NINETEENTH EUROPEAN ROTORCRAFT FORUM

Paper No. M6

THE APPLICATION OF INTEGRATED FLIGHT AND ENGINE CONTROL TO HELICOPTERS

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September 14-16, 1993
CERNOBBIO (Como)
ITALY

ASSOCIAZIONE INDUSTRIE AEROSPAZIALI
ASSOCIAZIONE ITALIANA DI AERONAUTICA ED ASTRONAUTICA

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ABSTRACT

In recent years, Westland Helicopters Limited (WHL) has undertaken wide ranging research into advanced helicopter flight control concepts. This paper presents an overview of WHL's work which includes Active Control Technology (ACT), Control Laws, Carefree Handling (CFH) and Integrated Flight and Engine Control (IFEC), describing the overall results of this work and WHL's perception of the potential opportunities for future helicopter flight control.

The major part of the paper concentrates on the IFEC programme undertaken in collaboration with Rolls-Royce plc under contract to the UK MoD, and presents the findings of the first phase of this study, including the potential benefits of improved integration and favoured implementation strategies.

The paper concludes with a discussion of possible routes towards developing and integrating IFEC features with other advances in helicopter flight control technology, and the importance of such features for future rotorcraft types and missions.

1 INTRODUCTION

Helicopters are known to present many problems for control system designers. They are usually inherently unstable, highly cross-coupled, highly non-linear vehicles which need to be controlled in six degrees of freedom through an extensive flight envelope. Additionally their rotor speed needs to be controlled within defined limits and they have a whole range of other dynamic system and flight envelope limits which must be respected in order to ensure an adequate fatigue life and ultimately structural and system integrity.

Automatic stabilisation systems and automatic rotor speed governing have reduced the severity of these problems, but the pilot is still faced with observing vehicle limits and flying an aircraft with handling characteristics which vary through the flight envelope, and which can degrade rapidly in aggressive manoeuvring flight. While pilot skill generally accommodates these inadequacies, high levels of pilot workload can result. As mission requirements become more demanding, with more performance required from the vehicle, its systems and crew, it is important to provide the pilot with as much assistance as possible in his basic flying tasks.

This paper describes work undertaken at Westland Helicopters Limited (WHL) on advanced control concepts aimed at providing this assistance, thereby making more performance available to the pilot and reducing his workload. Most of these control concepts have assumed the adoption of Active Control Technology (ACT) flight control systems and have examined the benefits which could be gained by exploiting the full authority control of such systems. These studies have included developing and evaluating ACT control laws, carefree handling systems and Integrated Flight and Engine Control (IFEC). Particular emphasis is given in this paper to the first phase of the IFEC programme which has been undertaken by WHL and Rolls Royce plc, under contract to the UK MoD.

The studies undertaken by WHL on ACT, control laws and carefree handling have shown that major gains may be made in terms of vehicle control, handling qualities, pilot workload and limit protection, but none of these technologies offer to improve the control of rotor speed. Neither do these technologies offer any benefits to the inherent performance of the helicopter, although they should make more of this performance more readily accessible to the pilot. It should be noted that where pilots do take advantage of these systems to use more of the aircraft's manoeuvre capability more frequently, then this will put greater demands on the rotor speed control system.

Digital flight control systems and Full Authority Digital Engine Control (FADEC) systems are becoming established on current helicopters and the progression towards Active Control Technology (ACT) flight control in the near future is expected. This wide use of digital control technology opens up new opportunities for closer integration of flight and engine controls.

The WHL/Rolls-Royce IFEC programme aims to explore the potential benefits for helicopter operations through greater communication across the flight/engine control system interface. The primary objectives of the recently completed first phase of this programme were to establish appropriate mathematical models and to identify and quantify the benefits of integration across the range of control technologies currently used and in the process of being developed. In addition, a preliminary look at the issues relating to implementation requirements were addressed, with system integrity and the choice of system architecture being assessed.

2 WHL ADVANCED CONTROL CONCEPTS

2.1 Active Control Technology

ACT is seen as the route to overcoming many of the control and piloting problems described above. It is expected to provide greatly enhanced handling qualities, with manoeuvre demand control strategies, reduced cross-coupling and consistent responses throughout the flight envelope, including aggressive manoeuvring flight. Mission related control laws can be envisaged to optimise the handling characteristics of the vehicle for particular mission requirements. These handling qualities improvements should reduce pilot workload and allow the pilot greater freedom to use the performance of his helicopter, eg. flying lower and faster, with consequent operational advantages.

ACT is also expected to offer many direct advantages for the basic vehicle design, and studies at WHL have attempted to identify/quantify these benefits when compared with conventional flight control systems, with the following results.

- Mass savings could be made for helicopters of all-up-weight of 5 tonnes or above, with savings of the order of 50 kg for a large transport helicopter.

- Ballistic tolerance of the helicopter could be improved by 25% compared with a helicopter with unprotected simplex mechanical control runs.

- Reliability of the flight control system could be improved through the removal of complex mechanical components and simplification of the actuation system.

- Maintenance activity could be greatly reduced through the elimination of mechanical linkages and through greater coverage of built-in-test (BIT).

- Benefits would be expected from the design freedom allowed by removal of mechanical control linkages leading to improved cockpit layout and improved crashworthiness.

- Further safety benefits could be expected from improved handling qualities leading to fewer handling related accidents (estimated to constitute 20% of all civil helicopter accidents).

2.2 ACT Control Laws

WHL ACT control law studies have been mainly based around the rate command attitude hold (RCAH) control strategy. Full flight envelope control laws have been developed and evaluated in piloted simulation at DRA Bedford. The control laws have included high levels of augmentation with full authority height, heading and airspeed holds as well as options for torque command and height rate command in the heave axis. With the exception of the torque command option, which was too sluggish with conventional engine control, the control laws have consistently produced Level 1 handling qualities ratings both in piloted simulation and against the criteria laid down in ADS-33c (Reference 1).

Further ACT control law development has been undertaken by WHL as part of the European ACT collaborative programme (Reference 2). This work has developed a full flight envelope translational rate command controller in which the pilot demands fore/aft and lateral velocities, height rate and heading rate. These control laws incorporate carefree handling algorithms for limit protection and represent a very high degree of control augmentation. Piloted simulation of these control laws produced encouraging results, particularly in the low speed envelope, although problems with the displays and inceptors prevented consistent Level 1 handing qualities from being recorded. This raises the issue that careful integration of control law, display and inceptor characteristics is required to achieve optimum handling qualities.

2.3 Carefree Handling

WHL's work on Carefree Handling features has developed algorithms for protecting a wide range of helicopter limits through a full authority ACT flight control system, as well as evaluating various warning and cueing features which could be applied to an ACT or a conventionally controlled helicopter. Results from piloted simulation of these features (Reference 3) has shown limited benefits for the warnings, mainly in the category of reduced pilot workload, but greater benefits for the tactile cues and particularly the intervention algorithms, with greatly reduced pilot workload combined with improved (up to 25%) task performance and excellent limit protection when compared with the baseline aircraft.

3 BACKGROUND TO THE IFEC STUDIES

In normal powered flight a helicopter's rotor system is designed to operate in a narrow rotational speed range about a well defined datum value. In early piston engined helicopters, rotor speed control was achieved manually via a twist grip "throttle" on the collective lever. With the introduction of gas turbine engines, primarily for power and weight reasons, this manual engine control was replaced by automatic free turbine speed, and hence rotor speed, governing. This change produced a major benefit for the pilot in terms of reduced pilot workload, but had two principal disadvantages. Firstly, the virtually instant response of the piston engine (when running at constant speed) was lost, the gas turbine requiring a finite time to change power level due to the inertia of its gas generator. Secondly, the ability to modify the power demand in anticipation of required power changes, as could be achieved by an experienced pilot, was lost. The net result was that gas turbine powered helicopters tended to suffer significant transient rotor speed variations with large power changes.

The basic concept of helicopter engine control has not changed since the introduction of gas turbine engines. Engine control technology has undoubtedly advanced, but even the latest full authority digital engine control (FADEC) systems rely on feedback of the engine power turbine speed, though usually now combined with a simple feedforward of collective stick position to give some measure of rotor load change anticipation. Equally, while gas turbine engine technology has also advanced, these engines still suffer a significant delay in response to demanded power changes, which hinders precise control of rotor speed.

4 POTENTIAL BENEFITS

Closer integration of flight and engine controls gives three distinct possibilities for improving current practice: it can reduce transient rotor speed excursions by matching the supplied engine torque to the rotor load requirements with greater accuracy; it frees the rotor speed datum to vary as a control parameter; and it expands on the level of data transfer across the airframe/engine interface.

A full list of potential benefits which have been identified during this study are summarised in Table 1 and some of the key benefits are discussed further below.

4.1 Enhanced Handling Qualities

The benefits of an IFEC system are likely to be most significant with respect to handling qualities of the helicopter. The ability of the engines to react quickly to changes in loads on the rotor will enable the aircraft to be more responsive in manoeuvres where rotor speed transients are encountered. With an Integrated Control System comes the possibility of altering the whole control philosophy and matching engine power and rotor speed to the type of manoeuvre the aircraft is being asked to perform. Increased agility and an expansion of the flight envelope are thus real possibilities, and together with improved rotor control, at reduced levels of pilot workload.

4.2 Variable Rotor Speed

Helicopter rotors are typically certificated to operate over a range of speed values, to allow for transient behaviour and different operating conditions. In normal operation, however, the nominal datum is fixed to one specific value which is dictated primarily by performance requirements and is optimised as a result of trade-off studies between rotor rpm and collective blade angles. Benefits were foreseen if this datum could be altered in flight within the existing operational range. This might be done statically, to optimise certain parameters in trimmed flight, such as minimising noise or fuel consumption, or dynamically, to store and release energy within the rotor to improve helicopter manoeuvrability. Reduction in transient rotor speed variations, can be considered as a prerequisite for this function; in order to achieve the maximum benefit, the rotor must be allowed to operate as close to its rotational speed limits as possible where additional transient speed variations may not be acceptable.

4.3 Improved Safety

The protection of rotor speed is fundamental to the safe operation of the helicopter. There are a number of failure conditions however, which require rapid inputs from the pilot in order to ensure safe recovery. Of these, loss of engine power and loss of tail rotor drive or control are potentially catastrophic.

Commercial considerations and aircraft performance criteria have tended to influence the development of the rotor system, leading to low inertia rotors with poor speed decay characteristics. This has led to reduced safety margins, in terms of the intervention times within which the pilot has to react to an engine failure. IFEC could alleviate this problem by monitoring engine and transmission states and, following a detected failure, take the appropriate immediate action automatically.

Enhanced Handing Qualities
reduced rotor droop increased agility expanded flight envelope reduced pilot workload matching of rotor speed and engine torque to manoeuvres improved torsional stability damped Dutch role mode
Improved Safety
automatic intervention in the event of engine failure of loss of tail rotor
Reduced Operating Costs
ability to minimise fuel consumption
Clearer Definition of the Engine/Airframe Interface
simplification of design and development processes
Reduced Wear and Tear
reduction of peak loads in engine, rotor, trans. etc
Enhanced Noise Characteristics
reduction in noise associated with lower rpm
Benefits for Advanced Rotorcraft Configurations
reduced pilot workload major improvements in handling qualities full realisation of aircraft's potential

TABLE 1: IFEC POTENTIAL BENEFITS

5 EVALUATION OF POTENTIAL BENEFITS

The following sections discuss the work done on quantifying the performance of three of the benefits identified in section 4: reducing rotor speed transient variations, improving aircraft manoeuvrability, and optimising rotor speed for fuel economy.

5.1 Mathematical Models

While the greatest benefits from IFEC were expected to emerge for helicopters equipped with advanced flight and engine control systems, it was also important to consider the benefits which may be achievable for helicopters with less advanced "older" systems. In this way, appropriate IFEC features could be identified for inclusion in new designs as well as for retrofit to a whole range of existing helicopters. The IFEC studies therefore established four baseline helicopter/engine combinations as detailed below.

- The Lynx helicopter with Gem engines represents the lowest level of control system technology to be studied, with a mechanical primary flight control system, an analogue automatic flight control system (AFCS) and hydromechanical engine control.

- The EH101 with RTM 322 engines retains mechanical primary flight control but has a digital AFCS and FADEC engine control.

- ACT Lynx and Gem engines retains the hydromechanical engine control system but introduces full authority digital flight control.

- ACT Lynx with "ideal" engines represents the highest level of technology considered, with full authority digital flight control and engines which can provide instant response to power demand changes.

Mathematical models of each of the four helicopter/engine combinations identified above were established to allow simulation of IFEC functions and hence quantification of the potential benefits.

Each model was developed from an existing generic, non-linear, individual blade model, and included flap/lag and rotor speed degrees of freedom. The engine models, supplied by Rolls-Royce plc, were integrated with the helicopter models by means of transmission modules, developed to be representative over the frequency region of interest.

An extensive validation exercise was conducted, using flight test data where available, to ensure the accuracy of the models.

5.2 Reduced Transient Rotor Speed Variations (RTRV)

As described briefly in Section 3, a conventional helicopter engine control system functions by detecting an increase or decrease in free turbine speed (Nf) caused by changes in the torque requirement of the aircraft's rotor system. The engine control system adjusts the fuel flow to the engines, and hence the power being supplied to the rotor, in order to return the rotor to its datum speed. The ability of the engines to eliminate any variation in rotor speed is directly related to how quickly each engine can increase or decrease its power output. In a situation where the torque rate being demanded by the rotor is very high, and hence the rate at which the rotor speed is decreasing is also high, rotor droop will be difficult to prevent since the engine(s) will only be given the signal to accelerate once the rotor speed, and hence free turbine speed has fallen to below its datum speed. Such a situation will be aggravated if the rotor torque demand follows a period of low power flight (such as autorotation) where the gas generator is running at a low speed. Although some helicopters incorporate a collective feed-forward control path to the engines which demands an increase in engine power coincident with an increase in collective pitch, the collective inceptor is not the only control input which can cause transient variations in rotor speed.

The objective of the IFEC/RTRV control system, was to develop a Flight/Engine control interface which could command engine torque changes more rapidly than a conventional system in response to any change in rotor load requirement, from either changes to the aircraft flight state caused by environmental effects such as gusts or from demanded inputs through any of the four primary control channels. The aim was to substantially reduce/eliminate transient rotor speed changes and thereby improve handling qualities, and further reduce pilot workload.

The approach adopted to achieve these objectives was to derive a torque requirement signal based on easily measured parameters. This torque requirement signal is then compared with the engine output torque to provide a torque error signal which is fed into the engine control system as an additional torque demand, as shown in Figure 1.

Results obtained from simulation using the RTRV system within a Lynx/Gem and an EH101/RTM322 model, has shown that rotor speed excursions can be reduced significantly for inputs in all four control channels. Typically, reductions of up to 80% in operational manoeuvres, such as Bob-up/down in hover, spot-turns, rapid acceleration/deceleration, and banked turns in forward flight, have been demonstrated. Figure 2 shows the results obtained from the Lynx/Gem model for sinusoidal inputs into all four channels. In addition to improved rotor speed control, it should be noted that peak engine torque values can be substantially reduced in high power manoeuvres. This should benefit engine/transmission wear and tear, increasing dynamic component life and leading to lower direct operating costs.

5.3 Optimum Rotor Speed for Fuel Economy

Various control methods were assessed to meet the objective of optimising rotor speed to minimise engine fuel consumption. This included: simple pilot selection; look-up tables as functions of aircraft speed, weight and altitude; and finally through self optimising search processes, which perturbed the rotor speed and monitored the fuel flow.

Look-up methods of datum optimisation have been demonstrated to be fast and reliable, the drawback being the limitation on the number of variables in the table. The omission of variables can reduce the accuracy of the optimisation. Self optimising search processes overcome this difficulty, but in initial simulation, have been slow and may take up to four minutes of sustained trimmed flight to converge on the desired solution. The preferred method of achieving the rotor speed optimisation is therefore through a combination of these two approaches, using the look-up tables to give a first approximation, followed by a simple search about this point.

In simulation using the Lynx and EH101 models, savings of 5-7% in total fuel burn were achieved for representative service missions, normally by reducing the rotor speed to its minimum normal operating limit. Perhaps more important than a pure fuel saving, the benefit can be utilised for mission enhancements, such as increasing the radius of action, or increasing the helicopter's available time-on-station. Alternatively, the mission fuel load may be reduced giving an additional payload carrying capability.

The simple algorithm developed in this phase of work relies on an isochronous engine Nf controller. The algorithm incorporates filters to remove noise from the rotor speed and fuel flow signals and includes a first order 'ramp' filter on the Nf datum output signal to limit the rate at which it can be changed, and hence eliminate undesirable fuel demand spikes. The robustness of the control algorithm has been successfully tested in simulation of external disturbances and pilot induced manoeuvres.

5.4 Improved Manoeuvre Performance

The main rotor of a helicopter can be thought of as an energy store, being capable of absorbing and releasing energy with changing rotor speed. It was therefore proposed to develop a control strategy that would manage this energy conversion, with the aim of improving vehicle manoeuvrability. Examples of where manoeuvrability could be enhanced include rapid accelerations from the hover and rapid decelerations from high speed flight. In an acceleration (vertical or horizontal) from low speed flight, the limiting factor is the power available from the engines. If, however, the rotor speed is at its normal upper limit at the start of the manoeuvre, then, when the engine torque limits are approached, rotor speed can be reduced to allow rotor thrust to be maintained without exceeding engine limits; rotor kinetic energy is effectively traded for vehicle kinetic energy. In a deceleration from high speed flight, the limiting factor is the maximum rotor speed limit as vehicle kinetic energy is absorbed and dissipated by the rotor. If the rotor speed is near its lower limit at the start of the manoeuvre, then more energy can be absorbed by the rotor before it reaches its upper speed limit.

Algorithms developed to explore these potential benefits scheduled the rotor speed according to helicopter airspeed and demanded additional controlled rotor speed changes on approach to torque limits. These demanded rotor speed changes were fed into the engine control systems as additional demands.

Initial results gained from step inputs in the collective channel indicated that the algorithm can boost the thrust which can be provided by the rotor over a short period by between 20-35% for each of the models used in the simulation. Further work using an ideal engine model, (one that gives an instantaneous response to a demand torque load), showed that while some additional benefit could be derived through engine control improvements, the energy released from the rotor was the primary means by which the benefit is achieved.

Table 2 highlights the potential performance increases for some defined mission task elements. The quick stop performance (shown in Figure 3) is improved through the increase in pitch attitude which is attainable by starting from a low datum rotor speed. Figure 4 shows the benefit in terms of height gain for the Lynx/Gem model with both the agility and RTRV systems engaged.

MODEL	MANOEUVRE	PERCENTAGE IMPROVEMENT
ACT Lynx-Ideal Engine	Collective Pull in Hover	40% increase in height after 4 secs
	Bob Up	35% increase in height or 22% quicker
ACT Lynx-Gem	Collective Pull in Hover	45% increase in height after 4 secs
	Bob up	10% quicker
	Bob down	20% quicker
	Deceleration 120 - 100 kts	15% reduction in time taken
	120 - hover	7% reduction in distance covered
EH101-RTM 322	Collective Pull in Hover	100% increase in height after 4 secs
	Bob up	200% increase in height or 40% quicker

TABLE 2: BENEFITS OF IFEC ENHANCED MANOEUVRABILITY

6 IFEC IMPLEMENTATION ISSUES

In designing the algorithms used to implement the IFEC features discussed above, care was taken to ensure that information required by the algorithms was either already available on the aircraft or could be easily measured or generated. There is therefore a high level of confidence that the benefits emerging from these studies are practically realisable and would be cost-effective. Implementation would be easier for FADEC equipped engines where the additional inputs could be accommodated through software changes; engines with hydromechanical control systems would require hardware modifications.

The three benefits described in detail in this paper can all be thought of as being enhancements to the engine control system, in that the only outputs are additional demands into the engine control system. The integrity of existing engine control laws are not affected, and therefore is independent of the level of control technology employed. The RTRV and fuel economy modes can be thought of as generic systems which, provided the additional inputs are available, are independent of aircraft type. For future engine developments, it would therefore be appropriate to incorporate these enhancements directly into the engine control system. The manoeuvre performance mode is aircraft specific and may therefore be more appropriately placed within the flight control system. An initial hazards assessment of these systems has established them to be non-critical provided certain constraints are applied, including limiting the authority of the system to cover only the normal operating rotor speed range, and provided checks are made on any input signals. Implementation could therefore be made via a simplex system and be relatively cheap.

Other benefits require the transfer of information from the engine(s) to the flight control system, such as safety enhancements. In the case of an engine failure which required a flight control input to maintain rotor speed, the system would operate by making automatic inputs to protect rotor speed limits once triggered by a failure signal sent from the engine control system. The development of this system is at an initial stage, but it has become clear that the integrity of such a system would need to be very high and would be more appropriate to an ACT type system.

Three fundamental options for the implementation of IFEC have been studied, including; a fully integrated system, where the functionality of the existing flight, engine and IFEC systems are combined; the integration of IFEC within the current control units; and a dedicated IFEC system as a separate unit. Each of these options were studied and the impact of various design parameters and constraints assessed. The final choice of implementation strategy was thought likely to be dominated by commercial considerations, and by the desire to maintain flexibility to develop airframe and engines independently. The recommended approach to IFEC implementation is therefore to incorporate the features within the existing flight and engine control systems wherever possible. For a possible retro-fit application this may be impractical and/or uneconomic to achieve, in which case a dedicated IFEC unit should be considered.

7 INTEGRATION OF IFEC WITH OTHER ADVANCES IN CONTROL TECHNOLOGY, AND THE APPLICABILITY OF IFEC TO ADVANCED ROTORCRAFT CONCEPTS

Advanced control concept research at WHL, including that undertaken in collaboration with Rolls-Royce on the IFEC programme, has identified many potential benefits for present and future helicopters. Many of the features emerging from the carefree handling and IFEC studies are applicable to conventionally controlled helicopters as well as those with ACT flight control systems. The applicability of these features is summarised in Table 3.

	CAREFREE HANDLING		IFEC	
	Warnings and Cues	Direct Intervention	RTRV, Variable Rotor Speed	Automatic Safety Features
Conventional Flight Control System	✓	-	✓	-
ACT Flight Control System	✓	✓	✓	✓

TABLE 3: APPLICABILITY OF ADVANCED CONTROL FEATURES

It can be seen that, with exception of the safety features, the IFEC functions have been found to be applicable to all of the flight and engine control technologies addressed, although the level of the existing technology may restrict the operating range of some functions. All sensor inputs are readily available with the exception of the Economy look-up mode which requires an AUW indication.

The IFEC safety feature is believed to be potentially safety critical in itself, in that an incorrect signal output to the engine or flight control systems may have a catastrophic effect on the helicopter. The airworthiness requirements for such a system dictate that it is incorporated within a high integrity architecture. This would make the safety features incompatible with traditional flight control systems, and make it an ideal candidate for inclusion in a high integrity ACT type system.

It can also be seen from Table 3 that warning and tactile cueing carefree handling features are applicable to all flight control technologies, while the direct intervention features can only be considered for ACT helicopters.

In terms of application of these concepts to helicopters, it can therefore be seen that conventionally controlled helicopters could be given, either at the design stage or as retrofit systems, facilities which could significantly enhance their usable performance. The IFEC features would reduce pilot workload, improve fuel economy and increase transient manoeuvre performance, while the carefree handling features would further reduce pilot workload and assist with observation of limits.

ACT brings all the vehicle design benefits listed in section 2.1 plus greatly improved and consistent handling qualities and also permits further IFEC and carefree handling features to be implemented. The IFEC safety features would provide greater chance of survival following engine or tail rotor failures, while the direct intervention carefree handling features would allow guaranteed limit protection, and greatly enhanced ability to use the full performance capability of the aircraft with acceptable pilot workload.

If we now consider future advanced rotorcraft such as compound helicopters or tilt rotors, many of these advanced control concepts change from being desirable features to being essential. A thrust and lift compounded helicopter will have additional engine and wing control motivators, the control of which will have to be coordinated with the standard rotor controls. Tilt rotors will have a vast number of fixed and rotary wing control motivators plus a rotor speed which will vary over a relatively large range; the control of these parameters must again be coordinated to allow the full potential of the vehicle to be exploited. Achievement of this coordinated control with acceptable levels of pilot workload will rely on incorporation of ACT with development of the IFEC and carefree handling features already considered for conventional helicopters.

8 CONCLUSIONS

The integration of flight and engine controls on rotorcraft is seen as offering worthwhile benefits in the short term, and will be an essential technology for future rotorcraft concepts.

The IFEC/RTRV system offers the ability to maintain rotor speed at a near constant level following a change in rotor load, (either from environmental effects or from demanded inputs through any of the pilot's four control channels). It is anticipated that this will lead to improved handling qualities and reduced pilot workload, although this has yet to be quantified. This opens up the possibility of utilising the full allowable rotor speed range as a control parameter and leads to the numerous other benefits identified, including improved fuel economy and improved transient manoeuvre capability.

It has been shown that the majority of IFEC benefits can be achieved with only minor changes to the existing control system. Physical integration of flight and engine control functions is not essential, nor even desirable, to achieve the benefits foreseen, with integration being achieved through improved communication and data transfer.

IFEC and CFH systems have been shown to be compatible with each other, and integration of these systems offer many advantages for both conventionally controlled helicopters as well as those with ACT flight control systems. The greatest benefits of the IFEC/CFH systems can only be realised, however, though the use of an ACT flight control system. This combined system would allow an increased performance capability to be used to the full, as well as offering the helicopter pilot a substantial workload reduction and a true carefree handling capability through guaranteed limit protection.

Future advanced rotorcraft concepts which are being developed demand the addition of further control motivators, which must be coordinated with the standard rotor controls, to allow the full potential benefit of the vehicle to be exploited. Achievement of this coordinated control with acceptable levels of pilot workload, will dictate that ACT with elements of IFEC and CFH become essential technologies.

9 ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support and guidance given by the UK MoD, and to Rolls-Royce plc for their contribution to the work performed in the IFEC study.

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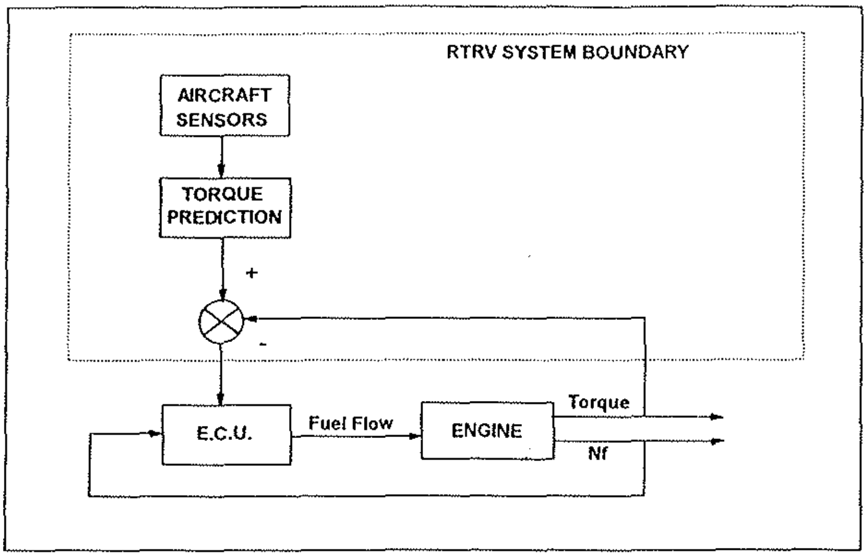

FIG 1: Schematic of IFEC/RTRV system

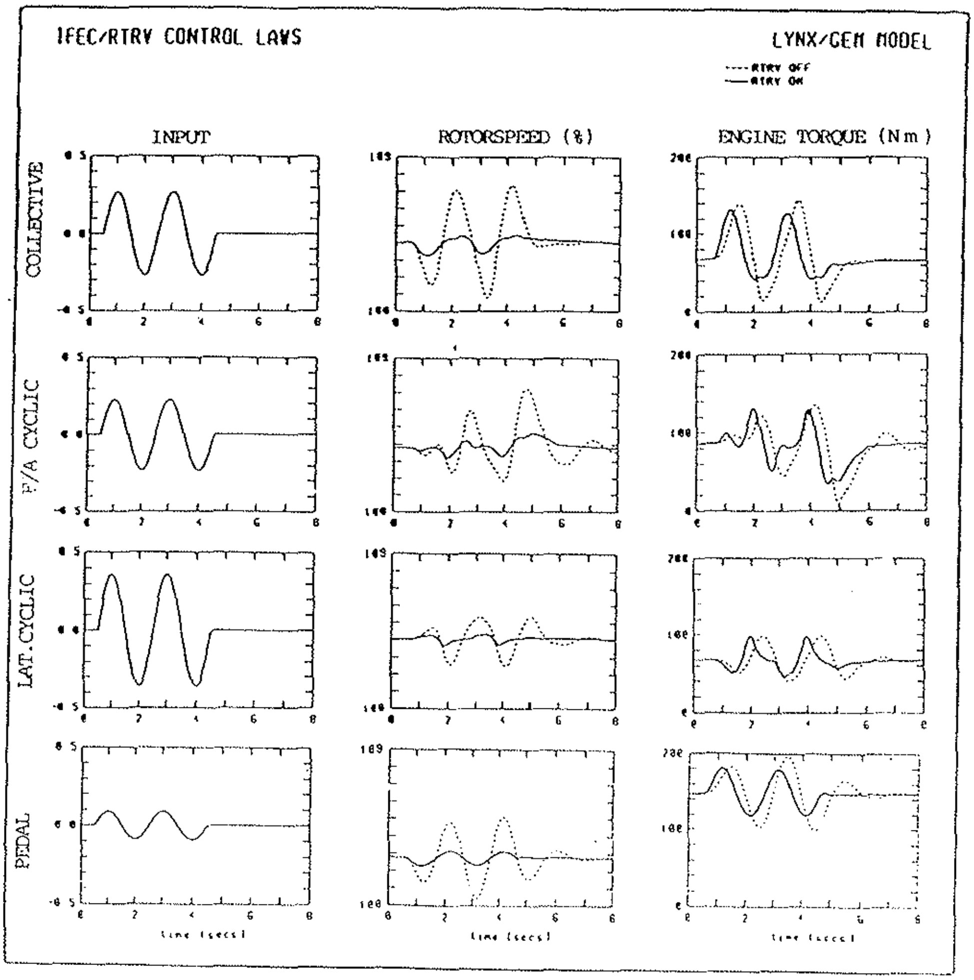

FIG 2: IFEC/RTRV system performance to sinusoidal inputs

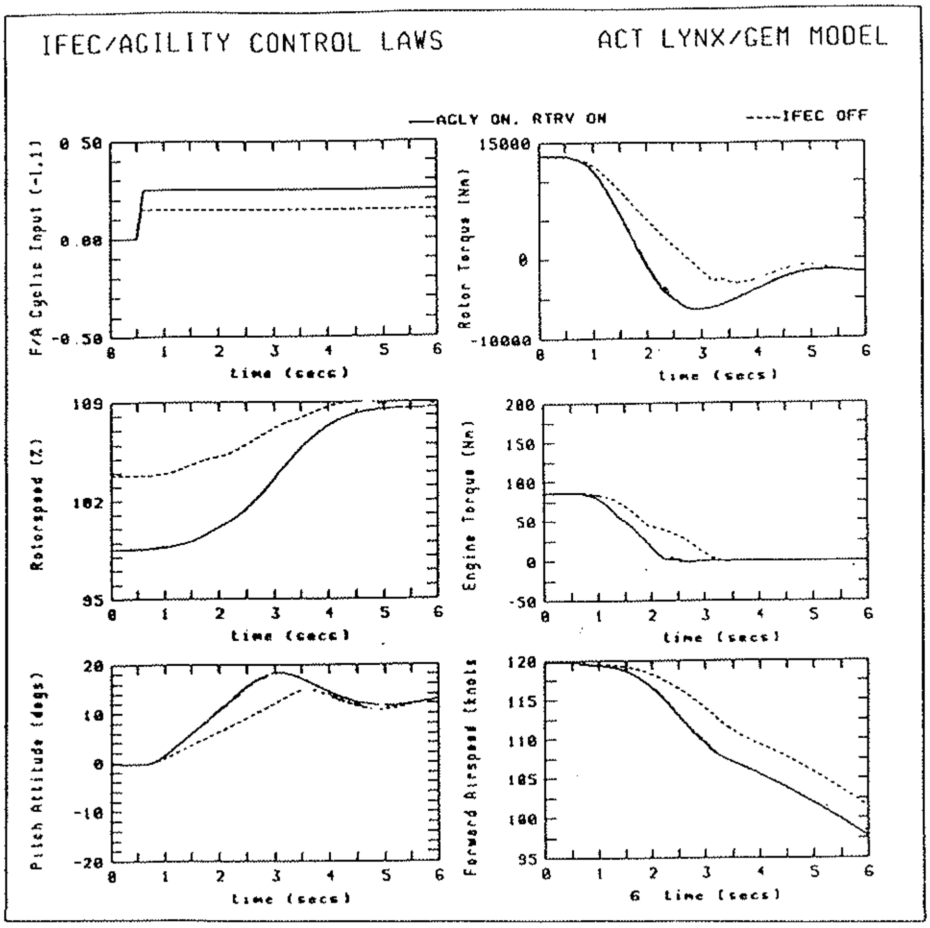

FIG 3: IFEC-RTRV/Manoeuvre system performance. Deceleration from 120knts.

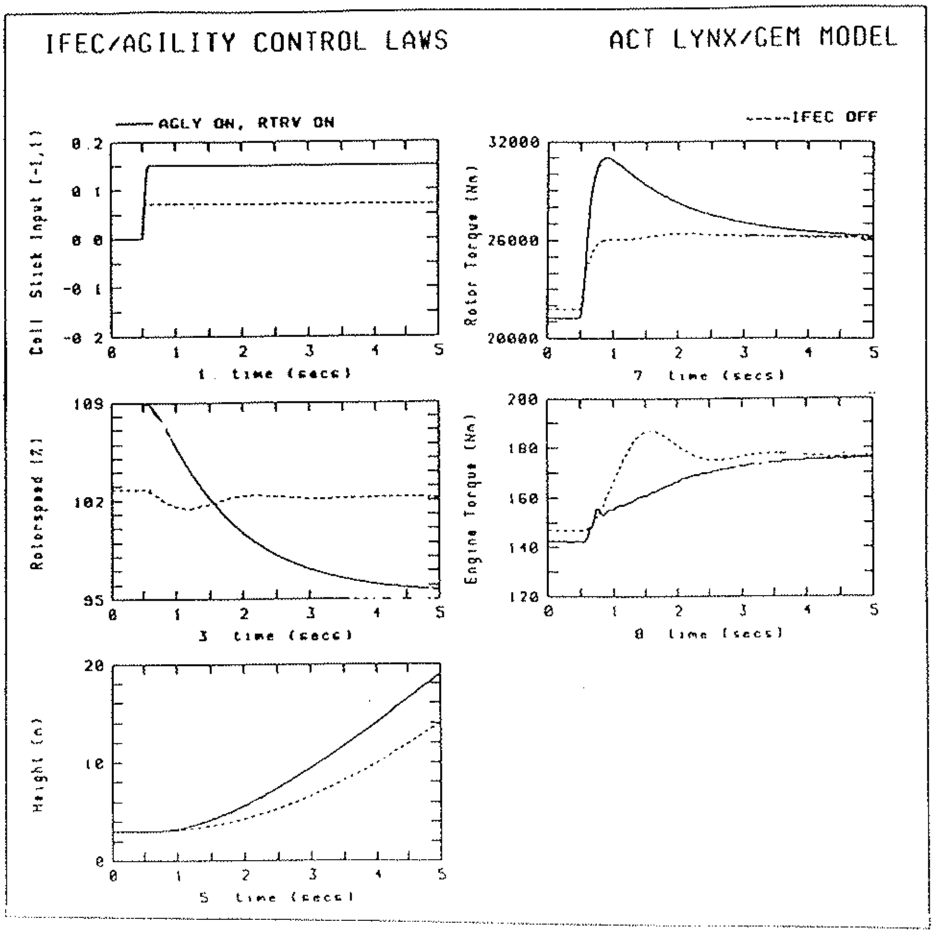

FIG 4: IFEC-RTRV/Manoeuvre system performance. Collective pull in hover