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FLIGHT CONTROL SYSTEMS FOR SAR

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FLIGHT CONTROL SYSTEMS FOR SEARCH AND RESCUE

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Abstract

The helicopter's ability to perform search and rescue (SAR) operations can be greatly enhanced by a suitably equipped flight control system. Outer loop modes specific to SAR include transitions to and from hover and a hover mode with a trim facility for manoeuvring over a survivor. The control of height in hover uses inertially smoothed height based on Rad Alt. Similarly the pitch and roll axes are controlled using smoothed ground velocity signals, with a Doppler input. Location of survivors and returning to the same spot in a hover are both important. Useful facilities therefore include coupled search patterns and an overfly mode which brings the aircraft back to the survivor and facing into wind. A good heading hold through yaw is essential.

Helicopters are now receiving civil certification that includes SAR operations. These civil requirements are likely to be applied to all SAR helicopters with obvious implications.

1. Introduction

The helicopter is uniquely suited to search and rescue (SAR) operations, and the effective SAR helicopter relies on modern avionics of which the flight control system (FCS) is an important part. This paper considers some of the factors which affect the design of the FCS.

Traditionally SAR aircraft have been designed for Anti-Submarine Warfare (ASW) and used for SAR as a peace time role. Louis Newmark have designed and built flight control systems for such helicopters over many years and the basic principles have changed little since we developed Wessex 3 and Sea King (Reference 1). With the advances in micro-electronics we can now do much more, and eliminate some of the compromises that had to be made earlier.

Most of the examples in this paper refer to the LN450 digital flight path control system (FPC) as fitted to Bell 212 and Sikorsky S61 aircraft. The Bell 212 system is flown as a flight director only, while the S61 system is fully coupled. Each approach has its advantages and its problems which will be discussed.

The main details of the two systems are:

Bell 212	LN450 driving a three cue flight director (pitch, roll and collective).

	Stabilisation using the existing Bell SCAS system.
	Heading Hold through yaw (when required) through the SCAS system.
Sikorsky S61	LN450 coupled through the stabiliser in pitch and roll, and directly driving the collective parallel actuator.
	LN400 autostabiliser providing duplex analogue pitch, roll and yaw (ASE).

Both developments were carried out in conjunction with Bristow Helicopters Limited.

2. The Mission

The identifiable phases of the mission are:

(i) Travel to the search area.
(ii) Search and Locate.
(iii) Circle and Transition to the Hover.
(iv) Winching.
(v) Transition from Hover.
(vi) Return journey.

The transit to the search area makes no call on the special capabilities of the helicopter. Bearing in mind however that weather conditions and/or visibility are probably bad, that the crew may be involved in planning the flight, receiving and transitting information over the radio, etc, and taking into account that the ensuing search and rescue operation will put a premium on alertness and concentration, the provision of coupled modes which minimise crew workload during this period is extremely desirable. Such modes involve control of airspeed, height and heading.

Searching for the survivors involves covering what may well be a considerable area as quickly and as thoroughly as possible and, if it is to be successful, the task of actually flying the aircraft should require minimum crew involvement. It is therefore highly beneficial for the search pattern to be computed automatically and controlled by coupling the steering commands generated in the navigation equipment into the flight control system. During this search pattern, close height holding at a datum typically of 200 ft above sea level will be required, airspeed will be held at speeds down to the order of 45 kts to allow maximum possibility of sighting the survivors, particularly if forward looking infra red is fitted, and co-ordinated turns on to headings selected by the navigation system must be accomplished smoothly and safely. The system performance throughout must be safe, requiring minimum pilot attention and monitoring, and this is reflected in the very exacting certification requirements imposed for pilot intervention times following failures (see para 4).

At the point at which the survivor is located and identified the helicopter can be flying in any direction, at any height and at any speed. The requirement is then to bring the helicopter finally to a hover into wind, alongside the survivor, and at a height suitable for the winching operation, and this will sometimes involve turning away from the survivor, and frequently losing contact temporarily. In addition, right up to the point almost of reaching the final hover height the entire manoeuvre may have to be performed in I.M.C. The design of transition profiles should take this factor into account and should also make provision for aborting the transition and returning to a safe height and speed if any problems are encountered, or visibility conditions preclude the possibility of completing a rescue. Once the helicopter has been brought into the expected vicinity of the survivor the main requirements of the system are that:

(1) it should maintain a very close constant height with respect to a selected datum in any wave conditions likely to be encountered and

(2) the pilot and/or winchman must have maximum flexibility to modify the aircraft speed, track and final hover height in the stages following visual contact.

During the rescue operation itself it has been shown to be essential to provide a good heading hold through the yaw channel. Maintaining a close height hold continues to be of paramount importance and there can be little doubt that, if the necessary actuation is available or can be fitted, automatic control of height is a very big bonus.

Finally to allow the winching operation to take place the winchman must be able to control the helicopter to acquire and then maintain an accurate position alongside the survivor. In a coupled system this can be done by feeding the signals from a small joystick fitted to the hover trim controller into the flight control system. In an uncoupled system the pilot obeys the winchman's directions by following the appropriate flight director command bars, which in turn respond to the winchman's joystick movements. Whilst the pilot's workload in this latter case is fairly high the accuracy of control achieved is much better than the alternative of voice communication.

At the completion of the rescue operation the aircraft must be returned to a safe height and forward speed ready for the return journey. The power requirements are very high during the hover period, particularly in zero wind conditions, and the initial climb away should therefore make no demands for increased collective. It is in fact interesting to note that in practice two different profiles were developed in this area for coupled and uncoupled systems. In coupled systems the profile was designed to produce as rapid a decrease in collective setting as was possible taking advantage of trim curve characteristics, whilst pilots flying an uncoupled system were reluctant to apply down collective in such circumstances. For the uncoupled system the profiles were therefore designed to maintain a virtually constant collective setting during the initial climb away.

The return journey apparently produces the least onerous requirements of the phases as defined. Bearing in mind, however, that the survivors may well need urgent medical attention, the return journey must be made as efficiently as possible despite probable crew fatigue, and may well terminate in a landing performed under instrument conditions. Whatever automatic navigational assistance can be provided under these circumstances will be of great benefit, as will also control of height and airspeed.

3. SAR Modes

The previous paragraphs have attempted to lay down the requirements as initially seen and as determined from practical experience. These requirements have been implemented in the LN450 FPC by the provision of a total of 7 modes. The main features of these modes, particularly as applied to the coupled system, are outlined below.

Bar and Rad Alt Holds

Both these modes are controlled through the collective channel and initially hold the aircraft at the height existing at the point of mode engagement. The pilot can subsequently alter the height datum by pressing the collective manoeuvre button and temporarily disengaging the mode.

Tight control of height in the Rad Alt mode minimises excursions during airspeed changes and turns. This is made possible by use of smoothed vertical velocity and height signals computed from a combination of filtered vertical acceleration and raw height signals. The raw height is measured by two radio altimeters, whilst the vertical acceleration is computed by resolving the outputs of orthogonal body-referenced accelerometers.

The current smoothed height is displayed at all times in the height display on the pilot's controller.

Airspeed Hold

The airspeed hold mode can be engaged at indicated airspeeds above approximately 45 knots and will normally hold the aircraft at the airspeed sensed at the point of engagement. The airspeed datum is shown in the airspeed display on the pilot's controller when the airspeed mode is engaged. The pilot can however modify this datum by pressing the pitch beep trim button on the cyclic stick, the change being proportional to the length of time for which the button is held.

Airspeed is controlled using a signal derived from a combination of raw airspeed and fore/aft acceleration.

Heading through Roll

The heading mode may be engaged at airspeeds above approximately 65 kts and will acquire and hold the heading selected on the HSI. The mode controls through the roll channel to provide an approximately rate one turn, and also causes the yaw channel of the autostabiliser to adopt the appropriate configuration.

RNAV

The RNAV mode operates in the same fashion as the roll heading mode, but uses steering commands from the RNAV computer to steer to navigation waypoints or to follow a standard search pattern.

Overfly

The overfly mode is designed to provide coupled control of the manoeuvre necessary to re-approach the survivor, heading into wind and at a suitable height and speed.

The mode is engaged by pressing the Overfly button as the aircraft flies over the survivor. Roll demands are then generated to cause the aircraft to re-approach the survivor, flying into the wind with sufficient separation for a standard transition. The final position of the aircraft relative to the survivor at the end of overfly is downwind and to the left. The shape of the overfly pattern will depend on the aircraft heading with respect to the wind at the time of engagement of overfly, and on the wind strength. Estimates of both these parameters are calculated continuously prior to engagement of overfly.

Orbits are composed of a combination of:

(1) turns
(2) straight legs and
(3) a transition down to a creep forward speed at Set Hover Height.

The pilot is given prior warning of turns by the lighting of right/left arrows on the warning panels. A down arrow performs a similar function with respect to down transitions. Since the object of the total overfly manoeuvre is to bring the helicopter to a point behind the survivor the transition does not reduce speed to the hover but to a creep forward speed of 10 knots. The height is reduced to the datum shown on the Set Hover Height display.

During the progress of the transition down the system will make lateral groundspeed changes to adjust the course, if found to be necessary, and the fact that this is happening will be indicated to the pilot by lighting the appropriate left/right arrow. However, if at any time the survivor becomes visible the pilot or winchman can modify the course, if required, by use of the roll beep trim switch on the cyclic stick or the hover trim controller respectively.

Transition Down

The mode operates through the pitch, roll and collective axes with the yaw channel of the autostabiliser providing control of heading. The transition profile is divided into phases designed to produce the optimum profile with the maximum safety.

Phase 1-Vertical Speed

Transition down can be engaged from heights as great as 750 ft and under these circumstances the aircraft is flown in a vertical speed mode. This phase is designed to provide maximum system flexibility but is not a part of the normal overfly mode. All overfly distance calculations assume that the pilot will have brought the aircraft to a height of 200 ft before the overfly transition is started.

Phase 2-Entry Gate Adjustment

For heights in the range of 200ft to 300ft the system is controlled by a height profile which directs the aircraft to the design entry gate height. Once this has been reached phase 3 is entered automatically.

Phase 3 - Glideslope

Under normal operating conditions, or if this mode is engaged automatically from an overfly, the aircraft will proceed directly into phase 3 control. The aircraft is controlled in height and speed during this phase to follow height and speed profiles which result in a sensibly constant glideslope angle. This is indicated by illumination of Glideslope (GS) and Deceleration (DCL) captions on the Pilot's Controller.

The speed profile is designed to maintain an approximately constant pitch attitude over the course of the transition. The deceleration rate is made a function of entry groundspeed and current airspeed (either measured, or estimated from doppler and calculated wind velocity). This results in the maximum deceleration rates being demanded in the first stages of the transition and at the same time produces an approximately constant transition time irrespective of wind speed - this being necessary to synchronise with the height profile which is independent of windspeed. This approach has the further advantages:-

First, it allows the transitions to be performed in the minimum time consistent with not exceeding a given pitch attitude, thus providing the optimum compromise between safety and speed.

Second, the relatively constant pitch attitude allows unprogrammed excursions to be recognised rapidly.

Third, the magnitude of demands after the initial attitude change can be limited, contributing to system safety.

Fourth, the relatively low final deceleration allows the aircraft to settle gently on to the drift forward speed.

The height profile is designed to provide a progressively decreasing vertical velocity. This minimises the rate of change of collective blade angle required once the initial vertical velocity has been achieved, thereby contributing to system safety.

This phase ends when the aircraft passes through a decision height (40ft above hover height) at which point the aircraft still has a reasonable airspeed (of the order of 50 knots). The GS captions extinguish.

Phase 4 - Flare

If the pilot does not intervene to abort the transition by disengaging Trans Down or engaging Trans Up, the system will continue to reduce height to the Set Hover Height. The groundspeed will be reduced to the drift forward datum during this phase, and when the speed programme reaches this datum the DCL light will go out but the Trans Down caption will remain lit. It is during this phase, of course, that the crew will expect to make visual contact with the survivor. Whilst the drift forward speed will normally be 10 kt groundspeed, once the DCL light has gone out this datum can be modified if the Hover Trim button on the pilot's controller is first pressed. This then allows the pilot to make speed changes by using the beep trim switch, or the winchman by using the hover trim controller. The hover height can be adjusted by use of the Set Hover Height knob. In conditions of poor visibility and/or high sea states the pilot can choose to perform the transition to a fairly high hover height and then ease down gradually on to the minimum safe height for the existing conditions.

Transition Abort

If at any stage of Transition Down the Trans Up button is pressed the system will control the aircraft initially to minimise further height loss and forward speed reduction.

Control is then passed automatically to the Transition Up mode which will control the helicopter back up to design exit gate conditions.

Doppler Hover

This is the mode which will normally be engaged at the appropriate point to bring the helicopter to a zero groundspeed hover alongside the survivor and will usually be engaged by the pilot from the drift forward condition. It can however be engaged irrespective of whether or not Trans Down has been engaged provided that height and speed are within certain limits.

Hover Trim

Engaging the hover trim mode during the hover mode will enable the signals from a winchman's control to provide limited control of the helicopter in the horizontal plane. Alternatively, if appropriate, the pilot may make changes to the mode datum by use of the beep trim switches on the cyclic stick. In either case the objective is to manoeuvre the helicopter about the hover point to assist winch pick-ups. As mentioned earlier the mode can also be engaged during the drift forward to modify the groundspeed datum.

Transition Up

Transition Up is initiated by pressing the Trans Up button which will illuminate to indicate engagement. As in Transition Down the LN450 controls through the Pitch, Roll, and Collective axes. The mode is only engageable from a Transition Down, a Drift Forward or a Hover mode.

The aircraft will first be controlled to accelerate to climbing speed, the rate of climb during this period being nominal. When the required airspeed has been reached the helicopter climbs at a predetermined rate to the design exit gate height whilst also accelerating to the design exit airspeed.

On completion of the transition up the Trans Up captions will go out and the RAD and IAS captions will illuminate, indicating that the aircraft is under the control of these modes, with exit gate height and speed as datum conditions.

The roll channel is controlled to maintain zero lateral groundspeed throughout the Transition Up. When the mode is disengaged the roll channel reverts to attitude hold through the autostabiliser only. The yaw channel of the autostabiliser provides heading hold throughout the Transition Up and remains in this condition unless the pilot puts his feet on the pedals.

4. Failure Modes and Certification

Safety is an obviously overriding criterion when designing flight control systems, no less so in one designed for the SAR role than for more conventional uses. The fact that an attempt is being made to save lives must not result in other lives being unnecessarily endangered. Both the uncoupled system fitted to the Bell 212 and the fully coupled system fitted to the S61 have now received certification by the CAA and these are the first helicopter SAR systems to achieve this successfully. We believe that civil certification of the flight control system and indeed of the whole aircraft constitutes a significant advance in the safety aspects of search and rescue.

Being pioneers in this area, however, meant that at the time the initial design concepts were laid down and the development system was being produced there were no published CAA requirements for such a role. The previous extensive experience gained with both Wessex and Sea King aircraft was invaluable under these circumstances in enabling Louis Newmark to assess the degree of hazard inherent in the various phases of operation and designing into the system the required levels of integrity. In almost all respects the system design laid down at the outset was found subsequently to meet CAA requirements when these became established.

The process of establishing these requirements was, in fact, one of sustained, very close cooperation between Louis Newmark, Bristow Helicopters and the CAA. Flight development was carried out using BHL's Empire Test Pilot School trained pilots and Louis Newmark Flight Trials Engineers and throughout both development programmes CAA pilots regularly assessed the system in terms of safety, performance, and management.

4.1 Uncoupled Systems

On the Bell 212 with its uncoupled flight director system all flying is "hands on" and therefore involves a degree of continuous attentiveness. This means, on the one hand, that the requirements for autostabiliser failures during cruising modes, say, are less stringent, since the pilot already has his hands on the stick, and the flight director will cause him to react to oppose the failure. A simplex stabiliser is therefore sufficient under these circumstances. However, dangers arise from the particular characteristics of flight directors which pilots often describe as 'compelling'. Under these circumstances failures which cause the flight director bar to move sharply are fairly readily recognised and therefore not followed, but the response from more gentle failures may seduce the pilot into following the erroneous command bar motion.

The design of a safe flight director system is, therefore, concerned predominantly with two areas:-

(1) The choice of control laws.
(2) The automatic recognition of failures.

Choice of Control Laws

The choice of control laws for an uncoupled system is in many ways more difficult than for a coupled system. The major objectives must be to keep the pilot's workload as low as possible and to make all movements and all manoeuvre profiles as natural as possible. This can only be done if close cooperation is achieved between pilots, flight test observers and system designers, and in the 212 development programme this resulted in system gains, flight path monitor thresholds, etc., being closely adjusted in relation to the accuracy with which a given flight path needed to be flown in each phase. This, and the ability to represent many of the highly non-linear characteristics of natural pilot manoeuvres, was greatly aided by the use of digital computing techniques. The resulting characteristics mean that:-

(a) the pilot is able far more readily to detect and ignore abnormal demands,

(b) the captain can more easily monitor manoeuvre patterns, etc, with the aid of the normal aircraft instruments.

As a particular example, the way in which the choice of transition profiles can contribute towards both these aims has already been discussed.

Automatic Recognition of Failures

Both the coupled and uncoupled systems use a simplex microprocessor to provide control of the FPC functions. The methods used to provide the required integrity are outlined later but make use of sensor and flight path monitors to detect failures.

Certification of the uncoupled system involved extensive analysis of possible failure modes which then had to be demonstrated in flight, since each failure case had to be considered on its own merits.

4.2 Coupled Systems

One aspect of the safety requirements for a coupled system is the *allowed pilot intervention time following a failure. Table 1,* reproduced by permission of CAA, details these in relation to the various phases of the SAR operation as applicable to the S61 system. The times vary from 2.5 seconds (including a 1 second recognition time) in the coupled hover, to 6 seconds in the cruise. The 6 seconds cruising requirement predominantly influences the design of the autostabiliser, since the most severe failure cases arise from hardovers, particularly in the actuation. Requirements such as this confirmed the necessity of replacing the simplex autostabiliser normally fitted to the S61 with the duplicated LN400, the latter having the additional feature essential for restricting the magnitude of runaways of an autotrim system which keeps the series actuators central. Even then special attention had to be given to using the beeper actuator to oppose some forms of series runaways. The resulting system is, however, extremely safe with demonstrably innocuous runaway characteristics.

The LN450 FPC uses a simplex microprocessor to provide outputs to 3 axes, pitch, roll, and collective. Whilst the microprocessor is continuously self-tested and various aspects of the system performance are monitored both in software and independently in hardware analogue monitors, it was demonstrated during the course of certification that the required intervention times could be met, even if the *microprocessor failed in the worst possible way.*

Having achieved the required intervention times in the worst case failure it is not then necessary to demonstrate the effects of particular failure forms resulting in potentially severe runaways. However, these are not the only forms of runaway, nor even necessarily the most dangerous. Failures which involve slowly progressive changes of flight path, particularly those involving loss of height in an IMC hover, are potentially very dangerous. The system design wherever possible must provide means of protecting against and/or identifying such failures and, if necessary, they must be examined in flight. A very extensive failure mode and effects analysis was carried out on both the FCS and the aircraft systems etc., and during the course of certification means were provided for either producing directly or simulating in flight all failures, the effects of which might give cause for concern.

4.3 System Management

An aspect of system certification which was the subject of extensive discussion with CAA were the details of system management with respect to failure warnings and mode status indications. The principles adopted in the S61 are outlined below since they contain features considered essential by the CAA.

Warning Panels (See Fig 3)

The pilot and copilot have identical warning panels provided within their normal instrument scan providing the following indications:-

(a) FPC. The amber FPC primary warning caption is used to draw the pilot's attention to all FPC malfunctions including mode engagement failures.

(b) ASE. This caption is driven by the LN400 autostabiliser to indicate detected malfunctions.

(c) UNCPL. The red UNCPL caption on the warning panels will operate under two conditions:-

   (1) The system uncouples one or more axes as a result of detecting a failure.

   (2) A channel has been uncoupled as a result of either automatic or pilot-controlled mode changing, or disengagement not resulting from a system-detected failure. In this case the caption will illuminate for 5 seconds.

(d) HT LOW. The height low caption (Red) will illuminate when an FPC monitor detects that the aircraft is significantly below the programmed height profile.

(e) A set of turn left, turn right and down arrows is supplied for both pilots. These are green and will provide prior warning of turns or lateral groundspeed corrections in the overfly sequence, or the start of any transition down.

Annunciator Panel

A single annunciator panel is fitted to the instrument panel in view of both pilots. This shows the mode(s) engaged at any time, and which axes of the autostabiliser are receiving coupled inputs from the FPC. Axis warning captions will distinguish which particular axes are involved in the failure or uncoupling indicated on the main warning panel.

LN450 Pilot's Controller (Fig 2)

The pilot's controller warning captions are grouped in the lower right hand corner of the front panel. Included in this group is the FPC engagement pushbutton which shows 'ON' when the FPC is engaged. The other captions are:-

FAIL - This caption indicates major system faults detected by the system self test.

FAULT - This is used predominantly to give warning of failures detected by software and hardware monitors.

INVALID - This illuminates when a sensor is judged invalid during operation of a mode which cannot function without that sensor. It will also light if the pilot attempts to engage a mode with an invalid sensor, and under these circumstances will remain lit for 5 seconds after he releases the mode button.

AXIS WARNING INDICATORS - These are used predominantly to indicate the affected axes whenever the fault or invalid captions illuminate.

COUPLED AXIS INDICATORS - The appropriate axis captions will be lit whenever the FPC is exercising coupled control through that axis.

5. System Design Considerations

5.1 Performance Aspects of Autostabilisation

The autostabiliser is the heart of the FCS, particularly in a coupled system.

The LN400 autostabiliser used in conjunction with the LN450 FPC in the S61 provides tight hands-off attitude holding in pitch and roll when the system is engaged without the FPC. Control is achieved by two independent lanes of analogue computing driving a series actuator through the two independent windings of an electrohydraulic actuator.

5.3 Performance Aspects of the Flight Path Controller

An essential feature of an SAR system is the ability to maintain good groundspeed control particularly in the hover, with the ability to modify the datum as necessary. This has been achieved by the use of smoothed groundspeed signals calculated from a combination of doppler velocity and acceleration measured along the appropriate earth axes. Such a signal has the advantages both of allowing tight control of speed, and minimising the effects of doppler irregularities, particularly fading in mirror-like sea states.

The value of being able to maintain a good height hold when in a 40ft hover over the water cannot be over-estimated. The sensors used in these circumstances are radio altimeters which provide accurate measurement of height with respect to the land or sea below. The IHS (Inertial Height Smoother) combines this rad alt signal with a vertical acceleration signal in such a manner that sea wave motion sensed by the Rad Alt is drastically reduced. The use of such smoothing is undoubtedly a very significant factor in making the rescue operation viable in very severe weather conditions. The calculation of these smoothed vertical velocity and height signals requires the provision of earth axes acceleration signals which in Wessex and Sea King were obtained from accelerometers mounted on a stabilised platform. The use of digital technology in the LN450 has allowed the much cheaper alternative of strap-down accelerometers to be used, their outputs being resolved within the FPC.

5.4 Safety Aspects of the Flight Path Controller

As will be apparent from previous paragraphs there are considerable advantages in using digital techniques to compute the required FPC functions, and the increased reliability combined with the ability to perform considerable amounts of both pre-flight and continuous in-flight testing results in a reduced probability of failure arising from the computing itself. However the microprocessor can still develop failures undetected by self-test, and these can produce 3-axis failures. There will also, of course, be FPC failures arising from sensors.

Rather than using a fully duplicated system Louis Newmark have chosen to provide a simplex microprocessor supplemented by independent analogue monitoring. This gives a less expensive, smaller and more reliable system. It also avoids the potential certification problems associated with identical computers.

Some of the particular features included to produce the required integrity are outlined below.

Sensors

The FPC uses a wide range of sensors, most of them simplex. However to provide the necessary integrity in particularly sensitive areas dual vertical gyros, normal accelerometers, and radio altimeters are used.

Duplex Vertical Gyros: These are already provided, of course, to feed each lane of the autostabiliser. In the FPC however attitude information is also required for the strapdown calculations. In order to limit the probability of axis coupling during failures these computations are done twice, once for cyclic channels and once for the collective channel. Each set of computations uses a different vertical gyro.

Duplex Normal Accelerometers: Since the system is sensitive to failures in this accelerometer the outputs of duplex accelerometers are compared in a hardware implemented monitor.

Duplex Radio Altimeters: Two radio altimeters are provided to give easily visible protection particularly against the possibility of slow runaways.

Other FPC Sensors: The results of failures of other sensors in critical modes will be detected, either, in a few cases by monitoring the inputs themselves, or by the use of flight path monitors. In many instances the use of a combination of sensor inputs to produce smoothed signals means that the effects of failures in one sensor are at least partially opposed by the other.

Collective Channel

Failures in the collective channel almost certainly present the potentially most hazardous conditions, particularly in the coupled hover. In the S61, collective control is applied through a collective parallel actuator, specially installed for the SAR role. The choice of speed for this actuator then becomes very important, since it must be fast enough to give the required control but, at the same time, slow enough to allow intervention times to be met. The first of these requirements is assisted by the design of transition profiles, the second by the use of a hardware implemented velocity restraint filter. The collective channel incorporates extensive monitoring, some implemented in software, some in hardware. The hardware monitors provide independent analogue comparisons of digitally computed signals from the microprocessor with analogue computed signals. It should be noted that, whilst these hardware monitors are involved particularly with collective channel parameters, they are designed to test correct operation of many aspects of the overall microprocessor configuration. All collective monitor warnings are handled by a dedicated collective warning facility which, in the event of a failure will:

1) operate the relevant visual warning,
2) initiate a short period fly-up where appropriate,
3) declutch the parallel actuator.

Cyclic Channels

The FPC pitch and roll outputs are limited within each lane of the autostabiliser and the magnitude of these limits therefore determines the maximum severity of any FPC runaway.

However the coupled signals are also passed through hardware rate and amplitude limits in the FPC, switchable between high and low levels. This switching is normally controlled from within the microprocessor, but a hardware low altitude over-ride is provided to ensure that only low level demands are coupled into the LN400 below 100ft.

6. Concluding Remarks

This paper has attempted to define the requirements for an SAR flight control system, and then outlined the way in which these have been implemented in the first SAR systems to receive civil certification.

Many of these principles have been based on the extensive experience gained with Wessex and Sea King aircraft and are therefore known to provide the basis for a good system. However some changes, which we believe constitute improvements, have been incorporated and, whilst first reactions have been very favourable there has, fortunately, been no call yet to evaluate it in a real rescue in IMC.

If the design of SAR flight control systems is to provide the maximum assistance to those attempting to save lives in hazardous weather conditions it is essential that the performance of such systems be continuously monitored.

Whilst Louis Newmark believe that the current flight control system design produces a versatile high performance system, involving minimum pilot workload, particularly in the coupled case, advantage must be taken of future practical experience with this system to reassess requirements and introduce further improvements where necessary.

Acknowledgements

The authors would like to acknowledge the contribution made by many colleagues within Louis Newmark plc. Flight development of the LN450 FPC on Bell 212 and Sikorsky S61 was carried out with Bristow Helicopters Limited and the flight control system is only a part of an integrated Search and Rescue aircraft.

We would also like to acknowledge the close cooperation given during the two developments by the Civil Aviation Authority.

Reference

1) H. Collomosse, All-Weather Operation for Helicopters: Flight Control Systems for Helicopters. The Aeronautical Journal of the Royal Aeronautical Society, Volume 73, No. 698, Feb 1969.

Table 1

PROVISIONAL GUIDANCE CONCERNING AFCS FAILURES APPLICABLE TO LOUIS NEWMARK SYSTEM FITTED TO BRISTOW S-61N MK 2

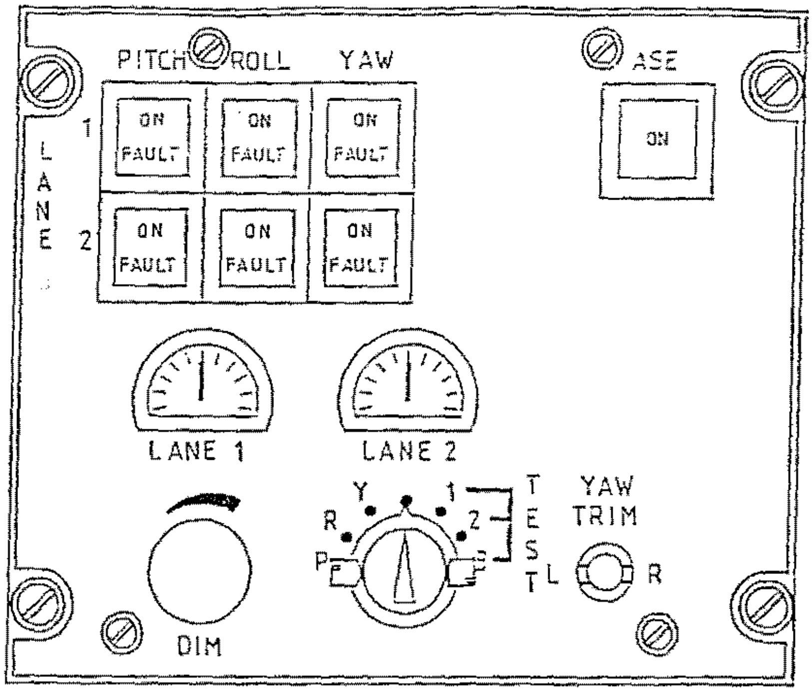
	FLT CONDITION	AFCS STATE	PHASE OF FLIGHT	RECOGNITION TIME (sec)	RESPONSE Time(sec)
1.	Cruise	(a) Automatic stabilisation only	Passive (Hands off)	See note (1)	5
		(b) Automatic stabilisation + coupled cruise modes	Passive (Hands off)	See note (1)	5
2.	Cruise - Low Altitude (Below 500 ft)	Automatic stabilisation + coupled cruise modes (inc Rad Alt Height Hold)	Passive (Hands on)	See note (1)	2½
3.	SAR Recovery Operations	Automatic stabilisation + coupled SAR modes (inc overfly, transitions, hover and AMC)	Attentive (Hands on)	See note (1)	1½
4.	Flight Conditions 1, 2 & 3 above following single AFCS failure	1(a) & (b) 2 & 3	Attentive (Hands on)	See note (1)	1½
5.	Flight Conditions 1 above, following single AFCS failure	1(a)	Active (see Note (2))	½ (minimum)	1

NOTES:

(1) The recognition time, which will depend upon the cue of failure, will be established during certification flying and would not normally be expected to be less than 1 second.

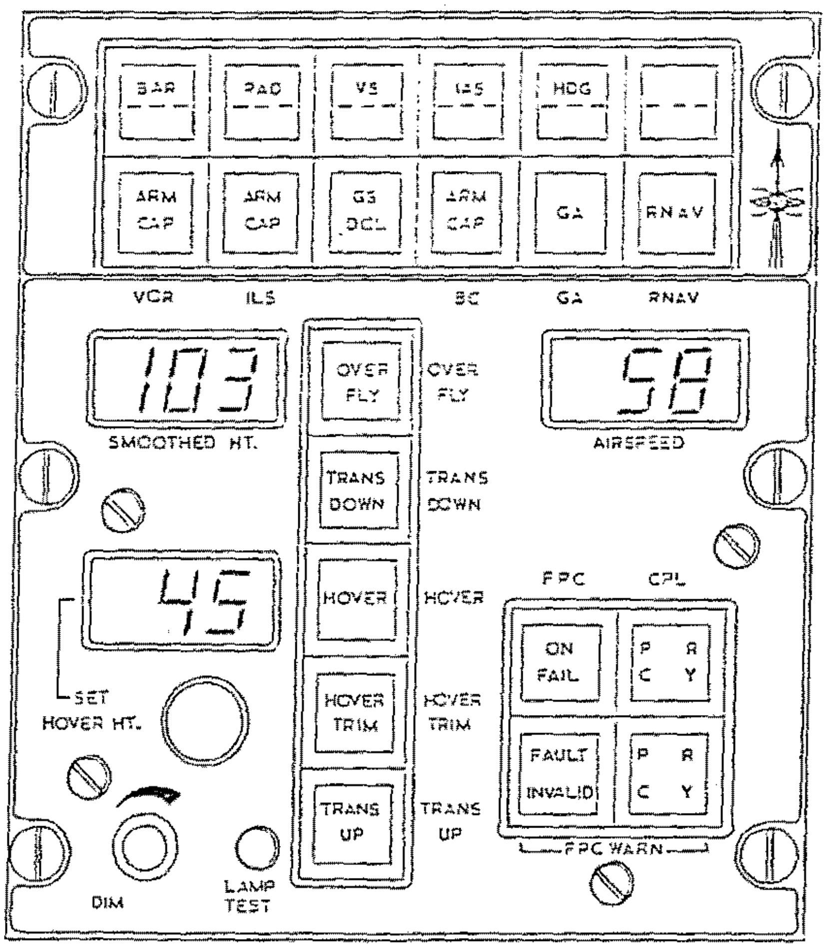
(2) Where it can be shown that the pilot is flying the aircraft manually and without the assistance of a coupled mode, active intervention time criteria may be applied.

Ref: Draft Proposals for British Civil Airworthiness Requirements for the certification of helicopters for approach to the hover and hover in non-visual conditions, Appendix 2.



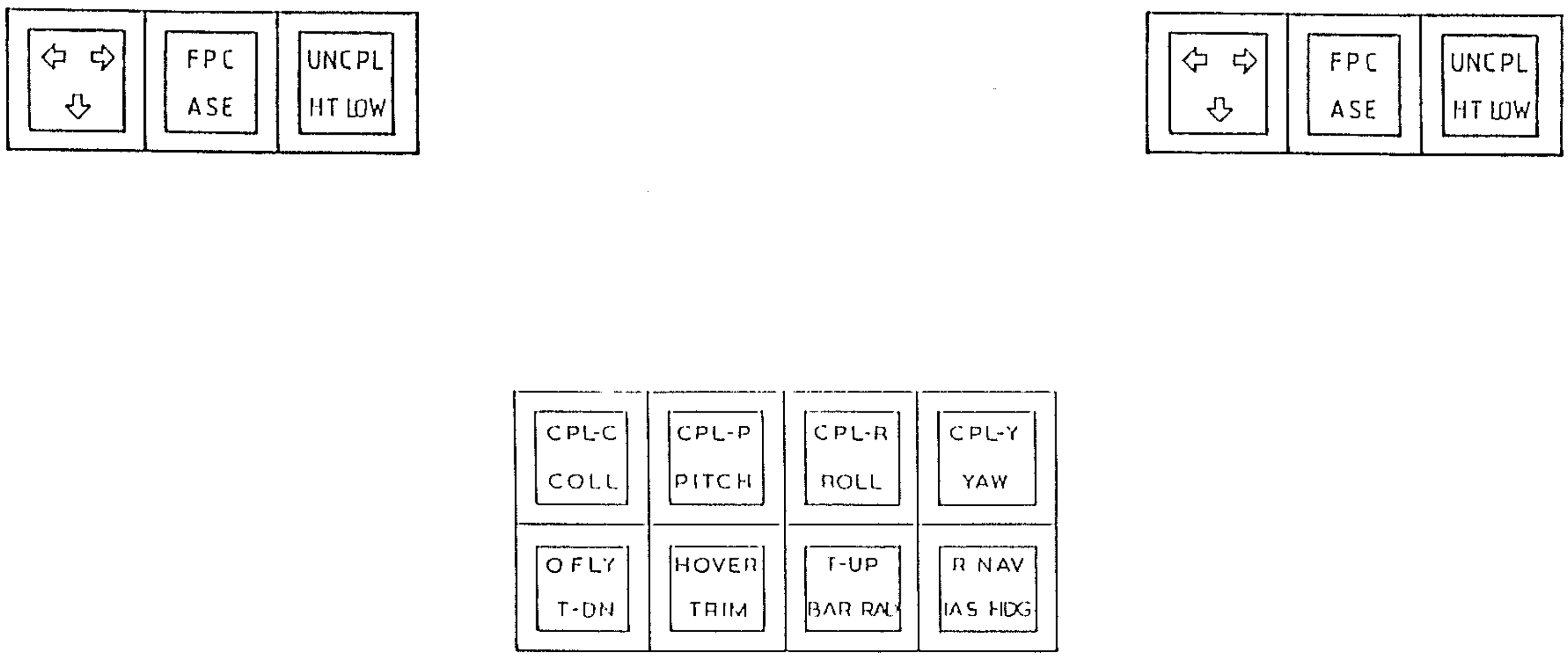
ASE PILOTS CONTROLLER

FIG. 1



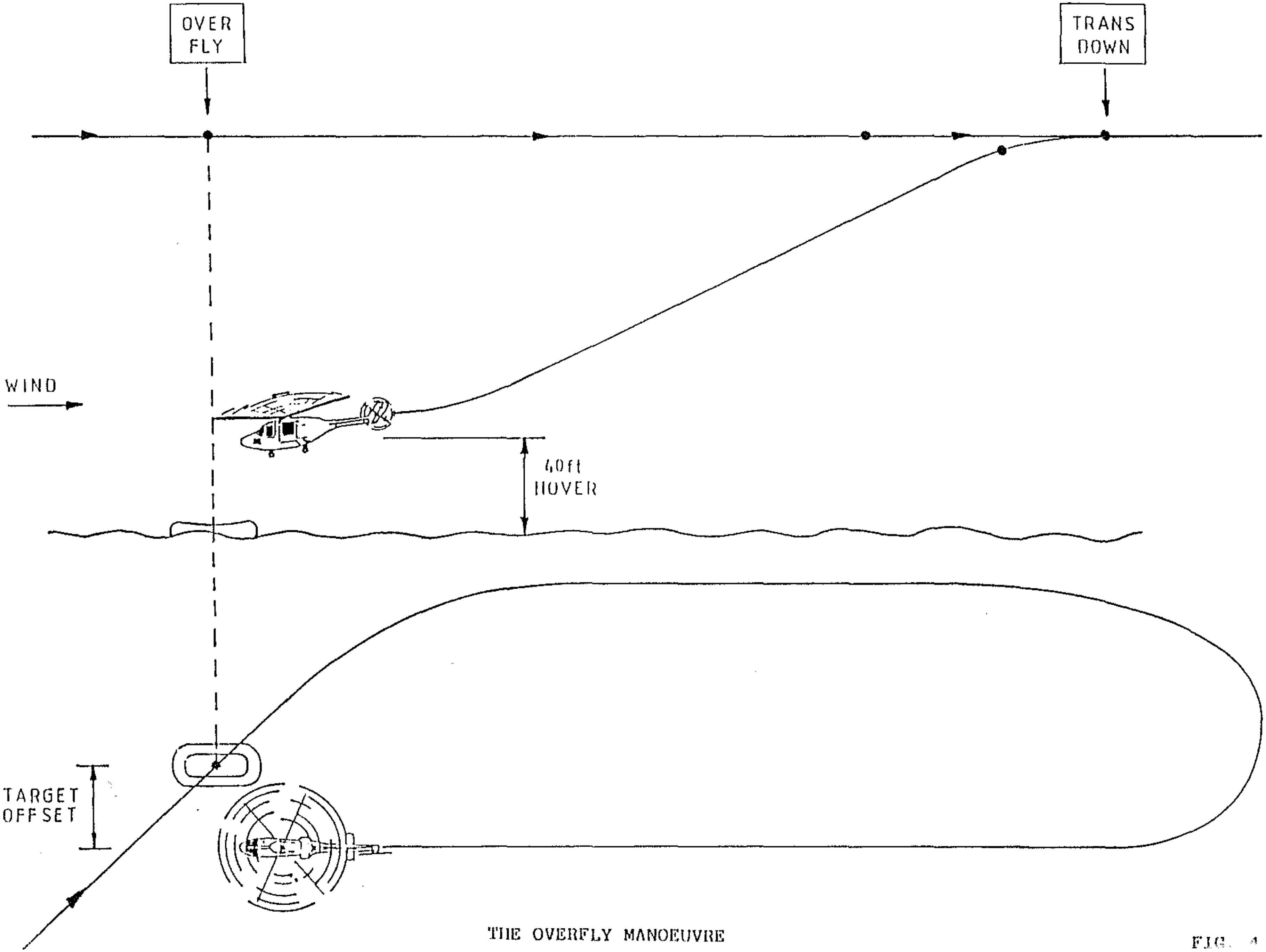
FPC PILOTS CONTROLLER

FIG. 2



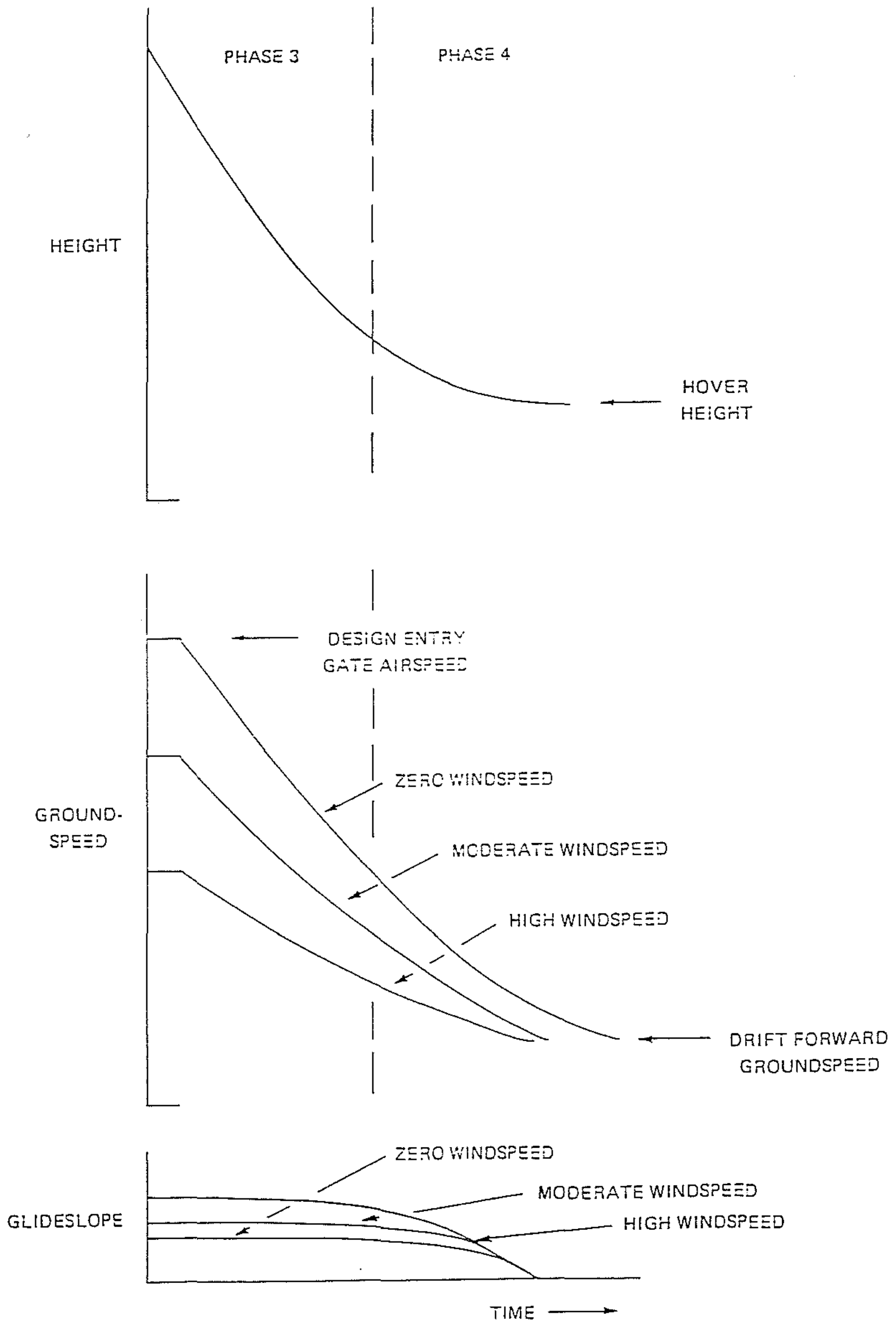
S61 – WARNING & ANNUNCIATOR PANELS

FIG. 3



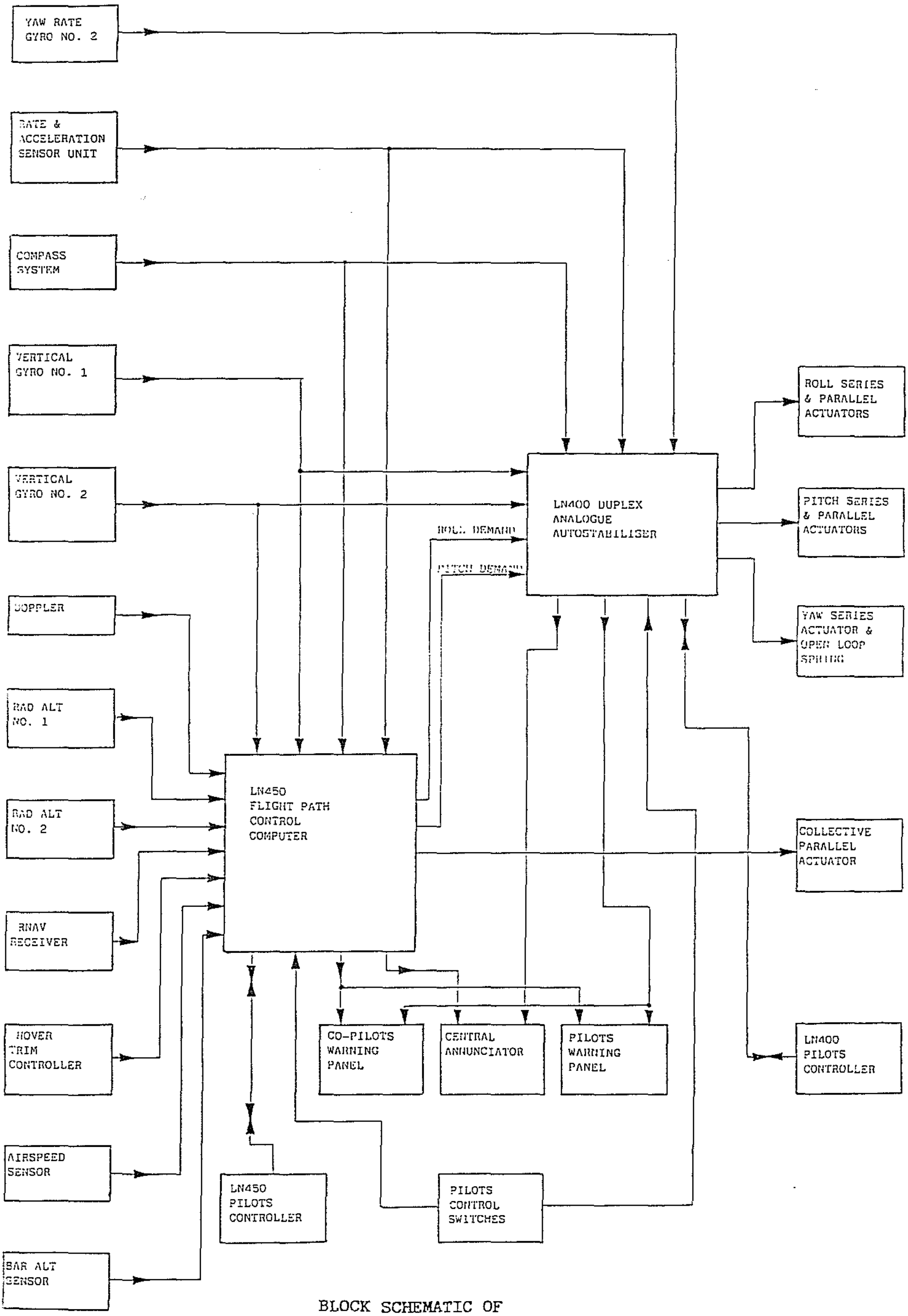
THE OVERFLY MANOEUVRE

FIG. 4



TRANSITION DOWN PROFILES

FIG. 5



BLOCK SCHEMATIC OF

S61 COUPLED SAR SYSTEM

FIG. 6