# The Digital Control System as Part of an Integrated Accessory Fit for Future Engines

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## ABSTRACT

The paper suggests that the traditional approach of designing the control system in isolation from the other accessories on a gas turbine engine may not provide the most cost effective total solution for an engine having a digital control system.

It is considered that the integrity of the digital control can be maintained whilst providing additional functions not associated with its prime control task. This could allow the development of advanced monitoring systems to minimise life cycle costs and achieve maximum aircraft utilisation.

The application of these principles to helicopter engines is discussed and an arrangement proposed which could provide substantial benefits both to the helicopter pilot and to the ground crew. Pilot workload would be substantially reduced by advising him of engine or aircraft management factors on a "need to know" basis. Operators would benefit from regular information on the operational status of the engines.

## INTRODUCTION

Electrical control of gas turbine engines has been an accomplished fact for over 30 years with control based on digital computers an accepted principle for at least the last 10 of these. Recent demonstrations of the virtues of full authority electrical control are believed to have provided the necessary stimulus for such controls now to be seriously considered for future gas turbine engines in helicopters worldwide. The argument as to whether an analogue or a digital based system would best satisfy the requirements of the particular market is a complex one; it is practically certain however that future military engines will be conceived from the outset as having digital control systems. In the military field the trend is likely to be more and more towards treating the engine as a subsystem in the aircraft, with commands transmitted and responses received along redundant data highways in the same way as for example, an air data computer. Digital systems generally are the obvious solution for such aircraft.

This paper does not set out to resolve the analogue versus digital question for the helicopter market but is intended to highlight the extended capabilities that a digital control can confer on an engine; these capabilities have obvious benefits in the military field and it is contended that such advantages should be made use of more generally. In defining the advantages, one should start by asking the question "What is the prime function of the helicopter, and what role does the pilot play in the achievement of this objective?" It is clear that the aircraft does not exist to transport the powerplant around and that the pilot has other things to do than look after the engine. These facts are often overlooked but if taken to their logical conclusion imply that the engine should be a fit and forget component.

It is interesting to note the differences in approach evident in two recent flight test evaluations carried out by a leading U.S. aerospace journal, one of the latest fly-by-wire single engined fighter and the other of a new civil helicopter. The former report hardly mentions the engine at all; the latter contains extensive sections on engine starting, operating limits, gas generator speeds, etc. Which approach ought to be the one for the future?

This paper proposes that digital control should be marketed on a more positive basis such as "It controls the engine, of course, but it also provides additional capabilities which no modern aircraft should be without." It is suggested that the approach most likely to prove attractive to potential aircraft operators is one where there is a significant level of integration of the control with a total engine and aircraft monitoring system. The overall capabilities of one such integrated arrangement are described in this paper and the potential operational advantages surveyed.

## CONTROL SYSTEM DESIGN

Many possible electronic control systems, both analogue and digital, have been described in technical literature over the last few years, one example being given in reference 1. There is no one "right way" to control a gas turbine engine, many quite different approaches having been adopted to starting schedules, acceleration laws, temperature limiting, etc: what may be suitable for one engine may be unsuitable for another. Further, control laws lending themselves readily to a hydromechanical solution may be difficult to implement within an electrical system and vice versa.

In this paper we are not concerned so much with engine control per se., more with the form of its interface with the rest of the aircraft, and in particular with the pilot. It is in the interface areas where the benefits of digital control as opposed to analogue can become most readily apparent, and where the deficiencies of current hydromechanical arrangements are most marked. There are basically two main interfaces in any aircraft between the pilot and the engine, that resulting from his direct link(s) with the engine control system and that associated with engine monitoring i.e. instrumentation. Both the pilot and the control system currently use essentially the same engine data to perform their respective tasks although additional information may be provided to the pilot for purposes outside the normal scope of the control system, for example, oil system monitoring.

This being so, it would seem reasonable to suggest that the digital control could undertake some of the engine monitoring functions itself, thus significantly offloading the pilot. Once this is accepted the whole concept of the man/machine interface may be re-evaluated against a new set of ground rules where, assuming integrity is safeguarded, the main requirement is to make flying the aircraft easier.

## MAN/MACHINE INTERFACE

### 1. Use of Interface

Any aircraft would require a number of functions to be performed relating to the operation of its power plant and associated systems. These functions may be listed as follows:-

(a) Select the engine operating condition required.

(b) Monitor the health of the engine and its control.

(c) Monitor the use of the engine.

(d) Ensure that engine operation is within cleared limits.

(e) Fly the aircraft to within its cleared limits.

(f) Control the engine directly when necessary.

Performance of each of these functions is affected by the form of the man/machine interface. Traditionally the necessary transfer of information between the pilot and the engine has been achieved by a mechanical link between the pilot and the control system to transmit demands to the engine for normal and direct (reversionary) control, and a display of information on engine operating conditions on standard instruments using electrical signals derived from engine transducers. Fig. 1 illustrates a typical modern helicopter cockpit.

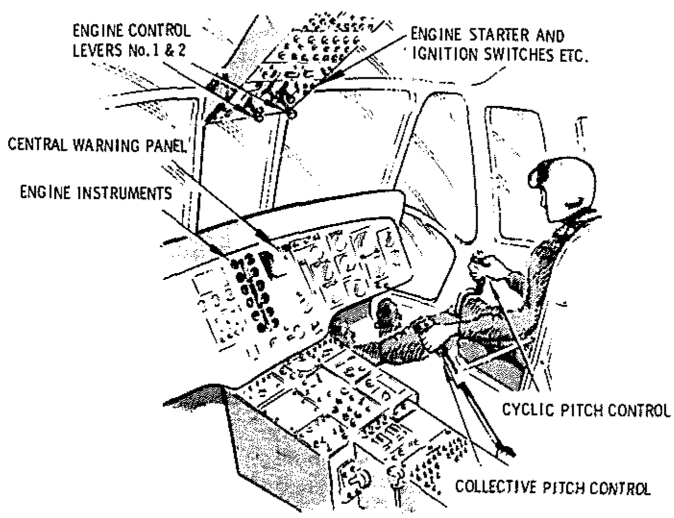


FIGURE 1 - TYPICAL HELICOPTER COCKPIT

### 2. Future Form of Control Interface

The logical consequences of an electrical control approach is that control information between the pilot and the engine should be transferred in the form of electrical signals. To maintain control integrity a backup path for control demands must also be provided: this could take the form of the traditional mechanical solution but it is considered that an alternative offering adequate integrity together with reduced pilot workload would also be by independent discrete electrical signals. The resultant system has many installational and operational advantages, its main disadvantage being a deep-rooted suspicion in the minds of many people that in the event of a major problem the electrical wire would let them down.

There is no real answer to this except to say that if a whole aircraft can be designed around a fly-by-wire concept then the small step of engine control-by-wire should appear relatively trivial. Another "anti" lobby argues the potential effects of electromagnetic interference: there is no doubt you have to be careful here but in 3 million hours of Rolls-Royce Gnome engine operation in civil and military helicopters with full authority electrical control (admittedly not digital) there has not been one instance of this sort of problem - and with long airframe leads carrying relatively low level transducer signals. The Gnome in its military role has operated perfectly safely off the decks of aircraft carriers carrying extremely powerful radar and radio systems. The still sceptical reader should also note two further facts about the Gnome control, firstly

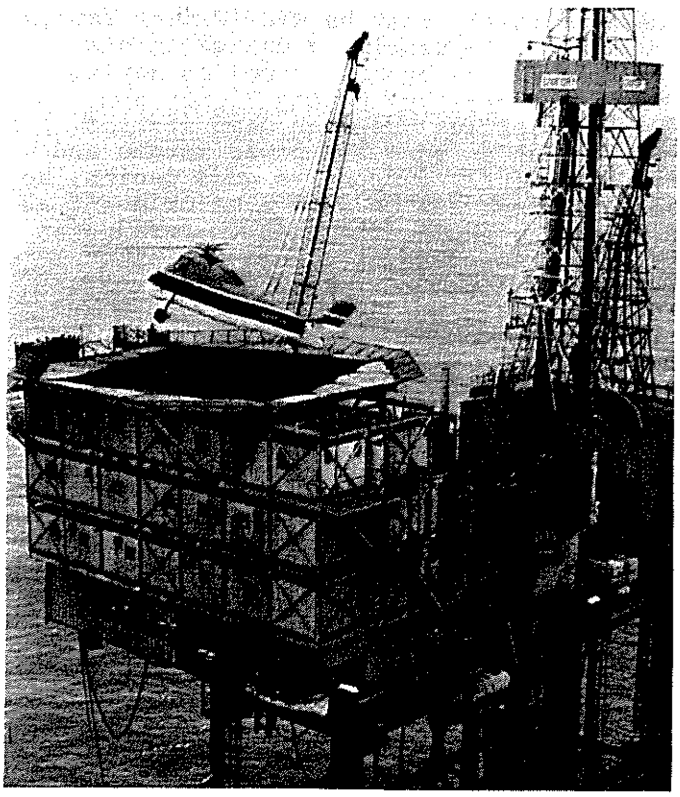

FIGURE 2 - WESTLAND WESSEX (FLY-BY-WIRE ENGINE CONTROL)

it draws power from the aircraft bus only and secondly in one civil application it was not considered necessary to include reversion at all - and versions of this aircraft are used for V.I.P. transport as well as commercial operations.

Assuming then that engine control is by electrical signals and that these signals are commanding the engine through a digital control system, a panel for a twin engined helicopter as shown diagrammatically in Figure 3 can be envisaged.

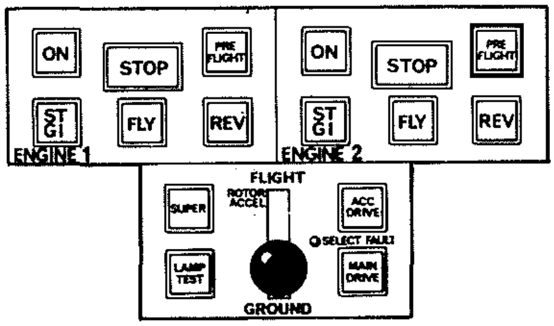


FIGURE 3 - FUTURE FORM OF CONTROL INTERFACE (TWIN ENGINED HELICOPTER)

The operation of the control panel would be as follows:-

( i) Computer On-Off Select

The digital control requires a switched 28V power supply for a number of reasons, including ground check and as a back up in the event of self-generated power failure.

( ii) Computer Pre-Flight Check Select

This is to allow a "go - no go" test of the control prior to engine start as an additional check to the normal in-flight self monitoring routine to check out normally dormant engine controls such as free turbine overspeed. The pre-flight check should not require any ground test equipment.

(iii) Engine Start/Ground Idle Select

Preferred engine start procedures may involve pre-selection of ground idling conditions and then initiation of engine start via the appropriate starter and ignition switches.

There may be some advantages in integrating the engine control with aircraft starter and ignition circuits to provide a simpler engine start procedure.

( iv) Flight Select

The transition from ground idle to the flight condition (i.e. governed at or near 100% speed) could, in isolation from consideration of aircraft rotor characteristics, be controlled automatically on pilot selection of the flight mode. The transition could be made to a schedule combining any of the parameters existing within the computer. An automatic transition would be applicable to the engine not associated with running up the aircraft rotor.

For the engine controlling the rotor run-up full pilot control of the rotor speed at all times is considered essential. Associated with each engine should therefore be a "fly" select control for automatic transition from ground idle to $N_F$ governing, but for the rotor run-up engine operation during the transition should be via an effective rotor speed control lever.

Where a separate accessory driving mode is required, a logic interlink between the engine controls and the selectable freewheel is proposed to replace the conventional condition lever microswitches to provide a simple safe selection procedure. The logic would require acceptable levels of speed signals before enabling freewheel actuation.

( v) Reversionary Control Select

The optimum arrangement for direct pilot control of the engine is considered to be where each engine control system is designed to fail frozen and to warn the pilot that a fault condition exists. The options then open to the pilot are to leave the engine in the frozen state and rely on the power modulation available from the "good" engine for rotor speed control, to shut the failed engine down or to reset the power level of the frozen engine. Such a reset of the engine condition may be done most conveniently through a beeper switch arrangement, preferably on the collective pitch lever.

( vi) Shut Down Select

It must be possible for the pilot to select shut down from any operating condition though normally shut down would only be initiated from ground idle. Two separate means of shutting off the engine fuel flow should be provided in the engine fuel delivery lines for fire zone precautions.

( vii) Super Contingency Select

A "super contingency select" facility could be required in some cases, the intention being to allow the pilot to raise the normal contingency limits restricting engine power to higher levels for emergency use in the aircraft. A single manual selection of super contingency for all engines is assumed; it is worth noting that the initiation of the condition could be automatic, using perhaps an aircraft low rotor speed signal.

## 3. Monitoring Interface

Provided that the power plant is perfectly healthy, that it is being operated within its cleared limits and is not within a time restricted domain, the pilot does not need to know any information on engine conditions at all. At other times, the pilot is a very inefficient engine monitor, particularly under failure conditions where the odds are he is not looking at the relevant instrument(s) at the instant of the fault developing and relies on training and instinct to do the right thing. It is more likely that he will detect faults by physically sensing a change in his environment or by his attention having been attracted by warning lights etc. A recent incident has even demonstrated that given an adequate power margin and a sufficiently responsive good engine, he may not even notice such a major event as a complete engine flame out. Perhaps as a monitor of gradual change the pilot is more effective, but unless the situation is relatively straightforward (such as slowy falling oil pressure) the likelihood is that his decisions as to actions to take may not be arrived at easily - which implies a high diagnostic workload.

It has been mentioned already that the digital control can aid the pilot by carrying out some limited monitoring functions since it uses similar engine information to that displayed to the pilot. This is the point where control functions and functions previously restricted to "engine health monitoring" systems begin to be seen as overlapping. The form of the interface here is less contentious than that for the control - surely simple lights are acceptable? It is envisaged that fault conditions not requiring immediate pilot action would be indicated by an amber warning with further information available through an automatic display facility. The more serious faults would be signalled by a red warning on a central warning panel, with unambiguous indication of what the fault was.

The extent to which additional hardware beyond that needed for the control task is required for the monitoring depends on the power of the basic computer, the parameters used for control and the configuration of the interface. If the task is accepted from the outset then the system can be designed to be compatible with the following monitoring without significant penalty:-

( i) Control Monitoring

As part of a normal self checking routine the computer would essentially monitor all the control system equipment and should detect system faults (e.g. loss of a control signal or a faulty drive motor) as well as faults within itself.

( ii) Limit Exceedence

Engine ratings are determined by speed, temperature, torque (power) etc., levels beyond which engine operation is time restricted for lifing and certification reasons. The observance of ratings below maximum contingency is generally a pilot function and can involve a significant workload since under different ambient conditions different parameters may be the rating limiting feature. For this reason, and the fact that time may be very important and therefore high powers may be demanded to accomplish the mission quickly irrespective of engine or even airframe limitations, strict observance of limits may be rather neglected. No monitoring system can prevent intentional misuse of course, but unintentional exceedence of limits can be reduced by improving the monitoring. The exceedence of rating conditions can simply be determined by the control computer by a suitable programme addition and the information relayed to the pilot in an unambiguous manner by annunciator lights, with usage of the engine being appropriately recorded.

Other engine limits such as vibration levels, oil pressures and oil temperatures can also be monitored by the computer and an indication given of limit exceedence. These parameters would require an extension of the computer hardware and, in the case of vibration monitoring, probably external transducer processing.

(iii) Engine Failure

Although the prime requirement here is to detect run down situations, the control cannot really be relied on for this since these faults may be caused by the control itself. It is possible however, to provide limited failure warning indication via the control computer by detecting such fault conditions as excessive temperature for a given speed or low engine power at a given temperature.

( iv) Engine Usage

As a background task for the control computer, a monitor of critical engine usage (low cycle fatigue, high cycle fatigue and creep life) can be provided with data storage for subsequent readout. The definition of how these parameters are derived is beyond the scope of this paper, but apart from being of interest to engine stressmen, engine usage monitoring can pay dividends in cost of ownership terms. Ultimately engines may be released without lives as such - overhauls being undertaken as and when necessary as judged by the usage of the fatigue cycles of critical components. Whereas a reasonable basis exists for such life assessment on fixed wing scheduled airline services, using the operational pattern of the aircraft, helicopters have no similarly predictable characteristics and bearing in mind the virtual impossibility of pilot evaluation of the fatigue cycles then an automatic monitoring system here would certainly be worthwhile.

## 4. Future Form of Monitoring Interfaces

The pushbutton control interface described in para. (ii) and shown on Figure 3 can be extended to include the monitoring performed by the basic control as shown on Figure 4.

The annunciation of control faults is via a red warning of "freeze" on the warning panel (or of "fail" if a run-down situation exists) together with an amber on the control panel for degraded control faults. Limit exceedence monitoring is indicated by amber rating lights on the control panel: other parameters such as vibration exceedence would require an extension to the indicating system. The limited engine failure detection capability of the control would also signal the pilot through the red "fail" on the warning panel.

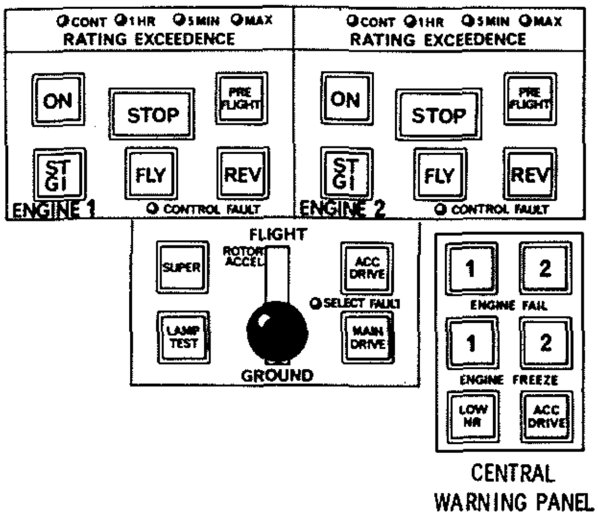


FIGURE 4 - CONTROL + LIMITED MONITORING INTERFACE (TWIN ENGINED HELICOPTER)

To obtain engine usage information from the control would require either ground based test equipment or some form of built-in interrogation arrangement. This latter represents a significant addition to the monitoring system which really becomes attractive only when its capabilities are utilised for more than usage information readout.

5. Extended Capability Control/ Monitoring Interface

Figure 5 shows a functional form of interface not only allowing readout of monitoring data but also entry of data for both control and monitoring purposes. It should be emphasised that Figure 5 is diagrammatic only and that the actual form of the console would need to be designed to be compatible with the overall cockpit. A simpler arrangement restricting the number of pushbuttons on the facia could well be feasible, as could a more advanced display system based on a cathode ray tube (CRT). The latter would allow the simultaneous display of several different parameters in digital, analogue or even graphical form, the actual display depending on the monitoring function.

The readout capability can make available on interrogation recorded usage data and also diagnostic information following the detection by the control computer of fault conditions. In addition pilot cues for system checkout could be provided, as could an accurate readout of the value of a number of selected parameters (speeds etc.) if required.

Although the use of digital techniques overcomes to a large extent the necessity for external adjustments of offset, datum drift etc., there may still be the necessity to set up the control to match specific engine or aircraft characteristics. The data recovery facility described would probably communicate with the engine control computer via a data highway and therefore the addition of limited authority adjustments to the control may be implemented using the same highway and a data entry panel.

The general configuration of the interface can now be seen as capable of allowing detailed information to be output from a more comprehensive system dedicated to monitoring the overall engine health and performing some general aircraft management functions. Such a total aircraft health monitoring system can have many important benefits both to the pilot, the ground crew, and last but by no means least, the aircraft operator.

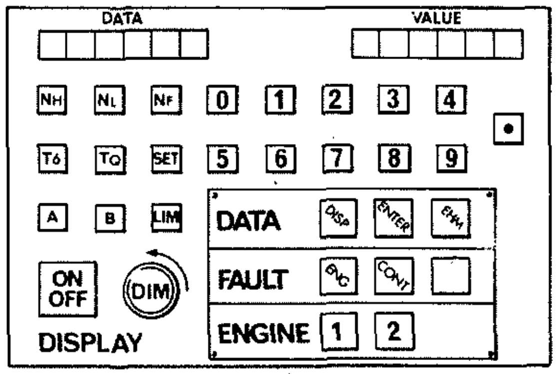


FIGURE 5 - ADDITIONAL CONTROL/MONITORING INTERFACE

## TOTAL AIRCRAFT HEALTH MONITORING SYSTEM

Though possibly only part of an even more comprehensive aircraft system, the scope of this paper only allows consideration of essentially the engine - related features of an aircraft health monitoring arrangement. The objectives here can be stated as:-

- Reduction of operating costs by providing the ground crew with appropriate data to take timely maintenance action, avoiding unnecessary work.

- Improvement of engine operating lives by accurately monitoring cumulative damage to critical components.

- Reduction in aircraft downtime by assisting in the diagnosis of engine and control malfunctions, including those caused by engine mechanical or aerodynamic deterioration.

- Reduction of pilot workload in flight by automatic monitoring of the engine and its control.

- Enhancement of the mission capabilities of the aircraft by providing pilot data relating to aircraft/engine performance on a "need to know" basis.

Not all operators would require or at least would be prepared to pay for such comprehensive capabilities and therefore to achieve the various levels of monitoring appropriate to each customer a modular system is desirable. We have seen that when engines are fitted with digital control some levels of monitoring can be incorporated within the basic control unit. As the complexity of health monitoring is increased, a point will be reached where it is more beneficial to acquire the data and output it for processing separately. The detail configuration of the total system must be a compromise between engineering and commercial pressures, and this is where the advantages of the integrated control and monitoring approach become most apparent since completely separate control and monitoring systems implies some duplication of both function and hardware. A certain amount of this may be inevitable to achieve the right levels of integrity but there are areas (such as the cockpit interface) where the two systems naturally come together and where integration can be more cost effective.

The total health monitoring system is therefore envisaged as the basic digital control computers performing limited monitoring tasks as described and communicating information to the pilot via the monitoring interface, together with microprocessor based data acquisition units providing information to a separate health monitoring central processing unit (CPU) which also communicates with the pilot through the interface. Figure 6 shows diagrammatically the system configuration: the control systems may be considered as operating in parallel with the data acquisition units and providing additional data to them.

With urgent tasks such as limit exceedence being undertaken by the digital control, the health monitoring dedicated CPU can even out its logic and computation workload, thus allowing a modest size of unit which can be maintained at a high utilisation level. The CPU would be connected to both engine and aircraft data sources, the monitoring interface and a data silo using suitable data highways with the necessary isolation for integrity.

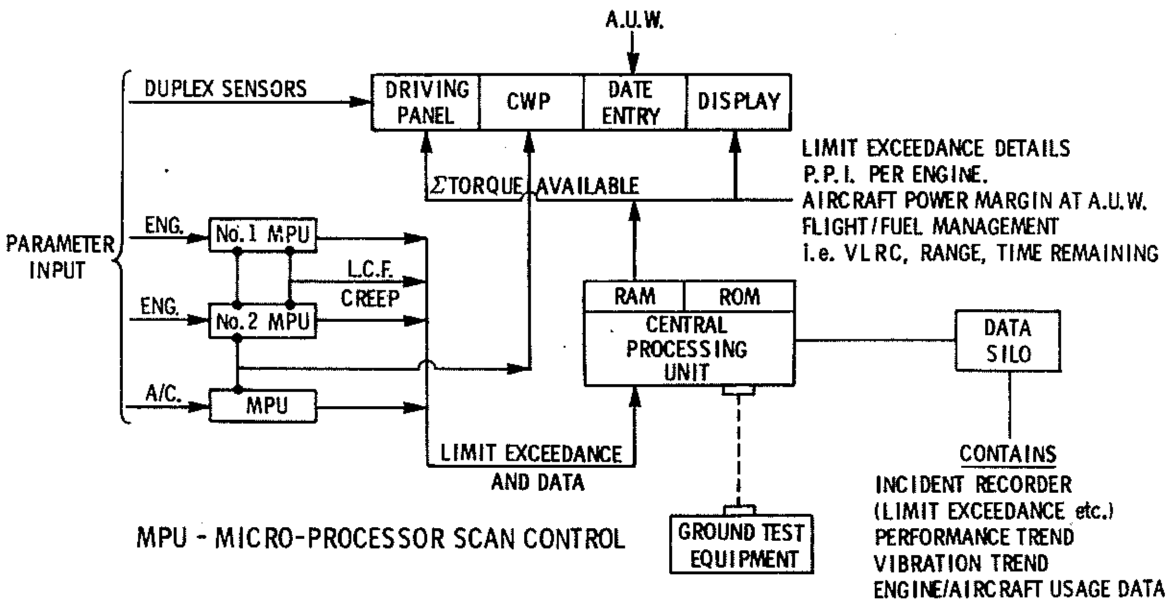


FIGURE 6 - INTEGRATED TOTAL HEALTH MONITORING SYSTEM

Basic integrity of the system can be further assured using CPU self checking procedure similar to those used for control, with a limited amount of duplicated processing for critical parameters carried out within the digital control. This ensures retention of vital data in the event of a system fault and also allows the next logical stage in the evolution of the total health monitoring concept to be considered, namely the removal of current pilot's monitoring instrumentation altogether and the substitution of fully automatic montitoring together with a display on demand of "essential" data. The operation of the total health monitoring system against the objectives stated earlier would be as follows.

(1) Maintenance Data for Ground Crew

Information concerning the engine behaviour since the last maintenance activity (general deterioration and health, life usage, oil or fuel system maintenance etc.) can be recovered either from alterable non-volatile read only memory within the system, using the cockpit data display for routine maintenance, or from the data silo using ground based equipment in the event of a major problem.

(2) Engine Usage

Low cycle fatigue and, where relevant, high cycle fatigue and creep life would be recorded and the relevant information made available for scheduling of aircraft maintenance or operational activities. Where on-going operation of the engine depends on the continuing accuracy of this data (i.e. the engine is released on a usage basis rather than with a defined life in hours) then separate records may be kept in the control computer and in the health monitoring CPU.

(3) Engine Defect Diagnosis

Assuming no major engine malfunctions occur, any deterioration of performance or increase in vibration will be slow. It is therefore necessary to take sample trend data during each flight which would be passed to the data silo. This will allow the ground station to look at trends over a long period and ascertain when irregularities are occuring. On-board processing of the information as a post-flight task would be possible though incurring a hardware penalty. The subsequent display of meaningful trend data from the processing would probably only be possible using a C.R.T. display as a pilot/ground crew interface.

Careful monitoring of trend patterns can often highlight a potential defect in the early stages, thus aiding maintenance forward programming. For major faults, it is proposed that both the engine and the aircraft data acquisition units continually pass data to a limited store in the data silo. This would contain the last few seconds or minutes of the flight prior to the fault occurring as an Incident Recorder.

Mechanical condition of the engine would be monitored using separate tracking filter units to assess each engine rotor out of balance. A vibration exceedence warning can be provided to the pilot, with further information available on demand from the pilot or ground crew.

Aerodynamic deterioration of the engine may be considered a "fault" situation only when it prevents the aircraft performing its mission. What is really needed is power margin measurement, assessing for the particular aircraft conditions how the predicted capabilities of the specific engines compare with the aircraft power demands under both normal and engine failure conditions. When a negative power margin exists it would be necessary to indicate a fault, with further diagnostic data being then available through the stored trend information or via the Incident Recorder. Power margin measurement is more fully discussed in a later paragraph, together with its use as a flying instrument rather than a fault indicator.

(4) In-Flight Monitoring

The replacement of the pilot function of monitoring such parameters as oil pressure and temperature by a simple automatic routine within the total health monitoring system should now be seen as a relatively straight-forward step. Control monitoring, limit exceedence, limited engine failure and engine usage monitoring have also all been discussed previously: with a separate health monitoring CPU and suitable transducer fit the system configuration should allow 100% engine health monitoring (including full control and engine failure detection), with the capability of surviving a single fault whilst retaining essential monitoring services. It is therefore argued that the provision of cockpit instruments is superfluous, their function being undertaken totally automatically. Again, the cathode ray tube form of interface would allow a flexible display format with diagnostic data on engine conditions visible immediately following detection of a fault or on demand by the pilot. Warning lights as previously described could provide independent fault/limit data in the event of a C.R.T. failure.

(5) Enhancement of Aircraft Capabilities

The foregoing description of the general technical capabilities of a total health monitoring system could be summed up by saying that, apart from adding one or two functions, the system can do what is currently done but very much better and with a much reduced pilot workload. Under some circumstances perhaps single pilot operation could become possible where before two were necessary, but in terms of an enhancement of capabilities this may not be seen as an overwhelming advantage. To an extent it would seem to be the aircraft manufacturer's prerogative to use the system capabilities to extend market appeal, but the following are given as examples of what is possible.

( i) Fuel Management

Whilst not strictly a health monitoring function more efficient aircraft fuel management can be obtained without unrealistic pilot workload by monitoring fuel states, aircraft speeds and range. It is assumed that a NAV-AIDS system can provide distance to base and vectored wind speed data, and that Flight Manual standard data such as maximum and optimum sustained speed for a weight and aircraft specific range are stored in the program. From this data and engine fuel flows, Instantaneous Specific Range can be calculated. A final specific range can be calculated based on an all up weight (AUW) with only reserve fuel. The average of these figures versus fuel content enables a calculation of range: as this figure approaches distance to base, the pilot can be advised that he has only X minutes before a return to base is necessary. This figure would also be available on demand at any point in the sortie together with the optimum cruise speed.

( ii) Flight Instruments

It is claimed that there are two really essential aircraft flying instruments associated with the engine, namely the power turbine/rotor speed indicator and the torquemeter - although other engine instruments are currently provided as well (see para. 1.) The case for a traditional rotor speed gauge is probably irrefutable unless it is accepted that the information need only be presented on a "need to know" basis, i.e. if the rotor or free turbine departs from its nominal value or range by more than, say 5%. It is doubtful if this "no news is good news" arrangement would really find ready acceptance and therefore in questioning the form of the essential instrumentation we will confine ourselves to the torquemeter only.

In a preceding paragraph reference to the use of an aerodynamic condition monitor as a fault diagnostic aid was made. In the context of an updated torquemeter display the monitor program resident in the health monitor CPU would contain a program assessing the potential power currently available from the engines and a program calculating the power required to fly the aircraft at the AUW and outside air temperature of the day. The former program would search for suitable steady state performance data and produce a matrix of power versus other parameters needed to define the aerodynamic state of the engine. This matrix will be continually compared with an aerodynamic model of the engine to perform data verifications. Any genuine change in the engine state will show a proportional effect on a number of parameters: if only one parameter is shown to be excessively outside this pattern, a fault warning will be generated. Once validated, this performance matrix will be used to update a data file periodically, say every 2 minutes. The data file may be used to compute the sum of potential power currently available from both engines or from the "worst" one. These figures can be directly compared on a revised torquemeter with the power requirement for the aircraft calculated using Flight Manual data or data derived from other on-board computation. The AUW figure would be input into the system prior to take off and updated during the flight from data produced by the fuel management program.

It should be noted that a less accurate version of this power margin indicator may be feasible with the basic control computer only, which would be used to predict the engine maximum power capability approximately. The torque indicator then uses the combined actual output torques from the engines to provide an actual total torque indication on one needle. Where an individual engine torque exceeds an aircraft limitation for the relevant number of engines operating, a warning of this may be given in the form of an indicator light. The torque indicator also includes a second needle which denotes the predicted maximum output torque capability of one or both engines. Thus in a high power condition or where the loss of an engine could hazard the aircraft, the pilot will be able to assess from a single indicator not only the total available torque margin but also the margin in an engine-out situation.

## DISCUSSION

This paper has not set out to describe any fundamentally new principles of control or engine health monitoring (EHM). What has been attempted is to define those features of control and monitoring which can be seen to have a close relationship, particularly where both aspects employ digital technology. By doing this, it has been argued that control and EHM can logically be integrated. This in turn implies that the total system capability and cost effectiveness is improved if it is recognised from the start that such an integration is possible, in that the control and EHM components of the system can be designed to be complementary to each other with duplication only where necessary for integrity. The approach allows the development of a modular EHM system, with basic functions available with the digital control by relatively minor extensions to its capabilities. The paper suggests that the advent of digital control should transform the interface between the pilot and his power plants: Figure 7 summarises this new interface.

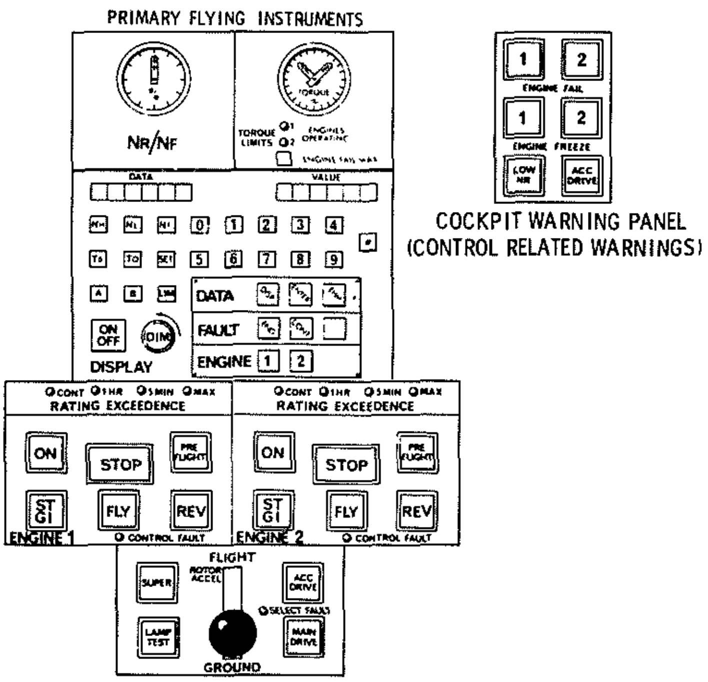


FIGURE 7 - MAN/MACHINE INTERFACE SUMMARY

Certain features of the interface suggested may be considered as controversial, such as the fly-by-wire control arrangement. The intention is to show what is possible if a sufficient determination exists to exploit the capabilities of digital systems. The trend in sophisticated military aircraft is certainly towards total fly-by-wire with the power plant seen as a sub-system addressed from a centralised digital data highway. It is suggested that this approach will eventually spread to helicopters, to reduce the pilot's workload in flight and to make most efficient overall use of the aircraft. In any event, why should the man/machine interface not be different? Perhaps mechanical levers do have a nice solid "feel" to them, but at some point the motion of metal rods must be translated into the motion of electrons and why not at source?

Although there are references to the difficulties of pilots in performing many monitoring tasks, it is recognised that helicopters have been flying very successfully for many years and therefore they undeniably have acquired adequate proficiency at it. However, piloting a helicopter is only a means to an end and there is little virtue in making the job more difficult than it need be. This is really why it is suggested that the total man/machine interface should be reconfigured, to allow a better monitoring job to be carried out automatically. Digital technology allows this to be done, and the resulting system capability is vastly superior in total aircraft health monitoring to the present "eyeball" arrangement.

Inherent in much of the foregoing is an acceptance by certification authorities of the approach taken. This paper is by no means a detailed system definition and much design work would need to be done to configure the system such that all operational and failure criteria are satisfied. It is believed that it could be easier to satisfy civil agencies on the system design than some military procurement authorities which specify how a job shall be done rather than what end result is required.

The technology to achieve the integrated system proposed basically exists. Rolls-Royce are currently involved in the design and development of digital controls for helicopter engines which could form part of such a system. Parallel EHM programmes are also in progress within Rolls-Royce aimed at full understanding of the technology, developing the software necessary to derive meaningful EHM data from helicopter engines in flight and also developing some of the necessary hardware. Significant experience has been gained in on-board digital data acquisition and with subsequent processing of data to produce engine usage and condition read-out.

The question arises as to whether any but the most complex helicopters could be fitted with such an integrated system from the cost viewpoint alone. The answer probably depends on the aircraft manufacturer's attitudes towards first cost and life cycle cost issues. Certainly the first cost is significantly higher and if this is seen as the overriding consideration then the answer is self-evident although there would be some associated reduction in the aircraft costs due to installation and instrumentation savings. If, however, the cost of ownership is seen as more important then such a system must have major advantages. It is, however, difficult to quantify these until the detail design of the system has been completed and costed and the benefits defined in terms of maintenance reduction and aircraft utilisation improvements. Some of the benefits are less tangible, for example a lower pilot workload which could lead to improved flight safety is not likely to have any attributed cost savings.

Another major difficulty in achieving further progress towards a system having the capabilities described in this paper is that it requires a number of different design and procurement areas of the aircraft to be embraced. Agreement must be reached between all interested parties as to overall requirements and system configuration: it is hoped that this paper will provide the basis for further discussions within both the engine and the aircraft industries.

## REFERENCES


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