GAS TURBINE PERFORMANCE TRENDS

A METHOD OF ONBOARD ANALYSIS

BY

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Summary

This article proposes a method of performance analysis for gas turbine engines that can be carried out on board ship by an operator who does not have a deep knowledge of gas turbine theory. Using the proposed method the operator will be able to diagnose a defective component, or components, from changes in easily measurable engine parameters.

A small change analysis of a Marine Olympus engine has shown that useful readings can be taken over the whole range of normal engine running conditions. This avoids the need for special trials at particular, and perhaps operationally inconvenient, speeds. A simple graphical method is suggested to enable the watchkeeper to correct and record the necessary readings.

The idea for this method came from work done during the Marine Engineering 'Dagger' Course at the Royal Naval Engineering College, Manadon, in 1975. (See Ref. 2.)

Introduction

All machinery is subject to wear which causes its performance to deteriorate and may eventually lead to its failure. The assessment of the condition of the engine is known as engine health monitoring, and performance analysis is one of the methods that can be used. In this an attempt is made to identify deterioration by monitoring measurable engine parameters such as pressures, temperatures, flow rates and speeds. In the past, either special trials have had to be held to provide readings for direct comparison with datum readings onboard by ship's staff or the day-to-day results have had to be analysed at base by specialists.

This article develops a simple method of trend analysis that can be used on board ship for performance testing gas turbine engines, and a method of correcting and recording data that can be carried out by the watchkeeper. The ship's marine engineer officer is then able to use the results of this analysis in conjunction with the other available methods of engine health monitoring described in (Ref. 1) to determine which component has deteriorated.

Principle of the Method

For given external conditions deterioration in the performance of an engine is due to the deterioration of the components that it comprises. In the case of a gas turbine these components are compressors, turbines, combustion chambers and auxiliaries.

The hypothesis upon which this method is founded is that the effect of deterioration in each component would cause different changes in the following set of measured parameters (Shown diagrammatically in FIG. 1).

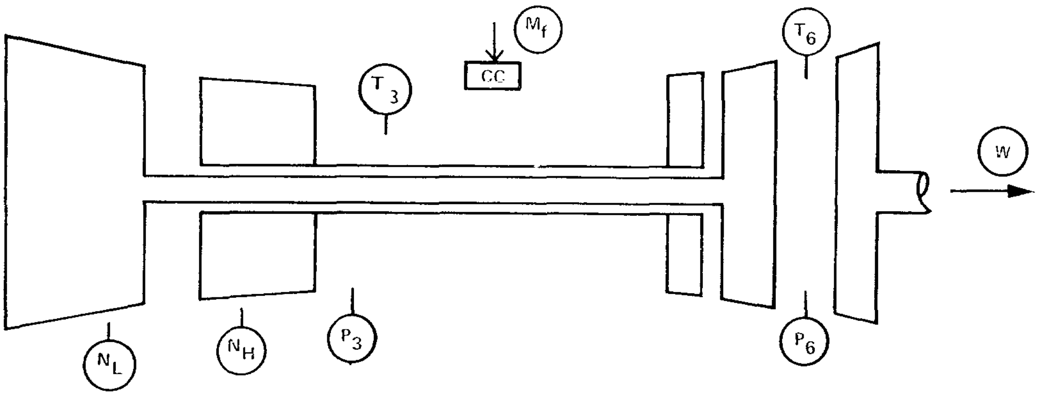

FIG. 1—DIAGRAM SHOWING PARAMETERS TO BE MEASURED

N_L—L.P. spool speed.
N_H—H.P. spool speed.
P_3 —H.P. compressor delivery pressure.
T_3 —H.P. compressor delivery temperature.
M_f—Fuel flow rate.
P_6 —Pressure at inlet to power turbine.
T_6 —Power turbine inlet temperature.
W —Shaft output power.

Hence a comparison of changes between two sets of readings of these parameters would identify the component with the altered performance.

TABLE I—*Comparison of percentage changes in parameters between measured values for an industrial Olympus and predicted values for an Olympus TM3B at the same L.P. spool speed*

	T_6	P_6	P_3	M_f	W	N_H	
−1 % L.P. compressor efficiency	+0·95 +0·65	+0·60 +0·41	+0·46 +0·40	+1·59 +1·19	+1·58 +1·13	+0·40 +0·40	Industrial TM3B
−1 % H.P. compressor efficiency	+0·78 +0·85	+0·28 +0·27	+0·16 +0·30	+1·12 +1·34	+0·92 +1·00	−0·46 −0·25	Industrial TM3B
−1 % Intake air mass flow	−0·64 −0·65	−1·25 −1·26	−1·21 −1·24	−1·94 −2·03	−2·69 −2·78	−0·29 −0·40	Industrial TM3B
−1 % H.P. turbine efficiency	+0·73 +1·16	+0·25 +0·48	+0·11 +0·34	+1·04 +1·82	+0·86 +1·48	−0·44 −0·30	Industrial TM3B
−1 % L.P. turbine efficiency	+0·76 +0·51	+0·44 +0·32	+0·32 +0·31	+1·26 +0·98	+1·22 +0·93	+0·19 +0·29	Industrial TM3B

Development of the Method

To investigate the changes that would occur two computer programmes were developed using a straight-line digital simulation of an Olympus TM3B gas turbine. The first of these was a dynamic simulation of the running engine and the second gave the expected changes of the measured parameters at

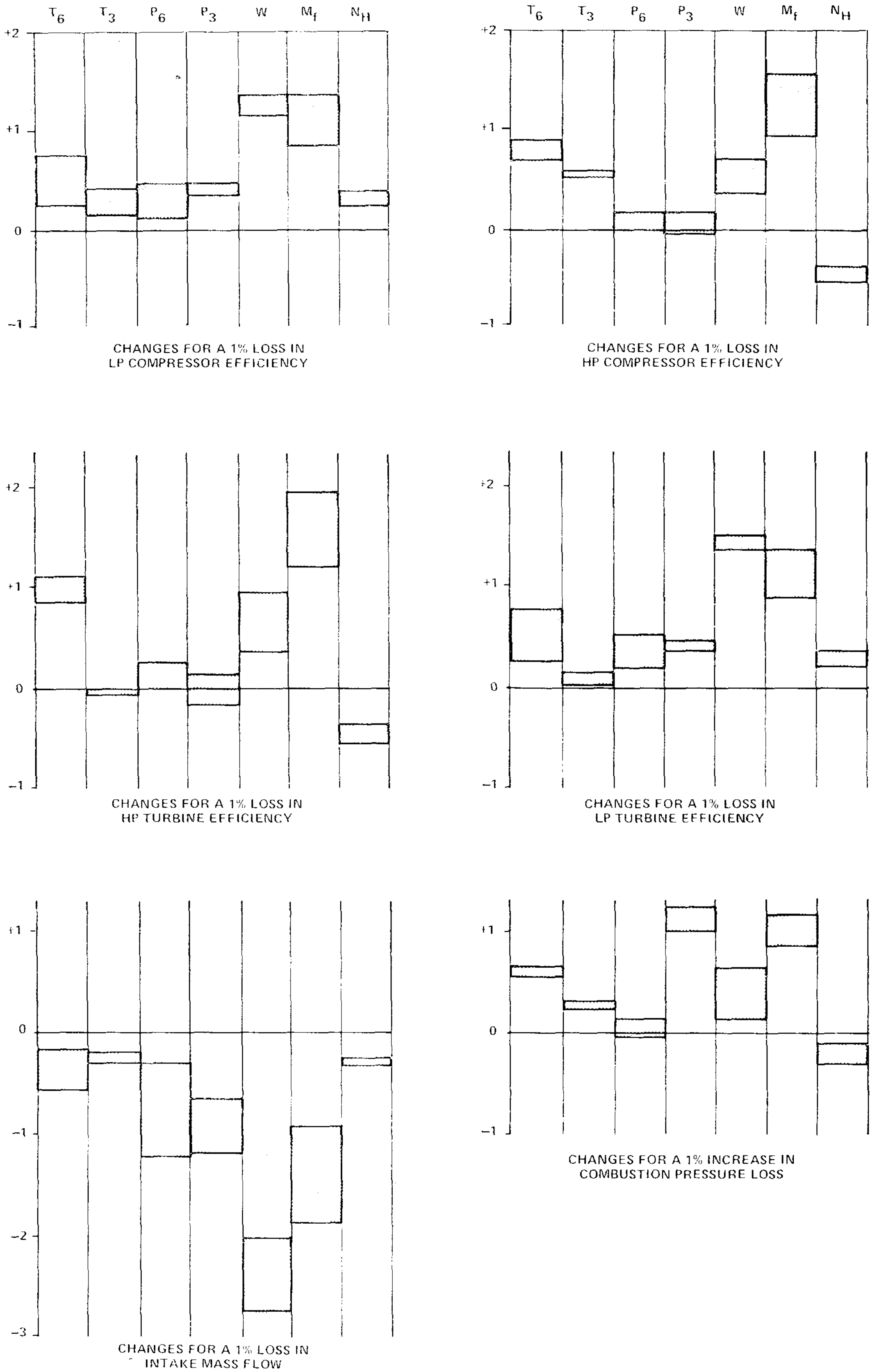

FIG. 2—PERCENTAGE CHANGES IN MEASURED PARAMETERS CAUSED BY SMALL CHANGES IN ENGINE PERFORMANCE

varying powers and with components running at off-design conditions. The predicted changes at full power were compared with those obtained by Rolls-Royce at corresponding spool speeds for an engine with similar operating characteristics (an industrial Olympus) and were found to be always in the same direction and of the same order of magnitude (TABLE I). This validated the computer programmes as tools for developing the method of analysis.

The changes in condition were kept small so that small change analysis theory could be used. This theory assumes that small changes in component condition do not alter the engine operating characteristics, and it has been successfully developed by Rolls-Royce for use with gas turbines operated by the Central Electricity Generating Board.

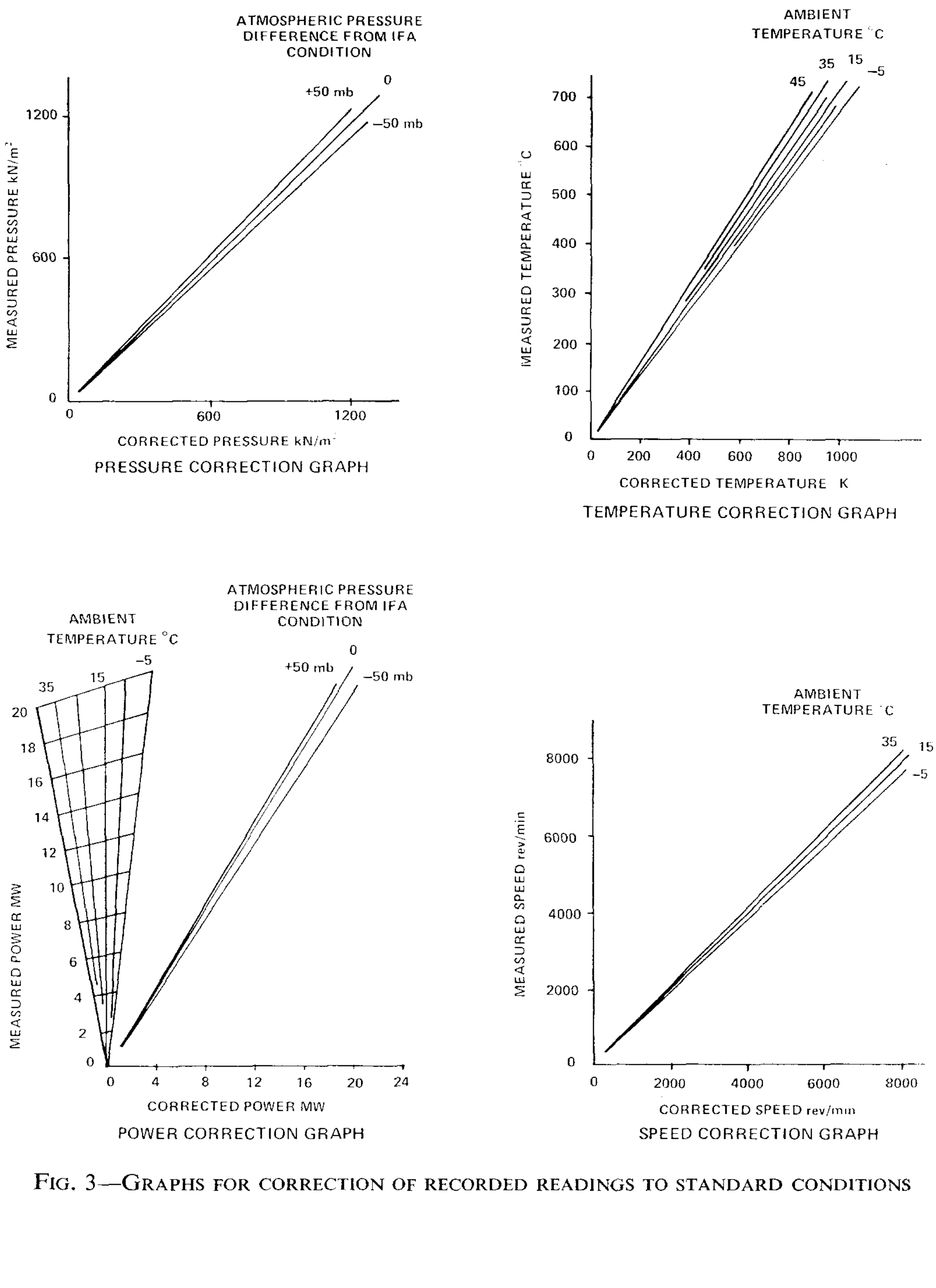

FIG. 3—GRAPHS FOR CORRECTION OF RECORDED READINGS TO STANDARD CONDITIONS

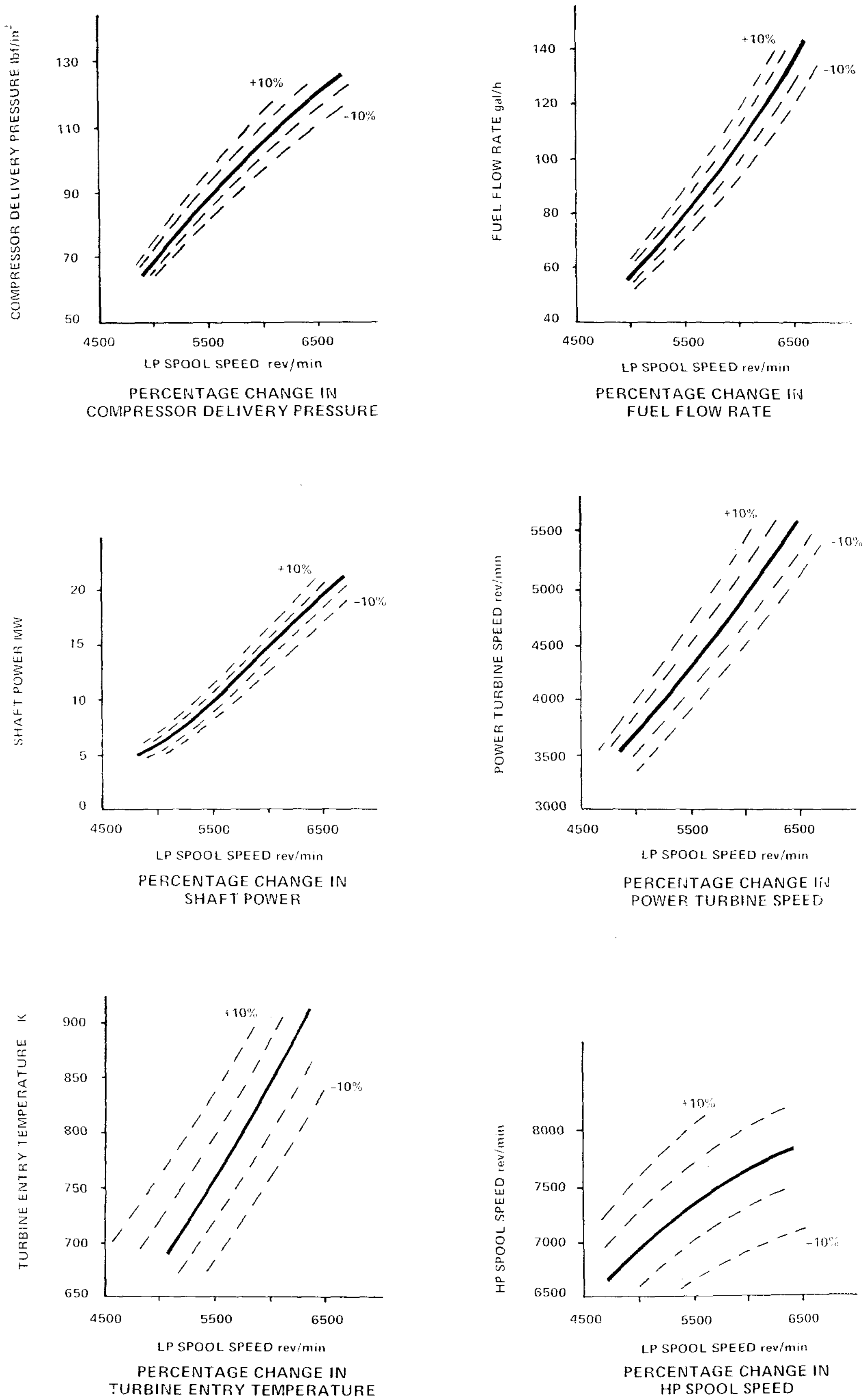

FIG. 4—GRAPHS TO FIND THE PERCENTAGE CHANGE OF PARAMETERS FROM DATUM VALUES

Validation of the Hypothesis

The computer programmes were now used to predict the small changes that would occur in the parameters at various L.P. spool speeds in the running range (4000–6000 rev/min) with set changes in the component characteristics. In each case it was found that the value of the changes fell inside a definable range and that the pattern of the changes was distinct for each of the different component malfunctions investigated (FIG. 2). This validated the hypothesis and showed that by examining the pattern of the measured changes the problem part of the engine could be correctly identified. It further showed that these readings may be taken at any power so that long periods at powers inconvenient to the ship's programme are avoided.

Practical Use of the Method

For two reasons, the measurement of the trend of performance is a practical approach to the diagnosis of defects. Normally, engines do not lose, say, one per cent L.P. compressor efficiency as a step change unless some disaster occurs which could probably be better detected by other means. The trend of performance fall-off, however, will provide useful and timely evidence. Secondly, although the slight inaccuracies of individual instruments may for absolute readings be misleading, being repeatable they will usefully indicate trend changes.

The procedure for using this method would be as follows:

(*a*) When they are steady, the watchkeeper takes readings of those parameters shown in FIG. 1.

(*b*) Using the graphs shown in FIG. 3, he corrects these readings for ambient conditions.

(*c*) From the datum graphs (FIG. 4), the watchkeeper then finds the percentage change for each parameter.

(*d*) He then plots the percentage changes on the trend plot and checks that they are sensible. Any serious anomalies can be rechecked at this stage.

(*e*) The trend plot would be checked by the M.E.O. or a delegated senior rating once each day or more often if a rapidly developing fault is indicated. A footprint, like those in FIG. 2, is now drawn.

Although it would obviously be possible for actions (*b*) and (*c*) to be performed by a small computer which would produce corrected percentage changes on being given the ambient conditions and the parameter readings, the graphical method proposed should produce good results.

For onboard diagnosis a set of overlays would be issued to each ship. Initially these would be as FIG. 2 drawn on transparent plastic. Provided the footprint is drawn to the same scale as these overlays then they can be fitted until a match is obtained and the fault therefore diagnosed. The scale used for the overlays is where the change in H.P. spool speed is set to unity. As more actual records are obtained and correlated with strip down reports, the overlays would be replaced with a revised footprint.

Multi-Component Off-Design Performance

It is possible that more than one component will operate off design at any time. If this happens then the method can be made to show up sequential faults, provided the trends of the existing faults have been identified.

If a second deterioration imposes itself on the first at time 'T' then a series of plots of changes in the measured parameters against time would look similar to FIG. 5. A trend plot at time 'T' could be matched by an overlay and a first fault diagnosed, but after that time the second, rapidly developing,

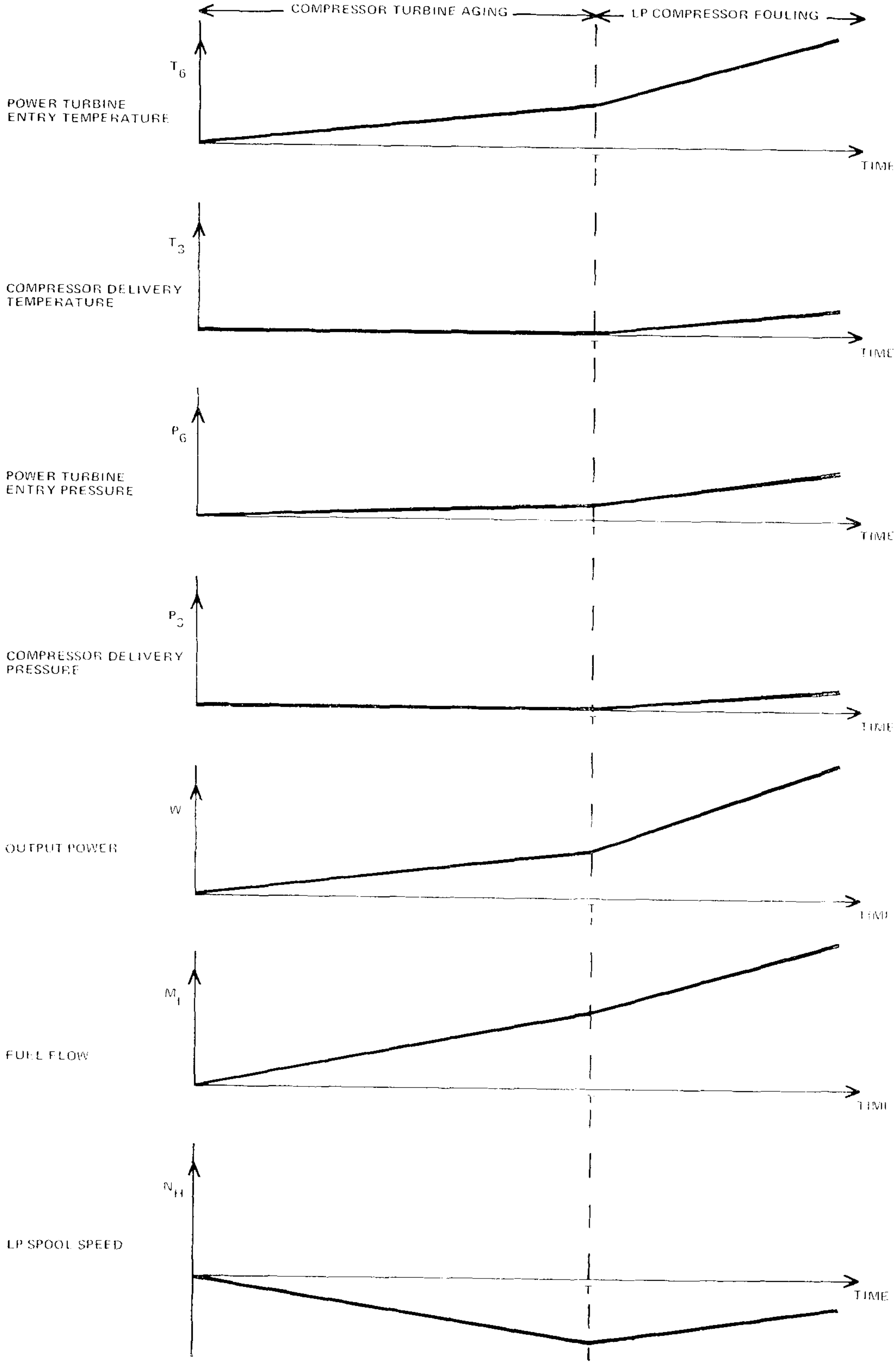

FIG. 5—CHANGES IN MEASURED PARAMETERS AGAINST TIME SHOWING THE EFFECT OF TWO-COMPONENT DETERIORATION

fault will mask the effects of the first. To investigate the second fault the values at time 'T' must be used as the datum. These values are held in the ship's records as a previous trend plot and by subtracting them from the most recent trend plot values a new plot can be made which can be compared with the overlays in the usual way. This will tend to show up the most rapidly developing, and hence most urgent, off-performance change at the time of the readings.

Implementation at Sea

The method is simple to operate and is designed so that the watchkeeper can take all the necessary readings as part of his normal duties. Having taken the readings he can construct a trend plot with little knowledge beyond the elementary use of graphs or of a computer if one is used instead. Since the readings that are taken are used by the watchkeeper himself he can see the reason for their collection and is thus personally involved in the fault diagnosis. This helps motivation.

The base reference for the percentage change curves must be a readily and accurately measurable quantity. For this reason L.P. spool speed has been chosen. Modern gas-turbine-driven ships are fitted with an accurate digital revolution counter to measure spool speeds and so it is appropriate to use this instrument rather than a pressure or temperature measuring device. The readings would have to be taken at least once every 24 hours and more frequently if correction of faults that can develop quickly, like L.P. compressor fouling, is to be made 'on condition'.

The ideal frequency would be determined by experience and would alter with the rate of component deterioration. Initially it is suggested that readings be taken once a watch to fall into line with traditional engineering practice but, since the diagnosis is done onboard, the ship's marine engineer officer could alter the frequency if necessary.

Acknowledgements

The author's acknowledge the assistance they received from Rolls-Royce (1971) Ltd and from the Ministry of Defence; however, the opinions stated in this article are their own.

References:

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2. Dyter, Lieut. D. M., R.N., 'An Investigation into the use of Performance Curve Trend Analysis within the Royal Navy', Marine Engineering Dagger Course Thesis T124, R.N.E.C. 1975.

Ship Department Comment

The method of on-board analysis proposed in the article is broadly in agreement with Ship Department thnking and usefully complements the in-house work being undertaken.

It is desirable that the R.N. moves on to 'on-condition' engine removal. Early experience from the engine health monitoring programme being run is encouraging (Ref. 2) and the development of an on-board fault diagnosis procedure, as proposed, is an important element of this programme. The method proposed in this article is a practical means of interpreting trend graphs.