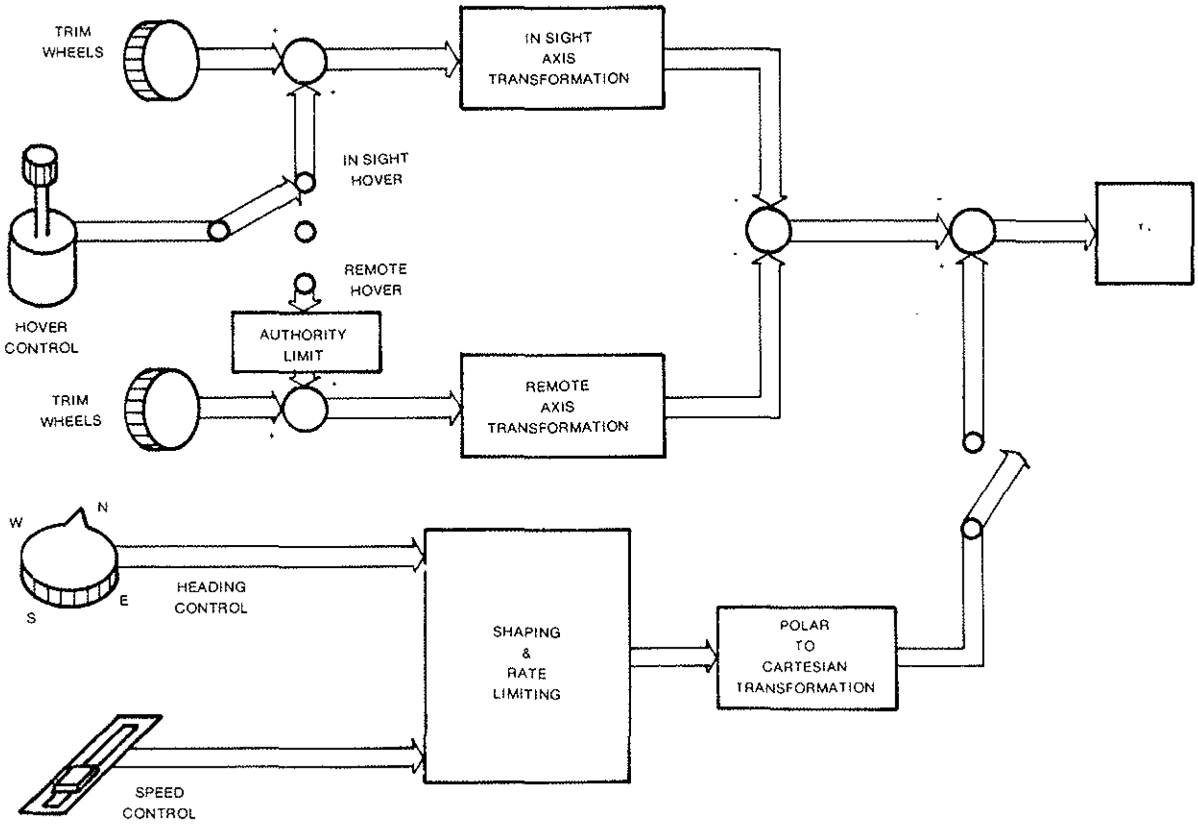

FIG.3 GROUND STATION FLIGHT CONTROL SYSTEM SCHEME

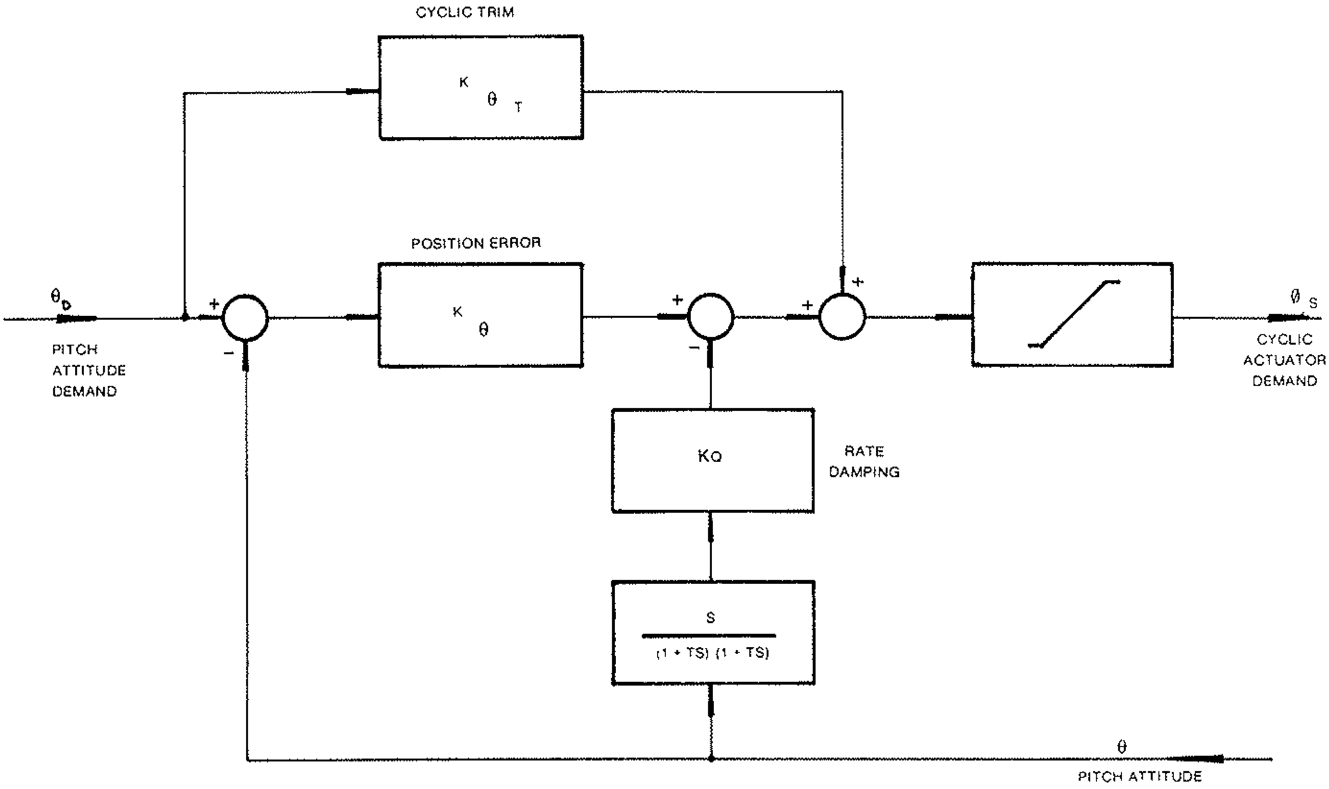

FIG.4 MOTE PITCH ATTITUDE CONTROL SYSTEM

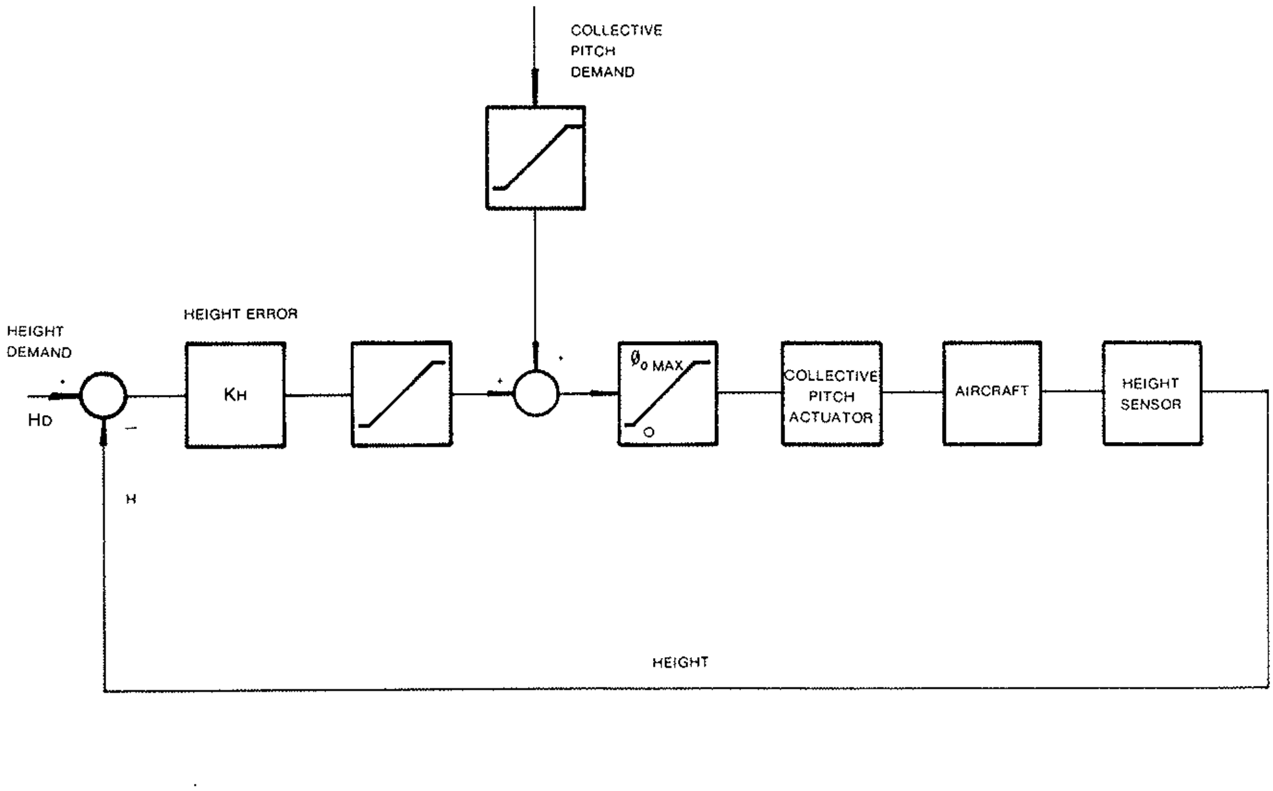

FIG. 5 HEIGHT CONTROL SYSTEM SCHEME

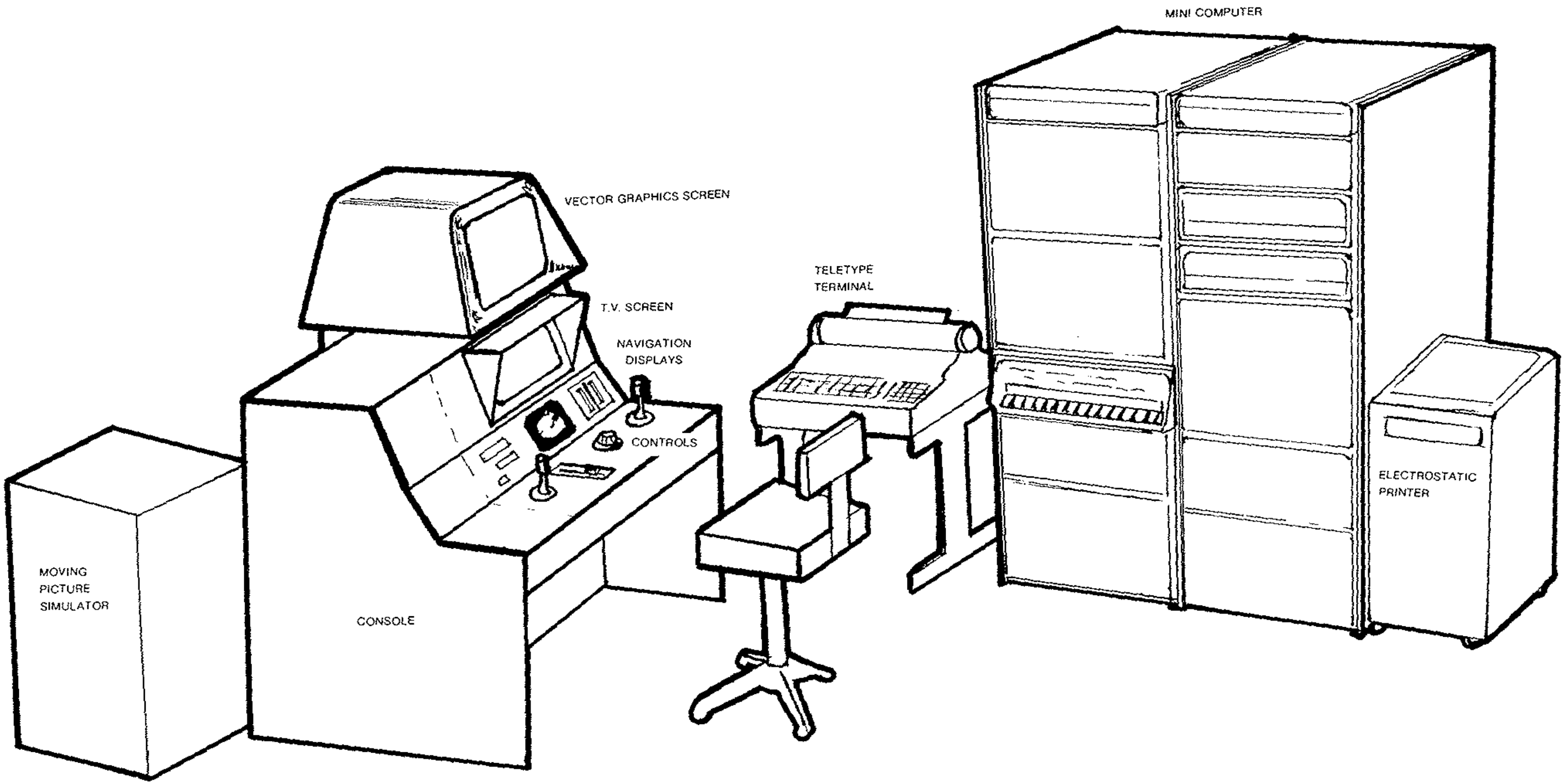

FIG.6 ARRANGEMENT OF SIMULATION FACILITIES

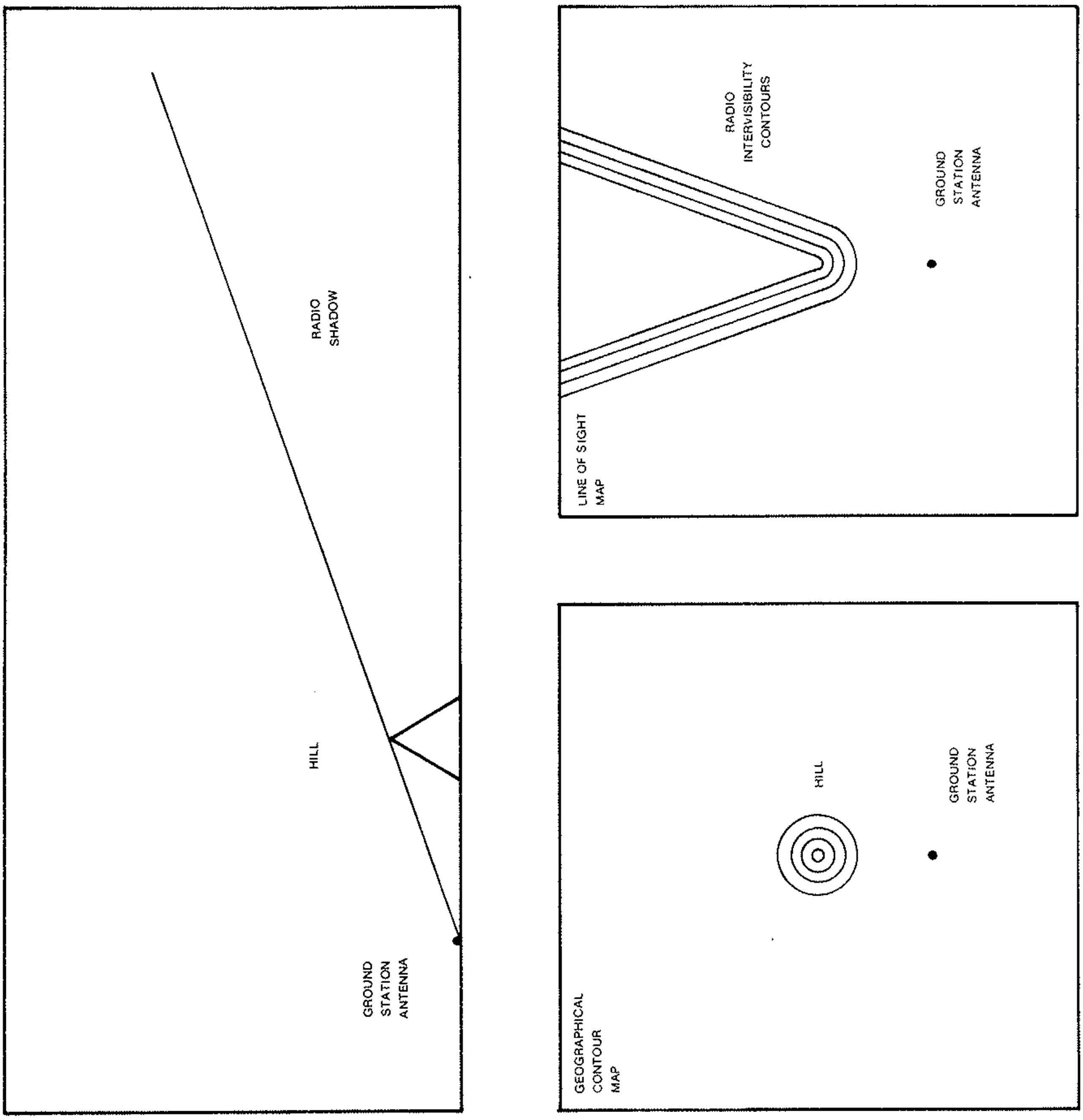

FIG. 7 RADIO INTERVISIBILITY MAPS