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DIGITAL ELECTRONICS ON SMALL HELICOPTER ENGINES

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ABSTRACT

Hydromechanical controls, torque meters and mechanical usage counters have been applied over the life of helicopters with varying degrees of success. Achieving satisfactory operation through mechanical routes has not been a problem for control and torque measurement but accuracy, cost, mechanical complexity and associated reliability are not very much effected by engine size and so design and cost improvements became heavy burdens on small engines. In the case of engine monitoring the parameters and sophistication of monitoring are very limited in purely mechanical devices.

The availability of processors able to withstand aircraft environments has opened up a large range of possibilities for control, measurement and monitoring in the small helicopter engine. This paper surveys recent experience in exploiting the available technology on Rolls-Royce helicopter engines. It reviews the evolution of electronics on Rolls-Royce helicopter engines and considers how and why digital technology is being adopted and considers the problems that it introduces and how they have been overcome.

BACKGROUND

In the late 1950s an electronic analogue control system was fitted to the Gnome engine and an updated version of this is still current production equipment. Its performance is good, but its cost, weight and maintainability are not competitive for a current new design. In the 1970s a digitised version was considered in depth, but the decision was taken to update the analogue version because the then available digital components were less attractive and the launch cost could not be seen to be justified (Figure 1).

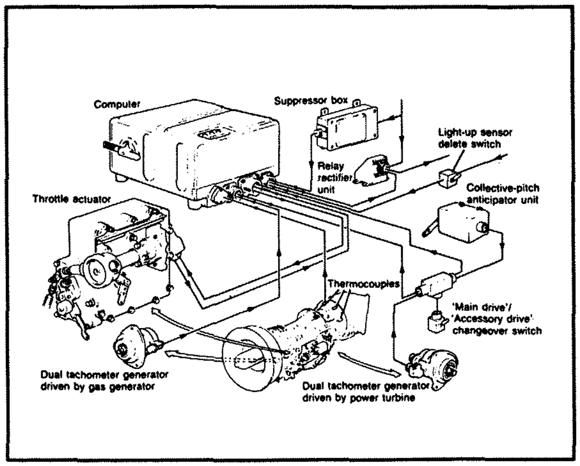

Figure 1 Gnome – Analogue control – 1960s

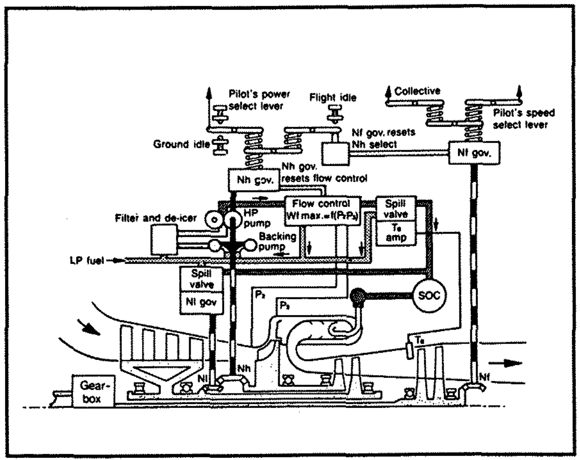

Figure 2 Gem – Hydromechanical control – 1970s

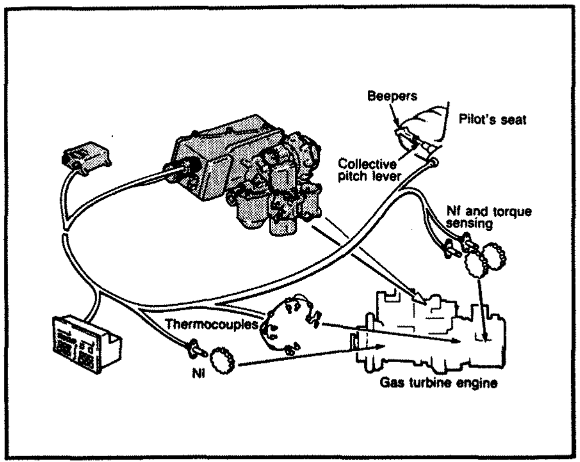

Figure 3 Gem – Demonstrator digital control

By 1979, when an update of the Gem (Figure 2) was undertaken, it was deemed that the technology was available to achieve a replacement digital control system for significantly lower first cost, with similar performance to the existing hydromechanical control and the prospect of a marked improvement in reliability and cost of ownership. We had carried out demonstrator programmes (Figure 3) to give confidence and a significant decision was taken not to mount the electronic part of the control on the engine, as it had proved very difficult to provide a cool, low vibration environment on high speed small gas turbine without considerable complexity. Figure 4 shows the layout selected, Figure 5 compares the Gnome analogue system with the Gem digital and Figure 6 the replacement unit installed on a Gem.

Roughly in the same timescale, the torquemeter for the Gem was updated and again an aircraft mounted microprocessor based system was selected to replace an electronic analogue system.

The monitoring systems have lagged behind because of lack of customer demand. Three demonstrator programmes have been completed varying in complexity and in the amount of onboard data processing carried out. This has now reached the stage of development for a sophisticated degree of monitoring, fully self contained and again aircraft mounted.

PROGRAMME HIGHLIGHTS

1. Digital Engine Control

There is a danger in turning this sort of presentation into a catalogue of the problems encountered. It is of course the aspects which do not work which are technically more interesting to engineers, but tend to mislead the unfamiliar about the overall success of the programme. It is common engineering experience that few things work first time and the nearer one is to the boundaries of established technology, the more likely it is that there will be problems. The Gem digital control was the first production committed helicopter control to be launched and was the first to get a civil air worthiness ticket. The point being that there was at that time, no established experience beyond demonstrator programmes, which one could look to for guidance.

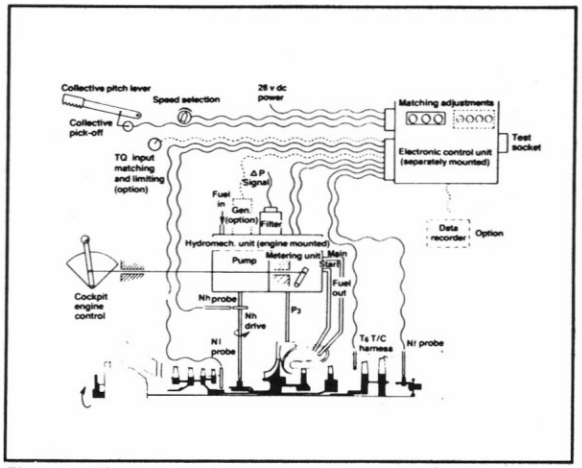

Figure 4 Gem – Digital control – 1980s

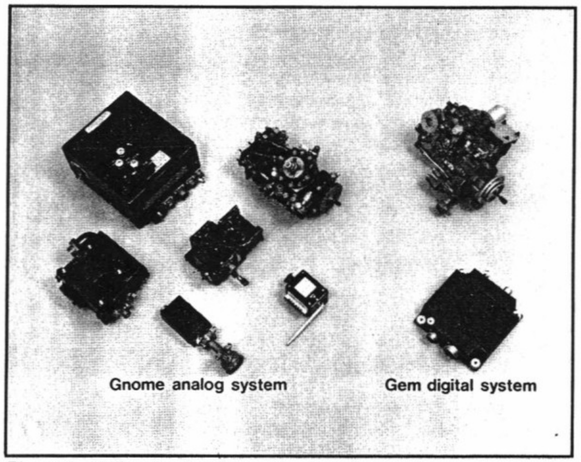

Figure 5 Full authority electronic control systems

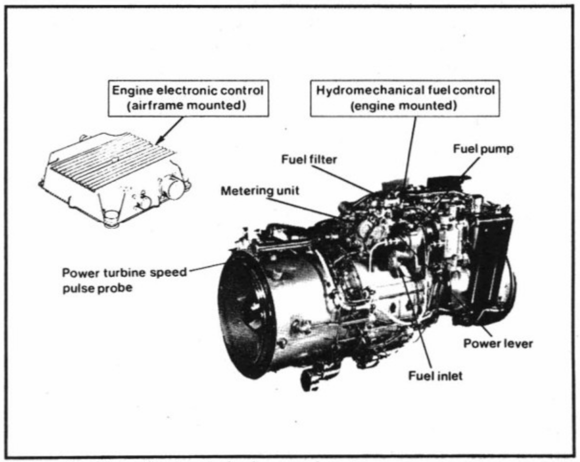

Figure 6 Gem electronic fuel control system

a) Available programme in the microprocessor

From an initial estimate of requiring approximately 2K of program memory to achieve the required sophistication of control, a micro processor with 4K was chosen. The detail work up to the first run had used most of the available capacity, and resolving the first 'off design point' problems quickly absorbed the rest as the development proceeded through bench test to flight test. Since then the limited capacity has been significant but bearable restraint, and a programme to launch a bigger capacity microprocessor is under discussion. These have now become readily available. Figure 7 shows some of the impacts of memory size.

b) Critical Category for Software

At the time of launch the certifying authorities had given little thought to the implications of software control. As we approached engine certification it became clear that software only cleared to 'essential' level, would lead to the assumption that a similar software 'fault' could occur simultaneously in both engines of a twin engined helicopter. The aircraft, therefore, would have to be cleared to fly with both engines' digital controls failed. Although this has been since shown to be achievable by a test pilot using the manual facility, it is highly undesirable and implies a complex reversionary system to avoid an unacceptable operational impact. It was possible and therefore, simpler to establish 'critical' approval of software where the certifying authorities will not assume that simultaneous software 'faults' can occur. This is now our normal requirement for helicopter engine controls.

Small Memory

- Requires compact software written in machine code
- 4 man-years to justify approval
- Difficult to change as large areas of programme changed

Large Memory

- Permits modular software which is independent of programmer
- Each small module separately validated
- 1 man-year to justify approval
- Easy to change as each change has only local effect

Figure 7 Critical category approval of software

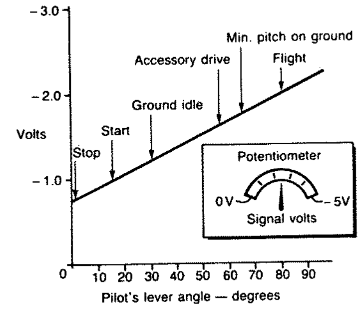

Figure 8 Pilot's lever angle vs potentiometer volts

c) Reliability

No significant problems of reliability have been encountered within the basic electronic control. However, the very low levels of voltage and current inherent in electronics has resulted in a number of detailed problems with the 'ears and Eyes' of the system, ie: the electromechanical transducers. An intermittent fault is often quite tolerable in a measuring system or in conjunction with an analogue control. In the case of a digital control it responds all too well to an inaccurate signal. When the full signal variation from min to max may be as little as 1 volt one must have integrity to better than 10 millivolts. Sliding contact potentiometers have been particularly troublesome, and pulse probe speed signals little better. Rigorous attention to detail design is absolutely essential to provide signals with good margins and high integrity. Figure 8 shows the potentiometer arrangement used on the Gem.

d) Electrical Failures

In the civil scene in particular, the integrity of the system, particularly of the overspeed protection, under electrical supply fault conditions was a further area where certification requirements have matured. Self powering or an appropriate high integrity aircraft power supply is necessary: in addition a completely independent overspeed trip is necessary to fully meet the requirements. This complication is much more severe than is required for a mechanical overspeed device where the mechanical reliability is more readily assessed and is based on a lot of experience.

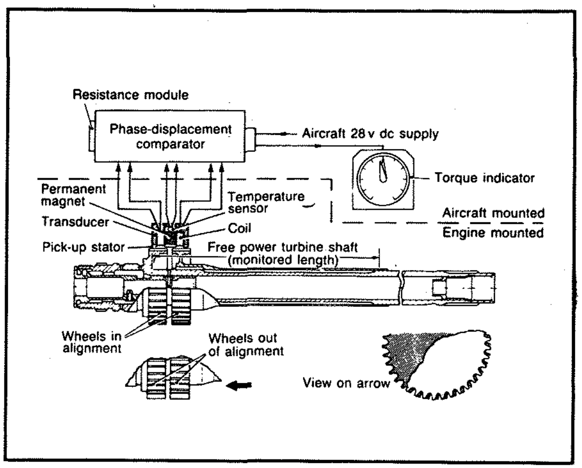

Figure 9 Torquemeter operation

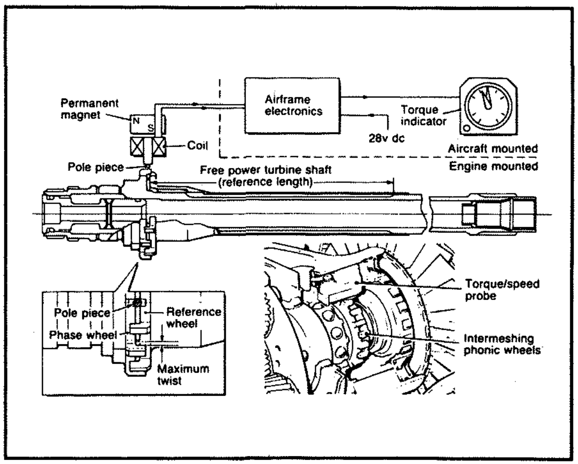

Figure 10 Monopole torquemeter

2 TORQUEMETERS

The experience here has been relatively painless. The parameter is used as an active control parameter and we have demonstrated the virtue and practicability of doing so. Compared to the control system, the computational task is simpler, and this combined with sound attention to detail has resulted in a high integrity unit with good reliability. It suffered from a similar maturing of certification thoughts and the original concept of the torque from both engines in a twin engined aircraft being computed in one box from one set of power supplies had to be abandoned because of the importance of the torque measurement in a helicopter and because the original design had common failure modes which could lose the indication from both engines. Figure 9 shows the original Phase Displacement System and Figure 11 the replacement digital system.

User Features

It is standard practice to use built in test features within the computer program of this type of system. Sophisticated self diagnosis can be built in. The maintenance task can thus be considerably simplified, quicker rectification action taken in response to a fault, requiring less skill from the maintenance staff, and keeping the helicopter operational more of the time.

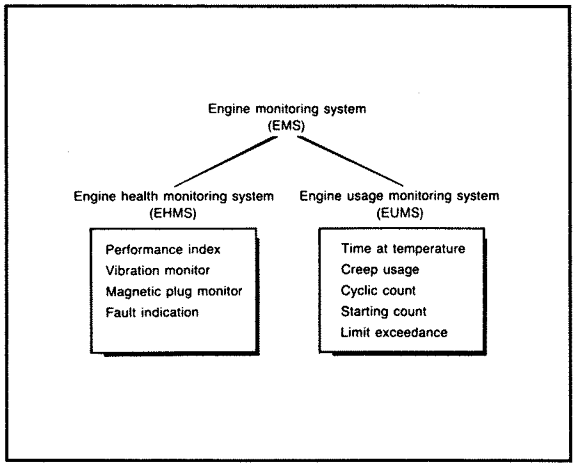

Figure 11 Engine monitoring definitions

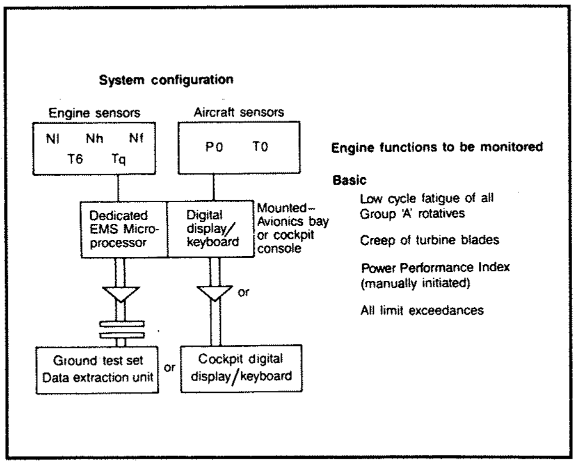

Figure 12 Engine monitoring system for Lynx 3

3. ENGINE MONITORING

The benefit of monitoring systems occurs entirely in the operational phase of the aircraft. The impact on first cost in providing the hardware for transducers and computation is wholly adverse - it just costs more money and weight to install the equipment. This has meant that customers have been much more reluctant to commit themselves. Figure 11 distinguishes between Health Monitoring and Usage Monitoring and Figure 12 shows the block diagram layout employed in the Gem/Lynx system. Satisfactory results from various levels of sophistication of monitoring on demonstrator programmes have all shown potential overall cost benefit. One of the more interesting evolutions of exploiting such a system has been to use the monitoring aspect to break away from the traditional rating structure for an engine and hence have a direct impact on the first cost of the power plant by increasing the power at critical points of the envelope so reducing the effective cost per horsepower. This will undoubtedly accelerate its acceptability, but has involved a major re-think of the certification aspects of an engine development programme and will no doubt lead to revisions of current certification authority rules. We regard this as a very healthy development and it will bring the gas turbine in helicopters more into line with conventional vehicle propulsion systems to greatly simplify the work load of pilots and maintenance staff. Figure 16 shows how we would propose to exploit EMS in modifying the Rating Structure for a Military Application.

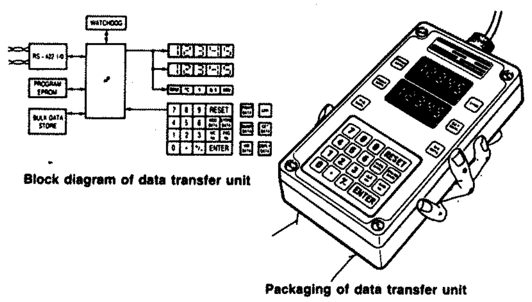

Figure 13 Read-out of store EMS data

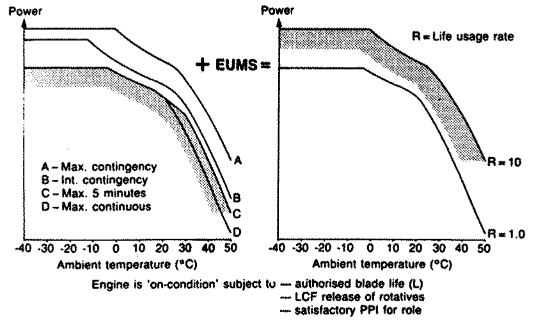

Figure 14 Engine performance benefits from EUMS