THIRD EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

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THE HELICOPTER RPV

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1. WHY RPV's

As an introduction to this paper it is pertinent again to ask the question - why RPV's?

The reply is usually that this is a means of saving the life of aircrew during hostilities in which a high rate of attrition must be expected. Whilst this is undoubtedly true, probably a more convincing military reason is that it is a means of saving aircraft and increasing the probability of mission success by an order of magnitude. Why should this be? the reason is two-fold.

(a) The presence of aircrew makes the size of an aircraft, necessary to accomplish many tasks, several times larger. In order to allow aircrew to have external vision, windows are introduced which, however small, can significantly increase the detectable signatures of the aircraft. The aircraft becomes an order of magnitude more vulnerable as it is more detectable and is a larger target.

(b) A controller removed from the immediate centre of hostility can concentrate more calmly upon the prosecution of the mission.

Figure 1 compares the size of a design for a small man-carrying surveillance aircraft with that of WISP, a surveillance RPV. The probability of detection of the man carrying aircraft by eye is 100 times greater than the RPV; the probability of detection by radar is of even greater difference.

A comparison of cost between an RPV like the WISP and a minimal single-seat surveillance helicopter is not easy to make as it depends upon a precise definition of the two systems. In round terms, however, it can be argued that the cost of the airborne equipments are not too dissimilar.

The cost of the sensor, communication link and additional flight control system of the RPV is roughly equal to the costs incurred by the greater size and power and pilot support systems of the man-carrying aircraft. Pilot traini costs are probably somewhat greater than the costs of a ground station and the small training costs of an RPV controller. The pilot is at considerable risk, however, the ground station and operator at low risk.

Pictures relayed back from the RPV can be readily available for expert interpretation on the ground, and for permament record. The pilot's view, though probably better if he can penetrate the target area, is available only for his interpretation.

2. WHY HELICOPTER RPV's

To carry a given weight of payload, helicopters of all sizes tend to be more expensive to buy than fixed wing aircraft due largely to the more complex control and transmission systems. They do however have the advantage of a hover capability and precise control at very low speeds. They tend also to be more compact than a fixed wing aircraft. These are qualities which offer considerable advantage to total system cost when that system is required to conduc surveillance and target acquisition/designation tasks controlled from a mobile base and operating out of small concealed sites on a battlefield. This will become more obvious as we now go on to consider the particular configuration that Westland have adopted for helicopter RPV's. That is the "Plan-Symmetric Helicopter."

3. THE PLAN-SYMMETRIC HELICOPTER, RPV

This description infers that the helicopter is sensibly symmetrical about the rotor shaft axis (Fig.2). The fuselage is a body of revolution described about the rotor shaft axis, and any undercarriage also maintains a symmetry of disposition about that axis. The rotor system uses a coaxial arrangement which provides a solution as near to symmetry as is possible. Pure symmetry would be achieved only if the rotor planes could be made coincident.

Climb control is obtained conventionally by increasing the pitch on both rotors together. Unlike the single rotor helicopter there is no significant resultant yaw torque applied to the aircraft.

Translational control is obtained by applying cyclic pitch to the two rotors simultaneously. Again, there is no significant cross-coupling affecting the yaw or roll attitude of the aircraft. As the moment of inertia of the aircraft is equal in all vertical planes, and the aerodynamic drag is equal in all directions, the response to control in all directions from the hover is equal.

Yaw control is achieved by differential change of collective pitch on the rotors. This is a very powerful control under normal flight conditions and again has no cross coupling affecting other control modes.

As with most other "tailless" aircraft, the aircraft is naturally unstable over the whole flight regime and so it has to be automatically stabilised.

Given this automatic stability equipment, the configuration offers a purity and simplicity of control. Response to gusts is basically direct (i.e. no significant cross-coupling) and should be low.

3.1. Simplicity of Command

The aircraft has no aerodynamically preferred direction of flight. The body axes can therefore be automatically controlled in azimuth by an onboard flight control system so that the aircraft remains "facing" a demanded compass heading or any point on the ground, irrespective of its flight path. This absolves the remote operator from any need to "steer" the aircraft in the direction of flight. With pressure or tape height automatically sensed and held, the operator is left merely with the task of positioning the aircraft in plan.

If azimuth control is set to a compass point, then the operator may command the aircraft on a rectangular co-ordinate control grid. If azimuth is slaved to a control base, the system may operate on polar co-ordinates.

3.2. Advantages for Take-off and Recovery

It was assumed from the start that in order to operate an RPV system from the battlefield (a) it should be possible to operate from small sites offering cover from enemy surveillance, (b) the minimum of support equipment should be used in order to assist in achieving (a) and to afford maximum mobility to the system.

The helicopter has the ability, of course, to take-off and land vertically so that it can operate from very restricted sites without recourse to complex launch equipment and can be recovered accurately under full control. The fixed wing aircraft by contrast has to use an inaccurate, and not too reliable, parachute recovery system or one of several proposed "netting" systems. These latter require considerable skill by the "pitcher" and extensive free air space and ground equipment. Both systems mean that the aircraft will risk damage and at best will be considerably delayed before readiness for the next mission. The helicopter can be replenished and airborne again within a few minutes of landing.

In particular the plan-symmetric helicopter with its simplicity of control, very low response to gusts and independence upon wind direction can be steadily manoeuvred into the smallest of sites. Compared with other rotorcraft configurations, it has no tail rotor or aerodynamic surfaces which could be damaged on rough ground or scrub.

3.3. Advantages in Operational Flight

The several roles that can be foreseen for RPV's make differing demands upon the system. The plan symmetric helicopter configuration has a versatility to adequately meet most roles not requiring a high speed capability.

3.3.1. Navigation

A pre-requisite to any operational role other than that of merely providing a static surveillance platform is the need to navigate the aircraft to the required scene of operation. It is necessary to know at any time where the aircraft is. This may be achieved by dead reckoning (i.e. where the aircraft should be) plus occasional updating from recognition of landmarks or from radio beacons if available. An alternative is direct tracking of the aircraft via the communications link.

Flying on a cartesian or polar co-ordinate control basis assists in accurate dead reckoning whatever the method.

The ability to align a downward pointing camera in the aircraft to a constant compass point, presumably north, irrespective of the aircraft flight path, facilitates the recognition of landmarks when comparison is made with a map. This alignment is readily achieved in the plan symmetric helicopter without recourse to mechanical steering of sensors or of electronic steering of the display.

Should direct tracking by radio link be employed, the plan symmetry enables a directional antenna to be aligned to base continuously, independent of aircraft flight path, again without complex turreting of the antenna.

3.3.2. Surveillance, target acquisition, fire control, target designation etc. Roles

The only way of monitoring a designated ground area with a "real time" surveillance sensor on board a fixed wing RPV or of illuminating a target with a laser beam, etc., is to overfly the area at the slowest possible speed in a number of alternate paths or to maintain a constant circular path above the ground whilst orientating the sensor and/or designator to retain the target. This is an extremely difficult task to achieve, especially under adverse wind and other weather conditions. The real aim must be to view the ground area without interruption from any required direction for as long as the operator requires.

With its hover capability, this is a task at which the helicopter is ideally suited and at which the plan symmetric helicopter with its purity of control and low response to gusts can excel.

4. SURVIVABILITY

It is not sufficient that a RPV system shall have the technical abilities outlined above to perform the transport function. It must also offer an acceptable level of survivability over the battlefield. This requires that it must be:

(a) Difficult to detect

(b) Difficult to acquire by air defence systems

(c) Difficult to hit

(d) Preferably have some chance of surviving a hit.

The potentially small size of RPV's may be taken to indicate that success in (a), (b) and (c) is more probable than success in (d).

4.1. Detectable Signatures

Detection and acquisition may be achieved by use of the radar, infra-red, optical and acoustic signatures of the airborne system either independently or in cominbation. Though deference to security classification prevents any detailed discussion of these aspects some general observations may be made to indicate the advantages of the plan-symmetric helicopter in this area.

Virtually all the signatures are reduced if the overall size of the aircraft is reduced. The plan-symmetric helicopter almost certainly offers the most dense means of packaging the payload lift and propulsion elements of any airborne system, e.g. Fig.3 compares Wisp with Aquila, an equivalent fixed wing RPV.

Radar Signature

Second to size, shape in the round and in detail is significant. Radar illumination may come from any direction. Only a symmetrical aircraft can hope to achieve anywhere near an optimum shape in all directions.

Fortunately the general fuselage and rotor configuration of the P.S.H. can be made to conform to acceptable shapes and also are suitable carriers of absorptive materials.

Optical

The high speed curved path of small diameter rotors is impossible for the eye to record, so long as the surface is matt and cannot return a glint.

The symmetric body shape also offers a chance to minimise the projected area in all directions. Attention to surface finish will ensure minimum contrast with a sky background.

The attention of the eye is attracted by linear motion or other change in the scene. A small non-reflecting, low contrast shape hanging motionless or moving slowly is a difficult object to detect unless the eye is cued by other means such as noise.

Noise

Rotor emitted noise varies approximately as the weight carried and as the 6th power of the rotor tip speed. A relatively low rotor tip speed combined with the light weights of RPV's will produce no significant noise from that source.

The area of concern is noise emanating from the power plant. The exhaust must be silenced as far as is possible and the remaining noise emitted in a direction away from the ground. Care is also taken to provide acoustic blankets around other noise sources. The P.S.H. offers a geometry compatible with these requirements.

Infra-Red

The small, low-power engines of RPH's emit relatively little thermal energy compared with the power plants of combat aircraft, tanks etc. However, complacency even here is not acceptable. Maximum efficiency is demanded of the power plants and heat energy radiated must be away from the ground. Exhaust gases should be cooled.

Again, the P.S.H. configuration allows attention to be paid realistically to these requirements.

4.2. Hit Probability

Although the P.S.H. will rely for its first line of defence in not being acquired, it is believed that it will not be easy to hit, even if acquired, due to its very small size. Single shot weapons will have a low probability of success unless proximity fused warheads are used. There must be great difficulty however, in designing a fuse to be activated by such a small body. Machine guns may be the greater threat though they are generally only of sufficient accuracy at relatively short ranges. It should be possible for the RPH to fly above the threat.

4.3. Integrity of the Communications Link

Jamming of the communications link is a problem common to all RPV's, and it is not intended to underestimate this problem. However, we do believe that if a very narrow beam link is a means of reducing this problem, then the plan-symmetric helicopter is most compatible with the control requirements of such a link. This is due to its ability to hold an accurate azimuth heading to base irrespective of its flight path, its relatively low response to atmospheric disturbance in yaw, and its inherent ability to carry out suitable re-acquisition flight programmes should the link be lost.

5. FUSELAGE AERODYNAMICS

The fuselage shapes which give the plan-symmetry, the symmetrical response, the compact packaging and the low detectable signatures, do lead to some other aerodynamic problems. These are principally high drag and/or adverse pitching moments.

Very little information previously existed for plan symmetric shapes other than for the sphere and the circular cylinder. Even this data did not, of course, cover the effect of air intakes and exhausts upon the basic shapes. We had, therefore to embark upon a programme of wind tunnel testing in which we are using full-scale models. There is much yet to be done but we have achieved a basic understanding of the characteristic trends which has enabled us to proceed with our current flight hardware programmes.

Basically the body shapes can be regarded as ellipsoids ranging from the prolate of, say, $\frac{1}{3}$ diameter to thickness ratio to the oblate of, say, 5/1 D/T ratio.

The prolate shape has a very high drag coefficient in the hover, though this rapidly reduces as the aircraft tilts forward for cruise flight in which it might typically fly at about 100 knots tilted over at about 20°. The pitching moment is positive (nose up) which results in a stable 'stick'-position to trim. On the other hand the oblate shape has fundamentally less drag though this increases as the aircraft tilts in forward flight. The pitching moment, however, tends to be nose-down and with the lack of the conventional tail plane will, with increasing speed, eventually result in a reversal of the trim curve. This trend can, however, be modified by the application of camber and is affected, of course by the addition of the rotor hub and intake/exhaust flows.

The characteristics of the sphere, as can be expected, are particularly changed by the addition of the hub with the drag increasing by as much as 200%.

6. CONTROL AND STABILITY

As previously stated, control is invested in four basic channels.

(a) Height or climb using collective pitch on both rotors.

(b) Translational flight X axis using cyclic pitch.

(c) Translational flight Y axis using cyclic pitch.

(d) Azimuth using differential collective pitch.

Stabilisation of the aircraft is required in all channels. The automatic flight control system that we are developing performs both auto pilot and stabilisation functions and is essentially an attitude control system.

(a) Height

A height demand is transmitted to the A.F.C.S. which compares the demand with the actual height obtained from the height sensors. A climb or descent rate is then demanded proportional to the height error. The autopilot function is performed through the error generation. No artificial damping is required in this channel as the rotor aerodynamic damping is adequate.

(b)&(c) Translational Flight

Provided that care has been taken in the aerodynamic design of the aircraft, there is a correlation between translational velocity and body attitude in that direction. This correlation varies slightly with aircraft weight and atmospheric conditions but is not a problem. The pilot can therefore demand flight velocity by demanding the relevant body attitude through the A.F.C.S. Due to the inherent attitude instability of the aircraft, this steady-state body attitude and velocity will not remain so for long. This is overcome by a stabilisation law which actuates the cyclic pitch controls as a function of attitude error and angular pitch rate.

As the rotor contributes significant damping in pitch and roll, it has been found satisfactory to date to take the attitude signals from a vertical gyro and to differentiate these to obtain the rate term.

In and about hover flight, the aerodynamic control and stability derivatives are obviously identical in both X and Y axes. As the aircraft trimmed speed is increased, the derivatives change and in particular the longitudinal and lateral derivatives become less similar. The worst instability occurs at the maximum forward speed and it is this condition which defines the control gains if the complexity of an adaptive system is to be avoided.

The question therefore was would the control law gains required for longitudinal stability at high speed suffice to provide both longitudinal and lateral stability at all speeds. This would remove the need for an adaptive system and control law indexing, thus allowing the provision of a relatively simple A.F.C.S. Computer simulation and airborne experiments with an experimental aircraft - MOTE - showed that this was indeed possible. The control law adopted in both axes is therefore: $\vartheta_s = k_\theta(\theta_D - \theta) - k_q \cdot q + k_{\theta_T}\theta_D$

where ϑ_s is the cyclic pitch applied

θ_D is the demanded body attitude

θ the actual body attitude

q the pitch or roll rate

k_x relevant coefficients

The last term is the feed-forward term required for trim and is applied as a function of demanded body attitude.

(d) Azimuthal control

The heading control system is of a similar form but does not require the feed-forward term. The amount of rotor damping available in yaw is small compared with that in pitch and roll so that azimuth rate is sensed directly from a rate gyro.

Block diagrams of the control systems are shown in Fig.4.

7. WISP DESIGN AND DEVELOPMENT PHILOSOPHY

This is our first RPH intended to be developed for operational use albeit initially in a limited surveillance role but with considerable development potential, Fig.5. We have built four aircraft to date. We were required by the Ministry of Defence to develop a complete short range, daylight only, surveillance system in a short timescale and at minimum cost.

We elected to adopt the following tenets as design requirements and believe that we have been able to go a significant way towards meeting them.

7.1. System Simplicity

Our development philosophy was to build towards a complete system on a step-by-step approach, always trying the simplest solution possible unless forced towards complexity, and particularly remembering the adage of the great Henry Ford - "What ain't there can't go wrong".

7.2. System Mobility

We chose to design the system so that it could be readily accommodated, with its operating crew of 2, within a single landrover, thus conferring it with good mobility at low cost. There should be no item of equipment that could not be carried by one man.

7.3. System Readiness

The system should be easily capable of being brought to mission readiness within 30 minutes of arrival on site.

7.4. System Ruggedness

Both aircraft and ground equipment should be rugged enough to reasonably withstand the military environment.

In the aircraft this policy is reflected in the use of an enveloping glass-reinforced-plastic body shell; the rugged undercarriage legs housing and protecting the aerials, and the boot-proof undercarriage feet. The control rods and linkage are of stout construction and are protected by a GRP rotor hub cowl.

7.5. Safety

During start up, the operators are protected against inadvertent rotor spin-up by two rotor tip gags either of which will prevent the rotors turning and stall the engines.

The rotor system is of relatively low energy so in the event of the rotor hitting an obstacle on landing, the blades will shatter and be contained within a small distance of the aircraft.

An engine ignition cut-off facility is provided in order to abort the mission if control has been entirely lost.

Inadvertent loss of the radio link will result in the control system bringing the aircraft to the hover and into a slow vertical descent. Ignition cut-off is also activated after a pre-set delay.

There is the optional capability of demanding fuel cut-off.

The aircraft has two engines and can maintain a hover at low altitude on one engine. Rotor speed is electronically governed. The failure modes are such that the engine throttles are opened should governor failure occur. In this event the rotor speed is limited at a higher level by topping governors on each engine which activate the advance/retard mechanism.

Should one engine fail, the throttle of the other is automatically opened to maintain normal rotor speed. Each engine has an independent fuel supply, ignition system and aspiration system.

The electrical power supply is duplicated and is backed up by an emergency battern.

7.6. System Reliability

The number of components on the aircraft was kept to a minimum by a value-analysis study. All mating components are locked together.

The probability of component failure was reduced by designing to a minimum life of 200 hours but to an infinite life wherever reasonable.

Wherever life/load data was limited, endurance testing was carried out, for example on control rod ends and on gear wheels. Other testing has included rotor overspeed testing and undercarriage drop-testing.

7.7. Ease of Manufacture

Much was learned from the construction of MOTE - an earlier experimental aircraft - as to the problems involved in the manufacture and assembly of small mechanical and structural components. Considerable thought was, therefore, given to means of easing manufacture and assembly with discussions continuing before and during detail design to workshop operator level.

Wherever possible standard catalogue items were adopted and special tools were avoided.

Modular construction was adopted which enables sub-assemblies to be completed independently. The final assembly can, therefore, be made by one operator.

7.8. Low Maintenance

In order to reduce maintenance requirements all bearings are sealed-for-life grease-packed except for control rod ends. The latter are readily accessible and require limited and infrequent attention. The transmission gears are non-lubricated.

7.9. Maintainability

The modular construction was also adopted to facilitate maintenance and component testing also the quick exchange of different payloads.

The dense packaging of the aircraft is shown in figure 6 where the aircraft is seen minus rotor cowl and upper shell fairings.

Four basic modules form the aircraft. They are:

(a) The mechanical module. This consists of the rotor systems, their drive, main power actuators and mechanical controls. The reduction gearbox and gearbox and electrical power generation. Removal of 4 caged sirens, a multi-pin electrical connector and two fuel connections enables the mechanical module to be removed as a unit and bench run to check power, thrust generation, control response etc.

(b) The Payload Module. This includes the stabilised camera system or other payload and is mounted in the airframe module on turnable anti-vibration mounts. Currently the automatic flight control system is also mounted here.

(c) The Gyro Module. This contains the three gyros and power amplifiers. It will later also contain the AFCS system.

(d) The airframe Module. When the other modules are removed, the airframe module is seen to be comprised of the basic structure and undercarriage lags, the fuel tanks and communications equipment plus, of course, the cable looms. Space is provided for the height sensing system in the base of the central structure. This system uses a barometric altimeter which is overridden by a laser range finder at lower altitudes. The airframe module is suspended in flight beneath the mechanical module on multi-directional anti-vibration mounts to protect the electronics from engine or rotor induced vibration.

8. SUMMARY OF LEADING PARTICULARS

Payload

Philips LDH 830 2/3" vidicon monochrome television camera trainable in elevation from 15° above to 105° below horizontal. Azimuth orientation by aircraft rotation in yaw. 28° fixed field of view.

Stabilised in pitch and roll

Omnidirectional video signal transmission

Range: 1000m

Weight: 2.5kg

Airframe

Rotors: Twin coaxially mounted contra rotating
Teetering flap hinge

Diameter	1525mm
Chord	55mm
Tip speed	116m/s
Overall Height	860mm
Body diameter	610mm
Typical all-up-weight	(30kg) 65lb
Typical Fuel Weight	2.3kg (5lb)

Power Plant

2 Kolbo D238 2-stroke engines with spark ignition

Aircraft Performance (ISA SL)

Typical Endurance	1 hour
Cruise Speed	55 kts

9. WISP GROUND EQUIPMENT

The Ground Equipment consists of a control console and seats for an operator and an observer on his left. The console mounts all controls required to command the aircraft and also a 12" video display and recorder for the surveillance imagery. The video receiver and aerial is mounted on the console but the command transmitter and aerial are separately freestanding. For security of electrical power supply the console has dedicated batteries.

Fig. 7 shows the general disposition of controls on the console with the translational stick falling naturally to the controller's right hand. To his left are the height control lever and rotor speed governor select lever. Further to his left is the azimuth control and the camera tilt control. Aircraft speed and height demand is displayed. Other equipments include a preset fuel state warning, a mission time indicator, ignition buttons, video signal strength and battery state. The currently empty table surface in front of the observer will eventually be filled by a plan position indicator.

The Support Equipment includes a compartmented tray, the extremities of which locate the aircraft undercarriage feet. Other compartments contain the hand held power drill for engine starting, rotor gags, spare fuel and refuelling gear, basic tools and check-out equipment, ground power supplies and operating manuals. Engine starting is achieved by entering the extension shaft from the electric drill into each air intake in turn. This locates onto the engine crankshaft and spins each engine via a small clutch up to idling speed.

For stowage into the landrover, the video aerial is released from the console and with the folded command aerial is stowed along opposite sides of the vehicle.

The support equipment tray, complete with equipment and the aircraft, is then slid into the well of the vehicle. Finally the console seats and legs are retracted and hooked onto the tailboard of the landrover. The tailboard is erected and the vehicle is now ready for driving away complete with the RPV surveillance system.

The system can be brought into action from a stowed position by two operators within 20 minutes.

11. FUTURE POTENTIAL OF THE RPH

We are currently building prototypes of a second type of RPH, WIDEYE, which will carry a greater payload and offer operation in more sophisticated roles and at even longer ranges. This activity is being carried out by Westland in collaboration with Marconi Elliott Ltd.

Project design work is proceeding on a still more advanced aircraft, WITE, which will be particularly relevant to Naval applications. Our philosophy, however, is for all types of RPH's to have the capability of carrying out a number of alternative roles by means of exchangeable payload and communications modules. The simplicity of control and the good station-keeping qualities of the plan-symmetric RPH are two of the qualities which will well suit it to many future applications.

Potential applications include the following:-

Military

Reconnaissance, Surveillance, Target acquisition and fire control.
Target designation/illumination
Autonomous ground target attack
Electronic intelligence and countermeasures
Missile direction
Anti-missile defence
Communications

and other applications which are of a more secure nature.

Civil

We are continuing discussions with the British Civil Airworthiness Authority with respect to requirements for the Civil Certification of RPH's, the formulation of categories in which certification could be made, and the licensing requirements for operators.

Potential civil roles include:-

Monitoring crop deseases
Crop spraying
Geophysical surveys
Pollution monitoring
Fire control
Security surveillance
Powerline and pipeline inspection
Search for missing persons
Shipping lanes patrol
Fisheries protection
Incident illumination
Emergency communications etc.

These are but a selection of presently foreseen applications for RPH's. We believe that as experience is gained in their operation, and aided by the growth of technology, many other roles, as yet not visualised, will become apparent.

12. CONCLUDING REMARKS

We believe that we have made an encouraging beginning in the development of an operational remotely piloted helicopter. Our work has confirmed to us that an RPV based upon a plan-symmetric helicopter has many advantages when compared with other configurations.

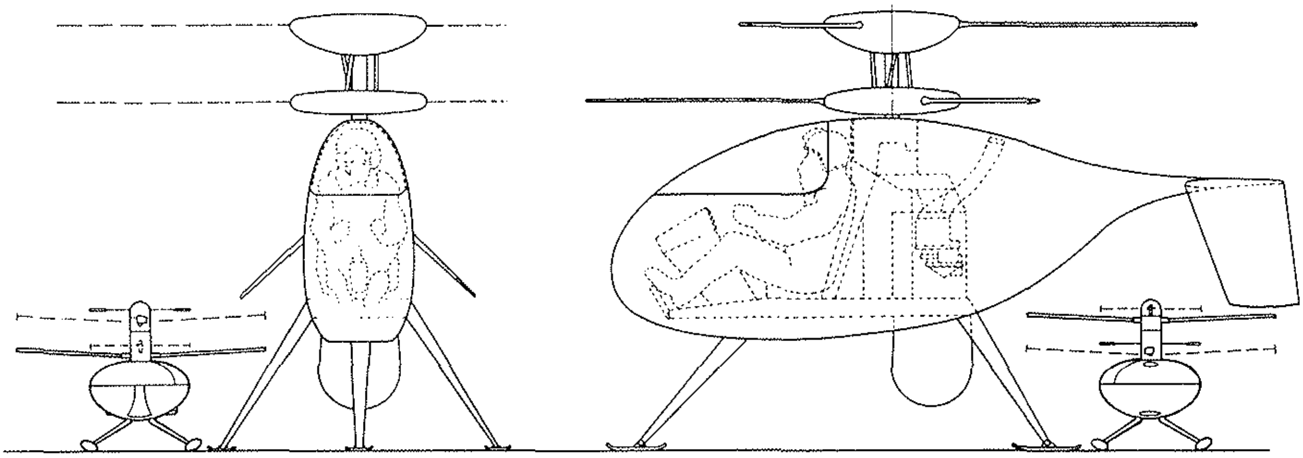

Figure 1 Comparison of Remotely and On-Board Piloted Airborne Surveillance Systems

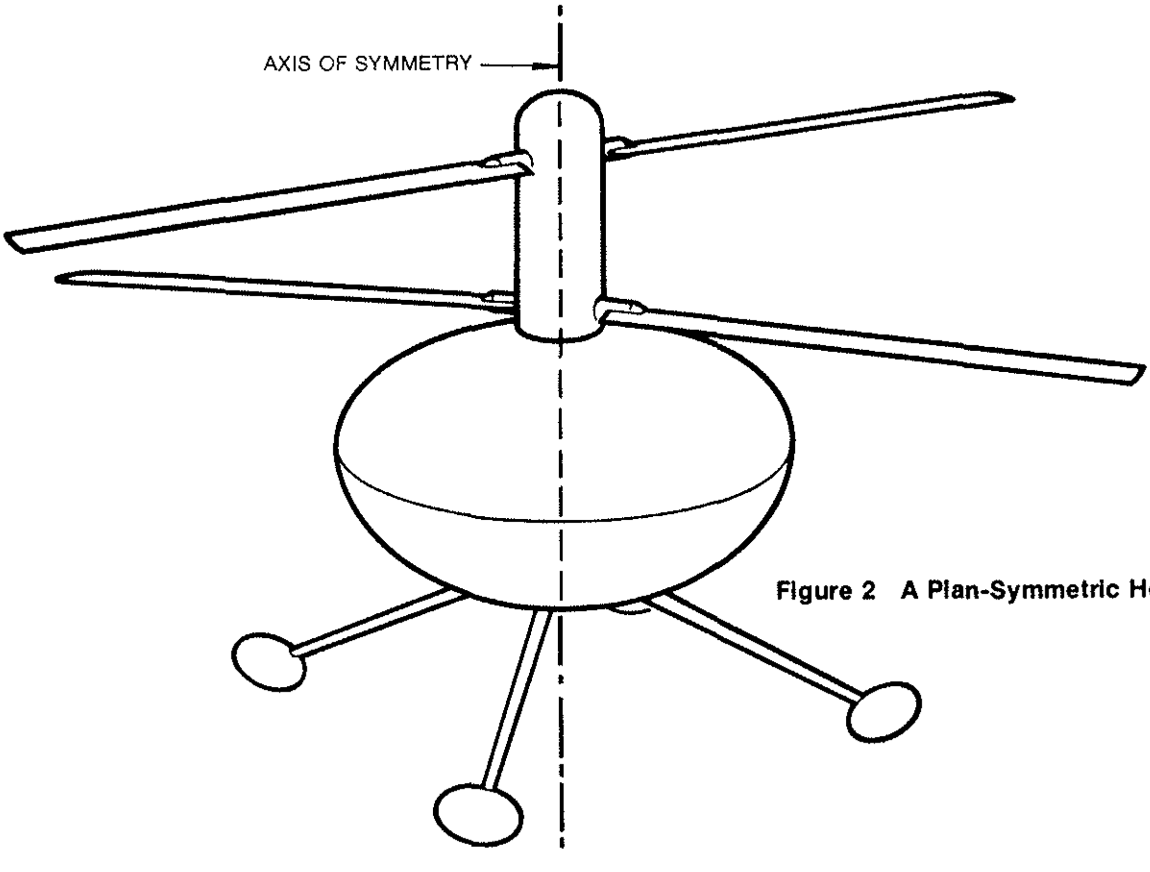

Figure 2 A Plan-Symmetric Helicopter

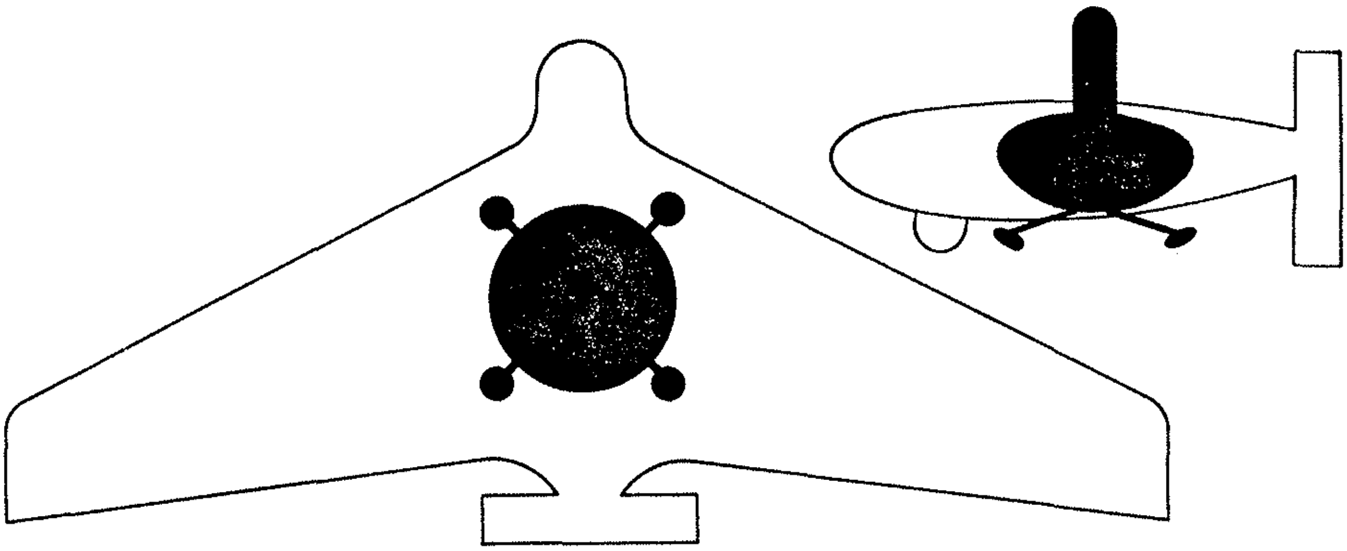

Figure 3 Wisp Compared with Aquila

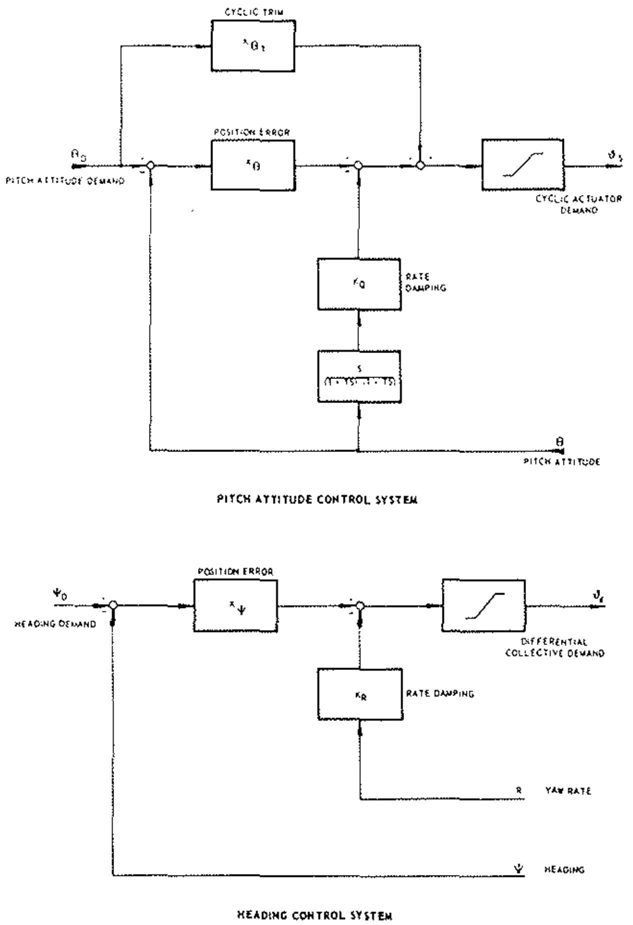

Figure 4 Flight Control System Block Diagram

Figure 5 Wisp

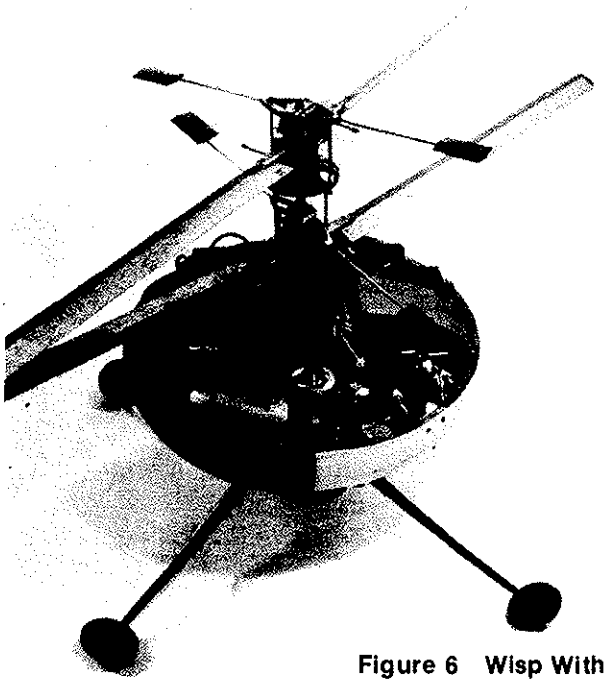

Figure 6 Wisp With Cowls Removed

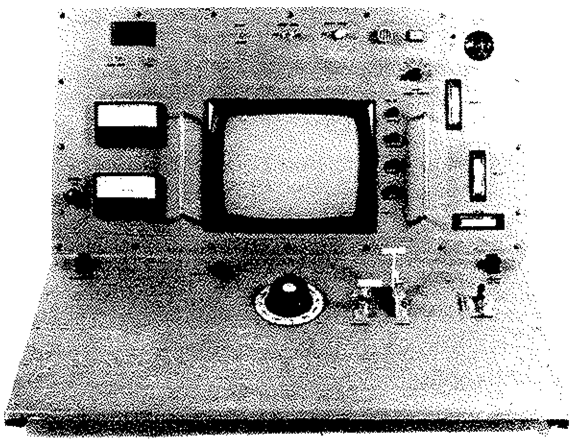

Figure 7 Wisp Control Console