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by

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FLIGHT SIMULATION OF A WESSEX HELICOPTER - A VALIDATION EXERCISE

by

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Ann C. Thorpe

SUMMARY

A piloted flight simulation of the Westland Wessex helicopter is described; the simulation was intended to investigate the validity of simulation for the representation of flight handling behaviour. Two areas were of concern: the representation of the Wessex within a limited computational capacity, and the suitable simulation of the flying environment so that handling characteristics were presented correctly to the pilots.

By limiting the scope of the simulation to the normal flying régime of the helicopter, an adequate representation of the Wessex was possible. Presentation of handling behaviour was satisfactory in pitch and roll; some difficulties were experienced in the representation of yawing behaviour and of height control near the hover, and were attributed to inadequate motion capability of the simulator. The results of this simulation have been used to give confidence in the interpretation of future helicopter simulation.

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* Replaces RAE Technical Report 73096 - ARC 35005

CONTENTS

1 INTRODUCTION

For more than a decade, the flight simulator of the Aerodynamics Flight Division at Bedford has been used for investigations into aircraft flight handling characteristics. The tasks of the simulator section have been threefold: basic handling research (stability and control requirements, operational techniques for new classes of aircraft, etc.), assessment of handling qualities of new aircraft during the early development stage, and advice on simulation to manufacturers and other users of simulators. Prior to the simulation described in this paper the work had been concerned with fixed-wing aircraft, particularly during take-off and landing, and with jet-borne VTOL aircraft during transition and hover. In 1969 the use of the simulator for a pre-flight handling investigation of the Westland Lynx was proposed, and this prompted a preliminary validation simulation of the Westland Wessex, aimed at establishing the simulation techniques required for effective representation of handling behaviour of helicopters. The present paper describes this Wessex simulation, which took place in the first few months of 1970; the Lynx simulation, which followed later in 1970 and was completed about four months before the first flight of the actual helicopter, will be described in a separate report[1].

The problems to be considered in the preparation of a piloted flight simulation can be split into three groups:

(a) obtaining the data required for representation of the vehicle aerodynamics,

(b) mechanisation of the aerodynamic data and equations of motion in a suitable form, bearing in mind any limitations of the computational equipment used,

(c) effective incorporation of the pilot in the control loop (i.e. suitable visual, aural and motion cues).

It is impossible to obtain some objective assessment of how well the problems of (a) and (b) have been overcome; for example, if approximations have been made, the régimes of flight for which these approximations are valid can be established and the simulator investigations can be limited to the valid régimes. However, the problems of (c) are, by their very nature, subjective, and extension of simulation techniques to new flight régimes must be accompanied wherever possible by similar aircraft flight tests for validation.

Because the simulator section had had no experience of helicopter simulation, it was felt necessary to perform a validation exercise before using the simulator for simulation of the Lynx. The Wessex was chosen for this exercise as a helicopter of this type was operated by the Aerodynamics Flight Division, and the pilots performing the major part of the simulation work were familiar with its handling features.

This paper discusses the simulation equipment used, tests made and problems encountered, and comments on the value and validity of simulation for assessment of helicopter handling features.

2 DESCRIPTION OF THE SIMULATION

2.1 Simulation equipment

The equipment used is shown in block diagram form in Fig.1; the various elements of the simulator are described briefly below. A fuller description appears in Ref.2, though numerous alterations have been made since that report. The motion system performance is discussed in Ref.3.

2.1.1 Computer

The representation of the Wessex was programmed on the 200-amplifier analogue computer, and responded to the pilot's control inputs and to disturbances introduced by the simulator operator. Computer outputs fed the sources of motion, visual and aural cues for the pilot, to enable him to complete the simulation loop. Sixteen computed variables were recorded by two 8-channel pen recorders, and records of pilot's and operators' commentary were made during the tests.

2.1.2 Cockpit interior

The simulator cockpit is normally equipped with conventional aircraft controls; these were removed for this simulation and replaced by cyclic stick, spring and trim units and collective lever from a crashed Wessex HAS Mk.3. Modifications were made to the friction lock on the collective lever to enable it to be mounted on existing cockpit structure. A Wessex yaw pedal damper was fitted to the simulator pedals, and the normal simulator feel system was disconnected. Figs.2 and 3 show the instrument and control layout in the cockpit.

The cockpit interior was by no means representative of a Wessex, being rather cramped, with the cyclic stick and instrument panel too close to the pilot. As the simulation was intended for the study of handling behaviour, the instrument display was limited to those flight instruments relevant to the task; instruments concerned with systems management were not included. The instruments and layout used approximated to that of the Wessex; instruments are labelled in Fig.2. A radio altimeter is shown; although such an instrument is not present in the mark of Wessex simulated (HC Mk.2) it was included in the simulation to supplement the television display if height judgement on that display were found to be insufficient for hovering flight.

The cyclic stick had the normal spring feel in both axes, with trim obtainable from a thumb-operated button on the handle (Fig.2). This button was from a Wessex HAS Mk.3 and differed in shape (and in ease of operation) from that used in the HC Mk.2. The feel forces could be removed temporarily by the 'trim release' button on the stick, or for a longer time by the 'trim release' switch on the instrument panel.

2.1.3 Visual display

The primary visual display of the outside world was provided by a closed circuit television display, in which a camera tracked over a scale model of an airfield and surrounding countryside in response to position and attitude signals from the computer. The picture so produced was presented to the pilot on a monochrome television monitor mounted above the instrument panel. Fig.4a is a side view of the cockpit and motion system; the monitor is visible at the front of the cockpit canopy. (The television monitor was replaced by a projected picture for two trials at the end of the simulation; the projector is shown in Fig.4a.) The angular field of view provided by the display was 45° in azimuth and 35° in pitch. Two models were used; one on a scale of 1:2000 covered an area approximately 12 nm by 4 nm, with a maximum altitude of 1500 ft. The other, of 1:700 scale, had more ground detail but linear travels of approximately one-third of those of the 1:2000 model.

The cockpit is situated inside a dome-shaped room which acts as a projection screen. Rotor flicker was simulated by mounting a rotating fan below a light bulb, the whole assembly being placed above the cockpit, and the flickering on the dome walls being visible through the opaque side windows of the cockpit. Towards the end of the simulation, this was replaced by a projected shadow horizon which gave peripheral attitude information to enhance the television picture. Fig.5 shows this shadow horizon when used, in an earlier simulation, as the sole source of outside visual cues.

2.1.4 Motion system

Cockpit motion was available in pitch, roll, heave and yaw. Fig.4a shows the motion system and Fig.4b illustrates the range of movement available. The system was originally built with two axes of motion (heave and roll); pitch and yaw were added just prior to this simulation. However, yaw motion was unsatisfactory; the available response was poor, and reversal of direction of motion was accompanied by a knock and some structural vibration which destroyed the value of the cues provided. For all but a few specialised tests, yaw motion was not used in this simulation. Fig.6 shows the motion system performance characteristics; a full description of the motion system, including the faults encountered and attempted solutions, is given in Ref.3.

The drive laws for the motion system are given in Appendix B; comments are given in the main text on the use and value of cockpit motion. In addition to the representation of aircraft motion by the motion system, vibration signals at 4 and 16 Hz were used to represent the 1/rev and 4/rev rotor vibrations experienced in the aircraft; the vibration level increased with increasing speed and rotor loading.

2.1.5 Aural cues

Simulated noise, incorporating engine noise, transmission and gear whine and blade slap, was fed into loudspeakers behind the pilot's seat. The blade slap noise level increased with increasing rotor loading.

2.2 The Wessex

The Westland Wessex HC Mk.2 (Fig.7) is a twin-turbine development of the Sikorsky S-58. Leading particulars are given in Appendix A, section 4. Wessex helicopters have been used by the Royal Navy since 1960, and the HC Mk.2 has been in RAF service since 1964. Pitch and roll auto-stabilization, with attitude and damping terms, is fitted, and a heading hold mode is available in yaw. Auto-stabilizer laws are described in Appendix A, section 2. The particular helicopter used for flight-simulator comparison, XR 503, was being used at RAE Bedford for development of radar equipment, and instrumentation of relevance to the comparison was limited to state variables (linear and angular velocities, attitude angles, etc.) and pilot's control inputs. No direct measurement of rotor behaviour was available.

2.3 Mathematical model of the Wessex

A comprehensive simulation of a helicopter is far more complex than the fixed-wing studies previously performed on the Aerodynamics Flight Division simulator, and there were some problems in fitting an adequate representation of the Wessex within the limited computer capacity of 200 amplifiers. Simplifications in the model were inevitable, but chosen, it was hoped, to give minimum loss of fidelity in those areas relevant to the aims of the simulation. It was decided to place emphasis on simulation of handling in normal flight conditions, paying reduced attention to extremes of speed or manoeuvre. The influence of some of the simplifications on the simulation is discussed in section 3.

In particular perfect engine governing was assumed, giving constant rotor rev/min, and a quasi-static representation of the main rotor was used. Main rotor forces and moments were generated in the usual coefficient form (e.g. Ref.4) and the standard simplifying assumptions were used. In addition several small terms and higher order powers of advance ratio were neglected. A much simplified tail rotor representation was used, synthesised from the results of wind tunnel tests described in Ref.6. Semi-empirical longitudinal forces and moments due to the fuselage and tail were adapted from values previously used in computer studies by Westland Helicopters Ltd.[5]. Lateral body forces and moments were derived from data on the Sikorsky S-58 given in Ref.7; these included only effects due to the free stream flow and not to the downwash from the main rotor. During the simulation, tentative contributions from the downwash were included in an attempt to compensate for deficiencies of the model; these are discussed in section 3.

Motion of the helicopter in six degrees of freedom as a result of the applied forces was computed, with numerous small angle assumptions being used during rotation of axes. The form of equations used led to indeterminacies at zero airspeed. Originally it was not intended to look at hovering flight in the simulation as it was felt that motion and visual deficiencies would not permit realistic simulation at the hover, but later it was decided to investigate the scope of the simulation at the hover. In order to avoid the computational indeterminacies, simulator flying was performed in winds of 10-15 kn so that hovering relative to the ground could be achieved with positive airspeed.

Aerodynamic ground effects and the dynamics of the landing gear were not included in the simulation. Ground contact was simulated by inhibiting portions of the computation until thrust exceeded weight.

3 VALIDATION OF THE SIMULATION

3.1 Assessment of the mathematical model

It was intended to assess the mathematical model of the Wessex by comparing trim and response data measured in flight with corresponding records from the simulator. A number of difficulties were encountered in this comparison. Firstly, measurements in flight were confined to state variables and pilot's control movements; no direct measurement of rotor movement relative to the fuselage was available. As the most significant pitching and rolling moments acting on the helicopter are generated by this relative movement between the rotor disc and fuselage, the lack of this information from flight tests introduced difficulties into the assessment and interpretation of differences between simulator and flight records. Also no measurement of lateral velocity was obtained in flight, this being another quantity of significance in the analysis of lateral motions of the helicopter.

Secondly, comparisons were made with the stabilizers disengaged. This was done for two reasons: no measurement of stabilizer demands was available, so that with stabilizer engaged the control demands were not directly recorded: also, there was little point in comparing stabilized responses from simulator and flight as this would measure little more than the stabilizer control laws, which would suppress the helicopter's natural modes of motion. However, with near to neutral stability in pitch, responses to cyclic control could only be sustained for a very few seconds without exceeding the limitations of the simulation (and of the aircraft). It was also difficult to establish steady trim conditions before applying the control input.

During validation of the simulation, pilots commented on a number of differences between the simulator and the real Wessex; some of these differences were identifiable as actual differences in response between the mathematical model of the Wessex and the real helicopter. Unfortunately, because of the restricted flight instrumentation, the causes of these discrepancies were not readily resolved in the time scale of the simulation. However, the fact that the pilots were able to detect and identify these deficiencies of the model was in itself a partial validation of the simulation aspects of the comparison. The need for improved representation in certain parts of the model was established and will be discussed later in this paper.

For convenience, the trim and response comparisons will be separated into discussions of the longitudinal and lateral phases of motion. Because of the inability to achieve effective comparison of flight and simulator, some of the comparisons described below were performed subsequent to the simulation.

3.1.1 Longitudinal comparison

Fig.9 shows level flight trim data from simulator and flight tests. In the longitudinal data (left-hand graphs) there is a close correspondence in the values of pitch attitude, though flight tests show a little more of a hump near 25 kn (there is some scatter of the flight values here, however). The shape of the flight values of fore-aft cyclic stick is repeated in the simulator results, with a small shift in absolute level, which might be due to small differences in CG position or inaccurate representation of the download on the tailplane from the main rotor wake.

There is a significant discrepancy between flight and simulator values of collective pitch (shown in terms of the pitch angle at 0.75 of the main rotor radius). The simulator values are, however, confirmed by data from other sources (e.g. Ref.5) and it is felt that the low values of flight measurements must be due to mismeasurement or misinterpretation of the measurements. In spite of checks on the flight measurements, the discrepancy has not been satisfactorily explained, but this illustrates some of the difficulty in deducing blade angles from the measured positions of the collective lever, where corrections have to be made for blade twist, pitch-lag coupling, possible control run distortion under flight conditions, etc.

The response of the unstabilized Wessex to fore-aft cyclic steps is shown in Fig.10. The time-histories of fore-aft cyclic show changes of cyclic angle from trim, not absolute values, and all values have been normalised by dividing by the appropriate step input size, to give a direct comparison. Only a short duration response was possible before corrective action had to be taken. The initial build-up of pitch rate and acceleration is generally similar, but (apart from the run at 70 kn) this build-up appears to occur earlier in the simulator case than in the flight results. One possible contribution to this lies in the quasi-static flapping assumption of the simulator; a cyclic input is converted to a pitching acceleration by tilt of the rotor disc. In the simulator this occurs instantaneously, whereas in real life the disc tilt takes a finite time - a little over one quarter of a revolution of the main rotor is often quoted, which would be about 0.1 second. A further source of delay could be in power control lags or in lost motion between the cyclic position at the point of control measurement and that at the rotor blades. This small delay between simulator and flight responses is unlikely to be of any significance to the pilot's assessment of the helicopter, but representation of flapping motion as a first-order system would improve the response comparison.

Further longitudinal comparison is available in Fig.11 which shows the response of the unstabilized helicopter to steps of collective pitch. Once more the results have been normalised to show the response to a 1° step. The initial peak normal acceleration is similar in flight and simulator (though with increasing speed the flight records show a little more g). The pitch rate induced initially is also similar in size and direction, but whereas in flight the pitch rate decreases, in the simulator the pitch rate is sustained, accompanied by an increase in values of normal acceleration over the flight values. This indicates a greater degree of instability in the simulator representation, which could be due to difference in CG position between flight and simulator, as stability is sensitive to CG position. Errors in the representation of downwash over the tailplane could also influence the stability.

As in the cyclic responses, the initial response build-up is more rapid in the simulator than in flight. The simulator assumes an instantaneous revision of inflow conditions, whereas in reality it takes a finite time for the flow to set up the new conditions.

A significant, and interesting, difference is shown in the time-histories of yaw rate following the collective step, stemming from the assumption of constant main rotor speed in the simulator equations. The change in collective angle produces a change in rotor torque, and hence in rotor rev/min. This rotor speed change is detected by the engine governor, which generates a compensating change in engine torque, to return the rotor speed to the correct value. The reaction to this engine torque change produces a yaw acceleration of the helicopter. In the simulator, with 'perfect' rotor governing, the collective change produces an immediate yaw acceleration of the helicopter, whereas in real flight there is a delay introduced by the time taken for the governor to react to the rotor speed change. The simulation could be improved - with little increase in complexity - by introducing a first-order lag in the equation for main rotor torque, to represent the governor reaction time, i.e. in Fig.8, the equation for main rotor yawing moment $(N_R = Q_S - Y_S \ell_R)$ could be replaced by $N_R = \big(1/(1 + \tau_s)\big)Q_S - Y_S \ell_R$.

In summary, the longitudinal comparison showed:

(a) similar trim curves (apart from assumed instrumentation errors in the flight collective values);

(b) similar response to cyclic pitch inputs (with a slight initial delay in the flight responses being detectable from the traces but probably not of significance to the pilot);

(c) basically similar peak vertical accelerations from collective inputs, though the subsequent response indicated a greater degree of pitch instability in the simulator;

(d) stronger coupling of yaw response from the collective input in the simulator, due to the assumption of constant rotor speed.

3.1.2 Lateral comparison

There is substantially more disagreement in the lateral comparison than in the longitudinal match. In particular, the tail rotor values for trim (Fig.9) are markedly different. In the simulator, the tail rotor thrust for a given angle was assumed independent of forward speed (at zero sideslip) and, initially, no static yawing moments due to the body were included (the fin moments were incorporated in the tail rotor representation as the wind tunnel tests of Ref.6 tested the fin and tail rotor in combination). Thus the tail rotor trim curve would be expected to reflect the shape of the torque trim curve. However, in flight this is not so, and the tail rotor values decrease as forward speed increases, implying that either some torque is being balanced by body moments, or the tail rotor thrust has increased for a given pitch angle (or both). There are a number of possible reasons for this difference, stemming from simulator simplifications or omissions:

(a) By flying with sideslip, some of the torque could be balanced by the yawing moment due to sideslip. The contribution from this source is likely to be small, as large sideslip angles would be required to provide significant torque alleviation, and the pilot would be aware of flying with slip.

(b) At low and moderate forward speeds, downwash from the main rotor flows over the rear fuselage, which in cross-section is a slim ellipse, with its major axis vertical. The rear fuselage thus acts as an aerofoil relative to the downwash, producing 'lift' forces at right angles to the flow, i.e. yawing moments relative to the CG. Tentative calculations were made on the contribution from this source, and were included in the simulation (downwash function $F_d(u)$ in Fig.8), giving the simulator trim curve shown in Fig.9, which still shows marked disagreement with the flight values.

(c) Closer inspection of the wind tunnel data of Ref.6 revealed that this data had been misinterpreted in preparing the simulation and that there is a significant change in tail rotor thrust with increase in forward speed. As speed increases and the main rotor wake moves back, relative flow at the rotor will consist of components in the plane of the disc from both the free stream flow and the downwash, acting so as to reduce the tail rotor angle required, and also a component normal to the plane of the disc from the swirl of the rotor wake which, though small, is also in the favourable direction. Had this dependence on forward speed been included in the simulation, a close match between simulator and flight tail rotor angles would have been obtained, but the omission was only discovered after the simulation.

The movement of lateral cyclic stick with increasing forward speed is in opposite directions in flight and simulator, though the actual angles are small, and a number of approximations were made in the generation of lateral flapping and rotor side force in the simulation.

The torquemeter values for hovering are less in the simulator than in flight; there were simplifications in the simulation (no rotor downwash load on the fuselage, rotor tip loss factor of unity) which reduced the thrust coefficient required for hover, and hence the hover torque.

The response to lateral control inputs is shown in Figs.12 and 13. The roll acceleration produced by lateral cyclic inputs (Fig.12) is similar for flight and simulator, with (as in the pitch response) a small delay in the flight traces, possibly due to the finite time required for flapping response. However, in flight the roll rate reaches a peak and then decays whereas in the simulator the roll rate is maintained near the peak value. A further difference is that in flight there is a delay in the growth of yaw rate. These differences can best be discussed in terms of aircraft stability notation. If there is a delay in the build-up of yaw into the turn, adverse sideslip will be generated which, through the rolling moment due to sideslip ℓ_v, will produce a decrease in rate of roll. As lateral cyclic inputs produce rolling by tilt of the main rotor, and no significant moments in yaw are generated, the yaw delay cannot be caused by adverse control response but implies a reduction in the directional stiffness n_v in flight in comparison with the simulation. This is further suggested by the overswing of yaw rate in flight after a few seconds. An exception is the flight response at 90 kn, where there is an early growth of yaw rate, but where the fall off in roll rate is delayed. However, there is some evidence of a gust disturbance in this run.

Turning to the response to yaw pedal inputs (Fig.13) the initial accelerations induced in both yaw and roll are similar, but the yaw acceleration rapidly decays in the simulator, though not in flight. This is a further indication of too great a value of n_v in the simulation, possibly coupled with too high a value of yaw damping n_r. Because higher yaw rates are achieved in flight, larger sideslip angles are generated, and through ℓ_v the initial roll rate changes to a strong roll into the yaw; the smaller sideslip in the simulator gives a smaller roll reversal.

At the time of the simulation, this increase of n_v in the simulator over flight values was not detected; in fact, pilots complained that the simulator appeared to have LESS directional stiffness and damping than the real helicopter - this is discussed in more detail in section 3.2. Subsequent to the simulation, response comparison has shown the converse to be true, and inspection of the data used has revealed a major error in compilation. The wind tunnel tests of Ref.6 give tail rotor thrust for the fin and tail rotor combined, and the simulation used these combined results. However, in assessing fuselage moments due to sideslip (from Ref.7) data for fuselage and fin was used, showing negligible moments from the fuselage and fin in combination. Thus the directional stiffness due to the fin has been included in both the fuselage effect and the tail rotor equation, i.e. double the fin contribution has been used. The body moment should have consisted of the fuselage less fin, and this would have given a destabilizing contribution and thus a much better fit to the flight responses at the higher speeds where the free stream velocity is sufficient to provide significant moments. At low speed in the simulation, the n_v was derived predominantly from the downwash term, and as this was deduced from tentative calculations the n_v contribution from this source could be too large.

Summarising the lateral comparison, there was a poorer match between simulator and flight than that obtained in the longitudinal comparison, but this was in the major part due to two errors in the simulation data; firstly the omission of the dependence of tail rotor thrust on forward speed, and secondly the omission of the destabilizing fuselage contribution to directional stability. Control powers appeared approximately correct, and the lag in cyclic response due to finite flapping time was again detectable in flight traces.

3.2 Assessment of the simulation - pilots' comments

The ultimate test of the validity of a simulation lies in pilot assessment - are the handling qualities realistically presented to the pilot? Because this simulation was the first attempt at simulating helicopter handling qualities, pilots with a wide background of training and experience were used for evaluation. Thirty-six pilots flew the simulator; of these, 12 were familiar with the Wessex.

This section has been compiled from comments made by the pilots during the simulation trials. One pilot later produced a report on the simulation; this has been given in full in Appendix C.

Although the cockpit was not representative of a Wessex, pilots generally accepted this limitation and were able to concentrate on the handling features of the simulation. Minor criticisms concerned the closeness of the flight instruments and incorrect position of the stick with respect to the seat. Though instrumentation was limited, there were sufficient flight instruments to permit instrument flying. The pressure instruments were criticised for lacking the continual fluctuations characteristic of helicopter instrumentation. The cyclic control was satisfactory, and well balanced with trim forces removed. The collective lever was well positioned, and smooth in operation with the friction clamp loosened; with friction applied small movements became a little jerky. Yaw pedal feel forces were supplied by a pedal damper; there was some lost motion between the pedals and the damper, and for small movements the pilots criticised the pedal action as being loose and light, giving rise to some control difficulties in yaw.

The television visual display was a source of comment and criticism for a number of reasons. The limited field of view, closeness of the picture and lack of definition of the displayed world were mentioned. Near the hover, there were insufficient cues of height or rate of descent to give realistic vertical control. It was also sometimes difficult to distinguish descent from rearward flight. A further complication was that lost motion and friction in the drive of the television belt produced a dead space on reversal of direction of motion along the belt, and a change of direction was often not detectable visually until a few knots of ground speed had been achieved; accurate speed control at the hover was therefore somewhat difficult. Towards the end of the simulation the television display was supplemented by the shadow horizon presentation shown in Fig.5; pilots felt that this improved the assessment of pitch and roll attitude.

The cockpit motion was universally appreciated. "Without motion it is a non-aircraft" - "I feel that I am sitting still with the world moving beneath me". With motion the handling behaviour of the simulator was thought similar to that of the real Wessex in pitch and roll in both stabilized and unstabilized flight, but in the absence of motion the instability of the unstabilized aircraft appeared to be accentuated. "Only the motion enables me to fly this aircraft in the unstabilized mode."

The simulated rotor flicker and vibration were considered to be useful contributions to the realism of the simulation. The lack of simulation of an undercarriage produced an unrealistic feeling at lift-off; there was no initial movement against the oleos to give warning of how the helicopter was going to move when off the ground. Unfortunately, limits of computational capacity prevented representation of the undercarriage.

Turning to the specific handling behaviour, there was little criticism of the representation of handling in pitch and roll, and what criticism there was was not consistent among pilots. However, the incorrect movement of the lateral cyclic for trim as speed increased was noticed. The yaw behaviour, however, attracted adverse, and consistent, comment. The incorrect pedal position for trim was obtrusive, and the reduced rolling response from pedal inputs was mentioned - in real life one is able to perform banked turns on pedals alone by using this coupling, but in the simulator this was not possible. The opinion also predominated that control in yaw was looser than in real life and that the simulated Wessex possessed a little less directional stability and yaw damping. This is particularly significant when one remembers that the time-histories of pedal response in flight and simulator show the real Wessex to have greater response and less directional stability or damping, and is discussed further in the next section.

A further deficiency receiving consistent criticism was the difficulty found in assessment and control of height near the hover. The television display was blamed for much of the difficulty - "Once off the ground the major problem was height judgement due to the poor visual cues" - and pilots suggested that peripheral vision might be required, or that improved picture quality would ease the assessment of height. Control of rate of descent was harder than in real life - "It is difficult to know when you have stopped moving" - and as a result overcontrolling with the collective often occurred when trying to establish a hover, a significant rate of ascent or descent being achieved before the pilot was aware of having passed through the hover. Pilots frequently had to resort to use of the radio altimeter presentation as a further source of fine height cues.

4 DISCUSSION

In discussion of the results of the simulation it is again convenient to consider separately points concerning the mathematical model of the Wessex, and features relating to the pilot-in-the-loop aspects of the simulation.

4.1 The mathematical model

Here the aim of the simulation was to discover whether the Wessex could be adequately represented within the limited computational capacity of the Aerodynamics Flight simulator. It is worth quoting here from a paper[9] which described a simulation of the CH-46 twin-rotor helicopter on a 950-amplifier computer: "Considerable manpower and effort ... and a constant struggle to remain within the limits of computer capacity and motion base travel were required to obtain a useful simulation".

For the Wessex simulation, only 200 amplifiers were available, which imposed the inevitable constraints on the scope of the simulation (constant rotor rev/min, no extremes of manoeuvre, avoidance of zero airspeed, simplifications in many equations). There were a number of discrepancies between the Wessex model and the real Wessex in terms of comparison of trim and control response data, but the majority of these can be attributed to error or omissions in the compilation of simulator data, and not to limitations imposed by the computer capacity; in particular, errors in the representation of fin and tail rotor caused significant disagreement between simulator and flight response. An improvement in the representation of yawing effects from collective changes could be achieved by representing (in the yawing equation) rotor speed control as a first-order system, and improved (though probably not significant) changes in the cyclic pitch responses could be obtained by assuming flapping motions to be of first order rather than quasi-static - both changes could be incorporated without adding significantly to the computational complexity. Thus the capacity of the Aerodynamics Flight computer seems to be adequate for the representation of normal handling behaviour of a helicopter.

4.2 The piloted simulation

Ignoring the deficiencies due to faults in the mathematical model, which have their own solution, there were two major aspects in which handling of the Wessex was not adequately represented. Firstly, the simulator appeared to the pilots to have less directional stability or yaw damping than the real Wessex, though the response time-histories showed the converse to be true. This false impression of the simulator response might be attributed in part to the lack of damping of the yaw pedals for small movements, or to false visual impressions received due to the restricted field of view of the television display, but in the opinion of the authors is most likely to be due to the lack of cockpit yaw motion in the simulation. In this simulation, and in previous ones, lack of motion in pitch or roll has led to criticisms of reduced damping in those axes; one can easily envisage that the lack of yaw motion would produce a similar impression in that axis. Because it was felt that yaw cues were necessary to improve the pilots' opinions of the simulation, efforts were made, without success, to improve the unsatisfactory mechanical features of the cockpit yaw motion. It is hoped to perform further helicopter research on this simulator in the near future, for which the yaw motion should be in a useable condition, and the significance of the yaw cues on opinions of handling behaviour will be investigated.

Secondly, there was the difficulty in control and assessment of height near the hover. The pilots generally laid the blame for this inadequacy on the visual display - poor resolution of the television picture, lack of ground detail, restricted field of view, etc. While the cues available from the television display are much reduced compared with real flight, it is the authors' opinion that once more the motion (or lack of it) is of greatest significance. Motion is a source of acceleration cues for the pilot; the visual display provides rate and positional information. Thus the pilot's first indication of the helicopter's reaction to a control input will be through the motion cues he receives; these will be supplemented subsequently by the visual cues of rate and position. It is the authors' hypothesis that, given real life motion cues but degraded visual cues (poor quality visual cues, not false ones), the information received from the motion will assist in the interpretation of the poor visual cues, whereas no matter how good visual cues are, in the absence of motion some phase advanced information will be lost and poorer control will result. In this simulation, this hypothesis could not be put to formal test, as the available vertical motion is so limited compared with real life. Some support was obtained in two brief trials at the end of the simulation, however, when the television monitor display was replaced by a projected display. The television projector on the gantry at the rear of the cockpit motion system (Fig.4a) was used to produce a picture on a screen mounted on the front of the cockpit. As the pitch axis of motion then lay between projector and screen, this axis of motion could not be used; the pitch axis was locked, and pitching cues were achieved by driving the heave axis with a signal proportional to pitch attitude, so that collective inputs near the hover, which produce little pitch attitude change, provided no heave cues. The pilots immediately commented on the loss of even the relatively small amount of heave normally available, and on the adverse effect on height control.

It is significant that height control became a significant problem only near the hover. At speed the collective lever is in general more of a trimming device than a continuous control, and short-term height control is achieved by pitch attitude changes as much as (if not more than) by collective lever inputs. In the simulator these pitching motions provided information about flight path changes at speed; only near the hover, where tight and independent control of vertical motion was required, did the deficiencies of motion and visual display intrude.

4.3 Future simulation of helicopters

This simulation served as a preliminary to the subsequent simulation of the Westland Lynx, and was intended to assess the limitations of a helicopter simulation so that sensible interpretation of the results of the Lynx simulation would be possible. Most of the deficiencies of the mathematical model of the Wessex were due to errors in preparation, and should not have had any bearing on the Lynx simulation. The representation of the Lynx was to be of similar, though more detailed, form, with flapping included as a first-order motion and a more detailed tail rotor representation was to be used. One model deficiency was, however, carried across to the Lynx exercise and only discovered subsequently to that simulation; this was the false coupling introduced into yawing motion due to torque changes incurred by the assumption of constant rotor speed in the simulation.

As far as pilot-in-the-loop activities were concerned, the Wessex simulation gave confidence in the representation of pitch and roll behaviour, but suggested that care would be needed in the interpretation of any problems encountered in height control near hovering flight and in yaw control, as motion and visual cues appeared to be inadequate for these aspects of control of the helicopter.

5 CONCLUSIONS

A piloted flight simulation of the Westland Wessex has been performed to evaluate the limitation of a simplified mathematical representation of the helicopter and the validity of the simulation environment for the representation and investigation of helicopter handling behaviour. Deficiencies of both the model and the environment have been discussed, and their influence on the representation of handling features has been considered, as a preliminary to a subsequent simulation of the Westland Lynx. In general, the mathematical representation was found adequate for simulation of flight behaviour. The importance of cockpit motion for handling work was highlighted, and in particular the small heave travel available and the absence of yaw motion were found to influence pilot opinion. The results of this simulation gave a measure of confidence for the Lynx simulation, and identified the areas where caution was to be exercised in interpretation of the results of that simulation.

Appendix A

DATA AND EQUATIONS

A.1 Simulation equations

Four right-handed orthogonal axis systems were defined:

(i) Earth axes; origin fixed on the earth's surface, z-axis downwards and perpendicular to the earth's surface, x-axis pointing north. (Subscript e is used for quantities resolved into earth axis components.)

(ii) Body axes; origin at the helicopter CG, x- and z-axis in the plane of symmetry of the fuselage, z-axis directed away from the rotor and parallel to the rotor shaft (no subscript).

(iii) Shaft axes; origin at the rotor hub, axes parallel to the corresponding body axes (subscript s).

(iv) No-feathering axes; origin at the rotor hub, z-axis directed towards the fuselage along the axis of no feathering, x-axis chosen to give no y-component of velocity relative to the free-stream air (the free-stream air to include the air motion from turbulence and steady winds). (Subscript w).

Forces and moments due to the rotor were generated in the standard coefficient form (e.g. Ref.4) and involved the usual simplifying assumptions made in stability work (described in Ref.4). Additional simplifications were made; in particular, constant rotor rev/min was assumed, and fore-and-aft variation of downwash was ignored completely. In many axis transformations and resolutions, minor terms have been neglected and small angle approximations used. The full equations used are listed below and illustrated in block diagram form in Fig.8. The values of constants used in the equations are given in Table 1.

Assuming a quasi-static representation of coning and flapping, flapping angles relative to the no-feathering axis system were derived from

$$a_{1w} = \mu\left(\frac{8}{3}\theta_0 + 2\lambda_w\right) + \frac{p_w}{\Omega} - \frac{16}{\gamma\Omega}q_w$$

$$b_{1w} = \frac{\gamma\mu}{6}\left[\theta_0(1+\mu^2) + \frac{4}{3}\lambda_w\right] - \frac{q_w}{\Omega} - \frac{16}{\gamma\Omega}p_w \quad .$$

From these, flapping angles relative to the shaft were

$$a_{1s} = a_{1w} \cos \varepsilon + b_{1w} \sin \varepsilon - B_1$$

$$b_{1s} = b_{1w} \cos \varepsilon - a_{1w} \sin \varepsilon + A_1 \quad .$$

Rotor forces and moments were generated in shaft axes from

force coefficients

$$\left(\frac{2C_H}{aS}\right)_s = \frac{\delta}{2a} \frac{u_s}{\Omega R} + a_{1s} \left(\frac{2C_T}{aS}\right)_s$$

$$\left(\frac{2C_Y}{aS}\right)_s = b_{1s} \left(\frac{2C_T}{aS}\right)_s$$

$$\left(\frac{2C_T}{aS}\right)_s = \theta_0 \left(\frac{1}{3} + \frac{\mu^2}{2}\right) + \frac{\lambda_w}{2} + \frac{\mu}{4} \frac{p_w}{\Omega}$$

forces

$$X_s = -\tfrac{1}{2}\rho\pi R^2 (\Omega R)^2 aS \left(\frac{2C_H}{aS}\right)_s$$

$$Y_s = \tfrac{1}{2}\rho\pi R^2 (\Omega R)^2 aS \left(\frac{2C_Y}{aS}\right)_s$$

$$Z_s = -\tfrac{1}{2}\rho\pi R^2 (\Omega R)^2 aS \left(\frac{2C_T}{aS}\right)_s$$

torque coefficient

$$\left(\frac{2C_Q}{aS}\right)_s = \frac{\delta}{4a} (1 + \mu^2) - \lambda_w \left(\frac{2C_T}{aS}\right)_s$$

moments

$$L_s = \frac{b}{2} eRI_1 \Omega^2 b_{1s}$$

$$M_s = \frac{b}{2} eRI_1 \Omega^2 a_{1s}$$

$$N_s = Q_s = \tfrac{1}{2}\rho\pi R^3 (\Omega R)^2 aS \left(\frac{2C_Q}{aS}\right)_s$$

blade drag coefficient

$$\delta = \delta_0 + \delta_2 \left(\frac{2C_T}{aS}\right)^2$$

and were then transformed into body axes

$$X_{rotor} = X_s$$

$$Y_{rotor} = Y_s$$

$$Z_{rotor} = Z_s$$

$$L_{rotor} = L_s + Y_s h_R$$

$$M_{rotor} = M_s - X_s h_R + Z_s \ell_R$$

$$N_{rotor} = N_s - Y_s \ell_R \ .$$

Complete forces and moments:

$$X = X_{rotor} + X_{tail\ rotor} + X_{body}$$

and similarly for Y, Z, L, M, N where tail rotor and body contributions are described in section A.3.

Equations of motion in body axes:

$$\dot{u}' = -(w'q - v'r) + \frac{X}{m} - g\theta$$

$$\dot{v}' = -(u'r - w'p) + \frac{Y}{m} + g\phi$$

$$\dot{w}' = -(v'p - u'q) + \frac{Z}{m} + g$$

$$I_{xx}\dot{p} = (I_{yy} - I_{zz})qr + I_{xz}\dot{r} + L$$

$$I_{yy}\dot{q} = (I_{zz} - I_{xx})rp + M$$

$$I_{zz}\dot{r} = (I_{xx} - I_{yy})pq + I_{xz}\dot{p} + N$$

where u', v' and w' are velocity components of the body with respect to an inertial frame of reference.

From these equations the Euler angles ψ, θ, ϕ were evaluated from

$$\dot{\psi} = r \cos \phi + q \sin \phi$$

$$\dot{\theta} = q \cos \phi - r \sin \phi$$

$$\dot{\phi} = p + \dot{\psi}\theta$$

and hence the helicopter velocity components in earth axes

$$\dot{x}_e = u' - v'\psi + w'\theta$$

$$\dot{y}_e = u'\psi + v' - w'\phi$$

$$\dot{h}_e = u'\theta - v'\phi - w' \quad .$$

Atmospheric movement was represented by a steady wind having earth axis components U_e and V_e, and a turbulence component with zero mean velocity having components u_{Te}, v_{Te}, w_{Te}.

Resolving this air movement into body axes gave, approximately

$$\Delta u = U_e + V_e\psi + u_{Te}$$

$$\Delta v = - U_e\psi + V_e + v_{Te}$$

$$\Delta w = U_e\theta - V_e\phi + w_{Te} \quad .$$

The aircraft velocity components relative to the free-stream air (including the air motion due to the steady and turbulent wind components) were

$$u = u' + \Delta u$$

$$v = v' + \Delta v$$

$$w = w' + \Delta w \quad .$$

In shaft axes:

$$u_s = u - qh_R$$

$$v_s = v + ph_R$$

$$w_s = w \quad .$$

Resolving into no-feathering axes

$$u_w = \sqrt{u_s^2 + v_s^2}$$

$$w_w = w_s - B_1 u_s - A_1 v_s$$

and v_w, by definition, is zero, giving the orientation angle ε as

$$\sin \varepsilon = \frac{v_s}{\sqrt{u_s^2 + v_s^2}} ,$$

$\cos \varepsilon$ being generated as $\sqrt{1 - \sin^2 \varepsilon}$.

From these were generated

advance ratio $\mu = \frac{u_w}{\Omega R}$

inflow ratio $\lambda_w = \frac{w_w + w_i}{\Omega R}$

rotor induced velocity $w_i = -\frac{\Omega RaS}{4} \frac{\left(\frac{2C_T}{aS}\right)_s}{\sqrt{\mu^2 + \lambda_w^2}}$

wake angle, χ, from $\sin \chi = \frac{\mu}{\sqrt{\mu^2 + \lambda_w^2}}$

rates of rotation in no-feathering axes

$$p_w = p \cos \varepsilon + q \sin \varepsilon$$

$$q_w = q \cos \varepsilon - p \sin \varepsilon \quad .$$

A.2 Controls

Pilot's control movements A_{1p}, B_{1p}, θ_{Bp}, θ_{Tp} were augmented by autostabilizer commands and a linkage from collective to lateral cyclic to give total control demands of

$$A_1' = A_{1p} - k\theta_{Bp} + \left[\left(\frac{0.373}{1 + 2.1s}\right)A_{1p} - 0.11(1 + s)\phi\right]_{a/s}$$

$$B_1' = B_{1p} + \left[0.52B_{1p} + 0.25(1 + 0.56s)\theta\right]_{a/s}$$

$$\theta_0 = \theta_{Bp} - \vartheta - kQ_s$$

$$\theta_T = \theta_{Tp} + \left[0.25(1 + 12.1s)\psi' + \frac{7.9s}{1 + 2s}\theta_{Bp}\right]_{a/s}$$

where $[\ ]_{a/s}$ terms were only present when the particular channel was engaged. Pitch and roll channels were engaged by a switch at the control desk, on demand of the pilot. When these were engaged, the tail rotor term ('heading hold') could be selected by the pilot through a two-way rocker switch on the cyclic stick grip. This differed from the system in the actual helicopter where heading hold, when demanded, is controlled by contacts on the yaw pedals which engage heading hold whenever the pilot's feet are off the pedals. The heading hold control law used was incorrect, but in fact was very little used during the simulation.

A mixing angle of 7½ degrees on the cyclic controls gave

$$A_1 = A_1' \cos 7\tfrac{1}{2}^\circ - B_1' \sin 7\tfrac{1}{2}^\circ$$

$$B_1 = B_1' \cos 7\tfrac{1}{2}^\circ + A_1' \sin 7\tfrac{1}{2}^\circ \ .$$

A.3 Forces and moments due to tail rotor and body

A much simplified representation of tail rotor and fin (derived from the tests of Ref.6) being limited to a force component along the Y-body axis of

$$Y_{\text{tail rotor}} = K_1\theta_T - (K_2 + K_3\mu)(v - \ell_T r)$$

$$S_{\text{tail rotor}} = Z_{\text{tail rotor}} = 0$$

and $Y_{\text{tail rotor}}$ has moments about the CG of

$$L_{\text{tail rotor}} = h_T Y_{\text{tail rotor}}$$

$$M_{\text{tail rotor}} = 0$$

$$N_{\text{tail rotor}} = -\ell_T Y_{\text{tail rotor}} \ .$$

Body forces and moments were changed in part during the simulation, as a result of flight-simulator comparisons.

Body drag (in body axes) was of the form

$$X_{body} = -k_1u^2 \quad .$$

Side force was initially

$$Y_{body} = -k_2uv$$

but later changed to

$$Y_{body} = -k_2uv + k_3ur - k_4F_d(u)(v - k_5r)$$

where the value of k_2 differed from that previously, and $F_d(u)$ is a function of u as shown in Fig.8.

The download due to downwash and vertical velocity, Z_{body}, was ignored, as was the rolling moment, L_{body}.

The pitching moment from body and tailplane, M_{body}, was generated as

$$M_{body} = -k_6u^2 - k_7uw + k_8f^2(\chi)w_i^2 - k_9qu$$

where $f^2(\chi)$ is the function of downwash angle shown in Fig.8.

For yawing moment

$$N_{body} = -k_{10}ur$$

was originally used, but was later changed to

$$N_{body} = -k_{10}ur + k_{11}F_d(u)(v - k_5r - k_{12}) \quad .$$

A.4 Westland Wessex HC Mk.2 - leading particulars

Weight (as simulated)	5783 kg
Main rotor diameter	17.07 m
Length overall	20.07 m
Height overall	4.93 m

Max level speed at sea level at 6123 kg AUW, 115 kn (212 km/h)

Engines: two coupled 1350shp Rolls-Royce Bristol Gnome Mk.110/111 shaft turbines.

Appendix B

MOTION DRIVE EQUATIONS

The aim of the motion drive equations is to give the pilot an impression of vehicle motion as closely related as possible to that which he would receive in real life, as he relies to a considerable extent on the motion cues received for control of an aircraft, particularly when the vehicle's stability is poor. The philosophy evolved at RAE Bedford for the form of the drive equations is outlined briefly below; further explanation is given in Ref.8. A similar form of drive laws is used in many other research and training simulators.

Motion cues are derived from a number of sources; one major source is the motion sensing apparatus of the inner ear (vestibular cues). The remaining sources are usually classed as kinaesthetic - the sensing of strain or movement in muscles, tendons and joints, pressures on the body surface, internal pressures due to displacement of organs under g conditions, etc. (though the term kinaesthetic is sometimes used to describe all motion cues, including vestibular ones).

Devices such as inflatable seat cushions, g-suits and servo-driven harness straps can be used to derive some of the cues due to pressures on the body surface; in the absence of these all motion sensations will be derived from simulator motion and some partial duplication of real life motion is required.

For the Wessex simulation, four axes of motion (pitch, roll, heave, yaw) were available.

(a) Pitch motion

This axis can be used in two ways; firstly, rotation in pitch can be used to simulate rotation of the real aircraft in pitch, and secondly, as rotation in pitch provides a fore-aft component of gravitational acceleration relative to the pilot, it can be used for simulation of longitudinal acceleration of the aircraft. However, it is impossible to provide one of these cues without inducing the other; if one pitches the cockpit to simulate pitch motion, a false fore-aft acceleration cue is obtained, and if cockpit tilt is used to represent fore-aft acceleration, pitching will be felt as the tilt is achieved. A compromise is reached by using pitch motion primarily as a source of pitching cues, but with the motion law 'washed-out' so that the cockpit tends to return to a level attitude, avoiding the spurious fore-aft acceleration. A secondary term provides a fore-aft cue for sustained accelerations, but this term is lagged so that the cockpit tilt is taken up slowly and the false rotational cues are minimised. Thus a drive law of the form (in Laplace notation)

$$\theta_{c/p} = K_1 \left(\frac{\tau_1 s}{1 + \tau_1 s}\right) \theta + K_2 \left(\frac{1}{1 + \tau_2 s}\right) \frac{\Sigma X}{mg} \tag{B-1}$$

is used, where $\theta_{c/p}$ is the pitch attitude of the cockpit, θ the aircraft pitch attitude and ΣX the sum of the forces (excluding gravitation) acting on the aircraft along the X-body axis.

In fact, at the start of the Wessex simulation, this form of motion law had not been tried in the simulator, and a simple law

$$\theta_{c/p} = 0.6\theta$$

was used for all but a few of the simulation trials reported here. The gain of 0.6 between aircraft and cockpit motion was required to keep the simulator travel within available limits.

Near the end of the simulation, a law of the form of equation (B-1) was used with success, with $K_1 = 0.8$, $K_2 = 1$, $\tau_1 = 2$ seconds, $\tau_2 = 1.5$ seconds, and this form of law is now normally used in the Aerodynamics Flight simulator.

Note that it is better to compute the first term as

$$K_1 \left(\frac{\tau_1}{1 + \tau_1 s}\right) q$$

rather than

$$K_1 \left(\frac{\tau_1 s}{1 + \tau_1 s}\right) \theta$$

as the motion is being used to represent a pitching rotation in the plane of symmetry (and q is pitch rate in the plane of symmetry) whereas θ is an earth-reference angle and unsuitable as a source of pitching cues when the aircraft is not near steady level flight conditions. (For example, in inverted flight, use of θ would give pitching cues of opposite sign to those obtained in the real aircraft.)

In addition to those described above, two further terms were fed to the pitch motion. One compensated for the fact that the pitch motion is carried on the heave arm (Fig.4b) and without this compensation the signals fed to the heave axis would also be felt as pitching cues. The other was a mixture of 4Hz and 16Hz sine waves, used to simulate 1/rev and 4/rev rotor vibrations, and attenuated in amplitude to give increased vibration for increased rotor loading.

(b) Roll motion

The reasoning outlined above for pitch motion applies equally to roll motion and a similar form of law was used.

$$\phi_{c/p} = K_3\left(\frac{\tau_3 s}{1 + \tau_3 s}\right)\phi - K_4\left(\frac{1}{1 + \tau_4 s}\right)\frac{\Sigma Y}{mg}$$

with $K_3 = 0.4$, $K_4 = 0.5$, $\tau_3 = 1.5$ seconds, $\tau_4 = 1$ second

where $\phi_{c/p}$ is simulator cockpit roll angle, ϕ is aircraft bank angle, and ΣY is the sum of the forces (excluding gravitation) acting on the helicopter along the Y-body axis. Again, it would be better to use $K_3(\tau_3/(1 + \tau_3 s))p$ instead of the first term, to improve the validity of the law to extreme attitudes.

(c) Yaw motion

This axis differs from pitch and roll in that no reorientation with respect to the gravity vector is involved. However, as in this simulator the pilot sits approximately 1.7 m ahead of the yaw pivot, yaw motion will produce both linear and rotational cues for the pilot (but the two cues are inherently related and inseparable). Yaw motion was not mechanically satisfactory, as explained in the main text, and was tried only briefly, with a law which considered the axis as a source of yawing cues:

$$\psi_{c/p} = K_5\left(\frac{\tau_5 s}{1 + \tau_5 s}\right)\psi$$

where $\psi_{c/p}$ is simulator cockpit yaw angle and ψ is the helicopter heading angle, $K_5 = 0.3$ and $\tau_5 = 3$ seconds.

(d) Heave motion

In this axis the cockpit motion is inevitably a much 'watered-down' simulation of the real-life motion. The pilot senses linear acceleration so, ideally, one would like to have

$$\ddot{h}_{c/p} = -\left(\frac{\Sigma Z + mg}{m}\right)$$

where $h_{c/p}$ is cockpit linear travel in heave, and ΣZ is the sum of the forces (excluding gravity) acting on the body along the Z-body axis.

Now it is possible for the helicopter to sustain a non-zero value of $(\Sigma Z + mg)$ - in a steady turn, for example - and in order that the cockpit motion should stay within available travel, it is necessary to 'washout' the signal to the cockpit; a second-order washout is in fact required so that cockpit displacement is finite. Thus

$$\ddot{h}_{c/p} = -K_6\left(\frac{\tau_6 s}{1 + \tau_6 s}\right)\left(\frac{\tau_7 s}{1 + \tau_7 s}\right)\left(\frac{\Sigma Z + mg}{m}\right)$$

i.e.

$$h_{c/p} = -K_6\left(\frac{\tau_6}{1 + \tau_6 s}\right)\left(\frac{\tau_7}{1 + \tau_7 s}\right)\left(\frac{\Sigma Z + mg}{m}\right)$$

is used. Note that the effective gain of the cues the pilot feels approaches K_6 as frequency approaches infinity, i.e. the maximum cue gain is K_6. Thus one would like the value of K_6 to be as close to 1 as possible. However, if one assumes a maximum value for the simulated aircraft for the function $((\Sigma Z + mg)/m)$, and one is faced with an available maximum for $h_{c/p}$, it can be seen that there is an upper limit to the value of $K_6.\tau_6.\tau_7$. So, as K_6 is increased, the 'washout' occurs more rapidly; apparently, one is faced with the choice of either a cue of high gain but sustained for a short time only, or a lower gain cue of longer duration. Fig.14 shows that this is not so. In the Wessex simulation, values of $K_6 = 1$, $\tau_6 = 0.2$ second, $\tau_7 = 0.5$ second were used, the limiting value of $K_6.\tau_6.\tau_7$ being 0.1. The cue gain as a function of frequency is shown in Fig.14. If a longer washout is used, e.g. $\tau_6 = 1.0$ second instead of 0.2 second, and $K_6.\tau_6.\tau_7$ is still limited to 0.1, no benefit in gain is obtained; in fact some loss of gain has occurred at high frequency. The left-hand end of the gain plot is fixed by the $K_6.\tau_6.\tau_7 = 0.1$ requirement, and variation of washout time constant affects only the gain at high frequencies. Time constants should therefore be chosen to keep the gain close to unity over as wide a frequency band as possible.

In addition to this heave cue, rotor vibration as fed to pitch was fed also to the heave motion, with a gain proportional to forward speed giving an increase in the vibration level with increase of speed.

Appendix C

REPORT ON AERODYNAMICS FLIGHT DIVISION WESSEX SIMULATION

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C.1 Introduction

A number of sorties were 'flown' in the Aerodynamics Flight simulator to assess the handling characteristics in comparison with those of a Wessex helicopter. It is not proposed to dwell on the obvious deficiencies of the simulator as such except where these were directly relevant to the handling characteristics.

C.2 Conditions relevant

C.2.1 Wind

A 'built-in' wind of 270/20 was used throughout.

C.2.3 Limitations

Height was limited to 700 ft although the indicated altitude would go above this. Heading was limited to $270^{\circ} \pm 45^{\circ}$.

C.2.3 Pilot's experience

Prior to the commencement of these tests the pilot had a total of 2650 flying hours, of which 2250 were in helicopters and of these approximately 1000 hours were in Wessex of all marks. He had little previous experience of moving base simulators.

C.3 Results of tests

C.3.1 Flying controls

The cyclic stick was of the type used in the Wessex III which has a very poor trimmer button. The feel and range of movement were correct. The collective lever hand grip was normal but the friction was apt to give a dead space round the basic position and a comparatively large break-out force, however this disappeared when the friction was removed. The yaw pedals were rather light and loose in operation.

C.3.2 Cockpit

The cockpit was not representative of a Wessex in shape, size or layout. However, the flying controls were correctly positioned and there were sufficient flight instruments for instrument flying to be carried out. The seat was laterally central within the cockpit.

C.3.3 Television picture

The picture quality was fair to good but only covered the sector directly ahead of the pilot. There was no sideview, which deprived the pilot of some visual cues, especially for vertical movement and hovering close to the ground. For later flights a shadow horizon was introduced covering the peripheral field of view. This assisted in visual assessment of turns but not landing and lift off. In cruise flight this limitation did not affect the handling of the aircraft.

C.3.4 Stabilization

Various combinations of stabilized and unstabilized modes of flight were examined. The basic simulation being of a Wessex II (or I or V) auto-stabilizer (ASE) which could be improved to a similar level to the Wessex III (dual channel in pitch, roll and yaw) or removed as in the Wessex II. The subsequent results were generally obtained with ASE engaged and compared with it disengaged. The real relationship was almost invariably reproduced in the simulation.

C.3.5 Turbulence

Turbulence was simulated and was apparent in all axes. The effect seemed disproportionately high in pitch compared with roll but not to an unacceptable extent.

C.3.6 Take-off

As the lever was raised there was a general absence of motion until after lift-off. For example the feel of the oleos extending was missing. This detracted from the pilot's awareness of the moment of leaving the ground, which came almost entirely by visual appreciation of the picture. However, having done so it was easy to control the upward movement and stabilize in a hover except when there was no friction applied to the lever. In this case over-controlling was almost inevitable and the motion more like a Scout than a Wessex. Once airborne the motion cues were good and despite the feeling of vertical 'lightness' the impression of flying was very real.

C.3.7 Hovering

It was difficult to maintain a hover height below 30 ft because of the pilot's inability to judge accurate heights visually and an inborne reluctance to get too low. Above this height it was easier to hold a reasonably steady height although it was necessary to refer regularly to the radio altimeter to do so. Heading and lateral position were very easy to maintain within narrow limits by normal and realistic control movements, although the yaw pedals did not have the correct Wessex feel. Fore and aft movement, however, was rather more of a problem because of a noticeable delay in pilot reaction to pitch changes. In particular a sudden backward motion occurred a number of times to a degree which would not occur in real life. The 20kn wind required a forward cyclic position which seemed rather unnatural because of the absence of other wind cues (e.g. turbulence) and on some occasions backward motion was almost certainly induced, initially, by an instinctive pilot input when some other facet of the simulator was being examined from the hover. Finally, the basic yaw pedal position was wrong - far too much left pedal being required for any given power setting.

C.3.8 Sideways movement

The sideways movement of the simulator was compared with that remembered from similar movements in a Wessex and the response of the simulator to 'normal' pulse and step inputs was approximately the same. It was considered that the roll damping of the simulator was probably too high but no other major discrepancy was apparent. It was also found that secondary power and yaw effects were substantially correct.

C.3.9 Forward movement at low speed

The acceleration in response to forward cyclic movements was probably slow but the error, if any, was small. Pulse and step inputs produced correct reactions and in particular correct flapback effect showed up well. Heading control was rather poor 'feet off', but adequate 'feet on' although the pedals were sloppy.

C.3.10 Backwards movement

It was always slightly unnerving to move backwards but recovery action to regain the hover was entirely normal. It seemed more difficult to maintain a low speed and steady movement than in a Wessex.

C.3.11 Rotational movement

Although limited to $\pm 45^{\circ}$ of the basic heading (270°) it was possible to assess rotational motion as visually correct but unrealistic as to yaw pedal pressures and movements because of the wrong foot positions and sloppy pedal feel.

C.3.12 Hovering manoeuvres without ASE

All manoeuvres based on the hover were repeated with the ASE disengaged and in general the results were the same as would be expected in a Wessex. Pilot workload was higher and those specific control inputs which were applied all produced correct responses. Particularly the flapback effect was reproduced exactly. Lift-off and landing were rather more erratic than with ASE in and this was attributed to the lack of side cues.

C.3.13 Cruising

The simulator could be cruised easily and accurately and in a realistic manner round the 'outside world'. The attitude/speed correlation was not quite correct - instead of 5^o nose down giving 90kn ias, it gave 74. Although some general vibration was missing sharp cyclic or lever inputs produced a reassuring judder. Heading hold was a variable feast but heading could be controlled satisfactorily by the pilot.

C.3.14 Approach and deceleration to hover

Although judging the approach path to hover over a given point was not as easy as in a Wessex it was sufficiently realistic to be acceptable. In the latter part of the approach the lack of sideview cues began to cause height assessment problems and it was not 'safe' to aim for an initial hover height much below 100 ft. During this manoeuvre the response to control movements was such that no deficiencies were noticed in this respect - the pilot being able to concentrate wholly on the external problem.

C.3.15 Instrument flying

It was not difficult to control the simulator by reference to the instruments and instrument approaches using a standard ILS presentation where possible to a BOH of 200 ft. However, it was noticeable that all the blind flying instruments were extremely 'dead-beat' which, particularly in the case of pressure instruments, is very unreal.

C.3.16 Landing

During the final part of the descent, immediately prior to landing, it was very difficult to judge height. Cross referring between outside the cockpit and the radio altimeter had a rather disorientating effect but without the radio altimeter it was impossible to judge the last 15 ft.

C.4 Discussion of results

C.4.1 Cockpit

The manifold deficiencies of the cockpit *vis-à-vis* a helicopter were considerably more apparent when entering than when flying the simulation. Once the pilot was involved in a task the fact that he was using 'normal' flying controls mostly overshadowed the strangeness of the surroundings.

C.4.2 Television picture

Clearly the quality of the television picture is of considerable importance in achieving as much realism as possible. It is considered that both pictures used were adequate for the job but any improvement in the clarity and sharpness of image would be an advantage.

C.4.3 Auto-stabilization

The ability to simulate combinations of stabilization was not only felt to be good in itself but enabled handling in a single plane to be examined quite carefully. However, a full twin channel system with speed, heading and height hold will be necessary to make a comprehensive study of a Wessex III or WG 13 situation.

C.4.4 Turbulence

The more varied and random turbulence that can be simulated the better will the pilot be able to assess the behaviour of the aircraft being simulated. Whilst the turbulence must be made to affect the simulator in all axes equally it is desirable that the amount can be varied as much as possible.

C.4.5 Take-off

During take-off the general lack of 'life' in the simulator reduced the pilot's awareness of what was happening and it is considered that some random vibration during this phase would be of value in creating an initial impression of 'flying' to the pilot. Once off the ground the only major problem was height judgement which is likely to be insurmountable using only a frontal picture, but this is an acceptable feature for all manoeuvring that is not dependent on a very low hover height.

C.4.6 Hovering

The problem of height holding in the hover is one of simulation and is not considered to invalidate in any way the usefulness of the simulator for this mode of flight although an artificially high hover is necessary for most purposes. The yaw pedal position caused a slight rise in workload to maintain heading and if this was not monitored carefully, particularly during vertical manoeuvres, quite large errors were apparent. It will be necessary to adjust the pedal position to eliminate this. The frequent departures backwards were probably in part due to the lack of sideways cues and in part to the apparently unnatural forward cyclic position. The presence of a constant 20kn wind was not readily apparent and there was a tendency to move the cyclic rearwards to a zero wind hover position which probably caused some of the early rather rapid backward movements. In general it was not possible to pinpoint any serious discrepancies between the simulation and a real Wessex aircraft.

C.4.7 Sideways movement

The sideways movement in the simulator was very realistic. The questionable roll damping did not obtrude during simple manoeuvres and was only apparent when specific inputs were made.

C.4.8 Forward movement at low speed

The acceleration rate depends on many variables and it is possible that the apparent slowness to do so was a faithful reproduction of real aircraft response. However, coupling with this the speed achieved at 5° nose down (74 kn), it may be that the aircraft attitude in the hover into the 'wind' is not quite correct *vis-à-vis* real life which would affect reaction to attitude changes throughout the speed range.

C.4.9 Backwards movement

The difficulties experienced in backwards flight would appear to be largely attributable to the limitations of vision. There was no suggestion of unreal behaviour from a handling or performance point of view.

C.4.10 Rotational movement

The inadequacy of the simulator was particularly relevant to rotational motion but the basic behaviour was normal and it is considered that this is an area where improvements should be easy to make.

C.4.11 Hovering manoeuvres without ASE

The comparison between hovering and manoeuvring with and without ASE corresponded well with the Wessex.

C.4.12 Cruising

The simulator behaved very realistically in the cruise both with and without ASE. The discrepancy of attitude/airspeed with the Wessex was not significant from the handling aspect but it did appear to be relevant to the apparently slow rate of acceleration. However, it must be emphasised that this was a matter of detail rather than one of major importance.

C.4.13 Approach and deceleration to the hover

The simulator 'flew' in an entirely normal manner during the approach and deceleration. Such difficulties as were experienced were relevant to view which was a true representation of the 'over-the-nose' situation but of course the lack of sideview was all-important. This 'over-the-nose' problem must be borne in mind and not dismissed as a simulator problem because many approaches, such as to jungle clearings, must be made where the sideview is of very little help to the pilot.

C.5 Conclusion

It is considered that the Aerodynamics Flight Wessex simulation was a highly successful representation of a Wessex helicopter and, within the limits imposed by the facilities available, there was very little room for further improvements and certainly none of a major nature were required.

Table 1

NUMERICAL DATA

a	$6.1\ rad^{-1}$	k_3	$32.7\ kg\ rad^{-1}$
b	4	k_4	$496\ kg\ s^{-1}$
c	$0.418\ m$	k_5	$6.74\ m\ rad^{-1}$
eR	$0.305\ m$	k_6	$0.563\ kg$
h_R	$2.12\ m$	k_7	$0.355\ kg$
h_T	$0.76\ m$	k_8	$13.7\ kg$
I_1	$280\ kg\ m$	k_9	$471\ kg\ rad^{-1}$
I_2	$1586\ kg\ m^2$	k_{10}	$1054\ kg\ rad^{-1}$
I_{xx}	$9578\ kg\ m^2$	k_{11}	$3336\ N\ s$
I_{yy}	$38688\ kg\ m^2$	k_{12}	$3.5\ m\ s^{-1}$
I_{zz}	$32482\ kg\ m^2$	ℓ_R	$-0.052\ m$
I_{xz}	$-1204\ kg\ m^2$	ℓ_T	$10.2\ m$
K	$3.72 \times 10^{-5}\ deg\ N^{-1}\ m^{-1}$	m	$5783\ kg$
K_1	$352.7\ N\ deg^{-1}$	R	$8.53\ m$
K_2	$67.1\ kg\ s^{-1}$	S	0.0621
K_3	$438\ kg\ s^{-1}$	γ	10.4
k	0.08	δ_0	0.009
k_1	$2.25\ kg\ m^{-1}$	δ_2	1.25
k_2	initially $9.6\ kg\ m^{-1}$	θ	5.5^o
	subsequently $13.4\ kg\ m^{-1}$	ρ	$1.225\ kg\ m^{-3}$

SYMBOLS

A_1, B_1	lateral and longitudinal cyclic pitch inputs, at rotor hub in shaft axes
A_1', B_1'	lateral and longitudinal cyclic pitch inputs, at swash plate
A_{1p}, B_{1p}	lateral and longitudinal cyclic pitch inputs, demanded by pilot
a	blade lift-curve slope
a_{1s}, b_{1s}	longitudinal and lateral flapping angles, relative to shaft
a_{1w}, b_{1w}	longitudinal and lateral flapping angles, relative to axis of no-feathering
b	number of main rotor blades
C_H, C_T, C_Y	rotor fore-aft, thrust and side force coefficients
C_Q	rotor torque coefficient
c	blade chord
eR	flapping hinge offset radius
e	(as subscript) earth axis
$F_d(u)$, $f^2(\chi)$	downwash functions, defined in Fig.8
g	gravitational constant
$h_{c/p}$	vertical displacement of simulator cockpit
h_e	altitude
h_R	height of main rotor hub above CG
h_T	height of tail rotor hub above CG
I_1	mass moment of blade about flapping hinge
I_2	moment of inertia of blade about flapping hinge
I_{xx}, I_{yy}, I_{zz}	moments of inertia in body axis
I_{xz}	product of inertia in body axes
K	pitch-lag coupling factor
K_1, K_2, K_3	constants in the expression for tail rotor force
K_1-K_6	(Appendix B) constants in the motion drive laws
k	cyclic-collective coupling factor
k_1-k_{12}	constants in the expressions for body forces and moments
L, M, N	rolling, pitching and yawing moments, in body axes
L_R, M_R, N_R	rolling, pitching and yawing moments due to the main rotor, in body axes
L_S, M_S, N_S	rolling, pitching and yawing moments due to the main rotor, in shaft axes
L_T, M_T, N_T	rolling, pitching and yawing moments due to the tail rotor, in body axes

SYMBOLS (continued)

ℓ_R	distance of main rotor hub behind CG
ℓ_T	distance of tail rotor hub behind CG
ℓ_v, n_r, n_v	stability derivatives, defined in the main text
m	helicopter mass
p, q, r	roll, pitch, yaw rates, in body axes
p_w, q_w	roll, pitch rates, in no-feathering axes
Q_S	main rotor torque, in shaft axes
R	main rotor radius
S	solidity ratio, $= \frac{bc}{\pi R}$
s	Laplace operator
s	(as subscript) shaft axes
U_e, V_e	steady wind components, earth axes
u, v, w	airspeed components, body axes
Δu, Δv, Δw	wind velocity components, body axes
u', v', w'	aircraft velocity components relative to the ground, body axes
u_s, v_s, w_s	airspeed components, shaft axes
u_w, v_w, w_w	airspeed components, no-feathering axes
u_{Te}, v_{Te}, w_{Te}	turbulence components, earth axes
w	(as subscript) no-feathering axes
w_i	induced velocity
X, Y, Z	force components, in body axes
X_R, Y_R, Z_R	main rotor force components, in body axes
X_s, Y_s, Z_s	main rotor force components, in shaft axes
X_T, Y_T, Z_T	tail rotor force components, in body axes
ΣX, ΣY, ΣZ	(Appendix B) $\equiv$ X, Y, Z
x_e, y_e	helicopter position coordinates, earth axes
γ	Lock's constant $= \frac{\rho a c R^4}{I_2}$
δ	blade drag coefficient
δ_0, δ_2	factors in the expression for δ
ε	orientation angle for no-feathering axis system: defined in Appendix A

SYMBOLS (concluded)

θ	pitch attitude
θ_0	collective pitch angle at 0.75R blade position
θ_{Bp}	collective pitch angle demanded by pilot
$\theta_{c/p}$	pitch angle of simulator cockpit
θ_T	tail rotor pitch angle
$\theta_{T_{a/s}}$	tail rotor pitch angle contribution from auto-stabilizer
θ_{Tp}	tail rotor pitch angle demanded by pilot
ϑ	blade twist angle between blade root and 0.75R
λ_w	inflow ratio
μ	advance ratio
ρ	air density
τ	time constant
τ_1-τ_7	(Appendix B), time constants in the motion drive laws
ϕ	roll attitude
$\phi_{c/p}$	roll angle of simulator cockpit
χ	downwash angle
ψ	yaw angle
ψ'	yaw angle change (in yaw stabilizer)
$\psi_{c/p}$	yaw angle of simulator cockpit
Ω	main rotor angular velocity

REFERENCES

No.	Author	Title, etc.
1	T. Wilcock	A piloted flight simulation of the Westland Lynx. RAE Technical Report in preparation
2	D.H. Perry L.H. Warton C.E. Welbourn	A flight simulator for research into aircraft handling characteristics. ARC R & M 3566 (1966)
3	L.H. Warton	A four degrees of freedom, cockpit motion machine for flight simulation. ARC R & M 3727 (1972)
4	E. Seckel H.C. Curtiss, Jr.	Aerodynamic characteristics of helicopter rotors. Princeton University Department of Aerospace and Mechanical Sciences Report 659 (1963)
5	B. Pitkin	Development of the non-linear longitudinal aerodynamic model for Wessex Mk.3. Part 1 Modifications to the aerodynamic model. Part 2 Definition of the developed model. Aerodynamics Department, Westland Aircraft Ltd., Technical Note AERO/SIM/008 (1965)
6	D.R. Shepherd	Wind tunnel tests of a full scale Wessex tail rotor with various fin blockages. Westland Aircraft Ltd. Report G1184, Part 1 (1966) Part 2 (1967)
7	E. Seckel	Stability and control of airplanes and helicopters. Academic Press (1964)
8	K.J. Staples	Motion, visual and aural cues in piloted flight simulation. RAE Technical Memo. Aero 1196 (ARC 32021) (1970) also AGARD Conference Proceedings 79 on Simulation (1970)
9	B.B. Blake N. Albion R.C. Radford	Flight simulation of the CH-46 helicopter. Paper 361, 25th Annual National Forum of the American Helicopter Society (1969)

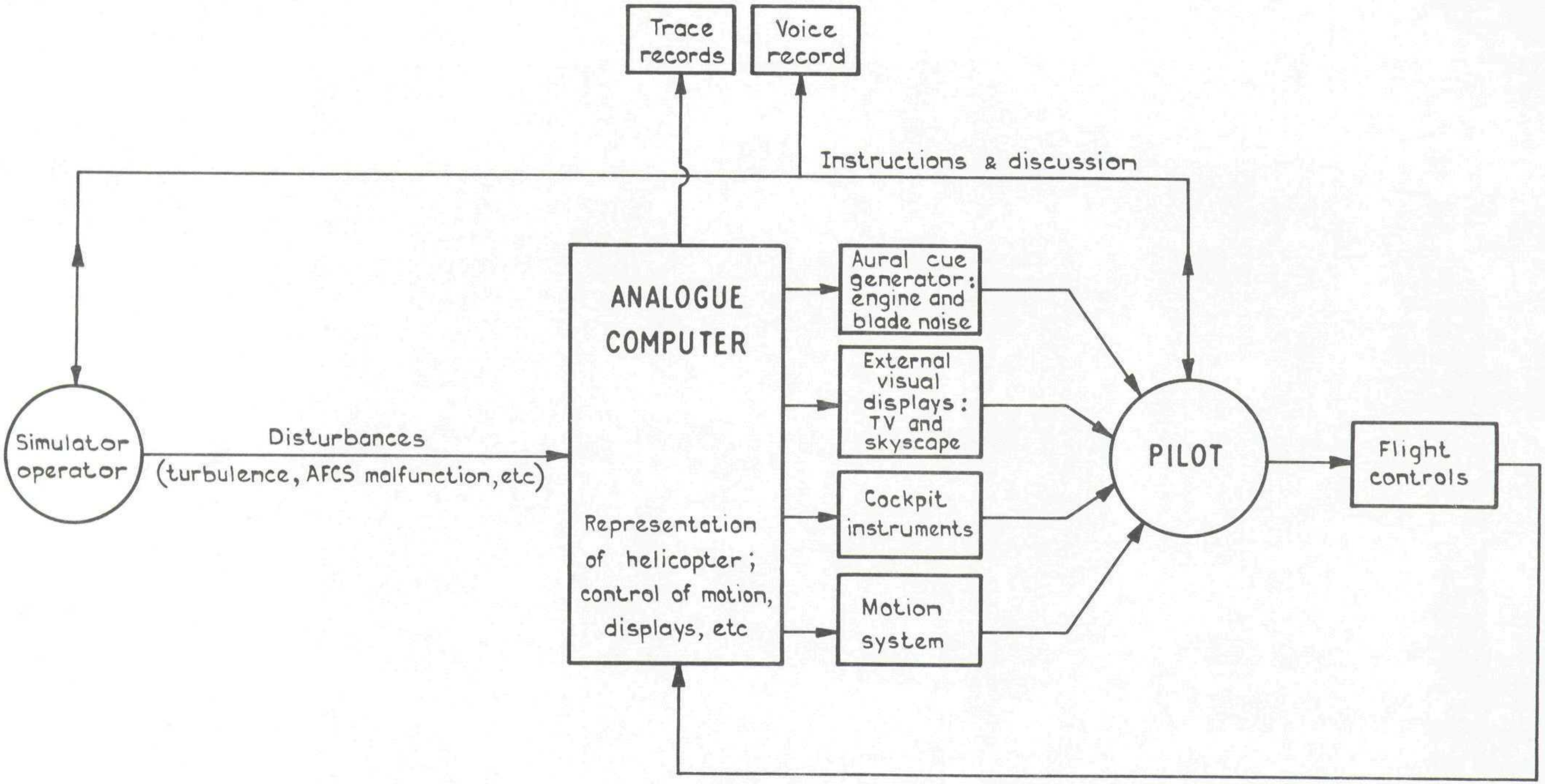


Fig.1 Block diagram of simulator

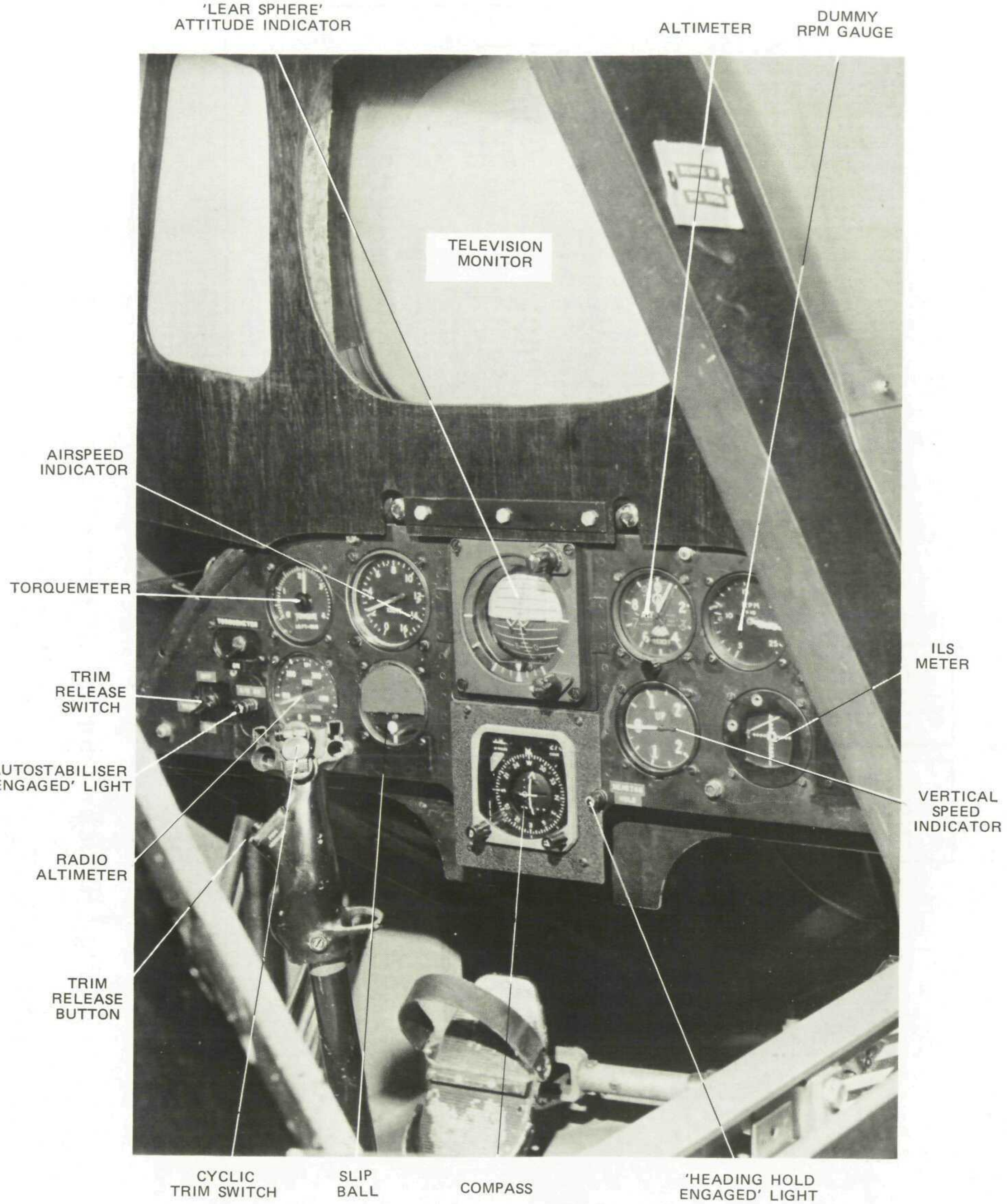


Fig.2 Cockpit interior

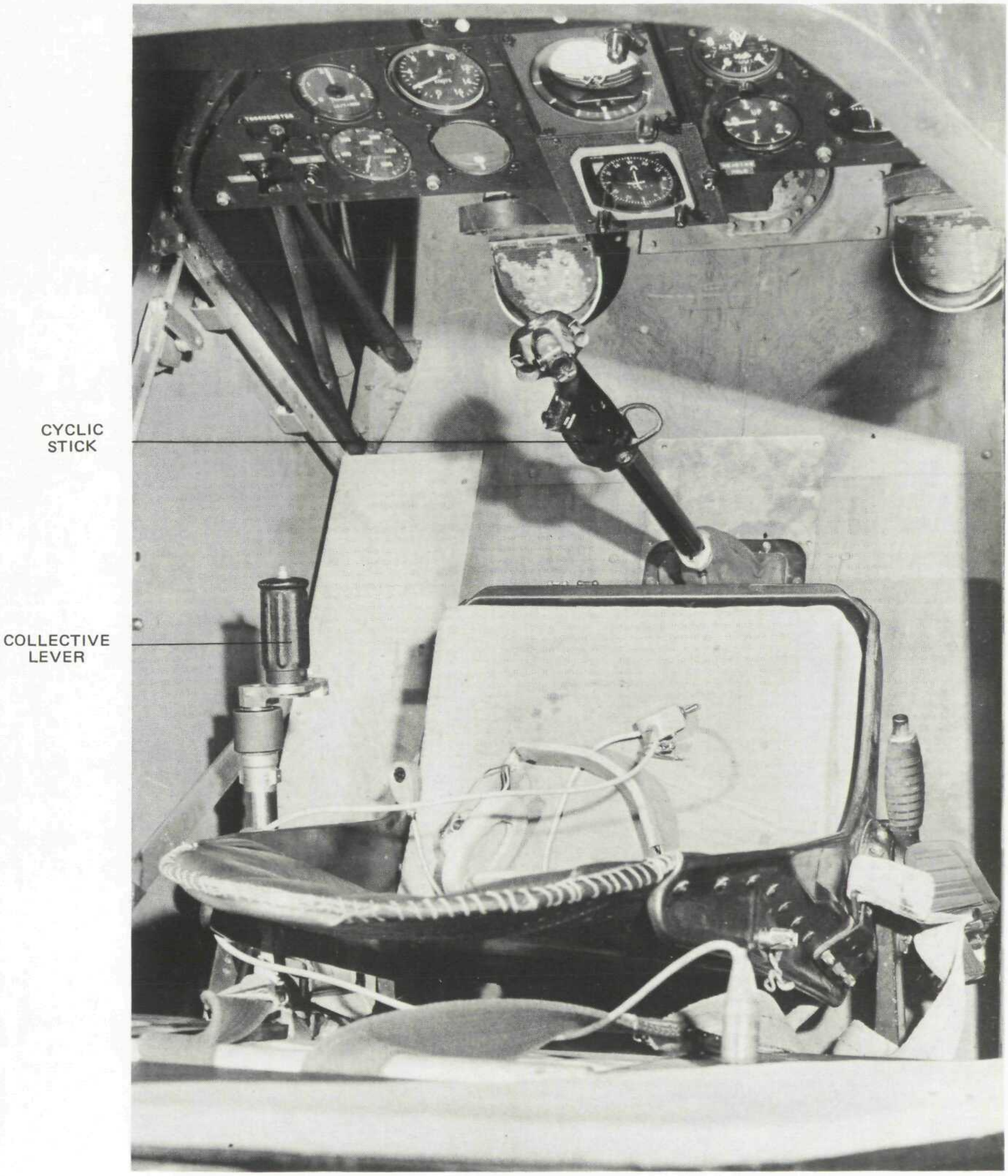
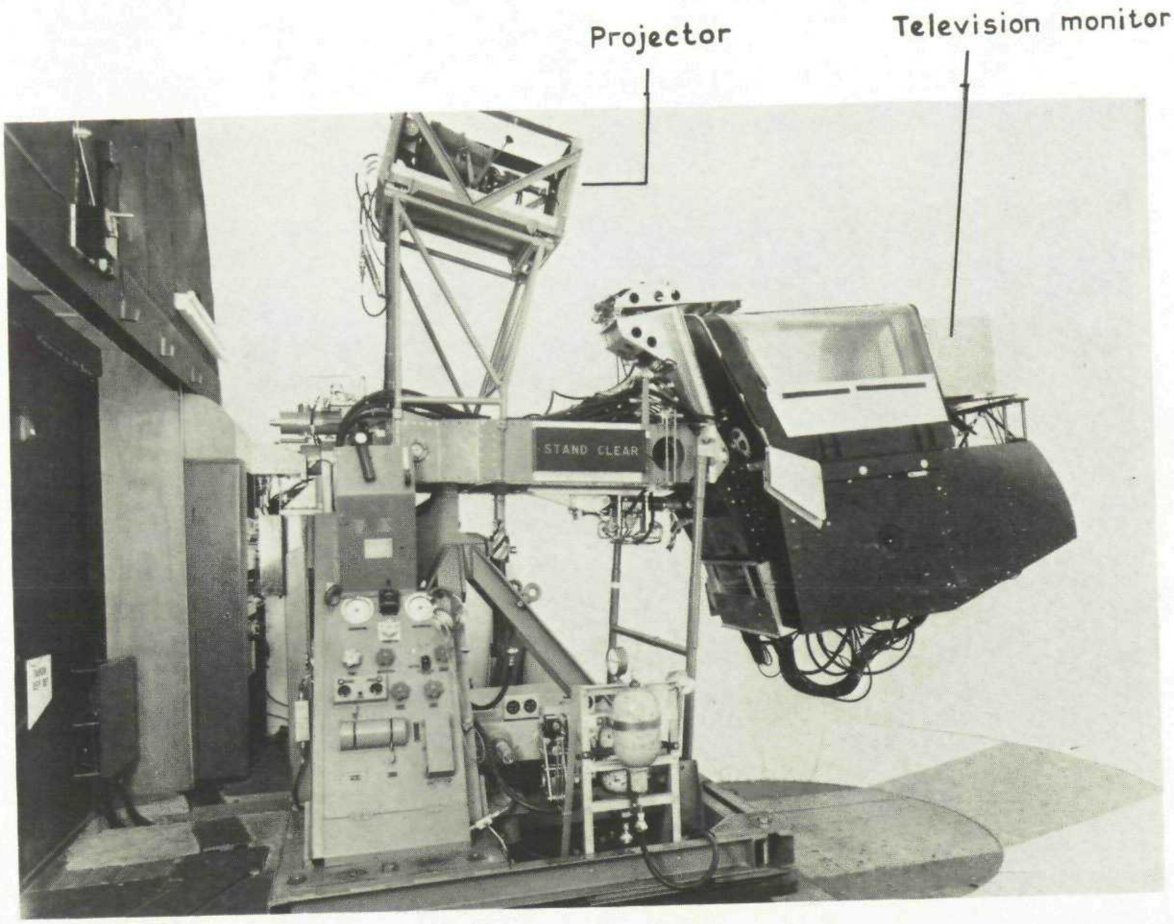
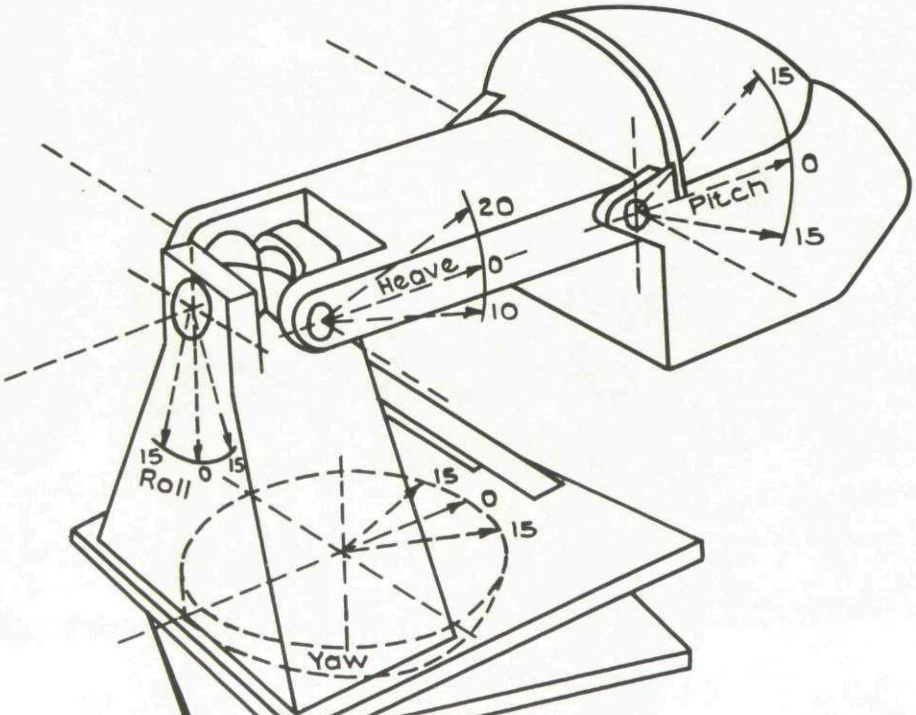


Fig.3 Control layout



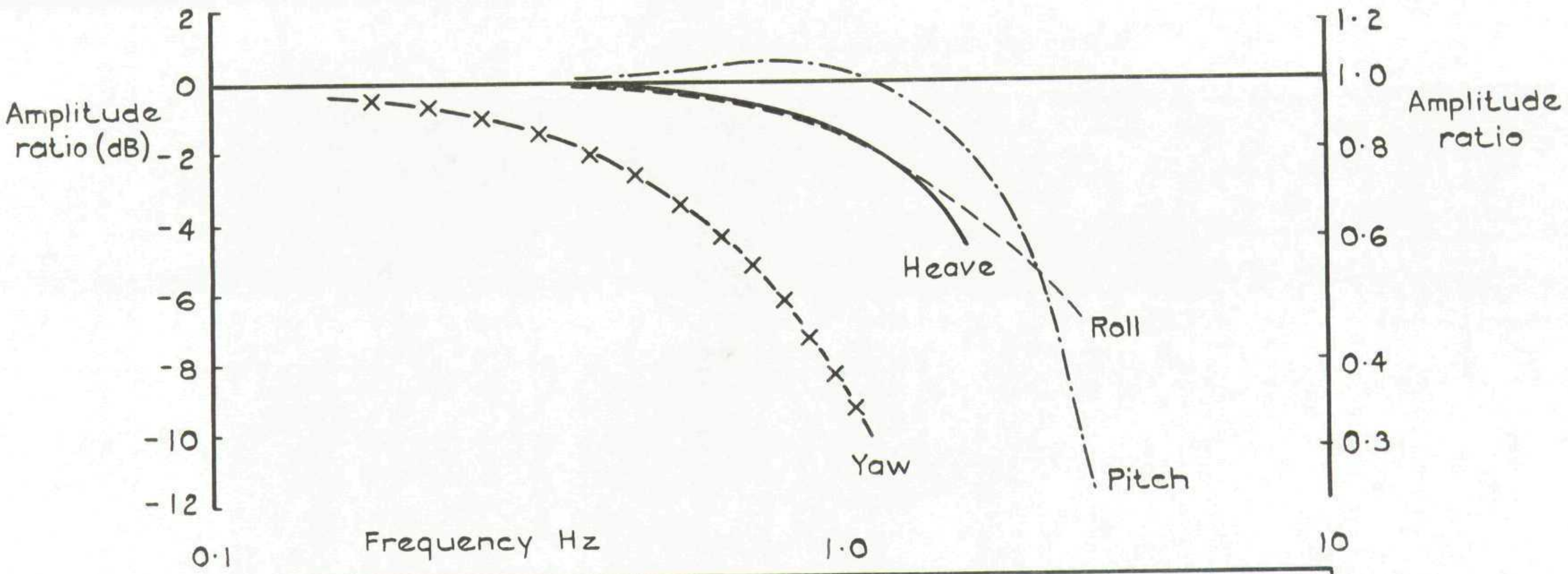
a Cockpit with TV monitor

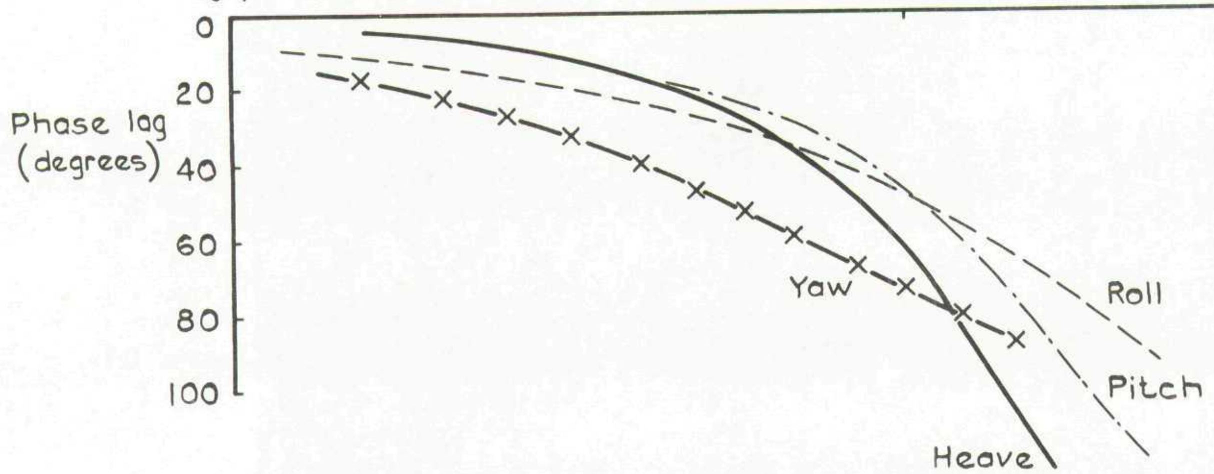


b Motion travel available

Fig. 4 a & b Cockpit and motion system

Fig.5 Shadow horizon display





	Maximum rate (measured)	Maximum acceleration (estimated)
Pitch	37 °/s up 72 °/s down	184 °/s² up 936 °/s² down
Roll	± 57 °/s	± 537 °/s²
Heave	± 23 °/s	± 122 °/s²
Yaw	30 °/s left 43 °/s right	234 °/s² left 445 °/s² right

Fig.6 Cockpit motion – response characteristics

Fig.7 Westland Wessex

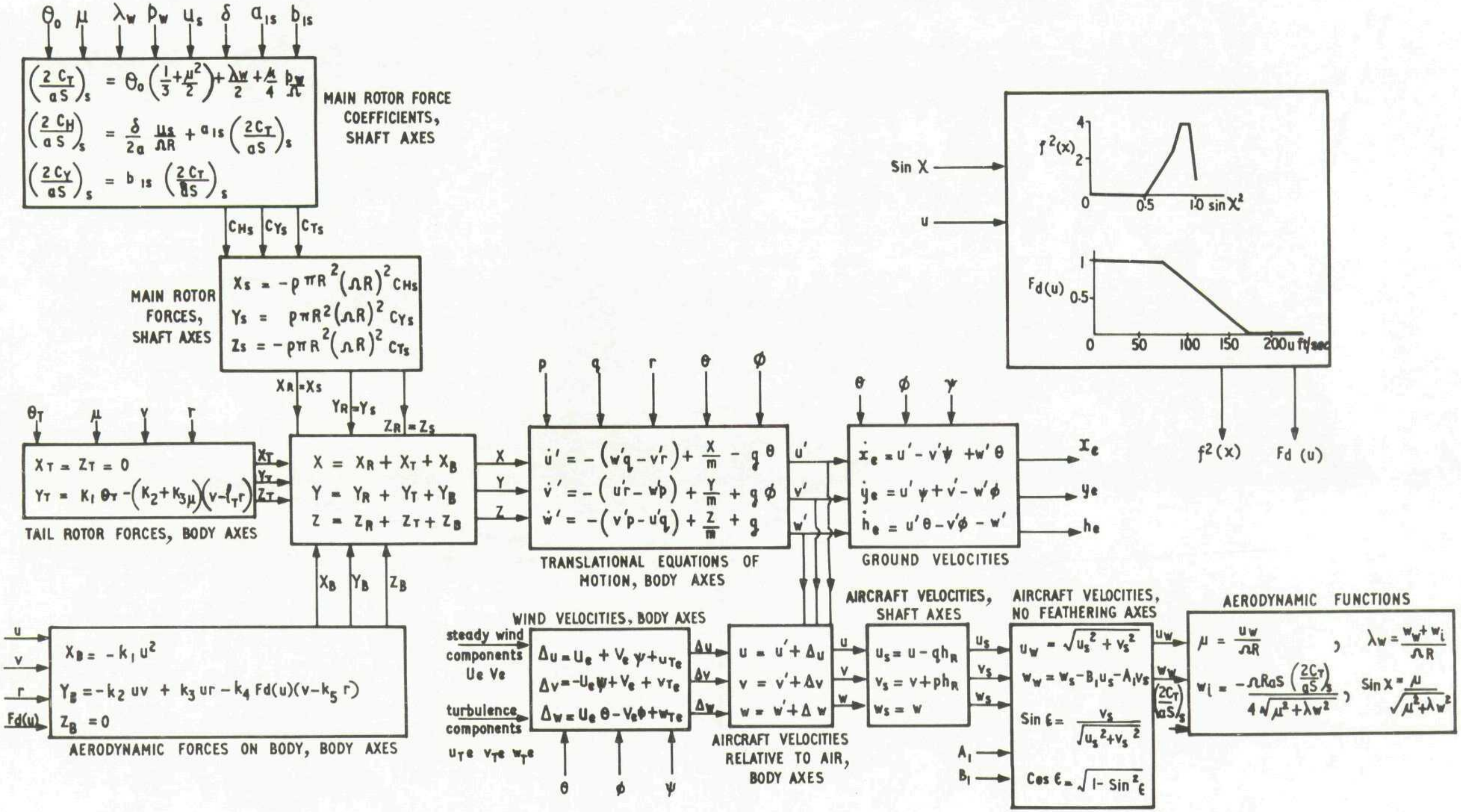


Fig.8 Simulator equations

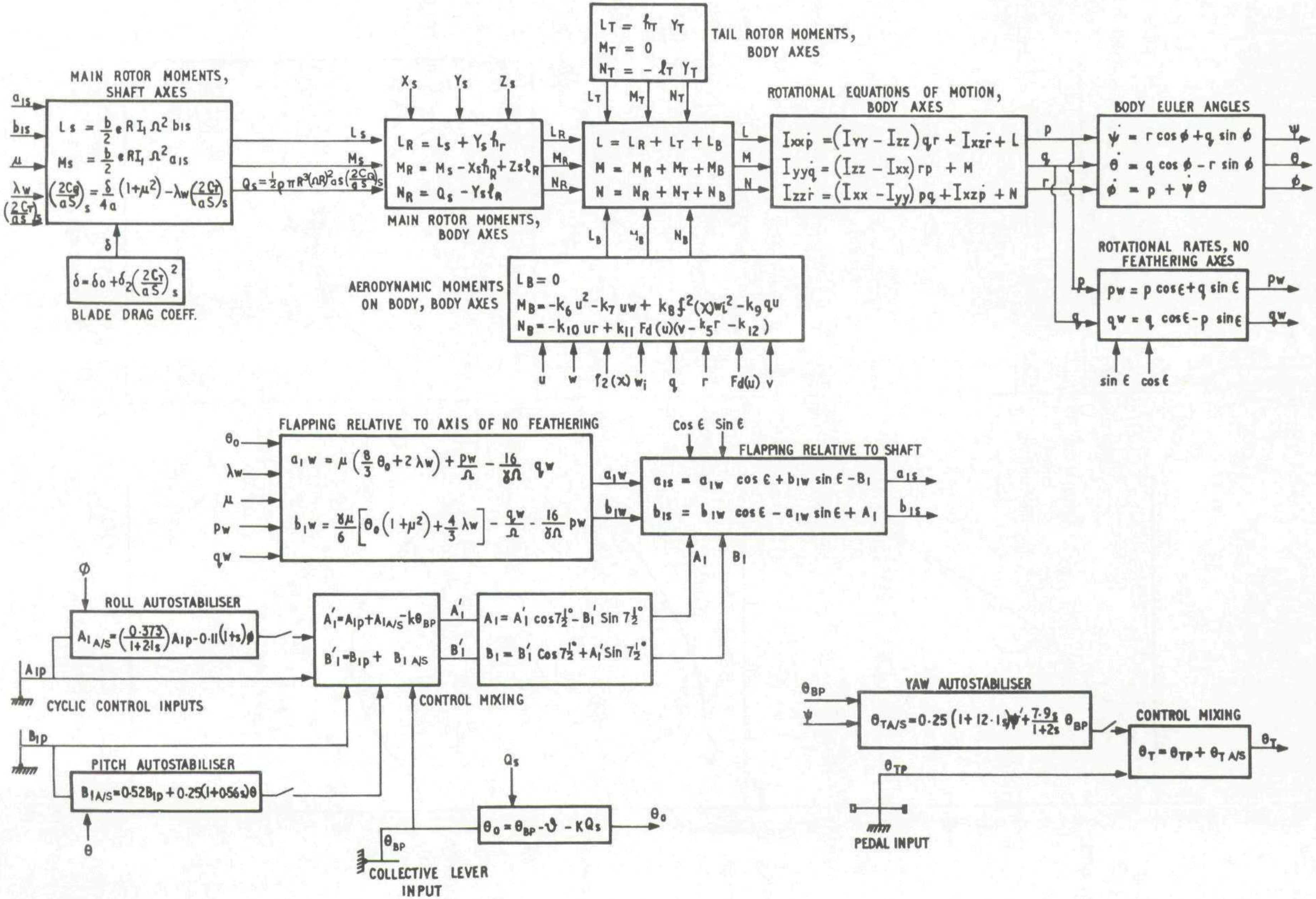


Fig.8 (Cont'd.) Simulator equations

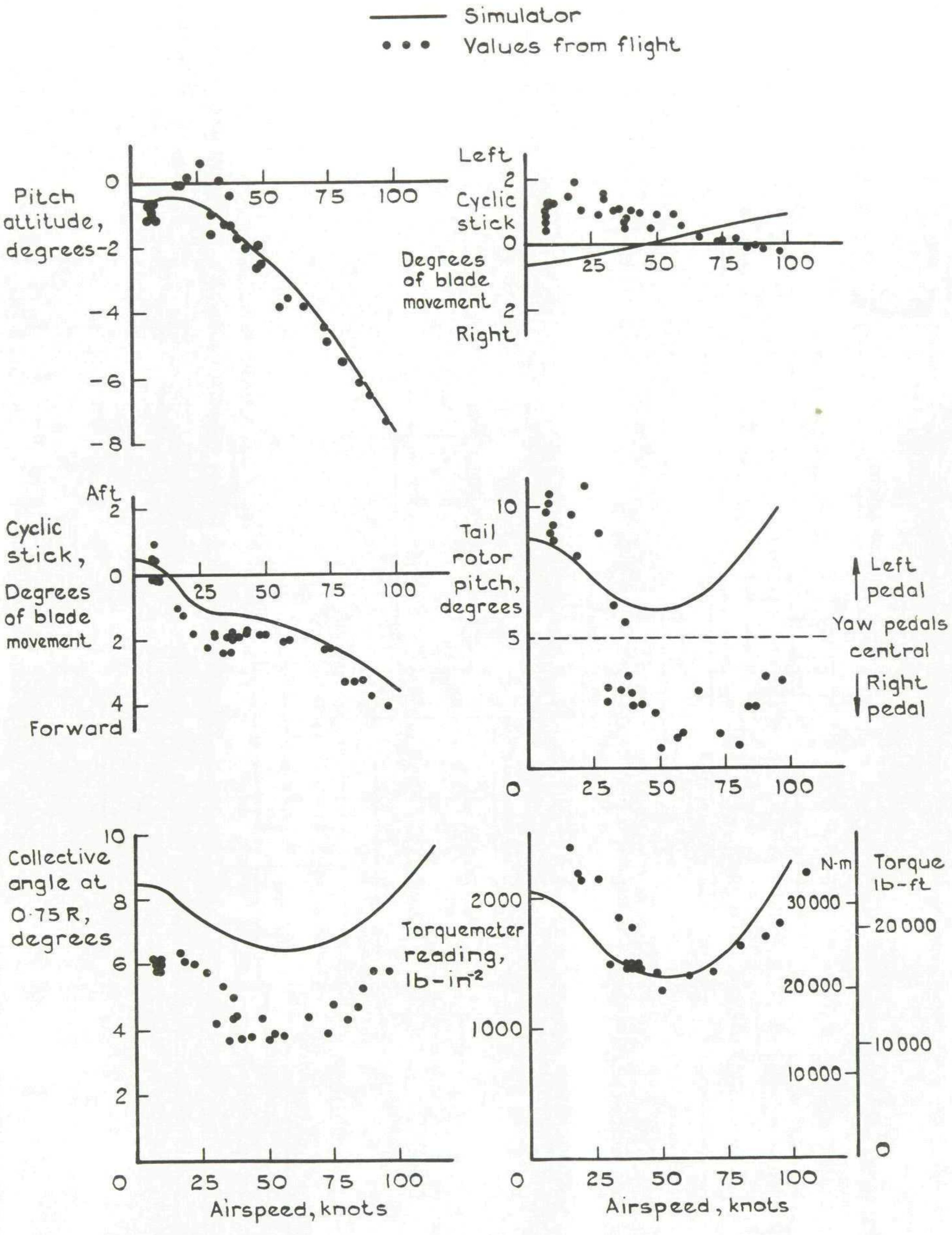
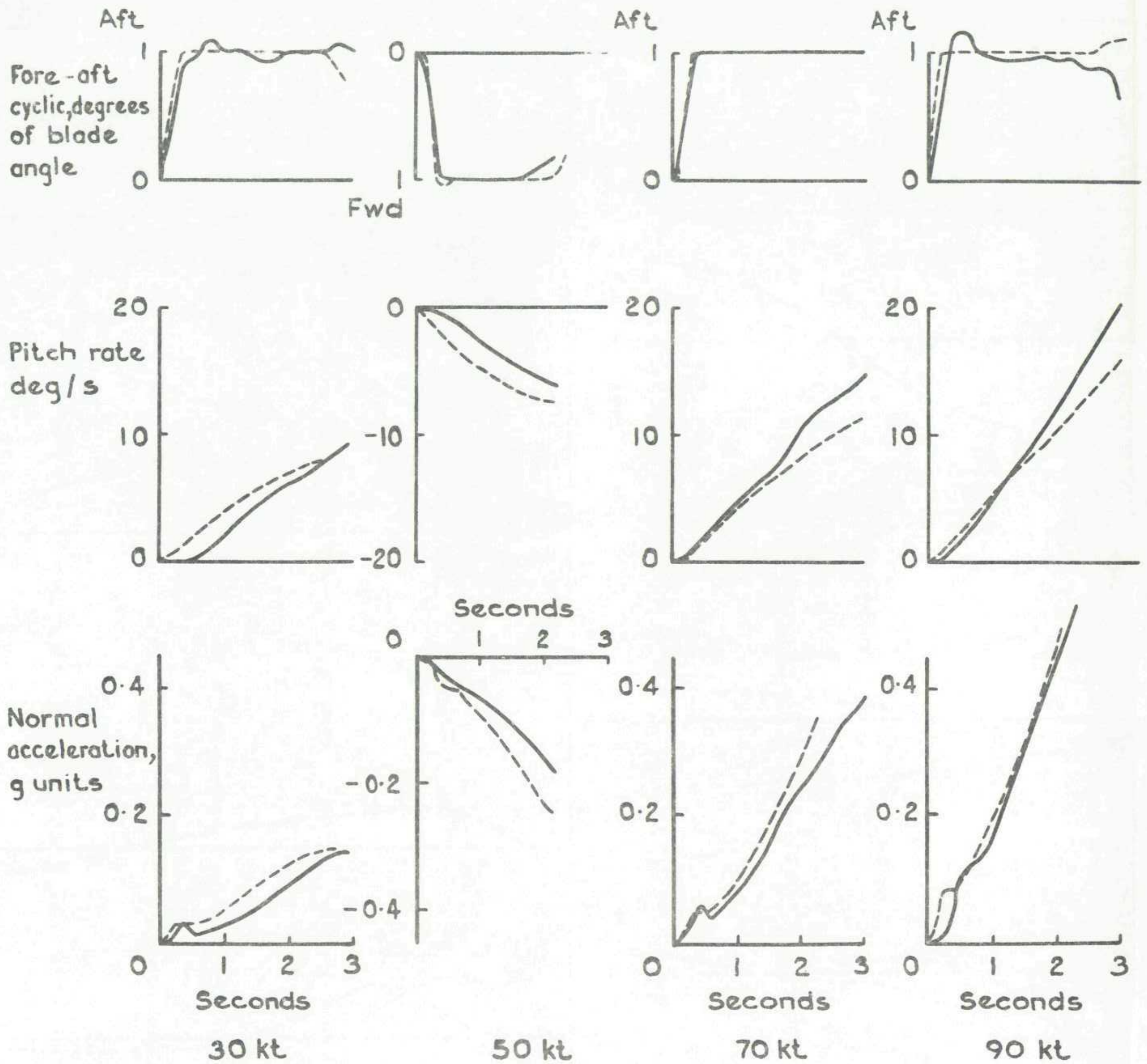


Fig.9 Level flight trim – flight and simulator



Step size:	30 kt	50 kt	70 kt	90 kt
Flight	0·9°	1·4°	0·9°	0·6°
Simulator	1·4°	1·65°	1·45°	0·9°

Flight ——— Simulator - - - - -

Values measured in flight and simulator have been divided by the cyclic step size to facilitate comparison; cyclic values shown are changes of position, not absolute values

Fig.10 Response to fore-aft cyclic step-flight and simulator

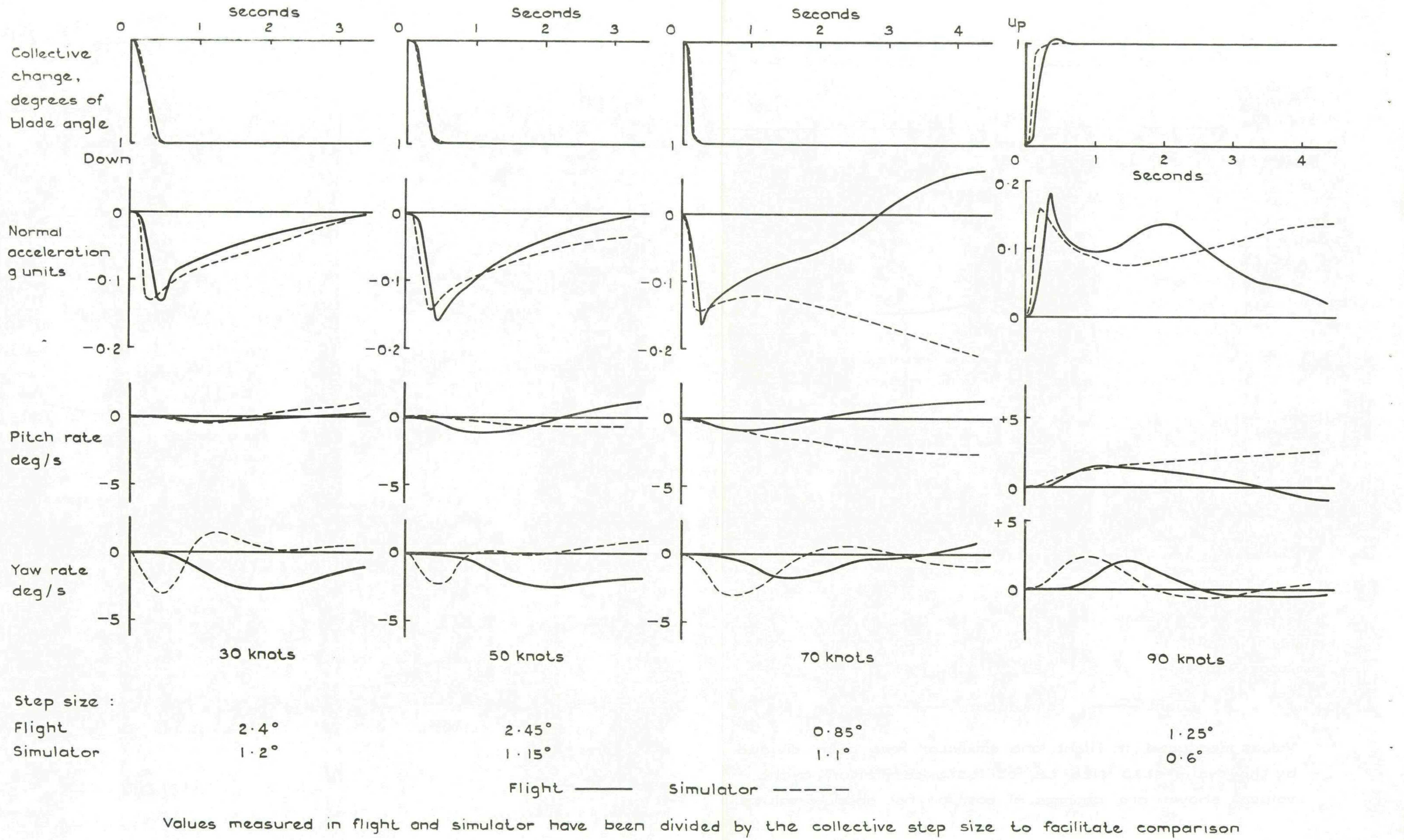
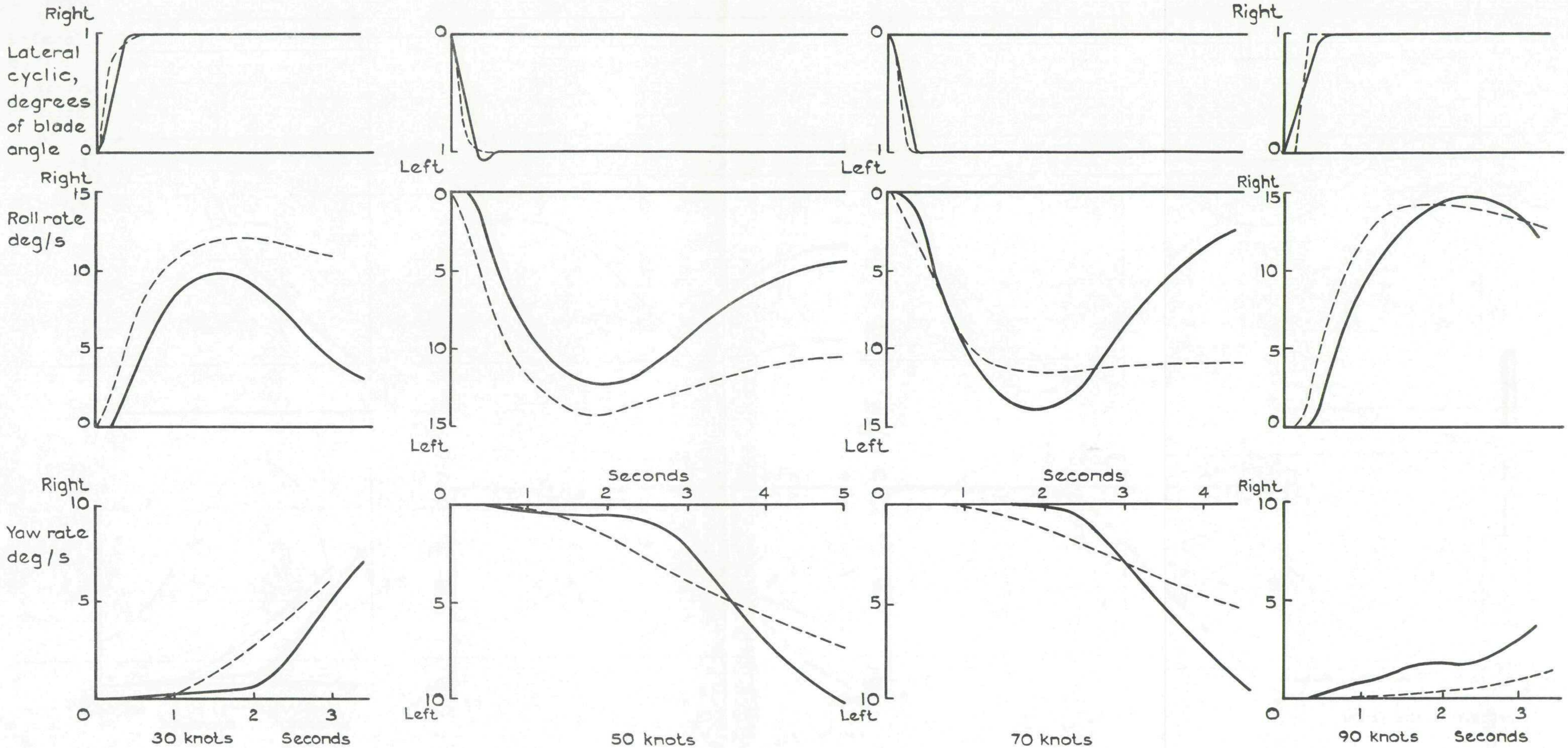


Fig.11 Response to collective step – flight and simulator

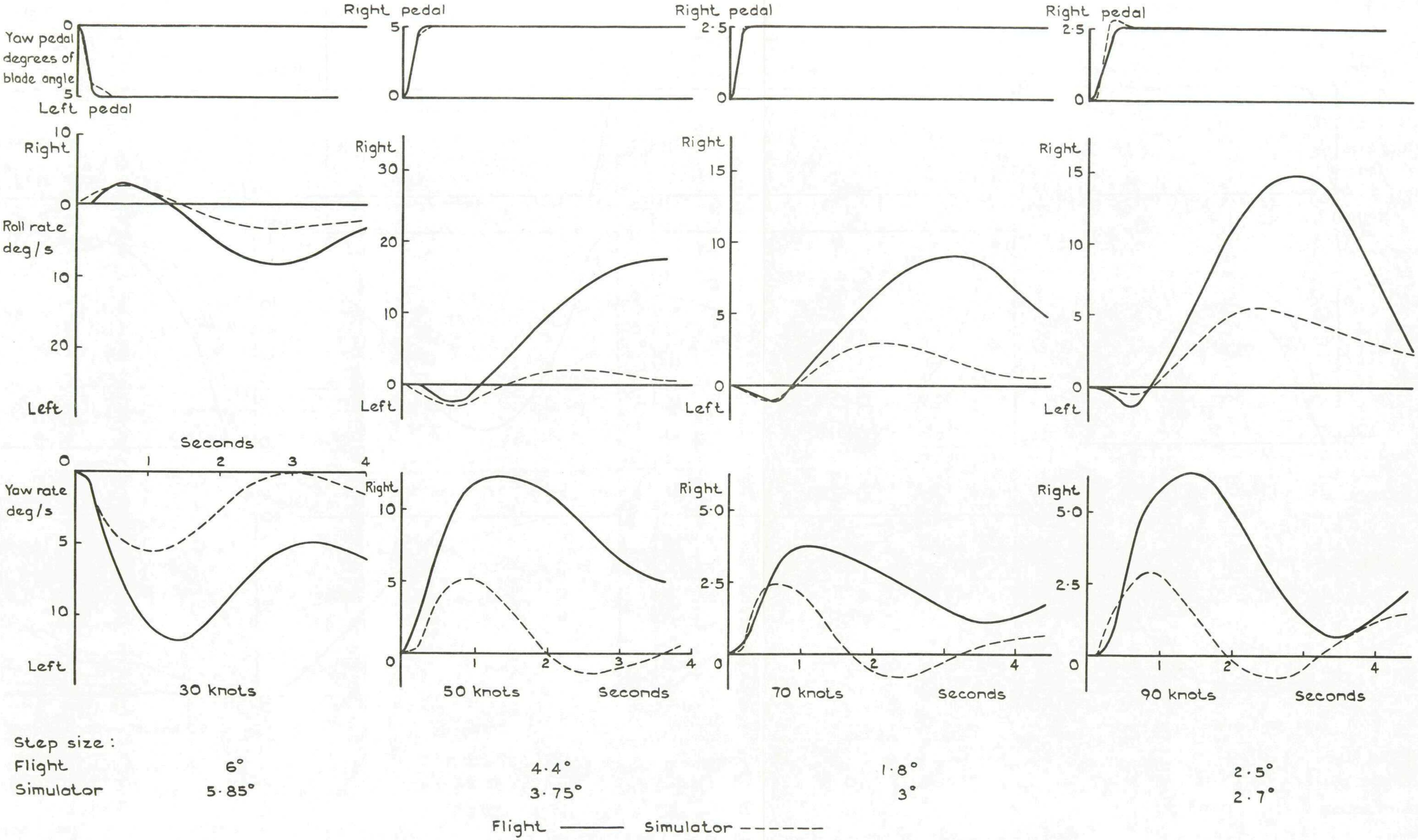


Step size,	30 knots	50 knots	70 knots	90 knots
Flight	1·15°	0·8°	0·7°	1·0°
Simulator	0·9°	0·35°	0·65°	0·55°

Flight ———— Simulator - - - - - -

Values measured in flight and simulator have been divided by the cyclic step size to facilitate comparison; cyclic values shown are changes of position, not absolute values

Fig. 12 Response to lateral cyclic step — flight and simulator



Values measured in flight and simulator have been scaled (to an equivalent 5° input at 30 and 50 knots and to a 2·5° input at 70 and 90 knots) to facilitate comparison; yaw pedal values shown are changes of position, not absolute values

Fig.13 Response to yaw pedal step — flight and simulator

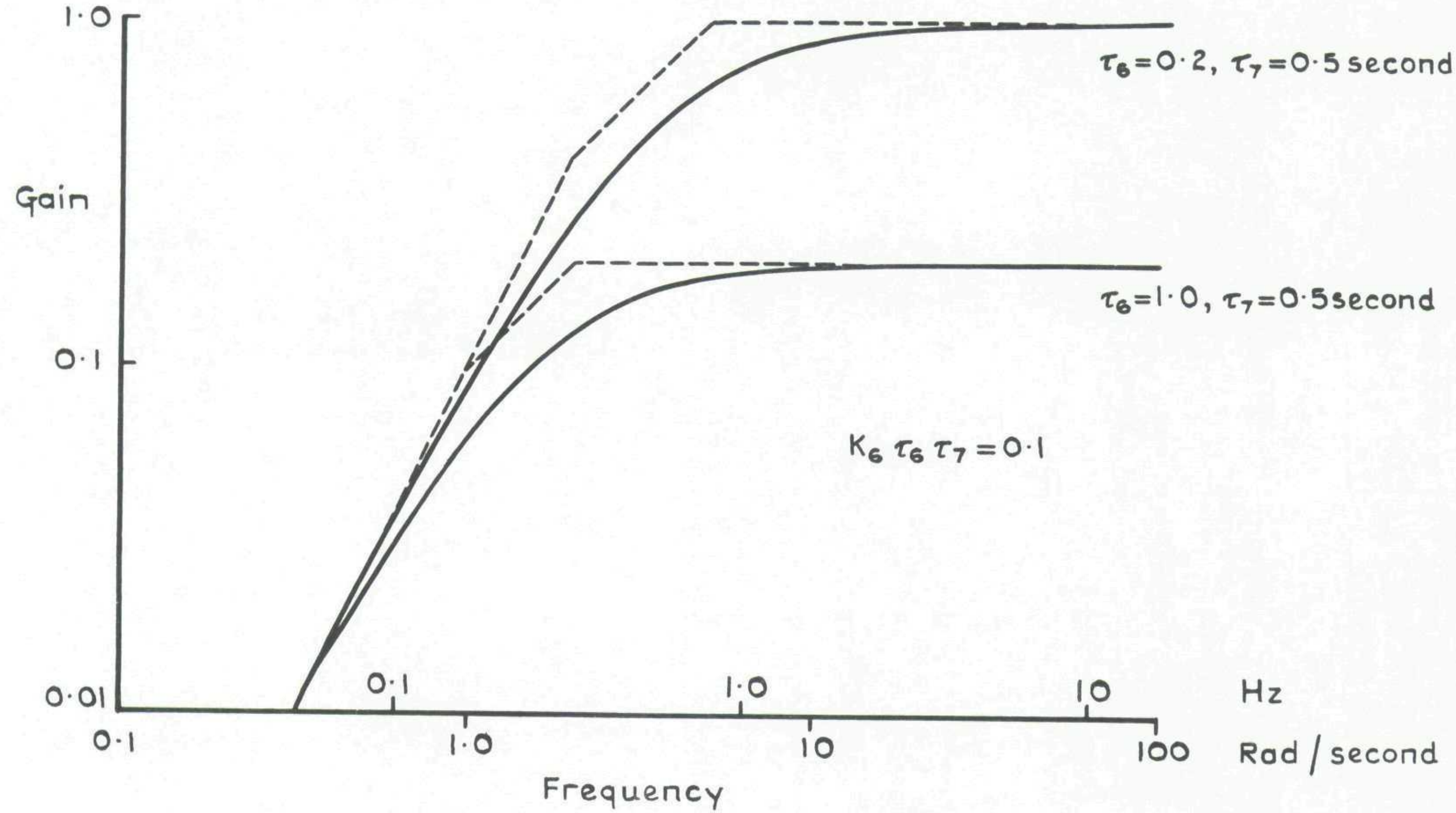


Fig.14 Heave motion laws – gain v frequency

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ARC CP No.1299
May 1973

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