# MARINE GAS TURBINE EVALUATION AND RESEARCH AT PYESTOCK

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ABSTRACT

This article describes the facilities of the Admiralty Test House following major refurbishment. The capabilities of the steady state and transient data gathering facilities are outlined, together with the automated engine and test control systems which provide cost-effective engine evaluation in both endurance and minor equipment trials.

## Background

The National Gas Turbine Establishment (NGTE) at Pyestock was formed in 1946 following the nationalization and relocation of Frank Whittle's original company, Power Jets Ltd, to a site close to the Royal Aircraft Establishment (RAE) at Farnborough.

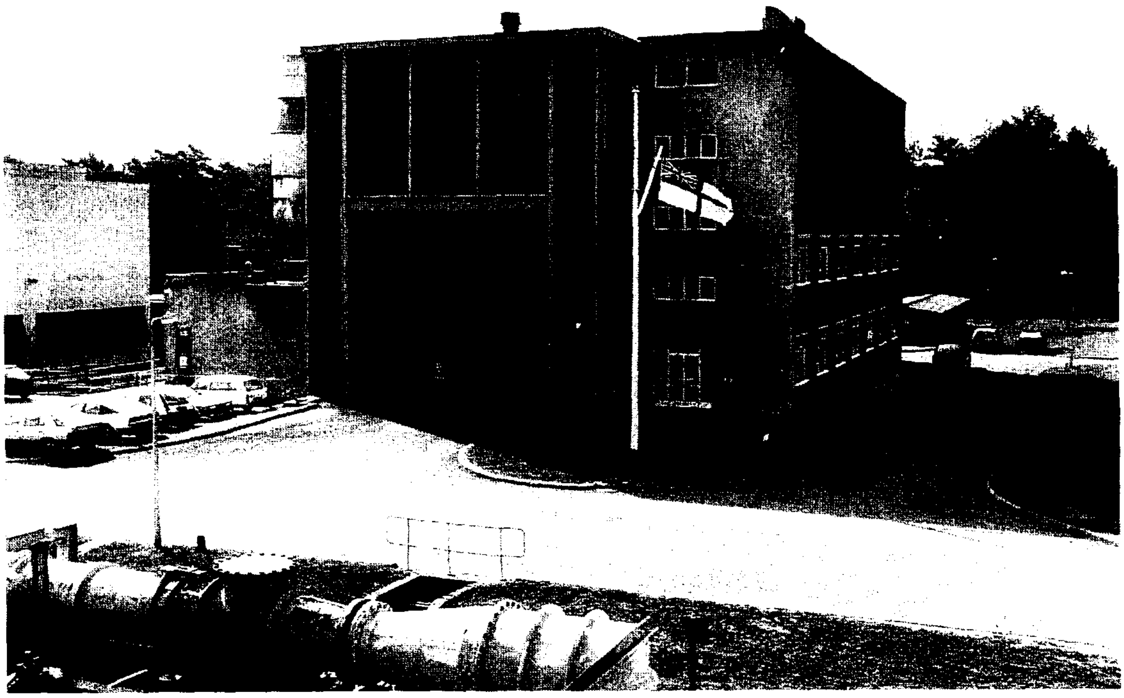

FIG. 1—THE ADMIRALTY TEST HOUSE, PYESTOCK

While the development work and manufacturing for the new technology was placed in the hands of the commercial aircraft engine companies, research and engine evaluation was continued at Pyestock where expertise and test resources, beyond the scope of any single manufacturer, were concentrated as a national asset.

The potential benefits of gas turbines as a means of marine propulsion, had been subject to investigation by the Admiralty in parallel to the advances in aero engine designs throughout the late 1940s. In 1948, plans were drawn up to incorporate a Marine Wing at the already expanding NGTE, where innovative designs of marine gas turbines could be more fully investigated before introduction into Royal Navy service.

The Admiralty Test House (ATH) (FIG. 1) was commissioned in 1952 and since then has provided test bed facilities for evaluation of a wide variety of marine gas turbine propulsion and generation units together with ancillary equipments for Royal Navy use. In 1989 the ATH organization was combined with that of the Marine Diesels Section to form the Marine Engines Section of the Royal Aerospace Establishment Propulsion Department.

Co-located with the Materials, Combustion, Turbomachinery and other specialist sections of the Propulsion Department, where much of Europe's gas turbine expertise is concentrated, the ATH is able to provide a unique independent service to both engine manufacturers and marine operators.

Development work by Rolls-Royce on the successful marinized versions of the Tyne and Olympus engine designs was closely associated with the ATH trials programme during the 1960s and 1970s. More recently, the 13MW Spey SM1A has undergone extensive evaluation and development work, accumulating over 5000 running hours on the test bed in a simulated marine environment. This engine is now entering service with the Royal Navy in Type 22 and 23 frigates and in other warship installations with the Japanese Defence Agency and the Royal Netherlands Navy.

This paper presents detail of the ATH facility following recent refurbishment in advance of trials on the 20 MW Rolls-Royce SM1C marine gas turbine. Examples of recent work are cited to illustrate the capability of the ATH, where comprehensive data gathering and automated test control systems combine to provide cost-effective engine evaluation in both endurance and minor equipment trials.

## Admiralty Test House Facilities

The ATH was primarily established for extended endurance running over several thousand hours under simulated marine environment conditions. The facilities are fully self-contained and require no external services other than electrical power. They have recently been refurbished and updated to meet the requirements of the SM1C and to overcome some of the short term expediency measures of the first Spey installation described by Kingsland[1]. The facilities comprise:

- A 22·25 m × 3·12 m reinforced concrete test bed.
- Three Heenan and Froude DA790 hydraulic dynamometers capable of 14·92 MW each. Two of these may be run in tandem as on the present Spey bed (FIG. 2), with a capacity of up to 29·8 MW. These brakes have accumulated a total of some 20 000 hours use. Major overhaul of the brakes will allow continuation of use through the next series of trials. Several studies into options for regenerative braking have been conducted but found that the capital expenditure involved could not be recovered in the relatively short (3000–5000 hours) period of time associated with a single engine trial.

- Inlet and exhaust ducting designed to allow free passage of the 20 tonne and 1 tonne overhead cranes.
- Recent work has involved the manufacture of new downtake sections to straighten the intake air flow and a new air meter more suitable for SM1C flow rates.
- Fuel, power turbine lub oil, and HP air storage and supply systems. Brake cooling water pumping and distribution systems, including an emergency header tank. All these systems have been subjected to major renovation and enhancement, following nearly 40 years of continuous use.
- Industrial grade air filters together with a salt ingestion system are used to clear inland pollutants for the intake air before the marine aerosol is created by the injection of measured levels of brine into the airstream. New equipment has been provided to maintain the salt/air weight ratios correct for the higher flow rates of the SM1C.
- A comprehensive data gathering and engine control system capable of recording of engine, plant and environmental data under both steady state and transient conditions.

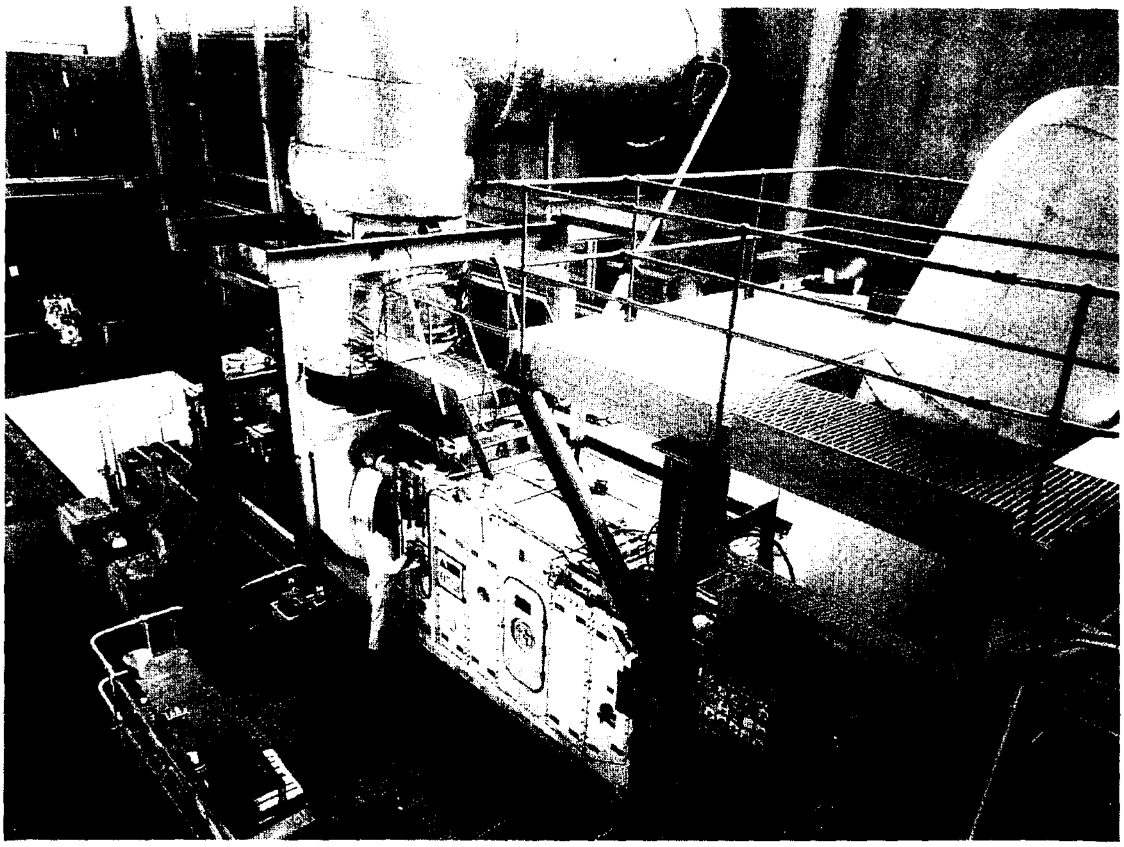

FIG. 2—THE SPEY SM1C MARINE GAS TURBINE INSTALLATION IN THE ADMIRALTY TEST HOUSE

In addition to those plant services currently in use on the Spey bed, facilities exist for a second test rig, using the third dynamometer, formerly occupied by the Tyne engine. A small wind tunnel is located on the second floor of the building, which has been used for authoritative investigations into marine aerosol conditions, intake filter packages and debris ingestion trials. Details of this work were reported by Hobday and Havill[2].

**Engine Control System**

Automatic control of the engine under test is achieved using an Intercole Systems Spectra minicomputer. Software is incorporated to allow endurance, performance assessment and other trials schedules to be written and subsequently selected to drive the engine throughout each day's trials.

A typical endurance mission will consist of a specified number of hours at representative engine power levels with regular handling acceleration/decelerations and performance-gathering schedules. Performance at steady state is assessed during the regular pre- and post-compressor wash performance map schedules, during which 86 items of data (pressures, temperatures, speeds, etc.) are captured at each of the 11 power settings ranging from idle to full power conditions. This data can be used for on-line monitoring of the engine or detailed analysis at a later occasion. More detail of this data system is given later in this article.

**Dynamometer Control System**

The Heenan and Froude DA790 hydraulic dynamometers are controlled to simulate the torque/speed characteristics of typical Royal Navy marine installations. Recently updated to microprocessor control, the dynamometer control system allows automatic variation of brake power in response to engine speed changes. When in automatic engine control, the Spectra computer provides the power demand signal to predetermined power schedules.

Brake control system schedules may be written and selected to drive the brakes on a variety of different ship speed/torque curves. In this way, the engine under examination may be tested in any proposed marine installation without the financial penalties caused by requirement for gearing and propeller systems. A recent trial was conducted where the specific fuel consumptions of the SM1C and SM1A were compared for all RN Spey installations, under both normal and 'one shaft trailing' conditions.

**Steady State Data Gathering**

The ATH Steady Data Gathering System (ATHSYS) uses the same Spectra computer for scan initiation, data logging and analysis as the engine control system. The system scans at medium speed (3 to 4 seconds per scan) and captures onto a rolling buffer. When engine conditions have steadied, data is automatically transferred to storage on hard disc in the Spectra computer. Thermodynamic calculations are carried out on the raw data by the computer and the resulting corrected and performance data stored with the raw data. At the end of a performance map, the whole data set may be printed out for analysis.

Data from the rolling buffer or from hard disc may also be analysed or plotted using the same data base. Over the length of an endurance trial, this data may be analysed in the 'power domain', in order to provide a picture of how the engine performs across its power range, or in the 'time domain' for trend predictions. Time domain trending has long been pursued in attempts to characterize the fall-off in performance as engine condition deteriorates. In-service and ATH test experience has shown that variations of only a few per cent. are likely to represent the difference between a new, healthy engine and one withdrawn from service after several thousand hours operation with significant component defects. Such small variations are normally undetectable due to the measurement uncertainties of in-service instrumentation. The main reasons for continuing a detailed assessment of steady state data within the ATH are:

(*a*) Accumulation of steady state data confirms that the instrumentation system is continuing to function correctly.

(*b*) The 'Time Trends' may be used to confirm that the endurance trial is being conducted strictly in accordance with the schedules agreed between the manufacturers, the customer and the test authority.

**Transient Data Gathering System**

There are many gas turbine characteristics which do not show up as steady state phenomena. A more detailed understanding of the engine's performance and the first signs of deterioration are most often more clearly shown under transient conditions.

The Very High Speed Transient Data Gathering System (VHS) is used to scan selected parameters at rates exceeding 1 kHz. This system was also supplied by Intercole Systems and uses a Research Machines Nimbus AX20 286 desktop machine for scan initiation and data storage and processing.

Throughout an endurance trial, sample transients are conducted on a regular basis in order to demonstrate the earliest signs of engine degradation. One of the most useful transients used is that of the start sequence, which will show faults in any of the controls, fuel and air systems as well as engine component defects.

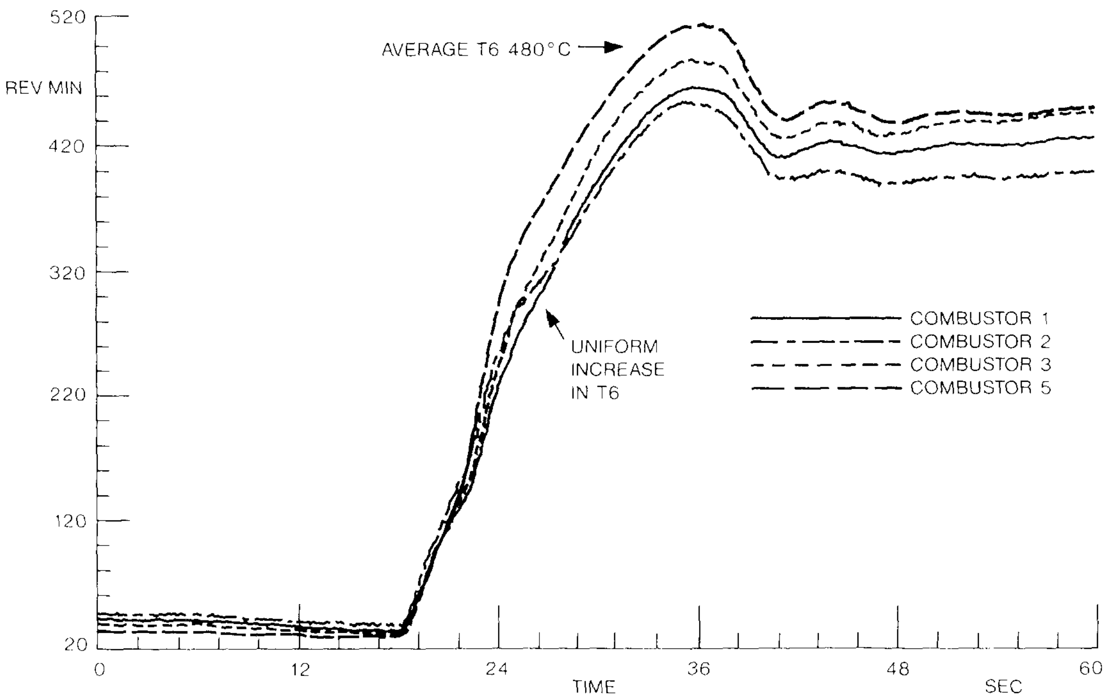


FIG. 3—VHS PLOT OF POWER TURBINE ENTRY TEMPERATURE (T6) DURING START SEQUENCE AFTER 1361 COMBUSTOR HOURS—A GOOD START

During a recent trial, analysis of this transient identified a number of minor faults as well as showing the effects of combustor degradation. FIGS. 3 and 4 show the effect of corrosion in combustor number three, where the excessive level or primary air has caused the flame to blow out. Re-ignition occurs some 4 to 5 seconds later through the inter-combustor duct but the excessive amount of unburnt fuel released during this period causes the maximum power turbine entry temperature to rise to within one degree of the trip level. It must be stressed that once this engine was running, no effects of this defect could be observed on its steady state or transient performance.

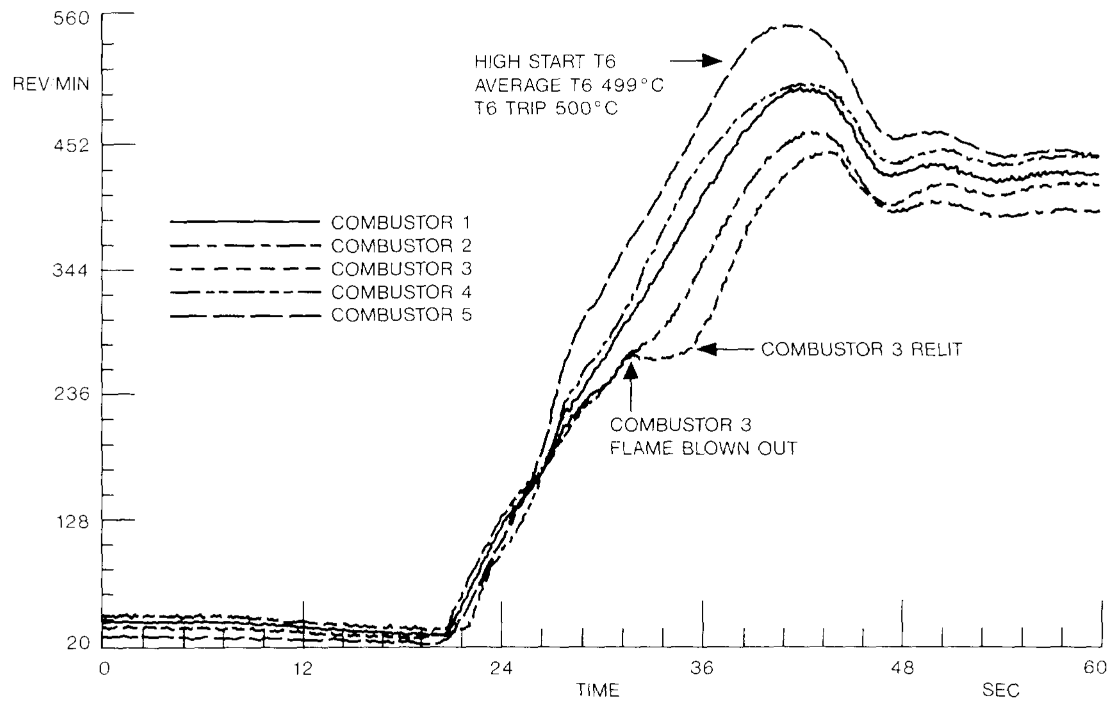


FIG. 4—VHS PLOT OF POWER TURBINE ENTRY TEMPERATURE (T6) DURING START SEQUENCE AFTER 1635 COMBUSTOR HOURS—A POOR START

## Engine Management Systems

The ATH facility is primarily intended for endurance running of engines over several thousands of hours. This is an expensive operation during which every opportunity is taken to mitigate the costs by research into engine management techniques. Such techniques include engine health and condition monitoring but collectively are targeted to more efficient and effective engine management. Such activities are run as research items within the Marine Engine Section with a view to providing first-hand indications as to their value for eventual RN use. During the recent SM1A trials, the following techniques have been under review.

### *Smoke Monitoring*

On-line smoke density monitoring is conducted using the Sigrist Photometer. Traces from this machine clearly show the overall level and eventing that occurs as carbon is shed from the combustors. In addition, RAE Combustion Division conduct regular chemical and physical analyses of the uptake gas throughout any endurance trials, to monitor combustion efficiency and overall emission levels. These tests provide depth to the ATH on-line results and also tie in well with the frequent video endoscope and visual engine inspections.

### *Vibration Analysis*

Vibration data is gathered from the compressors, turbines and power turbine by the ATHSYS using the manufacturer's velocity transducers. These give results which are satisfactory for in-service watchkeeping purposes but have insufficient high frequency response to be of any real value for condition monitoring.

Significant advances in the capabilities of the latest vibration analysis techniques have been seen in the commercial market. The benefits of these to the marine environment are under review at the ATH and an innovative system produced by Stewart Hughes Limited (SHL) has recently been acquired. This system offers considerably greater potential for obtaining early warning of developing faults from the engine's vibration signatures than previously possible by analysis of simple velocity probe signals.

The SHL Vibration Data Analysis System uses a suite of ten accelerometers to collect vibration data from significant sites around the engine. Complex signal processing and pattern recognition techniques are then used to identify the signature of particular faults (bearing failures, gear faults, etc.). This system has demonstrated the capability to identify certain engine faults down to component level.

*Electrostatic Debris Detection Systems*

Electrostatic detection for debris in the gas path is conducted using the Ingested Debris and Engine Distress Monitoring Systems (IDMS and EDMS), also produced by SHL.

The IDMS detects the ingress of foreign objects into the intake. The effects of blade or seal rubs as well as the effects of other gas path degradation in the exhaust gas are shown by analysis of the EDMS data. Although these systems are far from being ready for installation at sea, they demonstrate two clear benefits in the ATH trials environment:

(*a*) Following any catastrophic damage to the compressor elements during the trial, 'Foreign Object Damage' (FOD) can either be identified as the cause or, more importantly, positively excluded from the list of contributory factors. Manufacturers are often very quick to attribute any such failures to 'FOD' and blame the engine operator. This system will help to identify the true cause of any such unfortunate occurrence.

(*b*) Early warning of blade or seal rubs, which may go on to catastrophic failure, and other gas path degradation is provided by analysis of the EDMS signals.

A more detailed presentation of the results from the evaluation of these systems is the subject of another article in this issue[3].

*Visual Inspection Techniques*

Visual inspection of the gas path of an engine remains one of the most reliable methods of condition monitoring available to the engineer. However, until recently, the technique has been limited by the fact that conventional endoscopes are single user devices. This creates difficulty with training in their effective use and causes problems when one operator observes a defect, then has to describe his findings verbally or pass the instrument to another engineer. All too often the cry of 'The endoscope has moved' is heard and all signs of the defect are lost.

In order to overcome this problem and to provide a more permanent record of the engine inspections, the ATH has pioneered the use of video endoscope techniques for assessment of test engines. During this work, several equipments were investigated before the Videoprobe 2000 system was selected for evaluation. In this system a monochrome charged couple device is located at the tip of a 6 mm flexible endoscope, which gives greatly improved picture definition when compared to fibre optic bundle units. Light from a 300 W source is strobed through three colour filters and the returning signals recompiled to give a high definition full colour picture of the subject. Inspections of the engine are recorded onto a conventional video cassette recorder at frequent intervals throughout any period of trials.

A further development of the video inspection technique is the use of an image processing system with which stills from the recorded inspection can be digitized and stored as 'Pic' files on a Nimbus VX40 386 PC. The LazaReporter system, supplied by Thermoteknix Systems Ltd, allows the digitized pictures to be processed (enhanced, compared, etc.) and printed on a laser printer, together with titles and other text. An example from the LazaReporter system is given at FIG. 5 where loss of a compressor blade tip can clearly be seen. These pictures may be used for reporting or may be faxed for immediate briefing of a defect or occurrence.

FIG. 5—LAZAREPORTER DIGITIZED STILL FOR ENDOSCOPE INSPECTION. DAMAGE TO COMPRESSOR BLADE IS CLEARLY VISIBLE

*Lub Oil Monitoring*

Monitoring of engine lubricating oil for ferrous contamination has been conducted using magnetic chip detectors (MCDs) for several years. This technique has proven value but suffers from the major disadvantage that removal of MCD plugs requires the engine to be shut down. On-line detection using non-instrusive sensors is an attractive alternative. Two such systems, the SENSYS Ferroscan and TEDECO QDM, are currently under investigation but there is limited confidence in the results gathered to date.

*Performance Monitoring—MIDGTS*

The Model for Inspection and Diagnosis of Gas Turbine Systems (MIDGTS) is a trending and diagnostic program, based on the principle that trends in steady state data produced by a fault condition may, when examined as a set, represent one particular engine defect. The program was developed for the Canadian Navy by Gastops Ltd. A version of the software, supplied to the ATH for evaluation on the SM1A is now the subject of investigation and development by both ATH staff and Gastops Ltd.

*Performance Monitoring—System Identification*

Work has recently been undertaken to exploit the potential of engine transient performance for condition and performance monitoring purposes. On-line recursive System Identification techniques, originally intended for control system design, have been used to produce, and continually update a series of transfer function models characterizing the engine's dynamic performance. By either tracking the variation in estimated model parameters or statistically monitoring the differences between engine parameters and model predictions, it is possible to quantify the effects of fault conditions on performance variations. Feature maps, Fig. 6, of these variations for given fault conditions can then be constructed, and with the use of pattern recognition techniques a fully automated fault classification and diagnostic facility can be produced. This work is in its early stages of development but shows considerable promise.

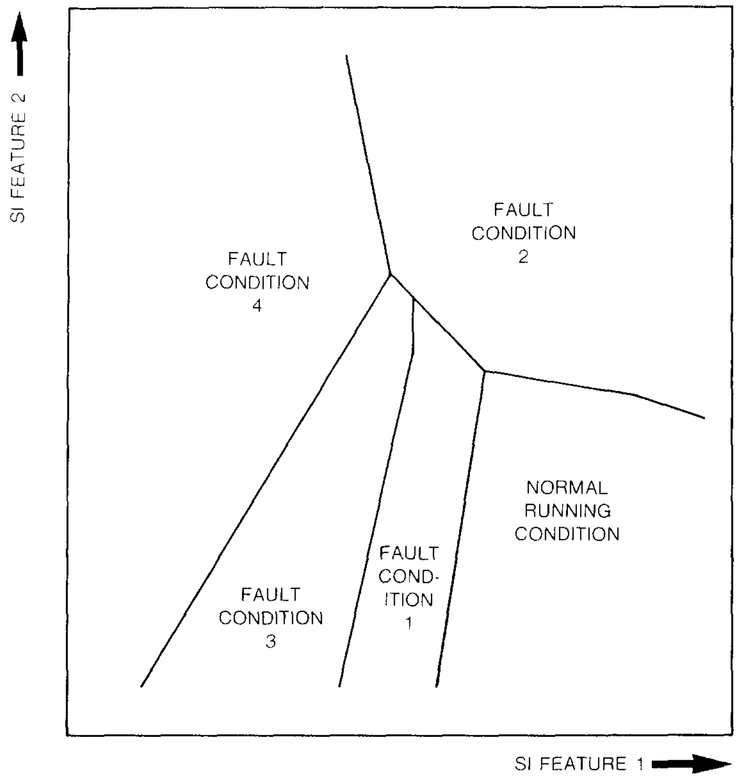


Fig. 6—System identification fault distribution

*Engine Lifing—Low Cycle Fatigue Monitoring*

The Life expectancy of major engine rotating components has been determined to date by recording of the accumulated engine hours. A more accurate and cost-effective technique, under review at the ATH, relies upon automatic counting of the low cycle fatigue (LCF) damage accumulation, using the Smiths Industries Engine Life Computer. A change to LCF count as the basis for engine overhaul management is expected to produce significant reductions in the through-life costs of maintaining the Royal Navy's fleet of marine gas turbines.

*Utilization of Gas Turbines in RN Service—ELMD*

Effective endurance testing of marine gas turbines requires detailed information to be available on precisely how the engines are utilized in the Fleet, in terms of accumulation of time at different power levels. The Engine Load Monitoring Device (ELMD) is a simple instrument, designed and produced by RAE staff, which monitors engine low pressure spool speed (N1) and 'clocks up' cumulative engine running time spent in each of ten speed bands. Because of the consistent relationship between N1 and engine power, not available on other engine measured parameters, the ELMD will identify how the engine is utilised in each of ten corresponding power bands.

Initial results from the ELMDs in the Fleet are beginning to identify precisely how Royal Navy frigates utilize their boost engines. Analysis of this data was instrumental in producing the most effective engine test profiles for the SM1C endurance trial currently in progress.

## Conclusion—The Independent Test Authority

The Admiralty Test House has a long history as an independent test authority for the assessment of gas turbines for potential Royal Naval use. The facilities have recently been comprehensively renovated and upgraded in preparation for the SM1C trials now in progress.

Advances in engine management techniques offer significant benefits in the way in which engine life cycles are managed. However, these techniques often rely upon the optimistic claims of the manufacturers and must be integrated into service only after independent evaluation under the rigorous conditions found in the marine environment.

Arguments exist as to the need for such facilities at a time when defence and ship procurement policies are under continued review. However, history has proven the value of testing, independent from the influences of the equipment manufacturers, as a means of highlighting those problems that would not have become evident until later in service. Rectification would then have become expensive both in terms of nugatory capital expenditure and in the operational restrictions imposed.

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