



INTRODUCTION OF THE RTM322 ENGINE INTO THE EH101 HELICOPTER

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## ABSTRACT

The contract for the EH101 Integrated Development Programme includes the parallel development of the Royal Navy (RN), Marina Militare Italiana and civil variants. The Rolls-Royce Turbomeca RTM322 engine has been selected to power the RN variant.

The RTM322 is based primarily on the achievements of a series of advanced engineering demonstrator programmes, including development of the Full Authority Digital Engine Control (FADEC) system. The engine was introduced into the EH101 programme on Pre-Production aircraft 4 (PP4). Installed engine ground testing commenced in February 1993, leading to the 160 hour flight programme which began on 6th July 1993.

This presentation covers features of the engine and its FADEC system from the initial development and flight testing conducted by RRTM through to introduction into the EH101. The collaborative integration and test programme to date will be discussed.

## LIST OF ABBREVIATIONS

Ag	Agusta Spa
AMS	Aircraft Management System
CCOC	Combustion Chamber Outer Casing
CLP	Collective Pitch
EECU	Engine Electronic Control Unit
EHI	European Helicopter Industries
FADEC	Full Authority Digital Engine Control

FM	Frequency Modulation
FMU	Fuel Metering Unit
ICD	Interface Control Document
IFM	Interface Memorandum
MoD	Ministry of Defence
MODAS	Modular Data Acquisition System
MMI	Marina Militare Italiana
NG	Gas Generator Speed
NP	Power Turbine Speed
NR	Main Rotor Speed
PP	Pre-Production
RN	Royal Navy
RRTM	Rolls-Royce Turbomeca Ltd
TGT	Turbine Gas Temperature
TQ	Engine Torque
VIGV	Variable Inlet Guide Vanes
WF	Mass Fuel Flow
WHL	Westland Helicopters Ltd

## 1 INTRODUCTION

### 1.1 EH101 Background

The contract for the EH101 Integrated Development Programme was signed in 1984 and included the parallel development of the Royal Navy (RN), Marina Militare Italiana (MMI), utility and civil variants. The design, development and manufacture of the EH101 is a collaborative venture between Agusta, Westland Helicopters and their respective governments. To manage the EH101 project Westland and Agusta created a management company called European Helicopter Industries (EHI). The power plant selected for the pre-production aircraft was the GE CT7-6/T700-401A. In 1988 the UK government announced at Farnborough that the Rolls-Royce

Turbomeca RTM322 engine had been selected to power the RN EH101 aircraft, now called the Merlin.

Following the necessary structural and electrical redesign to accommodate the new engines, Pre-Production aircraft 4 (PP4) was modified from September to December 1992. On 6 July 1993 EH101-PP4 successfully carried out the maiden flight of the EH101 helicopter with RTM322 engines fitted. This flight marked the commencement of a 160 hour flight test programme which will be discussed later.

### 1.2 RTM322 Background

The RTM322 development programme was launched by the established partnership of Rolls-Royce Turbomeca in 1983. The objective was to produce a low cost, rugged, modern technology certificated turboshaft engine compatible with existing and future helicopter applications. In addition, the engine was to have proven reliability and built-in growth potential from an initial take-off rating of 2100 shp. These requirements were to be achieved through a process of technology demonstration, followed by extensive design verification and reliability proving activities.

partner companies. The RTM322 is a direct descendant of these activities, shown in figure 1, representing an amalgamation and exploitation of the demonstrated advanced technologies.

This strategy minimised risk in the RTM322 development programme whilst enabling the production of an essentially simple, rugged design for intrinsic reliability, see figure 2.

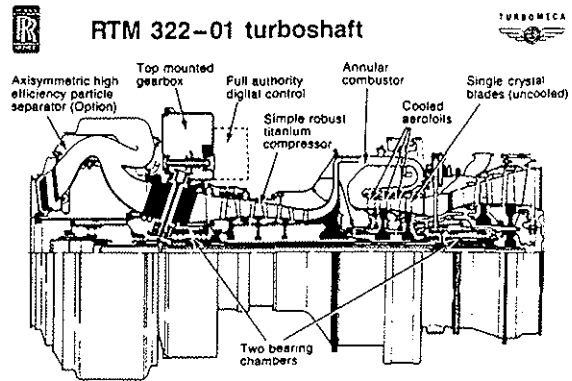


Figure 2 - RTM322-01 Engine

In 1986, the development programme was further enhanced by the purchase and conversion of a Sikorsky S70C helicopter to RTM322 powerplants, coupled with installation of comprehensive instrumentation. This dedicated flying test bed has been invaluable for the full evaluation and demonstration of successive engine and control system standards, the most recent activity being with EH101 specific control software.

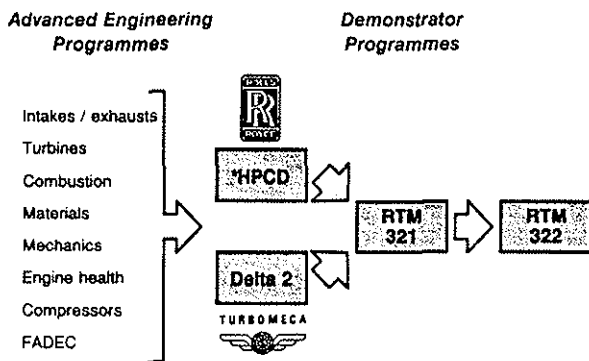


Figure 1 - RTM322 Background

Advanced technology demonstrator programmes, specifically designed to address high risk areas of new engine development, were already in place at the



Figure 3 - RTM322 Powered S70C

## 2 FADEC SYSTEM DEVELOPMENT

Development of the Full Authority Digital Engine Control system has represented a major part of the total S70C activity, as shown in figure 4. This system is able to combine sophisticated, carefree, engine control performance with simplicity of operation, so minimising pilot workload regarding the engine management task.

Single channel FADEC/Manual back-up

- Batch 1 engines in S70C
  - Basic engine to aircraft integration
  - Operation in both FADEC and manual modes
- Batch 2 engines in SH60B
  - US navy assessment
  - Requirement for continued mission capability



Dual channel FADEC



- Batch 5 engines in S70C
  - System operation and performance
  - Failure management
  - Functional revisions
  - EH101 specific items
- Batch 5 engines in EH101
  - Merlin integration programme

Figure 4 - FADEC Development

The initial flight configuration comprised a single FADEC channel coupled with a mechanical back-up facility, via which the pilot could directly modulate fuel flow. Whilst satisfactory for a "get home" facility, the back-up system characteristic was not considered to be mission capable as initially identified by the US Navy following

their assessment of the engine. This dictated upgrading of the system to its present dual channel configuration, which now satisfies the requirement for continued mission capability in the presence of a control system fault. In reality, failure management arrangements within the dual channel system enable mission performance to be maintained in the presence of most multiple faults, as will be seen later. This system directly benefits mission effectiveness by provision of these intrinsically simple, carefree, fault tolerant, engine handling characteristics.

## 3 ENGINE HANDLING AND CONTROL

The RTM322 FADEC system permits the use of a simple pilot interface in the helicopter for engine control. Figure 5 shows the interface panel as installed in the EH101, where start-up, transition to/from rotor governing and shut-down operations are combined into a single rotary condition switch for each engine.

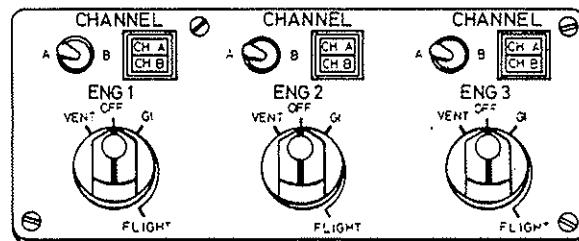


Figure 5 - Engine Control Panel in EH101

Carefree handling is afforded by the FADEC systems, which provide the following automatic control features.

- Start sequencing
- Rotor run-up limiting
- Isochronous governing
- Load sharing
- NG and NP transient limiting
- Load demand anticipation
- Engine limiting
- Contingency selection
- VIGV and bleed valve positioning
- Surge and flame-out protection
- Continuous Built In Test
- Comprehensive failure management

# RTM 322 FADEC - System Diagram

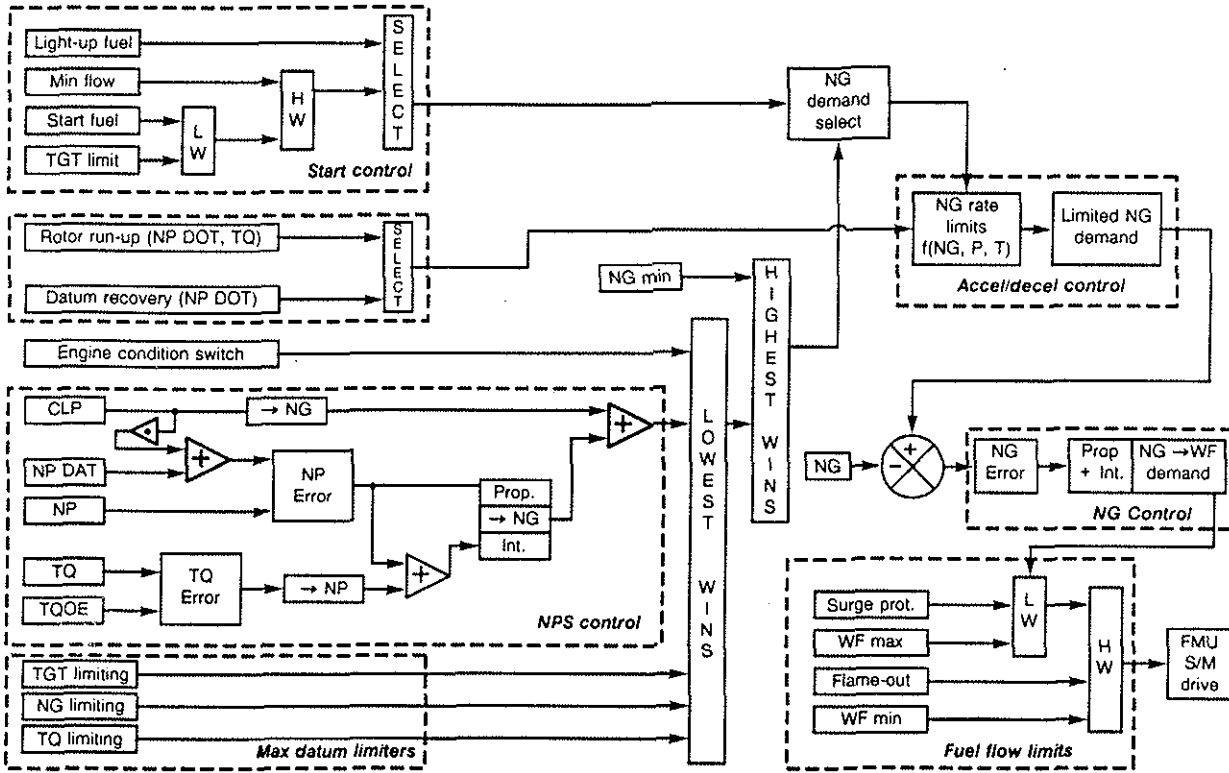


Figure 6 - RTM322 Fadec System Diagram

The methods employed in the FADEC to provide these features are illustrated in the simplified system diagram, figure 6, functions of which are briefly described below, supported with some S70C flight test data.

### 3.1 Starting and Rotor Run-up

The starting sequence is initiated by selecting the condition switch to Ground Idle. Operation of the starter air valve, fuel valve and ignition unit, coupled with acceleration and top temperature scheduling, to achieve a governed idle condition is commanded by the FADEC with no further pilot action.

Advancing the condition switch to Flight runs the rotor up into governing, subject to an interlock for rotor brake protection. The rate of condition switch movement is

unrestricted, slam inputs can be made which will invoke power shaft rate and torque limiting to automatically respect aircraft transmission limitations.

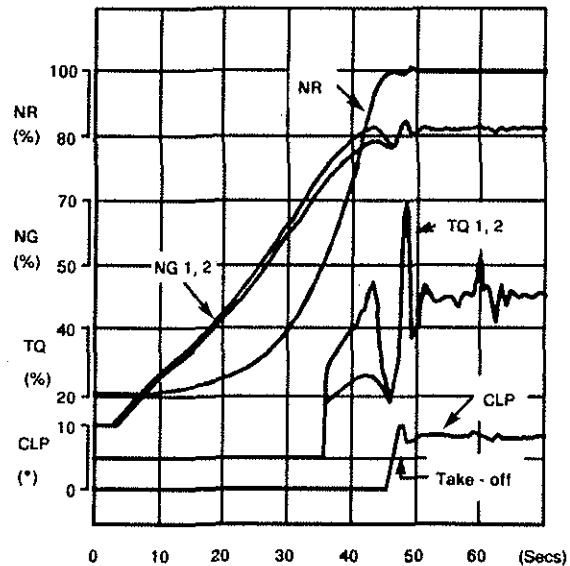


Figure 7 - Twin Engine Scramble Start

In the event of operational circumstances demanding an immediate scramble, a twin engine start can be conducted, directly to Flight, permitting lift off as soon as rotor governing is achieved. Typically, lift-off can be achieved within 50 seconds of selecting start by this method, with no further pilot action required on the engine controls, figure 7 illustrates the event.

### 3.2 Governing and Matching

The system provides truly isochronous rotor speed governing, single or multi-engine, coupled with precise torque matching over the whole power range, at the default, or pilot selected governing datum. These characteristics are achieved by a collective pitch based gas generator speed demand, in conjunction with proportional and integral components, which are responsive to rotor speed and torque matching errors. Load anticipation is included, signalled by the collective pitch input, to provide tight transient rotor speed control during gross power changes. The rate of rotor recovery to datum is also scheduled, through adaption of the run-up rate limiter, to minimise peak torque levels during vigorous, unrestricted handling.

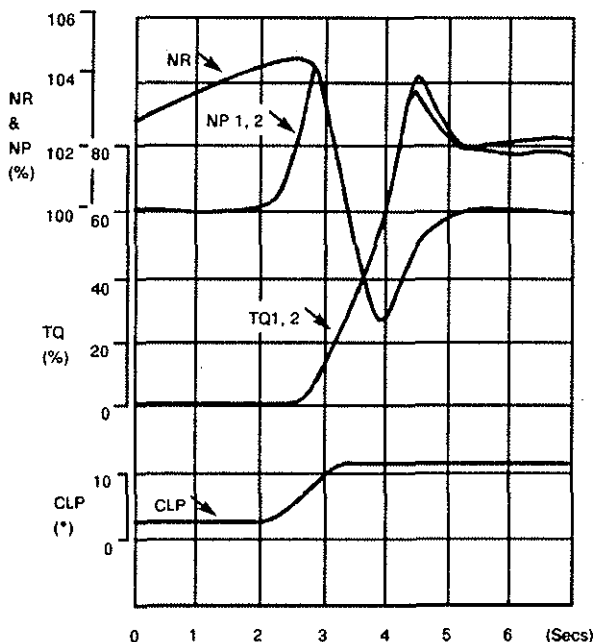


Figure 8 - Pitch Application From Split

A particular benefit of the load anticipator is revealed when pitch is rapidly applied from an autorotative condition, where the rotor is initially split-off above the governed engine power shaft speeds, figure 8 refers. Here, the anticipator has commanded engine response as soon as the collective is moved, the power shaft speeds being allowed to rise briefly above the governing datum to meet the rotor, resulting in minimal transient droop. Without this anticipation facility, no response would occur until the rotor speed had fallen to meet the governed engine datum, causing much increased transient droop.

In the case of a large load demand which is not the result of a collective pitch input, brisk engine response is provided by proportional and integral elements of the control alone. The standard of response obtained is well demonstrated in a rapid bank to bank roll, figure 9, where full cyclic stick deflection has been applied.

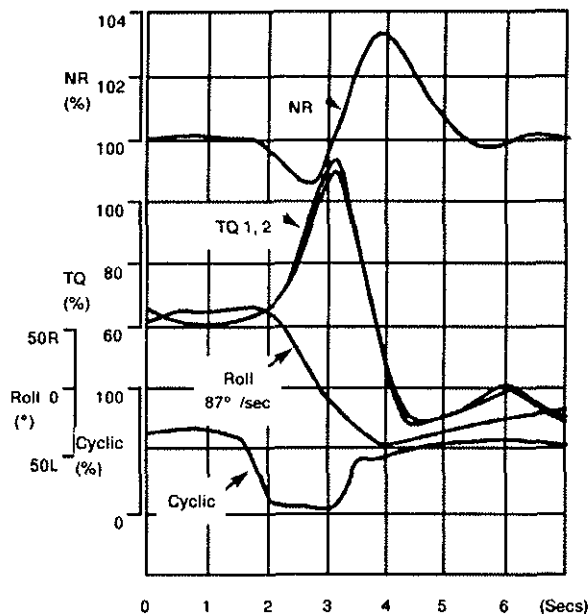


Figure 9 - Rapid Bank to Bank Roll

In this event, the rotor speed has still been tightly controlled in spite of rapid gross power changes. This level of response directly benefits helicopter handling, cross coupling being practically eliminated, resulting in clean, aeroplane like, roll behaviour.

### 3.3 Engine Limiting

The gas generator demand of the power turbine governor can be constrained by engine limiters, in a lowest wins gate, which restrict gas generator output at the qualified take-off and contingency ratings. The latter is automatically enabled upon detection of a torque split by the torque matching control loop. In addition to the engine limiters, an ultimate torque limit schedule is provided for transmission protection in the EH101.

### 3.4 Gas Generator Control

Here, the required gas generator speed change is determined by comparing actual and demand, then rate limited. The resulting permitted rate of change is primarily dependant on the prevailing error, subject to ultimate rate limiting schedules. These acceleration and deceleration schedules control the transient fuel flow, preserving engine surge and flame out margins under all operating conditions. It may be noted that the rotor run-up control

is adapted to schedule the rate of recovery to datum in this section of the control.

A simulated engine failure, by slam selection of one engine from flight to ground idle, serves to illustrate these acceleration, deceleration and recovery to datum characteristics, see figure 10. The prompt response provided by the proportional and integral elements minimises time off, and transit displacement from, the datum, resulting in negligible yaw disturbance whilst the live engine power is doubled.

### 3.5 Fuel Flow Limiting

A final check of the control demand is provided by surge and flame-out protection schedules, based on commanded fuel flow and measured compressor delivery pressure. These effectively sit outside the gas generator rate limit schedules, but will provide ultimate protection for the engine, if necessary, irrespective of upstream control demands. It is this rate limited and protected fuel change demand which is fed to the stepper motor, for direct actuation of the full authority fuel metering valve.

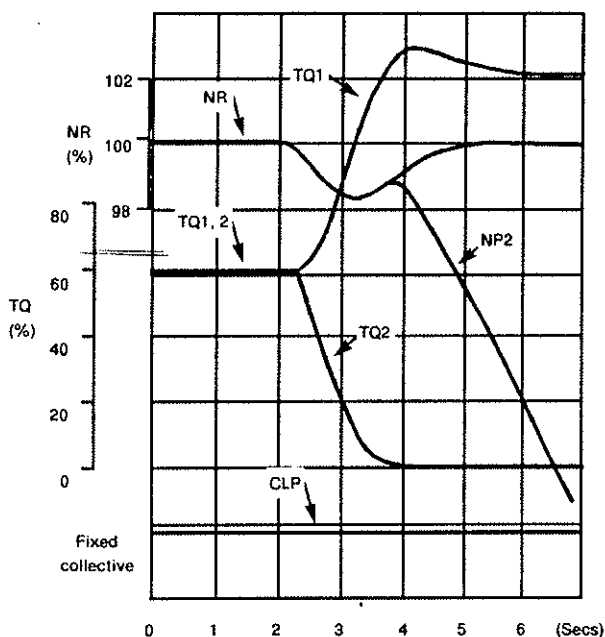


Figure 10 - Simulated Engine Failure

## 4 FADEC FAILURE MANAGEMENT

As mentioned earlier, the dual channel system was introduced in light of the requirement to maintain full mission capability in the presence of a fault. In consequence, as well as the duplicated primary control channels, with their dedicated sensors and actuator drives, a sophisticated failure management system has been incorporated, capable of maintaining a mission operable standard of control in the presence of both simplex and many multiple faults. This tolerance is provided by various back-up and default arrangements, specifically contrived to produce a graceful degradation in performance, rather than a sudden total loss of engine control.

## RTM322 FADEC - Functional Partitions

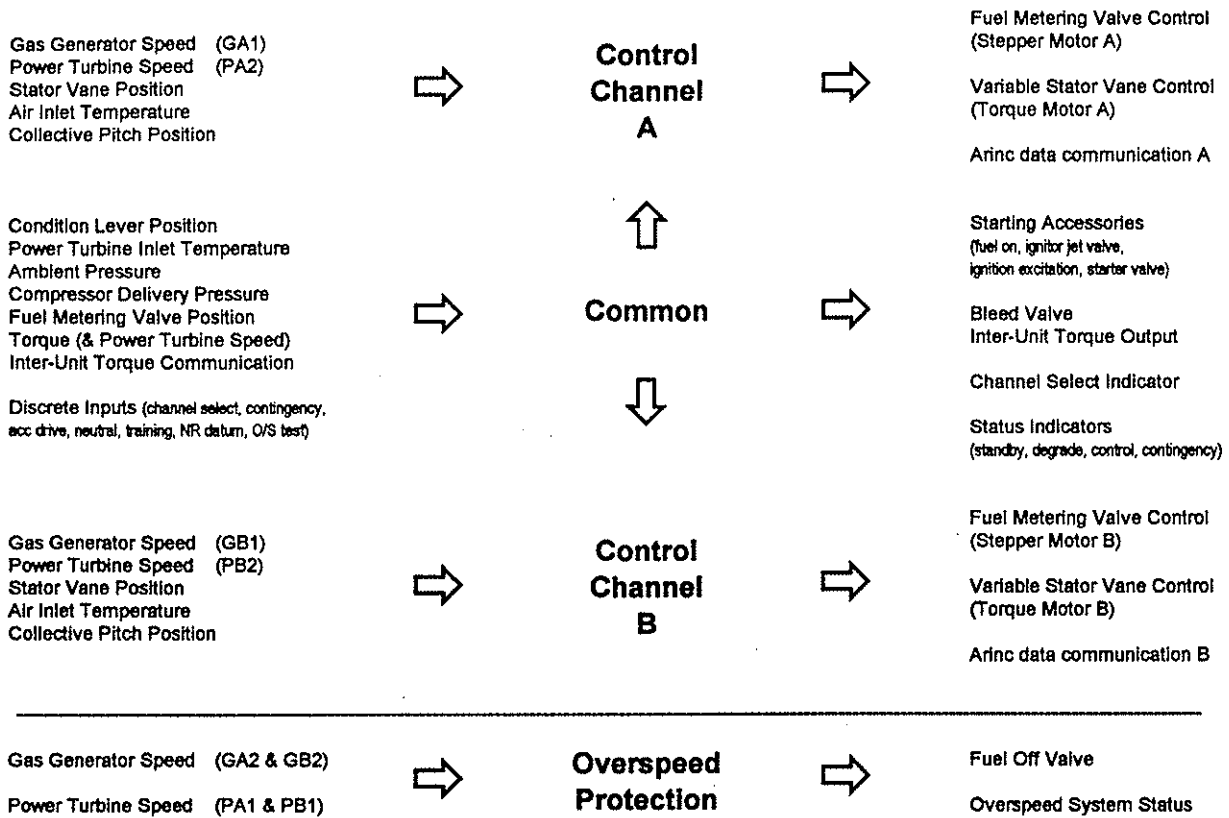


Figure 12 - Functional Partitions of the RTM322 FADEC System

### 4.1 Fault Detection

Fault detection is the responsibility of the integral continuous Built In Test facility within the FADEC unit. All input, output and feedback signals, as well as internal signal processing, are continuously monitored by validation methods particular to their individual characteristics. Examples of the methods employed are range and rate of change checks, output drive load monitoring and control program execution time.

### 4.2 Consequence of a Failure

In the event of a fault occurrence, following detection it is signalled to the failure management system to initiate containment action with the minimum possible disruption, if any, to continued normal control performance. The action

taken depends on the fault source and the prevailing status of the overall system. Figure 12 illustrates the functional partitions of the RTM322 FADEC system, where the fully duplicated channels and shared common paths can be seen. By use of this configuration, the failure system will respond to a fault condition in one of two ways, accompanied by an appropriate indication to the pilot.

- 1 A fault in one of the duplicated channels will result in deselection of that channel, if in control, with automatic bump-free transfer to the identical alternate channel. This represents a loss of redundancy, but not a loss of normal control performance, so no handling restrictions need be imposed. An example would be the loss of one of the gas generator speed signals,



without which the affected channel is unable to govern.

- 2 A shared signal fault will cause automatic implementation of default settings, or adoption of fallback control methods, as appropriate. The outcome could range from a degradation of control performance, to mere loss of a secondary facility with no reduction in normal control performance. Examples are a torque system fault, causing limited steady-state power mismatching, and a condition switch fault, which merely prevents attainment of ground idle during engine shutdown.

As previously mentioned, channel transfer is essentially bump free, in that control calculations are continuously conducted by both channels, irrespective of which is providing the output drive. In typical, quasi steady-state, operating conditions a channel changeover is entirely bump free and as such, invisible in terms of a disturbance in governing.

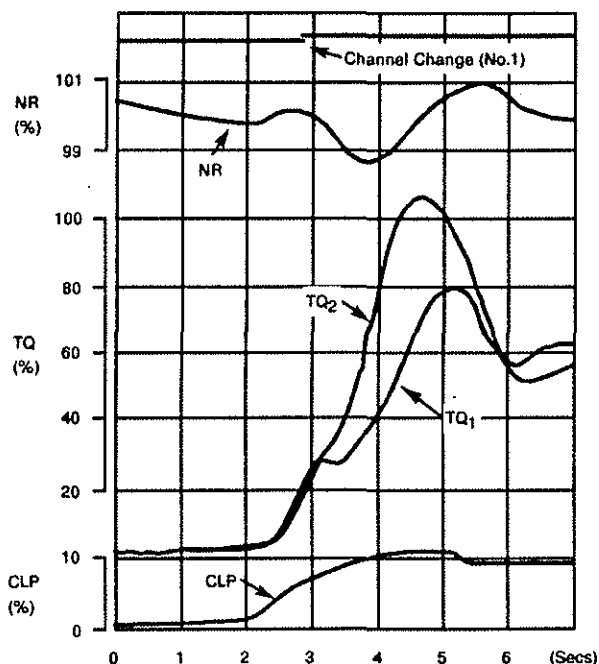


Figure 12 - Channel Change during Pitch-on  
At the point of handover between channels

there is, however, momentary freezing of the stepper motor, the effect of which can be seen by commanding a channel change during a rapid transient. Figure 13 illustrates such an event, where the channel change produces a brief transient torque split before matched governing behaviour can be resumed.

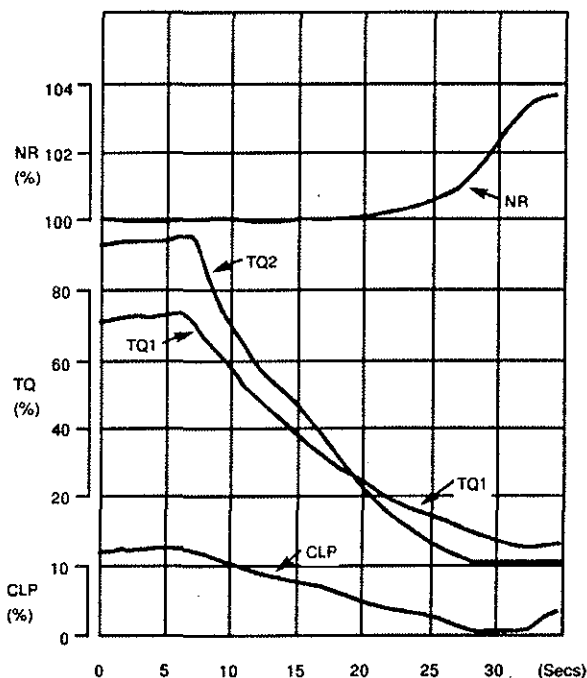


Figure 13 - Effect of a Torque Fault

Figure 13 shows the effect that a significant fault in the torque matching system has on twin engine governing and matching. In this instance, torque communication from engine 2 has been cut, causing engine 1 to adopt a fallback control method. This results in limited steady-state torque splits, due to the necessarily compromised fallback arrangement, but isochronous governing is retained over all except the low power range. Transient response is unaffected in practical terms, so mission performance is retained, through effective failure management, in the presence of this relatively serious fault.

It may be noted that these examples consider single faults only. The system is, however, able to maintain a mission

operable level of performance in the presence of many multiple faults, by virtue of the comprehensive management facilities provided. These cover all of the shared signals and, with the exception of gas generator speed and stator vane position, the duplicated signals are further managed, or suitably backed up, as necessary to retain an operable standard of control, even in the most adverse circumstances.

#### 4.3 Fault Indications and Required Actions

In pursuit of operational simplicity, the failure management system distils all possible fault conditions into just three discrete levels, for indication to the pilot.

**STANDBY** Indicates presence of a fault causing a loss of redundancy, or secondary facility of no consequence to the mission in hand.

No actions are required or handling limitations imposed as full control performance is retained.

**DEGRADE** Indicates presence of a fault which may cause some limited disruption in control performance, but not severe enough to affect continuation of the mission.

In this instance it is recommended that vigorous handling be avoided where possible.

**CONTROL** Indicates a double, critical signal failure, such that the ability to govern is lost, or a hydromechanical failure which prevents actuation of the metering valve or inlet guide vanes as commanded.

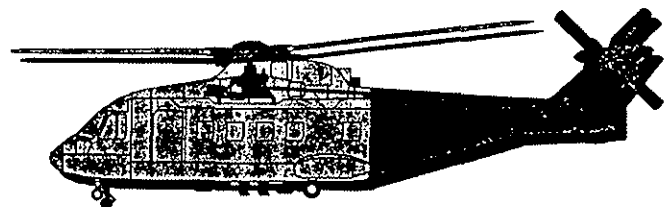
It is recommended that the engine be shutdown, unless power is still being provided and needed.

In summary, this system combines simplicity of operation with state of the art, fault tolerant control performance, enabling full crew concentration to be devoted to the mission itself.

### 5 EH101 PROJECT REQUIREMENTS

To satisfy the requirements of such a wide range of EH101 variants 9 prototype aircraft were built with the following task responsibilities:

PP1 (WHL)	Basic vehicle development
PP2 (Ag)	Basic vehicle development
PP3 (WHL)	Basic civil and climatic vehicle
PP4 (WHL/Ag)	Common naval avionics
PP5 (WHL)	RN specific equipment and avionics
PP6 (Ag)	MMI specific equipment and avionics
PP7 (Ag)	Military utility
PP8 (WHL)	Civil development and proving (mainly avionics)
PP9 (Ag)	Civil utility development and proving



WHL
Main Rotor Blades
Forward Fuselage
Cabin
Furnishings
U/C and Sponsons
Coverings and F/W
Engines and APU Installation
Pneumatics
Fuel System
F/Fl/Con. (Cockpit First Design)
50% Electrical System
50% Avionics Inc. Nav.
ECS
Flotation
Deck Lock
OP/Seats

AGUSTA
Main Gearbox and AGB
Main Rotor Head
Main Rotor Controls
Tail Rotor Hub and Controls
Tail Gearbox
Tail Rotor Blades
Mountings
Shafts/Couplings
Rear Fuselage
Tail Unit
Hydraulics
F/Fl/Con.
50% Electrical System
50% Avionics Inc. Nav.

Figure 14 - EH101 Workshare Split

The workshare responsibilities between Westland and Agusta are split approximately 50:50, as shown in figure 14. The impact of the design modifications will be discussed later.

Many options were considered as to which aircraft should carry out the RTM322 engine installation development and integration. It was decided to modify PP4 to RTM322 standard despite the aircraft being a shared asset between Westland and Agusta. PP4 was assembled in Britain, operated from Yeovil and its primary task of development and proving of the aircraft avionic systems of the Naval variant (both RN and MMI) was nearing completion. PP4 has a full suite of aircraft avionics and so integration of the engine and airframe systems has been possible. The RN specific aircraft, PP5, continued with its primary task of RN mission avionics before being converted to a full Merlin with RTM322 engines. With PP4 dedicated to engine installation development, PP5 had

the extra tasks of 'tying up' the last of the testing on common naval avionics, transferred from PP4. Using this combination of PP4 and PP5 minimised any delays on the MMI programme due to the RTM322 installation.

## 6 INSTALLATION MODIFICATIONS

The modifications required to install the RTM322 engines into PP4 are illustrated in figure 15.

The engine mounting configuration has remained the same for both engine types which has prevented major load bearing structural change. The engine bays themselves have required a profile change to suit the shape of the RTM322. This has resulted in the firewalls and the bay doors being reshaped, the definitive production standard now being common for either engine installation. The engine intakes and exhausts and the interfaces with the Main Gearbox have remained unchanged.

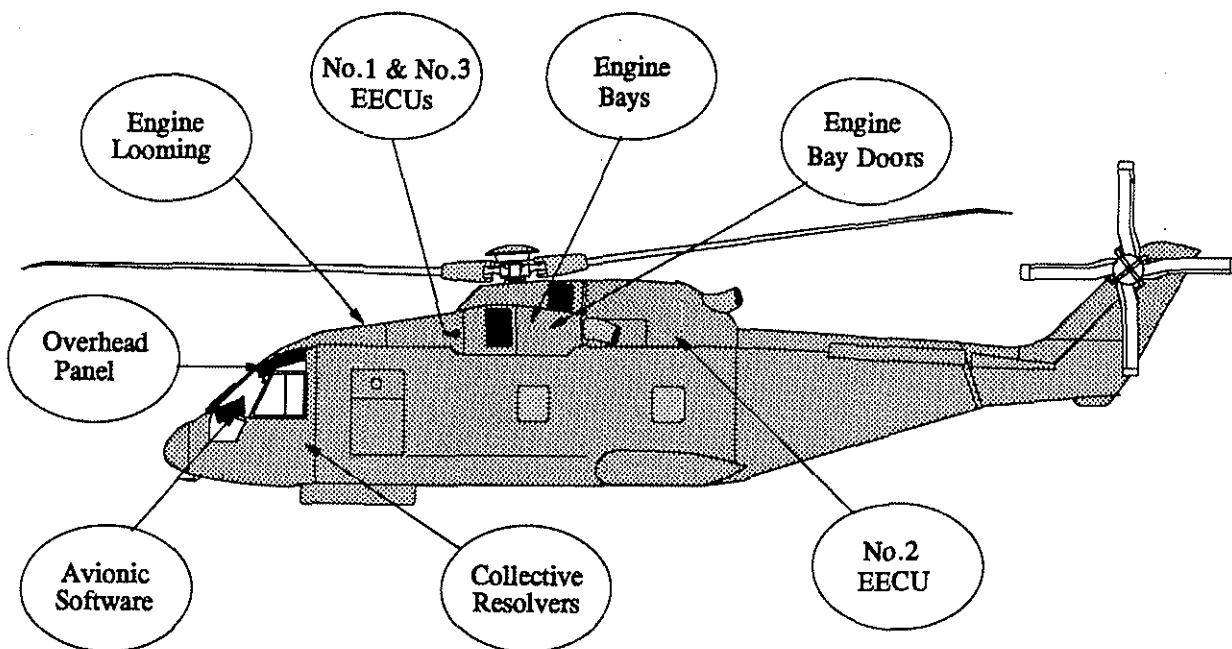


Figure 15 - PP4 Modifications for RTM322

The No.1 and No.3 forward bulkheads in front of the intakes were locally strengthened to accept the No.1 and No.3 EECUs. On PP4 the No.2 EECU has been placed on a chair structure aft of the gearbox but for production this unit will be installed under the No.2 engine. The EECUs are Line Replaceable Units and so ease of access and replacement has been an essential design requirement. In order to accommodate the EECUs, other ancillary items were relocated, including some minor rerouting of hydraulic pipes. As can be expected with the introduction of FADEC systems, specific engine control looming arrangements are required, with overall EMC hardness being a prime design consideration.

In the cockpit the overhead panel has been modified to suit the new engine control panel, as seen earlier, the traditional control levers being replaced by rotary switches. Not only has engine control been simplified with these switches but the field of view has been greatly improved. At the base of the collective lever, the collective resolvers have replaced a similar potentiometer device providing engine anticipation.

The suite of aircraft avionics also needed adapting for the RTM322. The Aircraft Management System (AMS) has been reprogrammed to accept the change in engine parameters for display and monitoring interfaces. The AMS also provides fault monitoring, life cycle counting and health monitoring, known as Engine Health and Usage Monitoring (commonly abbreviated to EHUM). In addition real time Power Performance Index calculation is also performed by the AMS. The Electronic Instrument System has been changed to incorporate the engine limit and caution list changes. Westland and Agusta share the design responsibility for the electrical and avionic systems, resulting in a significant effort from both companies, as the avionic changes account for a major proportion of

the overall RTM322 installation activity.

During the redesign process consideration was given to maintain as much commonality as possible to production components regardless of engine option. This has led to the number of unique engine bay components being minimised. The avionics have been designed so that most of the units are common to both engine types, with signature pins used to identify the difference. The commonality of the majority of parts not only benefits the production stage but minimises the amount of testing required, for example, the static strength of the engine bay doors need be tested only once because the doors are common across the fleet.

## 7 FLIGHT TEST PROGRAMME

### 7.1 Instrumentation

The PP4 instrumentation package primarily comprises a Modular Data Acquisition System (MODAS) which records data digitally at a rate of between 16 and 1200 Hz, for 1700 parameters. For engine installation development the EECU output data on ARINC links have proven to be invaluable. Each engine control cycle at 50 Hz is recorded which has permitted the diagnosis of some of the integration issues, discussed later. The Westland instrumentation system is identical with data analysis equipment at Rolls-Royce Filton, so by supplying copy tapes parallel analysis has been possible, greatly improving data turnaround. Using this arrangement RRTM has been able to concentrate on installed engine characteristics whilst Westland concentrates on airframe and integration issues. To complement the MODAS, an FM recording system has been used for installed vibration measurements and two cockpit video cameras have also proved valuable for rapid analysis of the displayed engine parameters.

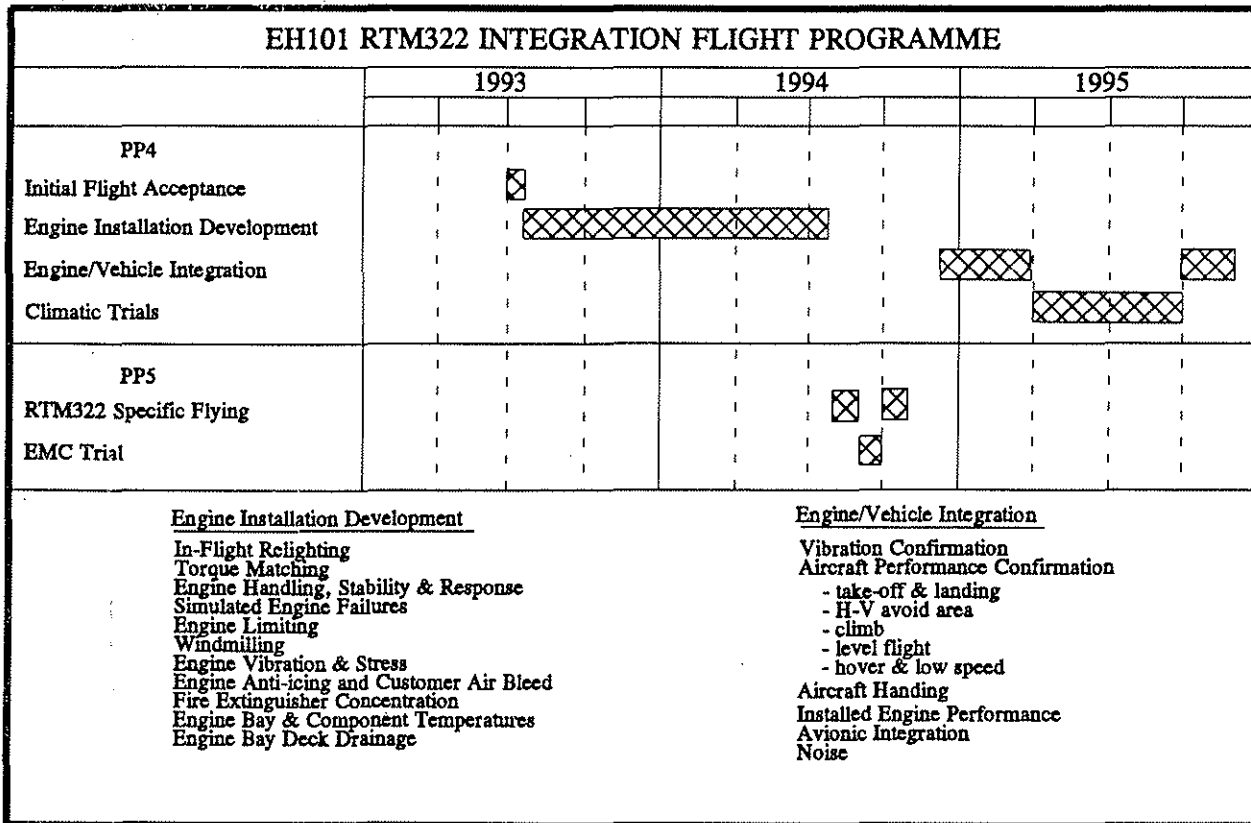


Figure 16 - EH101 RTM322 Integration Programme

## 7.2 Programme

The RTM322 installation flight test programme is summarised in figure 16.

The initial flight acceptance was scheduled to last for 10 flight hours and was designed to ensure that the aircraft was acceptable to commence the detailed engine installation activity. The engine installation development and the engine/vehicle integration tasks have been listed in figure 16 but will not be covered in any more detail. At present, PP4 is in between the two major phases of flying, the planned lay-up activities including engine calibrations for definitive installed performance assessments, updating the aircraft to Merlin production standard equipment and detailed inspections. The update to production equipment, for example the anti-vibration system, will

permit definitive testing to be performed so that clearances for the production aircraft can be written. The climatic trials consist of hot and high testing and will take place over the summer of 1995 in North America.

RTM322 specific testing on PP5 is limited to initial aircraft acceptance, similar to PP4, an EMC trial, engine/avionic integration and an Officials' review. The EMC trial will be carried out at the Radio Environment Generator at Boscombe Down, England which has specifically been updated to meet the Merlin specification. The complete aircraft with engines running will be subjected to controlled radiation illuminations over a wide frequency spectrum into the radar frequencies. The engine/avionic assessment will confirm that no anomalies exist when operating the aircraft with a full mission avionic suite.

Following completion of the engine installation tasks on PP4 and PP5, both aircraft will then transfer to the dedicated Merlin programme for continued role specific flight trials in support of clearance into service.

### 7.3 Ground Test Results

Prior to first flight 25 hours of ground testing was carried out which proceeded smoothly with no engine installation changes required. Some engine control functional anomalies had been identified during the ground running but they were of a relatively benign nature and it was considered that an optimal solution would benefit from flight experience. On balance it was therefore decided beneficial to conduct the initial part of the flight programme, clearing basic integration aspects, temperature, vibration and operability whilst gathering detailed installed characteristics to enable an engine software enhancement to be defined. The ground testing included extensive EMC trials consisting of low level sweeps and bulk current injection to confirm that the introduction of a FADEC engine into a complex avionic airframe did not compromise flight safety.

### 7.4 Flight Test Results



Figure 17 - PP4 First RTM322 Flight

To date PP4 has flown 170 hours with RTM322 engines fitted of which 100 hours have concerned engine specific testing. This has led to the collection of an enormous amount of data, a sample of which is shown below.

### 7.4.1 Rapid Engine Start-up

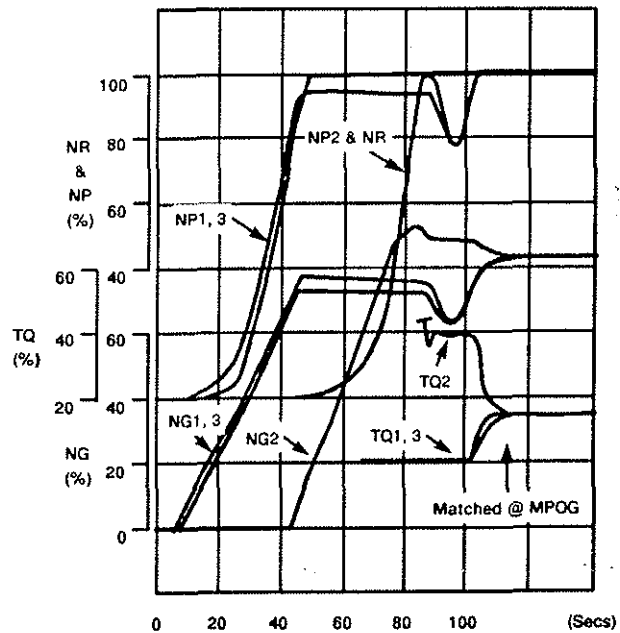


Figure 18 - Rapid Engine Start-up

Currently on the EH101 in the absence of a rotor brake engines 1 and 3 are typically started in accessory drive and neutral drive respectively, enabling full system checks to be conducted prior to rotor start using engine 2. As with the S70C, twin engine starting directly to flight is an expedient proposition, as shown in figure 18. Using this technique, immediately followed by the No.2 engine start, main rotor engagement and transfer to main drive, rapid lift off times have been achieved. With a rotor brake fitted any combination of twin engine starts will be possible. Triple engine starts are not advised due to the Auxiliary Power Unit bleed air supply limitations.

### 7.4.2 Collective Inputs

The full suite of collective handling tests has been completed entirely uneventfully,

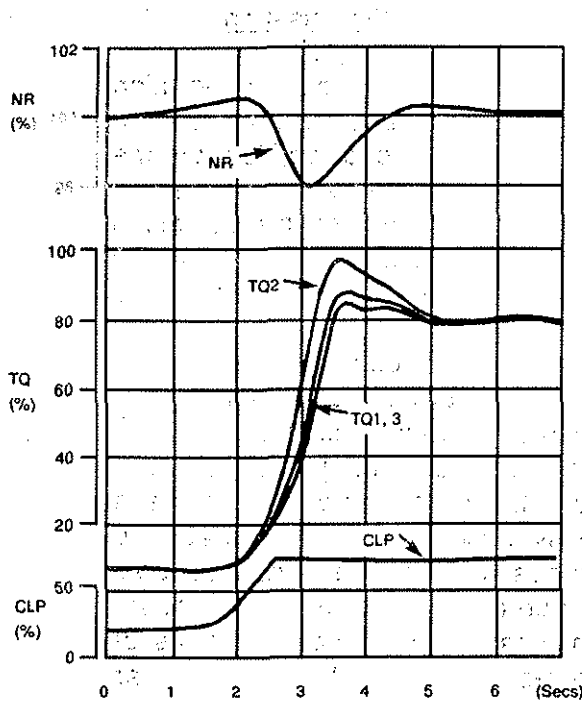


Figure 19 - Rapid Collective Pitch On

throughout the Merlin Flight envelope, with crisp, well damped control behaviour corresponding to that seen in the S70C. In general, triple engine transient matching has been tight although it is possible to generate brief torque splits by extreme provocation. In figure 19, a one second pitch-on, it can be seen that the centre engine torque rises ahead of the others, producing a brief transient split. This is caused by minor installation differences, which slightly raise the centre engine condition causing it to lead in a very rapid, Ng rate controlled acceleration. Even so, it can be seen that peak torques are moderate and comparable, largely due to the scheduled return to datum, despite the severity of this load demand.

#### 7.4.3 Simulated Engine Failures

Figure 20 shows live engine response to a simulated failure, whilst in a climb out by slam selection of the engine 1 condition switch to ground idle. The triple engine configuration favours this eventuality, as the loss of one engine can be shared between the remaining two, rather than all

burdened onto one in the case of the S70C as illustrated in figure 10. It can be seen that the transfer from triple to twin engine matching and return to nominal governing datum is again executed promptly and smoothly with minimal rotor droop and torque overshoot.

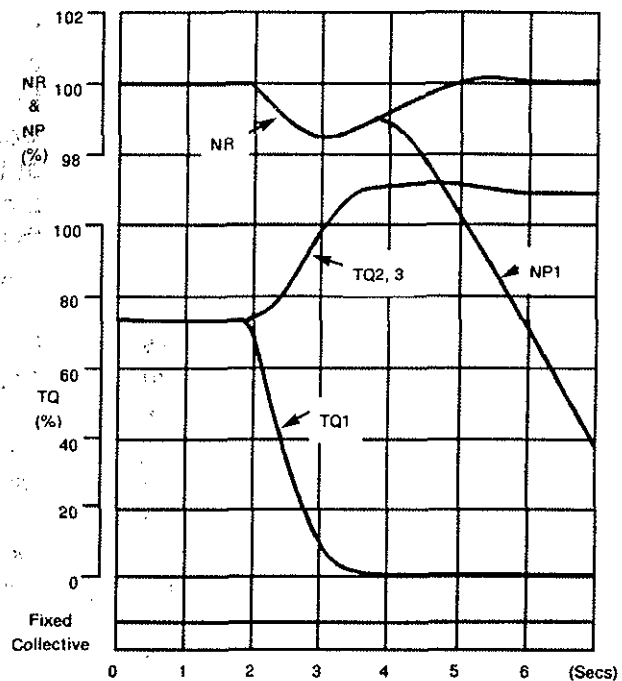


Figure 20 - Simulated Engine Failure

### 7.5 Integration Issues

The main integration issues concerned engine vibration measurement, collective map optimisation and compatibility of condition switch tolerance. The manifestations and solutions are discussed below:

#### 7.5.1 Engine Vibration Measurement

From the first ground run difficulty has been experienced recording the engine carcass vibration. As can be seen in figure 21, the initial accelerometer locations were 3 at the front of the engine, 3 on the combustion chamber outer casing (CCOC) and 2 on the exhaust frame. The front frame accelerometers were Endevco 2221F and gave good results. Endevco 2276 accelerometers were to be used at

the other locations although no direct experience of these types had been gathered at Westland and RRTM. These gave unusable readings because the signals were saturating the conditioning and recording equipment. The initial remedial action was to add 2kHz low pass filters to the raw signal. This gave readings which could be used to gain a feel for the levels of vibration to which the engines were being subjected in the 0 - 50Hz band but did not provide sufficient, reliable data for qualification purposes. Following lengthy discussions the accelerometer block on the CCOC (a triaxial block) was considered to be resonating, a fact confirmed by a series of impact resonance tests. The accelerometer configuration was altered to incorporate new blocks. From previous experience Westland was very keen to use only single axis blocks but RRTM preferred multi-axis blocks. Finally the configuration shown in figure 21 was tried with a change of accelerometers to Endevco 6222M20 on the CCOC and Endevco 6233 on the exhaust frame. This arrangement has given acceptable data permitting qualification of the installation.

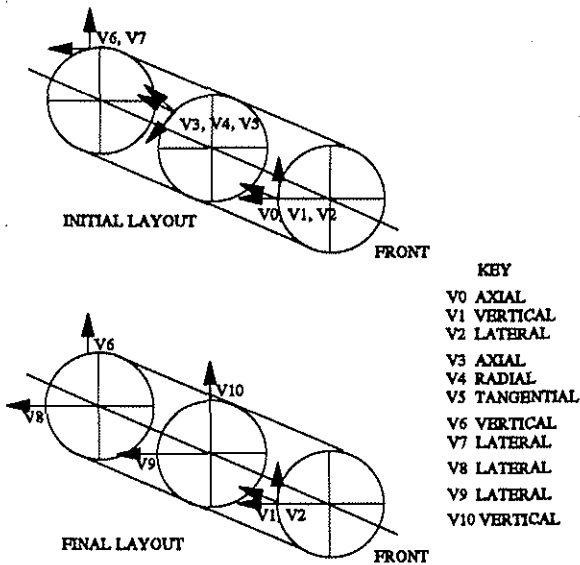


Figure 21 - Accelerometer Positions

### 7.5.2 Collective Map Optimisation

One of the primary engine integration aspects concerned matching of the engine output demand to load applied by the collective pitch lever. This is facilitated by definition of the collective pitch map, within the engine control software, which produces the fundamental engine speed demand. If this map was perfectly defined for a particular operating condition, isochronous governing could be achieved at that condition with no contribution from the proportional and integral elements of the power turbine governor. Whilst this is not strictly necessary, it is desirable to obtain a close compromise match, suitable for all operating conditions, to ensure optimum characteristics both in terms of ultimate response and when in particular fault conditions, notably those associated with torque matching.

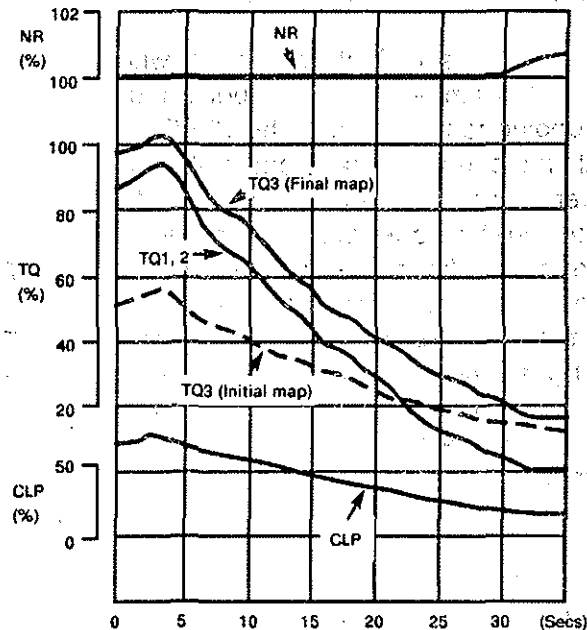


Figure 22 - Collective Map Optimisation

During the design integration phase, the initial map was derived from data supplied by Westland and was found during the ground running phase to be a poor match. As an interim solution a rigging change was made, providing a partial compensation for the mismatch during the first phase of flying. The collective load and



engine characteristics were subsequently measured in flight and following careful analysis, this situation was successfully remedied in an EECU software revision.

As mentioned above, the collective map influences the outcome of certain faults in the torque matching system, where the fallback arrangements depend primarily on the map demand. Figure 22 illustrates the effect that the presence of a double secondary torque fault has on engine matching with both the initial and revised collective maps. The benefit of the correction, reduced torque mismatch, can clearly be seen.

### 7.5.3 Condition Switch Tolerances

As previously seen in figure 5 the engine condition switches consist of four 'gates', Vent, Off, Ground Idle and Flight. Each gate contains a microswitch which interfaces with the EECU. Between the Ground Idle and Flight gates a potentiometer is used for manually controlling the rate of rotor run-up, primarily in icy conditions when a slow rate may be required.

During the flight programme two problems have been identified with the Condition Switch/EECU interface. The EECU has a Flight/Not Flight status which is dependent on the Flight gate microswitch and the potentiometer. It was found that the setting between the potentiometer and the microswitch was critical. If the EECU detected that the switch position was not in the potentiometer range but had not triggered the Flight microswitch a fault was assumed. The issue was resolved by introducing diodes in the Condition Switch/EECU wiring which effectively gave the Flight/Not Flight discretises a common ground. The second problem arose between the Off and Ground Idle microswitches. The initially prescribed EECU range tolerance for these statuses was found to be not always achievable due to the use of a rotary switch. This will be

cured using a software update to increase the range check limits in the EECU.

## 8 COLLABORATIVE WORKING

The RTM322 integration has involved two partnership companies, EHI and RRTM, from three nations Britain, France and Italy within a major design and development project. Communication, fundamental to the success of the programme, has been formalised by the following documentation and methods:

### 8.1 Installation Manual IM15

IM15 was written by RRTM and issued to EHI defining the interface requirements for the design of hardware and software associated with the engine integration. The document also defines the installed engine environmental limits, compliance with which needed to be demonstrated during the programme.

### 8.2 Interface Control Document (ICD)

The ICD is a 'live' document and has been continually updated as experience of the installation has been gained. The interface requirements of IM15 are referenced and how these requirements have been met or will be demonstrated are detailed, for example by design or test. The first issue was agreed between RRTM and EHI and approved by the MoD prior to commencement of the flight programme.

Despite the use of this document to control the airframe to engine interfaces some deviations have occurred. An example was definition of the PP4 aircraft wiring standard. IM15 called up an ideal standard which Westland considered to be unachievable and the standard was not agreed. As a consequence the wiring standard was under debate when the aircraft was approaching the first ground run. Fortunately this situation was resolved by some minor but important changes, primarily the installation of filter connectors.

It has served as a reminder of the importance of agreeing interfaces at the initial design stage. Following this experience a major effort was made to guarantee that PP5 did not suffer and all parties agreed to the interfaces before the engine installation activity began.

### 8.3 Other Formal Channels

Formal communication on a routine basis between RRTM and EHI, is conveyed by use of Interface Memoranda. The IFM permits casual communication but on a formal, traceable basis. The UK MoD is on the distribution list for these memoranda and so visibility can be maintained on a day to day basis.

Prior to the first ground run of PP4 a 'Ready to Run' review was carried out where RRTM was formally invited to physically inspect the engine installation and to pass comment. The observations were placed in three categories: essential, highly desirable and routine. Essential items needed to be rectified before the first run, highly desirable before first flight and routine at some convenient time during the flying programme. This review proved to be invaluable and prevented potential problems before they arose. Typically the changes involved rerouting instrumentation looms and repositioning sensors to avoid disruption of cooling flows, invalidating test results.

By open communication many technical and programme difficulties have been addressed and overcome to ensure that the programme has been run on time and within cost targets.

## 9 SUMMARY

The RTM322 integration programme into the EH101 has been an extremely successful activity. Upfront engine development conducted by RRTM on the S70C permitted the control laws for the EH101 to be at a mature state prior to delivery for installation testing. This has proved to be invaluable, no fundamental problems have been encountered with the triple engine configuration and only fine tuning has been necessary.

Integration issues have been resolved quickly between the partner companies as they arose, enabling the overall programme objectives to be met.

The ongoing flying programme is primarily concerned with qualification testing of the Merlin variant. Based on the achievements of the programme and the experience gathered to date all parties involved anticipate a smooth progression towards qualification of this helicopter into service.