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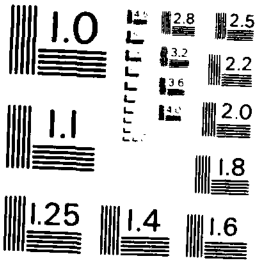

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MECHANICAL ENGINEERING NOTE 387

AN EVALUATION OF ENGINE PERFORMANCE ASSESSMENT PROCEDURES FOR THE LYCOMING T53 ENGINE AS INSTALLED IN THE IROQUOIS HELICOPTER

by

D. E. GLENNY

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SUMMARY

An evaluation of a number of engine performance assessment procedures, including TEAC, SFI 21, HIT and IFM, has been carried out for the Lycoming T53 engine installed in the Iroquois helicopter. The data used in this evaluation were obtained from a comprehensive trial undertaken by No. 5 Squadron at RAAF Fairbairn and elsewhere. The results show that IFM and HIT procedures can be used to assess engine performance and indicate engine degradation.

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16. *ABSTRACT*

An evaluation of a number of engine performance assessment procedures, including TEAC, SFI 21, HIT and IFM, has been carried out for the Lycoming T53 engine installed in the Iroquois helicopter. The data used in the evaluation were obtained from a trial carried out by RAAF No. 5 squadron.

Following an analysis of the results a number of recommendations regarding engine performance monitoring-procedures in the Iroquois helicopter were made.

It is recommended that the number of performance monitoring procedures currently being used by the RAAF should be rationalised. Further it is recommended that:

(a) *TEAC should be used as the basic means for determining maximum power available.*

(b) *IFM, with provision for compressor pressure ratio monitoring in addition to the normal torque and exhaust gas temperature monitoring, should be used to assess day-to-day installed engine performance.*

(c) *The pilot should be provided with computational facilities to calculate, during flight, trends in ΔCPR, ΔTOR and ΔEGT.*

(d) *Topping checks as required in SFI 21 should only be carried out if an absolute assurance of power is required.*

(e) *The requirements for HIT checks should be deleted.*

(f) *As a means of improving the reliability and consistency of the aircraft OAT readings, consideration should be given to re-locating the position of the OAT gauge.*

CONTENTS

1. INTRODUCTION

Since the introduction of the Iroquois/Lycoming T53 helicopter into service with the US Forces and its subsequent use by the RAAF, the aircraft and, in particular, its engine have been subject to an exhaustive series of regular in-service tests* to determine the installed power available and thus the aircraft performance capabilities.

The Lycoming T53-L11/L13 engine, as with most other turboshaft engines, is fitted with a torque indicating system. The torque meter can be used in conjunction with other engine/aircraft instrumentation to assess engine performance on initial installation or during subsequent service life.

A synopsis of the many engine performance assessment procedures used by various operators throughout the world is given, ~~below:~~

(a) Turbine Engine Analysis Check—TEAC/Topping
This check is used on initial installation of an engine or when the power available is suspect; it relates maximum power available to gas generator speed and engine exhaust gas temperature. The procedures involved are specified in the T53 Maintenance Manual.

(b) Health Indicator Test—HIT
This check, developed by the US Army, is used as a GO/NO-GO criterion for power available. It is carried out at part engine power prior to take-off and compares actual exhaust gas temperature, for given operating conditions, to previously determined baseline values.

(c) Daily Engine Condition Analysis—DECA
This check is the same as the HIT check, but it has been renamed by the US Air Force.

(d) Daily Engine Records—DER
This check was used by the US Army and Air Force prior to the implementation of the HIT/DECA check. It was carried out at part power condition, just after take-off; it was discontinued because of difficulties in carrying out the tests whilst flying in formation and because there were inaccuracies in the correction procedures used to determine reference exhaust gas temperatures.

(e) Special Flying Instruction 21—SFI 21
This procedure, developed by the RAAF, requires pilots on the first flight of each day to determine maximum power available, in comparison with minimum acceptable torque curves. The magnitude of N_1 at maximum power is used in subsequent flight planning to set aircraft operating limits.

(f) In Flight Monitoring—IFM
This procedure, developed at ARL in conjunction with RAAF HQSC, was designed to complement and if possible supplement the daily maximum power checks used in SFI 21. Full details of the method and trial results are given in Section 2.4.

(g) Civilian—Engine Operation Check Charts
These checks, published in the civilian Iroquois/Bell 205 Flight Manual (3), are used to determine values of N_1, EGT, Torque and Fuel Flow. Basically the checks are a combination of the TEAC and HIT, using as reference the manufacturer's specification for engine performance.

(h) Numerous "experimental" performance monitoring procedures initiated by the US Army, (4) and (5).

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* References (1) and (2) detail two of the many flight test programmes carried out by various operators.

2. INSTALLED ENGINE PERFORMANCE—RAAF IROQUOIS HELICOPTER

Currently the RAAF uses a combination of TEAC, SFI 21, HIT and IFM checks to determine installed engine performance. The first procedure is used on initial installation of an engine or whenever the power level is suspect. SFI 21 is used on a daily basis, whilst the last two, HIT and IFM have been used on a more or less day to day basis during a trial period of approximately 18 months.

2.1 TEAC

The TEAC, or topping check as it is more colloquially known, is used by maintenance personnel to set the initial maximum power level of the T53 engine when it is first installed in the aircraft, and for investigating reported power deficiencies. Detailed procedures for carrying out the TEAC are given in (6). Briefly it involves, "Climbing the aircraft" until maximum power available is achieved (as indicated by a "Droop" in power turbine output speed) and then recording the following engine/aircraft operating parameters:

(a) Pressure Altitude — H_p

(b) Outside Air Temperature — OAT

(c) Torque — TOR

(d) Exhaust Gas Temperature — EGT

(e) Compressor Turbine Speed — N_1

(f) Power Turbine Speed — N_2

From these parameters, corrected values of N_1 and EGT for maximum power are calculated, whilst the minimum acceptable level of torque is determined from Figure 1, (Lycoming T53-L13) using the instructions detailed on the graph. On completion of the check, if it is found that the observed torque differs from that given by the minimum acceptable torque level chart, Figure 1, then the engine must be re-trimmed, by adjusting the fuel control unit (FCU). After readjustment, another TEAC is carried out and further FCU adjustments made, if necessary. The final corrected values of N_1 and EGT are then used as the initial baseline reference figures for subsequent maximum power assurance checks.

In subsequent topping checks new corrected values of N_1 and EGT are determined together with the minimum acceptable torque level obtained from Figure 1, their values are then compared with the initial baseline values and the achieved torque level. Failure to meet the original limits of N_1 and EGT or the minimum acceptable torque will indicate some degree of engine deterioration.

The deficiency in torque level can be corrected by re-trimming the FCU to obtain the required torque level provided the manufacturer's maximum N_1 and EGT limits are not exceeded.

2.1.1 RAAF Operating Procedure

The RAAF use of the TEAC method whilst conforming in most part to the procedures given in (6) does not fully utilize the potential of this, the most accurate method available to date, for assessing maximum installed power. RAAF maintenance personnel, having calculated the corrected maximum values of N_1 and EGT and the torque differential, do not monitor parameter variations from their baseline values even on a simple trend chart. Using such a method, a simple and accurate assessment of engine deterioration can be obtained. The only limitation in this monitoring procedure is the large time interval between each TEAC; more frequent application of the check could be detrimental to engine life and hence counter-productive.

2.2 Special Flying Instruction/Iroquois/21

RAAF SFI 21 (7) was written following the completion of an ARDU report (2) on the performance of the Iroquois UH-1H helicopter and the Lycoming T53-L13 engine. This report (2) defines aircraft performance limits for maximum power available, take-off and approach gross weight limitations and hover performance. The inservice use of SFI 21 relies to a large extent on the pilot knowing the maximum rated speed, N_1 max, and torque level, which can be achieved; in order to confirm these values the pilots are required to carry out a power check on the first flight of each day.

The relevant procedures, as defined in SFI 21, are given by the following extracts:

"8. On the first flight of the day, captains are to carry out a maximum power check, if possible above topping altitude, as follows:

(a) increase power until N_2 bleeds to 6400 rpm (from a normal operating speed of 6600 rpm) or 50 psi torque is reached. (Note: Engine power (SHP) is specified in terms of an oil (torque) pressure, and engine transmission is limited to a torque equivalent of 50 psi).

(b) note the maximum N_1 reached and record on the "TOLD"* card, and

(c) record the maximum torque (achieved) and compare with that obtained from the Minimum Acceptable Torque Chart.

If the maximum N_1 (recorded) is lower than the decal N_1 (i.e. the maximum rated N_1 for that given engine) by more than 0·2%, or the maximum torque available is less than the appropriate chart figure, the aircraft is to be landed and placed unserviceable.

9. If the topping altitude cannot be reached the power checks should, if possible, be carried out at or above the highest landing place (LP) altitude to be used during the sortie and the maximum N_1 obtained should be recorded on the TOLD card. If a landing is intended above the altitude reached, or an increase of 2°C or more in temperature occurs, a further power check at or above the intended LP altitude is required.

10. Where topping altitude is reached during a power check further checks are not required during that day. The captain is to annotate the EE500** whether or not a power check has been carried out above topping altitude. Captains on subsequent flights are not required to carry out a maximum power check if topping altitude has been reached and recorded in the EE500.

11. If at any stage engine performance is in doubt, a further power check is to be carried out".

(The remainder of the SFI describes numerous procedures for Take-Off, Hovers, Approaches and Landings, all of which are conditional upon the value of N_1 max achieved during the daily SFI 21 power check).

2.2.1 RAAF Operating Procedure

Numerous discussions held with RAAF aircrew highlighted the regard with which SFI 21 and its maximum power check was held; however little concern was expressed as to the damage which repeated maximum power checks could do to the engine. In addition there was little real appreciation that, even though a torque of 50 psi was obtained, it did not confirm that maximum power would be available, nor was it realised that as such there was no relevance in undertaking such a limited power check without alternative supporting checks being carried out.

From inspection of EE500's it was evident that little information, including data, was being recorded (as is specified in the instructions for SFI 21) on the occurrence of SFI 21 topping checks. It can only be concluded that:

(a) topping check results were not being entered on the EE500,

(b) the torque limit of 50 psi was being obtained on many of the power checks, or

(c) the check was not being carried out at all—a most unlikely reason.

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* Take-off and Landing Data card.

** EE500 is the form used by aircrew and maintenance personnel to record any aircraft/engine fault and its subsequent rectification.

2.2.2 Implications of SFI 21

The most significant implication of the use of SFI 21, notwithstanding the confidence which assurance of maximum power may give a pilot, is the serious damage that repeated excursions to maximum power can have on engine condition and life. It is understood that only in Australia are such stringent and frequent power checks carried out. It is unlikely that the manufacturer designed or lifed the engine to cope with such severe operating conditions.

With reference to Section 2.2.1 and, in particular, sub section (b), it is difficult to comprehend the value of carrying out a power check to a limit of 50 psi which represents a low power setting for some prevailing ambient conditions, without carrying out supplementary checks as given in the IFM procedures.

2.3 HIT

The Health Indicator Test is a part load ground power check developed and carried out extensively by the US Army where it is used by pilots, prior to take-off, as a GO/NO-GO indicator for confirmation of engine performance. Detailed operating procedures are given in (6). Briefly the HIT check requires the pilot to set the engine up to a speed, N_1* determined by the prevailing outside air temperature (OAT) and to record the indicated exhaust gas temperature (EGT). An indicated EGT of ≥ (20–30 C) from predetermined EGT baseline values** has to be reported at the end of the flight, whilst an EGT difference greater than 35 C is reason to ground the aircraft.

2.3.1 RAAF Usage

To date, even though the HIT procedures are defined in the RAAF T53 maintenance manual (6), the usage of this ground, part-load power check has been spasmodic, and has been dependent wholly on the co-operation between aircrew and maintenance personnel and the enthusiasm of the local engineering officer. As a consequence there are no details of the effectiveness of the HIT check within the RAAF. (In contrast examples of the confidence expressed by the U.S. military in the TEAC HIT systems are given in (8), (9), which state that regular turbine hot end inspections may be deleted if daily HIT checks are carried out).

2.4 IFM

The In Flight Monitoring (IFM) procedures were developed by an ARL officer seconded to RAAF to investigate engine performance assessment procedures on a number of RAAF aircraft. The rationale for developing the IFM procedures was to provide an alternative (part load) power assessment check to supplant the maximum power topping checks carried out in accordance with SFI 21, and hence minimise the potential damage being inflicted on the engine by "repeated" application of maximum power.

2.4.1 IFM System

The basic principle on which the IFM monitoring system is based is that turboshaft engines, such as the T53, always deliver the same corrected torque and register the same corrected EGT

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* The basic criterion for determining the operating values of N_1 is that no matter what the value of OAT, the engine will be set to a fixed point on the corrected power/temperature operating line, i.e. $N_1/\sqrt{\theta}$ and EGT/θ will be constant values.

** The EGT baseline values which are also functions of the prevailing OAT are determined by maintenance personnel subsequent to carrying out an installation topping check.

and fuel flow (FF) for a given corrected N_1 unless the engine characteristics have changed through deterioration in service. The corrected parameters are defined as follows,

$$TOR_c = TOR/\delta\sqrt{\theta}$$

$$EGT_c = EGT/\theta$$

$$FF_c = FF/\delta\sqrt{\theta}$$

$$N_{1c} = N_1/\sqrt{\theta}$$

where
$$\delta = \frac{\text{Ambient Pressure}}{\text{Standard Sea Level Pressure}}$$

$$\theta = \frac{\text{OAT} + 273}{\text{Standard OAT} + 273}$$

From the above it follows that for a given set of values for N_1, OAT, H_p and engine specification performance data (for the T53 engine) then the expected, uncorrected values of Torque, EGT and FF can be calculated. Differences of the observed performance parameters (TOR, EGT)* from the expected values of TOR and EGT can be used to assess engine condition; large variations in ΔTOR and ΔEGT would be cause for maintenance action.

Using the above system, an IFM procedure was developed which could be used either by aircrew or maintenance personnel.

In the former case the aircrew could by simply entering data into a pre-programmed calculator determine decrements in Torque or increments in EGT, whilst in the latter case maintenance personnel could use the data to produce trends in engine performance.

Basically the procedure involves the pilot recording the following aircraft engine parameters, whilst the aircraft is in steady flight conditions:

(a) Pressure Altitude — H_p
(b) Outside Air Temperature — OAT
(c) N_1 — N_1
(d) N_2 — N_2
(e) Torque — TOR
(f) Exhaust Gas Temperature — EGT

These data are then used as input to a hand held programmable calculator (in this instance a HP25) which had been pre-programmed to contain the relevant TOR_c versus N_{1c} and EGT_c versus N_{1c} engine performance specification curves. Details of a typical data analysis program are given in Appendix A.

The outputs from the program are deviations in torque and EGT i.e. ΔTOR and ΔEGT from standard specification values. Variations in these two parameters can be monitored to indicate deterioration of engine performance.

The advantages of the IFM system are:

1. Engine performance assessment can be carried out at power levels greater than the HIT check, yet not necessarily at the maximum powers involved in the TEAC or SFI 21.
2. Both torque and EGT performance may be monitored.
3. Results can be analysed in flight by the pilot provided calculators are available, and the results used by maintenance personnel to determine trends in engine performance.
4. Direct pilot involvement in IFM checks would result in more consistent data recording and also provide the pilot with an immediate record of engine condition degradation.
5. If required, the engine specification data curves held in the calculator can be re-configured to reflect the performance of the actual engine being tested.

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* A fuel flow meter is not fitted to the RAAF Iroquois helicopter.

2.4.2 IFM Trial

At the instigation of RAAF, HQSC Aircraft Engineering Division and with the cooperation of No. 5 Squadron based at RAAF Fairbairn, a trial of the IFM system was undertaken on both the B and H model Iroquois helicopters. Co-operation with the No. 5 Squadron had the added advantage that some of the helicopters would be operating in the arduous conditions of the Sinai Desert, where Australia was contributing to the United Nations peace-keeping force.

The IFM trial commenced in August 1976, following numerous discussions with RAAF aircrew and maintenance personnel. The instructions covering the implementation of the trial are given in (10). Briefly this instruction required the aircrew to record on a special Engine Parameter Record Card, once per flight under stabilized operating conditions, the operating parameters listed in Section 2.4.1. A copy of the Record Card is given in Figure 2. Once the card was complete, 10 consecutive readings, it was to be dispatched to the Early Failure Detection Cell (EFDC) at Fairbairn for data processing on an HP25 calculator.

For this limited trial, it was not proposed to carry out in-flight analysis of the raw data, and consequently the pilot involvement was limited to recording the required engine/aircraft data.

At the same time as the IFM trial was carried out the pilots were requested:

(a) to record results of a HIT check, and

(b) to record details of any maximum power check undertaken.

Both sets of data were to be noted on the card shown in Fig. 2; the HIT results in the columns marked EGT Trend Log, whilst the TEACs were to be included as part of the IFM records on the Engine Parameter Record Card.

2.4.3 Results of IFM Trial

In the course of the trial, engine data was logged for 22, T53-L13 engines and 17, T53-L11 engines. Some of the data obtained were limited in range as engine removals in the Iroquois can, on occasions, be very frequent.

Torque and exhaust gas temperature deviations for each of the engines were analysed both at RAAF Fairbairn, where corrective action could be undertaken if found necessary, and at ARL where an overall analysis of the IFM, HIT and topping checks was carried out. Typical results of the ARL analysis are given in Fig. 3a, b, c and d. The respective plots show the following:

(a) Figure 3a—Comparison of SHP$_c$ versus N$_{1c}$ derived from observed engine results, with engine specification performance and the engine's actual* baseline performance.

(b) Figure 3b—Comparison of EGT$_c$ versus N$_{1c}$ derived from observed engine results, with engine specification performance and the engine's actual baseline performance.

(c) Figure 3c—Deviations of observed engine torque from both specification and actual baseline performance of engine being monitored.

(d) Figure 3d—Deviation of observed engine exhaust gas temperature from both specification and actual baseline performance of engine being monitored.

In Figure 3c and d a rolling averaging technique for each data point, defined by Δ_{RA5} at $n = (\Delta n + \Delta n-1 + \Delta n-2 + \Delta n-3 + \Delta n-4)/5$, was used to reduce the scatter in the results and give a smoother trend graph; the Δ_{RA5} results are given by the continuous line. The IFM results analysed in the EFDC, at RAAF Fairbairn, were also smoothed, but in this case the smoothing was obtained by dividing the data into groups each consisting of five results and then taking the average of each group. The effect of this technique can be observed in later presentations of the IFM results in Section 2.4.5.

An analysis of the results given in Figure 3a and b, which are typical of all engines monitored, shows that even though the slopes of the baseline performance curves (for both torque/SHP

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* Actual baseline engine performance was calculated from the first 20 IFM readings obtained.

and EGT) can be different from the specification performance curves, the overall differences in results for the torque and EGT deviation plots given in Figure 3c and d respectively are minimal. Consequently in computing torque and EGT differences, either of the performance curves, specification or baseline, may be used. The advantage of using engine baseline data is that at the commencement of plotting ΔTOR and ΔEGT, the deviations are sensibly 'scattered' around the zero deviation line: see lower curves in Figures 3c and d.

The major limitation in the IFM trend plots is the scatter of individual readings, and this is the reason for using a smoothing or averaging technique. The scatter is a direct result of instrumentation reading error. If the pilot had access to a programmable calculator then the IFM results could have been checked inflight and if necessary retaken.

The following table shows the sensitivity of instrument reading errors on the resultant ΔTOR and ΔEGT values.

Instrument Resolution	TORQUE	EGT
100 ft (Altitude)	± 0·1 psi	0 C
1 C OAT	± 0·4 psi	± 1 C
$0{\cdot}1\%\ N_1$	0·3 psi	1 C
50 rpm N_2	± 0·2 psi	0 C

From the above table it can be seen that the OAT measurement has a most significant effect on the resultant 'calculated torque'. The location of the OAT gauge, at the top righthand side of the aircraft windscreen is not conducive to giving consistent values of the ambient outside air temperature, as on many occasions the probe is exposed to direct sunlight. Figure 4 shows the location of the remaining aircraft instrumentation and exemplifies the difficulties which pilots can have in reading the required data.

Further detailed analyses of all T53 engines monitored are not presented here, rather 5 examples are given in the next section. These limited samples of trial results are sufficient to enable a comparison of IFM, HIT and TEAC checks to be made.

2.4.4. Comparitive Monitoring Results

The monitoring results given in this section are presented in three groups:

(a) Two T53-L13 engines operated from RAAF Base Fairbairn, Figures 5 and 6.

(b) One T53-L11 engine operated from RAAF Base Fairbairn, Figure 7.

(c) Two T53-L13 engines operated by the RAAF with the UNEF in Sinai, Figures 8 and 9.

In each figure the IFM results have been presented using a simple average of each group of five data points (● – ●) rather than the rolling average technique used in Figures 3c and 3d. Individual engine baselines for both ΔTOR and ΔEGT have been calculated from the first 30 data points recorded and are denoted by the dashed line ( ), the difference between the individual baselines and the ΔTOR = 0, ΔEGT = 0 abscissa represents the variation of a given engine from the data base used to define the performance of an "average" engine. The TEAC or topping checks carried out on each aircraft are indicated at the point *: included at that point is the degree of concurrence of engine torque with the Minimum "Acceptable" torque derived from Figure 1. Also included in Figures 5–9 are the EGT trends derived from the HIT checks.

A. Analysis of the results for the first engine, Figure 5, shows that during the first 1200 hours there was no significant change in torque or EGT differences; however in the period 1300-1400 hours there was a step change, 3 psi, in torque level: throughout this period the EGT level stayed fairly constant. The initial torque levels are confirmed by the two TEACs carried out at time 1075 and 1235 hours. A comparison of the HIT results shows a slightly erratic response part way through the reading but in general conforms to the values calculated from the IFM results. The fall in torque level could not be related to any discernible faults when the engine was eventually removed from the aircraft. The deterioration could have been simply attributed to erosion of the compressor blading which was evident. Analysis of the results given in Figure 6 for the second engine shows that again there was general agreement between the torque level trends as determined from the IFM monitoring and the TEACs carried out at time 255, 420 and 500 hours, and the temperature levels indicated in the HIT and IFM trends. The latter agreement is most significant in that during the final 100 hours of monitoring, there was rapid increase in the EGT difference levels. An increase of over 30 C was indicated by both methods (it should be noted that the differences in levels for the two EGT trends results, can be attributed to an initial incorrect estimation of the HIT baseline values). Inspection of the torque trends shows that there was a gradual rise in torque levels until the last twenty hours of monitoring when there was a drop of approximately 3 psi. This fall was associated with the rapid rise in EGT, where a peak unaveraged value of 78 C was recorded. On inspection of the engine it was found that severe cracking over 13 of the 1st stage power turbine nozzle guide vanes had occurred. Replacement of the power turbine nozzle ring reduced the difference to approximately 20 C, a level consistent with the initial installed value.

B. A similar consistency of results is shown in Figure 7 for 153-L11 engine (B model Iroquois aircraft). In this case however no engine deterioration was indicated by either the ΔTOR or ΔEGT trends. Limited cross checking with known TEACs as indicated on the figure, confirms that little if any engine degradation had occurred during the monitoring period. Comparison of ΔEGT trends with HIT data was not possible as at that time HIT procedures for L-11 engines had not been introduced.

C. The results given in Figures 8 and 9 are for two of the helicopters which were operated in the Middle East with the UNEF. The desert environment is particularly arduous on L-13 engines as can be seen by the marked fall off in torque levels for both engines. The EGT trends given in Figure 8 show a moderate rise in levels, whilst that in Figure 9 does not deviate, until the last 15 readings. At this point a maximum decrement of −42 C from the mean line can be observed. (The change in EGT was immediately identified as a fault in the EGT harness). Analysis of the torque and EGT trends suggests that there had been a gradual change in the variable inlet guide vane (VIGV) scheduling. This conclusion was confirmed on servicing the engine when severe erosion and "roll over" was observed on the 1st and 2nd stage compressor blades. A modification to the leading edge section of the transonic blades would, even though the VIVG actuation system was operating correctly, result in an effective change in the VIGV schedule. The torque trends determined from the IFM were confirmed by a number of TEACs undertaken during the monitoring period. These are also indicated on Figures 8 and 9. The TEACs for the engine given in Figure 9 are complicated by the fact that a Fuel Control Unit change was made during the course of the IFM and the effects on torque level have had to be compensated for. It is perhaps unfortunate that no HIT results were available, even though it is understood that HIT monitoring was being carried out whilst the aircraft were being operated in the Middle East. For if the HIT trends had mirrored the IFM-EGT trends, and reliance had been limited to HIT trends alone then the severe compressor wear indicated by the changes in the IFM torque levels would not have been picked up.

2.4.5 In Service Evaluation of Monitoring System

An analysis of the IFM and HIT results was undertaken by the EEDC of No. 5 Squadron, at RAAF Fairbairn. A comprehensive report of engine defects and their related causes is given in (11) for the period 1976-1978. For 15 months of this period, when engine monitoring was being carried out, a total of 53 engines were defected, comprised of 16 for mechanical causes (wear debris in oil, and spectrometric oil analysis), 13 for thermodynamic related causes and the remaining 24 for other reasons.

Of the 13 engines defected for thermodynamics causes, maintenance action on four engines was initiated directly as a result of the monitoring procedures, either HIT or IFM. The remaining nine defects were indicated by other means; for example, as a result of schedule servicing or through engine torque fluctuations. Retrospective analysis of the performance trends, which were not always able to be kept up to date, showed that in four cases the IFM trends had reflected the defect, whilst in two cases marginal trends were apparent.

For the remaining three defects no monitoring information was available.

A survey into engine rectifications as distinct from engine defects indicated that:

(a) three cases of burnt or damaged turbine nozzle guide vanes,

(b) three cases of compressor blade erosion, and

(c) at least four cases of gauge malfunction,

had been positively identified by the IFM and HIT monitoring procedures. The total number of rectifications carried out during the period and the number which were thermodynamically related is not known.

2.4.5.1. EFD Cell—Comments

A summary of the EFDC analysis can best be given by quoting the following extracts from their report (11).

"(a) HIT as a GO NO-GO system has been successful in confirming defective engines and initiating increased pilot recording, leading to full investigation of engine (condition). The system has been most successful in such areas as indicating to the pilot that the engine anti-ice system is operating prior to take-off.

(b) The HIT system has experienced several small problems, primarily in the setting of the Baseline EGT. It has been found that there could be a Heat Soak through the engine during any sustained period of operation; this has led to lower Baseline EGT values being set.

(c) IFM, the long term monitoring procedure has been successful in two* cases. Because of difficulties in the interpretation of results due to EFDC inexperience, and (accuracy of) pilot recording or lack of, several situations have occurred where the system indicated the problem but it was not recognised. However this situation is gradually being overcome.

(d) IFM problems experienced have been: irregular pilot recording of parameters and instrument reading repeatability, leading to error results in ΔEGT and ΔTOR which can have large variations between readings. This has led to a system of averaging where the last known average figure is averaged with the last ten factors. This had led to a more consistent 'Signature of engine health'. It has also been found that when a problem is initially indicated by an increasing HIT EGT, the number of IFM pilot recordings increases. Pilots are also using previously recorded figures as an average of their cruise parameters. This has made them more aware of actual cruise values.**" (End of quotation from (11).)

2.4.6 Interpretation of Trends

Throughout the analysis of the IFM HIT results there has appeared to be some difficulty in interpreting any particular deviation of torque or deviation in exhaust gas temperature, in

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* Comments were written prior to complete evaluation data being available.

** Whilst not disagreeing with these last two sentences, problems can arise in comparing actual engine performance, if the H_p and OAT are markedly different. Pilot analysis of recorded data (using an HP25 say) would obviate this problem and would appear to have a further beneficial result, in that any suggested deviation in either ΔTOR or ΔEGT would be more rigorously monitored by the pilot.

terms of whether there was an engine fault or not. With these simple, limited, data recording techniques it is not possible to diagnose rigorously engine faults. Problem areas can only be inferred with the build up of experience. More comprehensive gas path analysis techniques can only be used with an increased range of data collection and hence engine instrumentation. In the case of the Lycoming T53 engine, which suffers very markedly from compressor erosion, a compromise may be achieved by monitoring compressor pressure ratio (CPR), and determining its variation with corrected engine speed. A decreasing ΔCPR* with time would give a more specific and immediate indication of erosion than that achieved by inference from ΔTOR and ΔEGT. The required CPR versus N_{1C} performance data and analysis technique could be combined with the current IFM procedures: the resulting trend plots would monitor ΔCPR as well as ΔTOR and ΔEGT. For this system to be effective the calculator programming capacity would have to be increased and, if possible, furnished with a continuous memory facility.

3. CONSPECTUS

From the analysis of the IFM data (and HIT results when available) it can be stated, notwithstanding particular comments made previously, that:

(a) Similar trend in EGT are produced using either IFM or HIT procedures.

(b) The HIT system is unable to indicate some forms of engine degradation, notably compressor erosion. Hence some reliance must be given to a form of torque (IFM) monitoring.

(c) Trending of IFM data in terms of ΔTOR and ΔEGT can adequately indicate engine deterioration over a period of time, and can thus be used to indicate power available without resort to frequent topping checks.

(d) There is a requirement for a complementary check to assess directly the compressor performance and its deterioration. This could be achieved by having an IFM type check for the compressor pressure ratio, i.e. CPR monitoring.

(e) Maximum power checks are only required whenever installed engine performance is suspect. In this case, detailed turbine analysis check (TEAC) should be carried out so that N_1 and EGT reference levels are recorded as well as the minimum acceptable torque figures.

(f) All checks, TEAC, HIT and IFM, are compromised by the location of the OAT gauge; consideration should be given to locating the instrument so that it is out of the line of direct sunlight.

Currently there is a surfeit of engine monitoring procedures being carried out on the Lycoming engines of the Iroquois helicopter. The IFM and HIT procedures introduced, as a trial, to overcome the detrimental effects of the topping checks carried out in SFI 21 have the potential to furnish equal if not superior information regarding engine conditions provided the operating instructions are carried out correctly. It is to be noted that checking the engine to a maximum torque of 50 psi (as detailed in SFI 21) does not give any indication of engine performance unless engine speeds and temperature are recorded and analysed: this would then be equivalent to an IFM check.

In summary the number of engine checks should be reduced and effort concentrated on accurately recording and analysing those results obtained from the remaining, more precise and potentially less damaging checks.

4. RECOMMENDATIONS

1. TEAC should be used as a basic, reference maximum power available check. The check should be carried out by squadron test pilots and data should be fully analysed by

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* ΔCPR = Actual Compressor Pressure Ratio for actual corrected engine speed—Baseline Compressure Pressure Ratio at same corrected engine speed.

maintenance personnel to define N_1 and EGT limits as well as minimum acceptable torque levels. The results of TEAC should be monitored (trended) from one check to the next.

2. IFM, with the provision for CPR monitoring, should be used as the pilot's day to day method for assessing power available. Data should be analysed inflight giving trends for ΔTOR, ΔCPR and ΔEGT; these results would be subsequently used by maintenance personnel for determining trends in engine degradation. Under these conditions SFI 21 topping checks need only be carried out if an absolute assurance of power is required: the requirement for HIT checks would be deleted.

   The consequences of these recommendations are that:

   (a) The pilots should have access to a programmable electronic calculator with an enlarged and continuous memory—e.g. HP 34C.

   (b) An engine compressor pressure ratio gauge, or means for calculating engine compressor pressure ratio should be included in the engine aircraft instrumentation. (It is to be noted that pressure tapping points are available, as CPR is determined on the engine test bed).

3. If Recommendation 2 above is unacceptable (cost only) then the IFM monitoring procedure should be combined with SFI 21 such that any time the SFI is carried out, the data (including N_1, torque, EGT etc) should be recorded and made available for analysis by base maintenance personnel.

   The HIT check should then be retained as a GO NO-GO indicator prior to take-off.

4. Finally, consideration should be given to relocating the position of the aircraft OAT gauge and sensor to reduce the effects of direct sunlight on its readings.

REFERENCES

1. Kos, J. M. *et al.* Feasibility Investigation for Determining Army Helicopter Gas Turbine Engine Maximum Power Available. USAAMRDL TECH. Report 72-58, Feb. 1973

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3. — MODEL 205A-1 Flight Manual T5313A or T5313B engine. Section IV, p. 4-1, 4-8. Bell Helicopter Co. Dec. 1971.

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5. Butcher, R. R., *et al.* UH-IH AIDAPS Test Bed Program. USAAVSCOM TECH. REPORT 72-19, June 1972.

6. — T53 Maintenance Manual RAAF-AAP 7113-003-2. Section 5-73 - 5-74.

7. - Special Flying Instruction: SFI-Iroquois/21, 5 May 1975. Subject: UH-IH Take-off Landing Procedures.

8. McHugh P.C., U.S. Army Aviation Digest, Oct. 1973, p. 10-15.

9. RAAF File W1520/4/418 (38). Subject--T 53 Engines--UHI Aircraft 18 Dec. 1975.

10. — RAAF HQSC 2602/17/76, Pt. 1 (25), 12/Aug./76.

11. RAAF HQSC 2608/132/20-6, Pt. 1 (41), 31/May/78, ANNEX B. Early Failure Detection-- General Analysis.

NOTATION

CPR	Compressor Pressure Ratio
DECA	Daily Engine Condition Analysis
DER	Daily Engine Record
EGT	Exhaust Gas Temperature
FCU	Fuel Control Unit
FF	Fuel Flow
HIT	Health Indicator Test
H_p	Pressure Altitude
IFM	In Flight Monitoring
K	Conversion Factor for Torque in lb ft to SHP
N	Engine Speed
n	Data point
OAT	Outside Air Temperature
SFI	Special Flying Instruction
TEAC	Turbine Engine Analysis Check
TOR	Torque
VIGV	Variable Inlet Guide Vane
θ	Temperature Ratio
δ	Pressure Ratio
Δ	Increment or Decrement

Subscripts

1	Inlet
2	Outlet
C	Corrected
Max	Maximum
RAN	Rolling Average N (Where N is number of items being averaged)

INSTRUCTIONS

Using the recorded values of H_p, OAT and Torque pressure achieved during the topping check the following procedure is carried out.

(a) Enter the power adjustment chart at the compensated temperature at the test altitude (OAT + 3 C) recorded, and go vertically up to the test pressure altitude H_p.

(b) Proceed horizontally to the left to the engine data plate torque pressure (DPTP) bias line which is closest to the DPTP value of the engine under test, and then proceed vertically down to determine the required torque pressure.

(c) The torque pressure measured during the flight test must be within ± l psi of that determined from the minimum acceptable torque pressure chart.

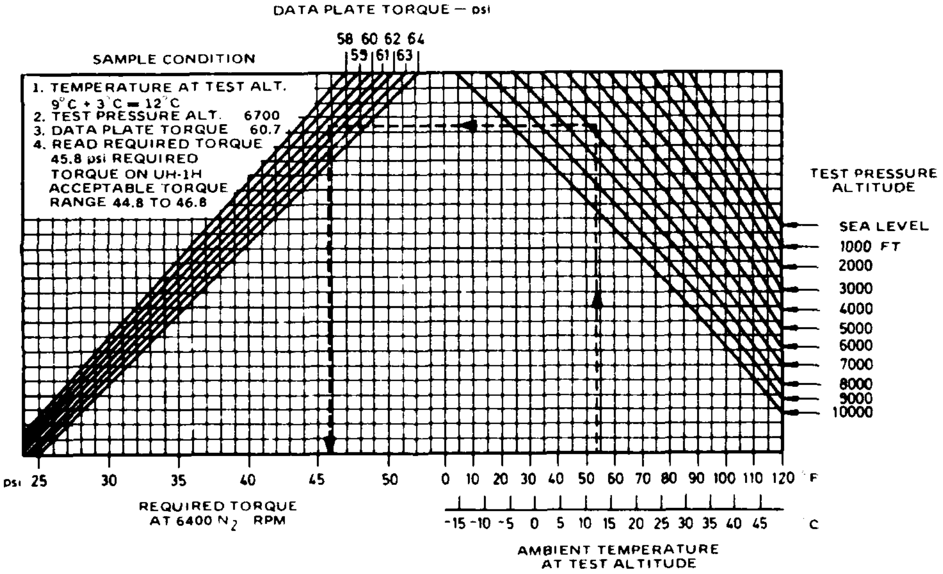
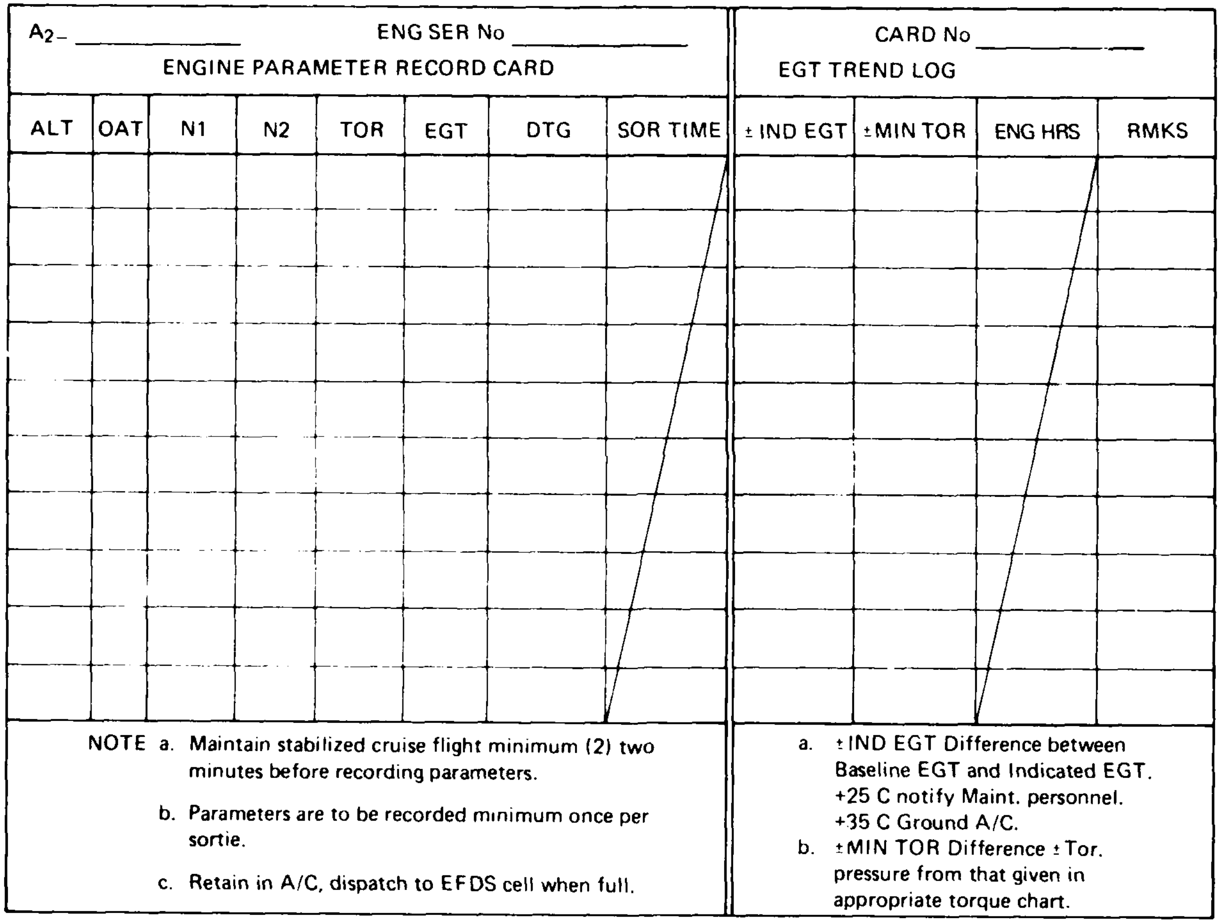


FIG. 1 T53–L13 MINIMUM ACCEPTABLE TORQUE CHART



A2- ______ ENG SER No ______

ENGINE PARAMETER RECORD CARD

CARD No ______

EGT TREND LOG

ALT	OAT	N1	N2	TOR	EGT	DTG	SOR TIME	± IND EGT	±MIN TOR	ENG HRS	RMKS

NOTE
- a. Maintain stabilized cruise flight minimum (2) two minutes before recording parameters.
- b. Parameters are to be recorded minimum once per sortie.
- c. Retain in A/C, dispatch to EFDS cell when full.

- a. ± IND EGT Difference between Baseline EGT and Indicated EGT. +25 C notify Maint. personnel. +35 C Ground A/C.
- b. ±MIN TOR Difference ± Tor. pressure from that given in appropriate torque chart.

FIG. 2 ENGINE PARAMETER RECORD CARD

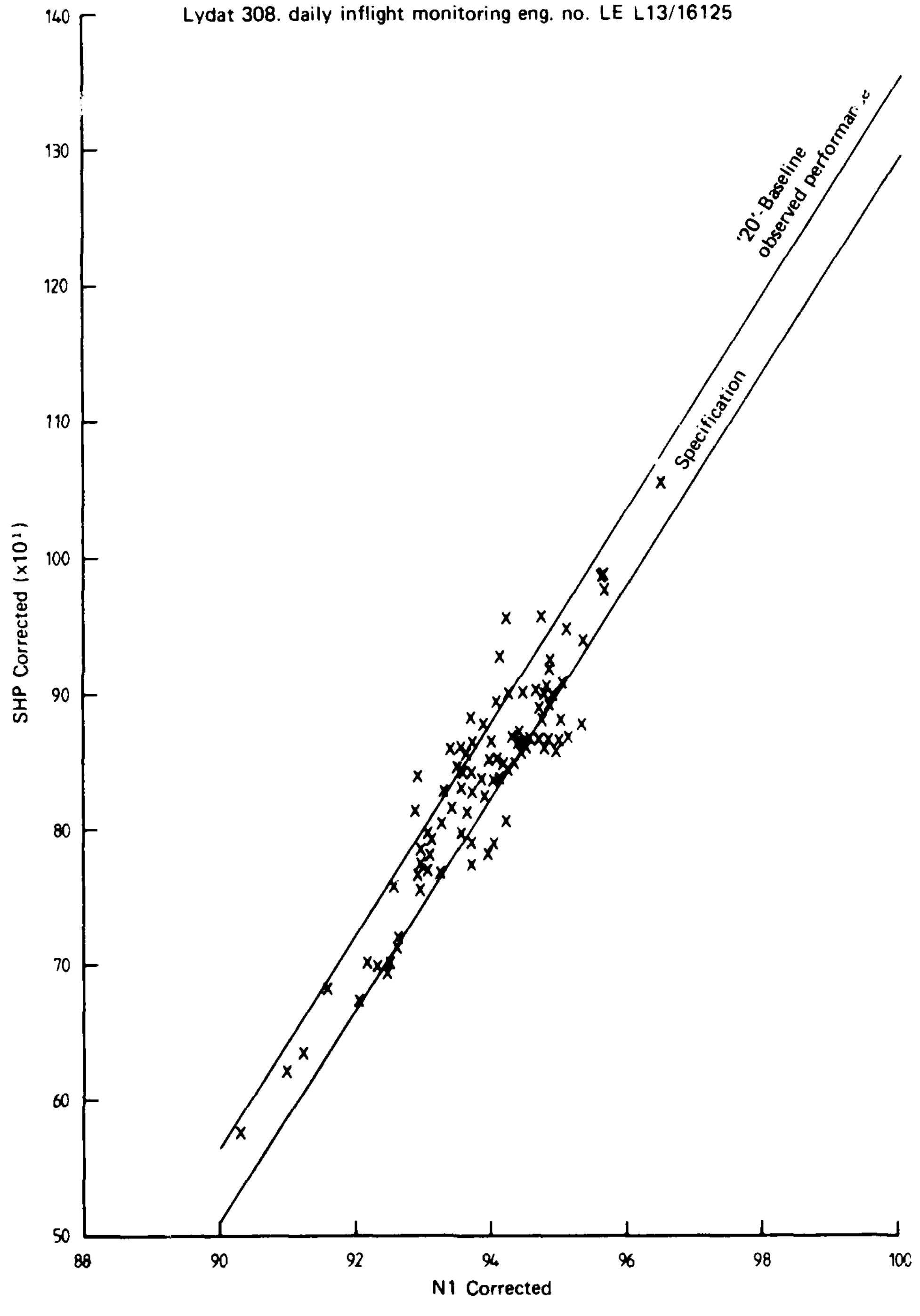


FIG. 3(a) COMPARISON BETWEEN SHP_C AND N_{1C} FOR BOTH OBSERVED AND SPECIFICATION PERFORMANCE

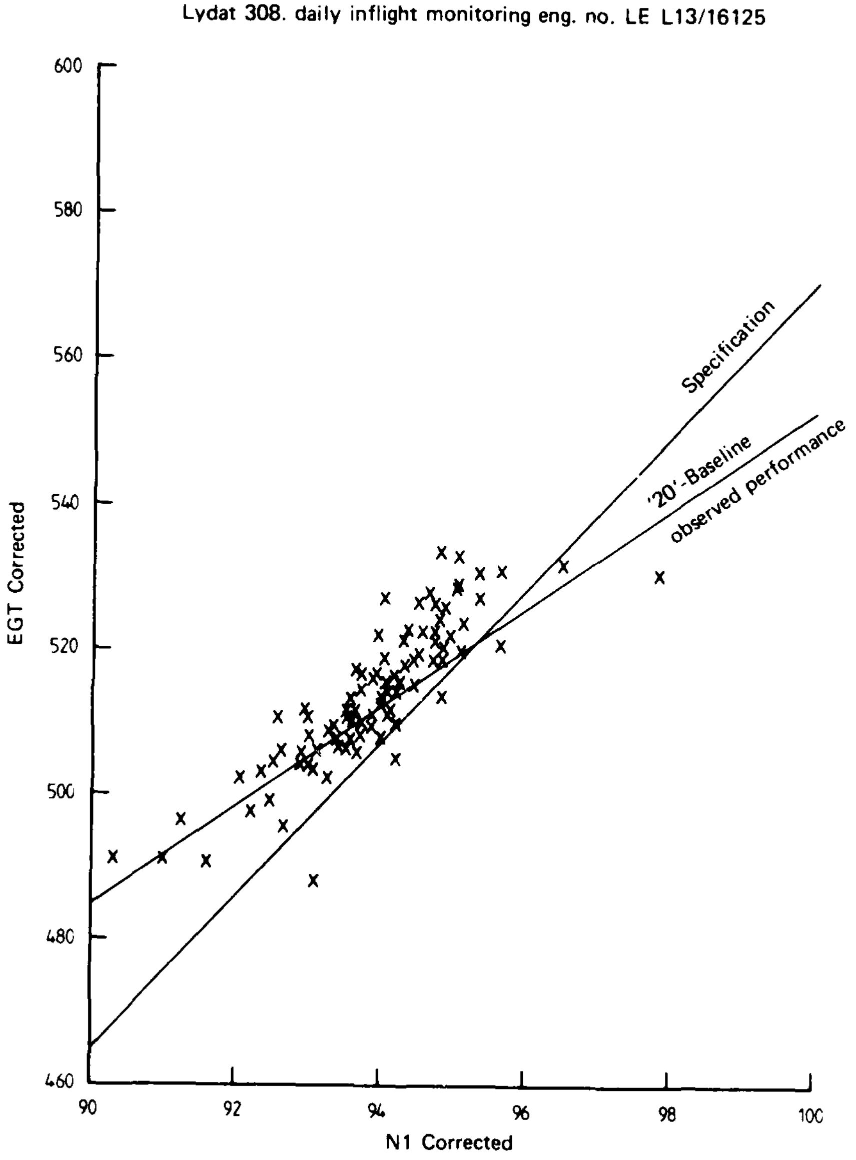
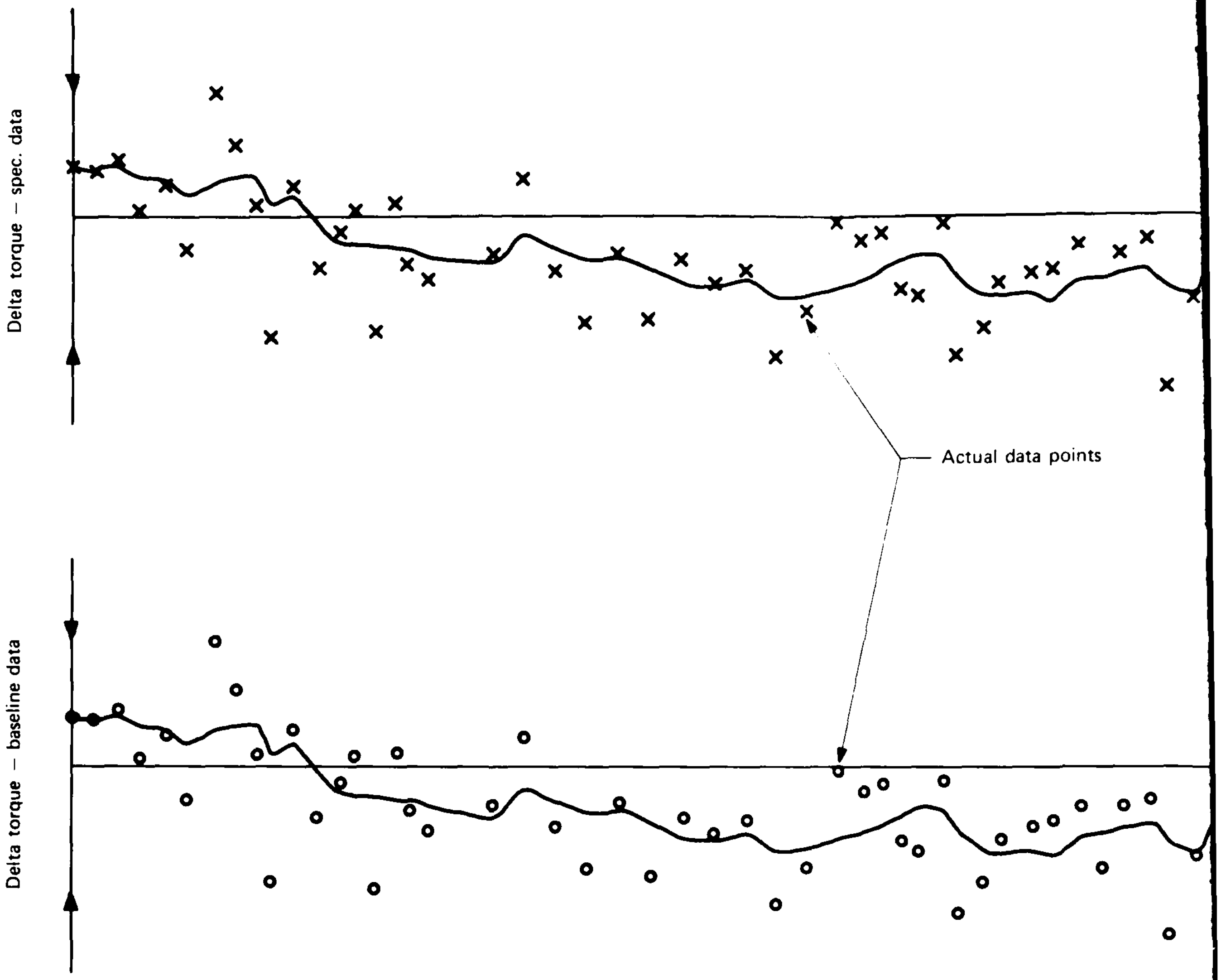


FIG. 3(b) COMPARISON BETWEEN EGT_c AND N_{1c} FOR BOTH OBSERVED AND SPECIFICATION PERFORMANCE


Delta torque – spec. data
Delta torque – baseline data
Actual data points

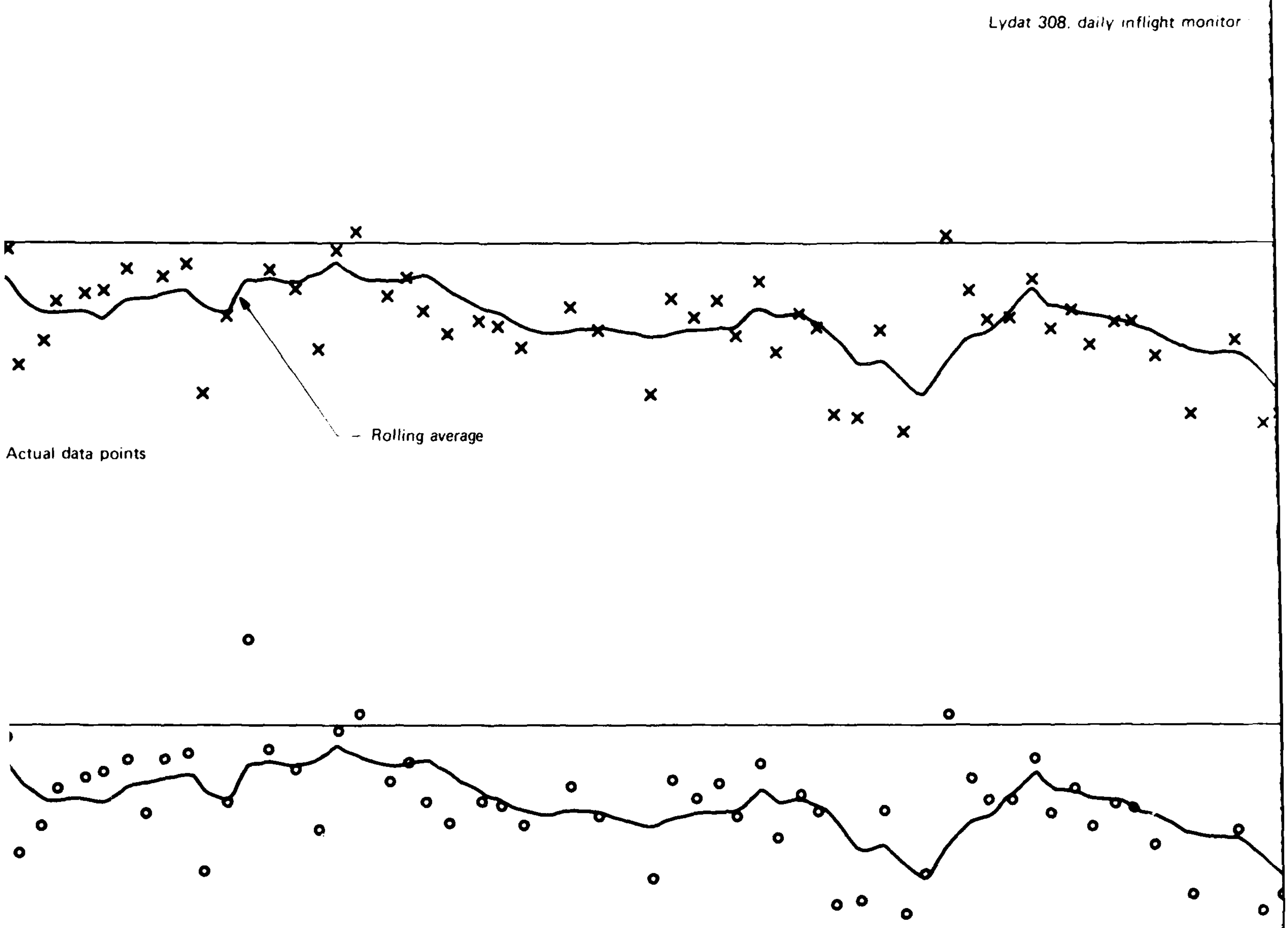


FIG. 3(c) DEVIATION OF OBSERVED TORQUE FR
ACTUAL BASELINE ENGINE PERFORMA

Lydat 308. daily inflight monitoring eng. no. LE L13/16125

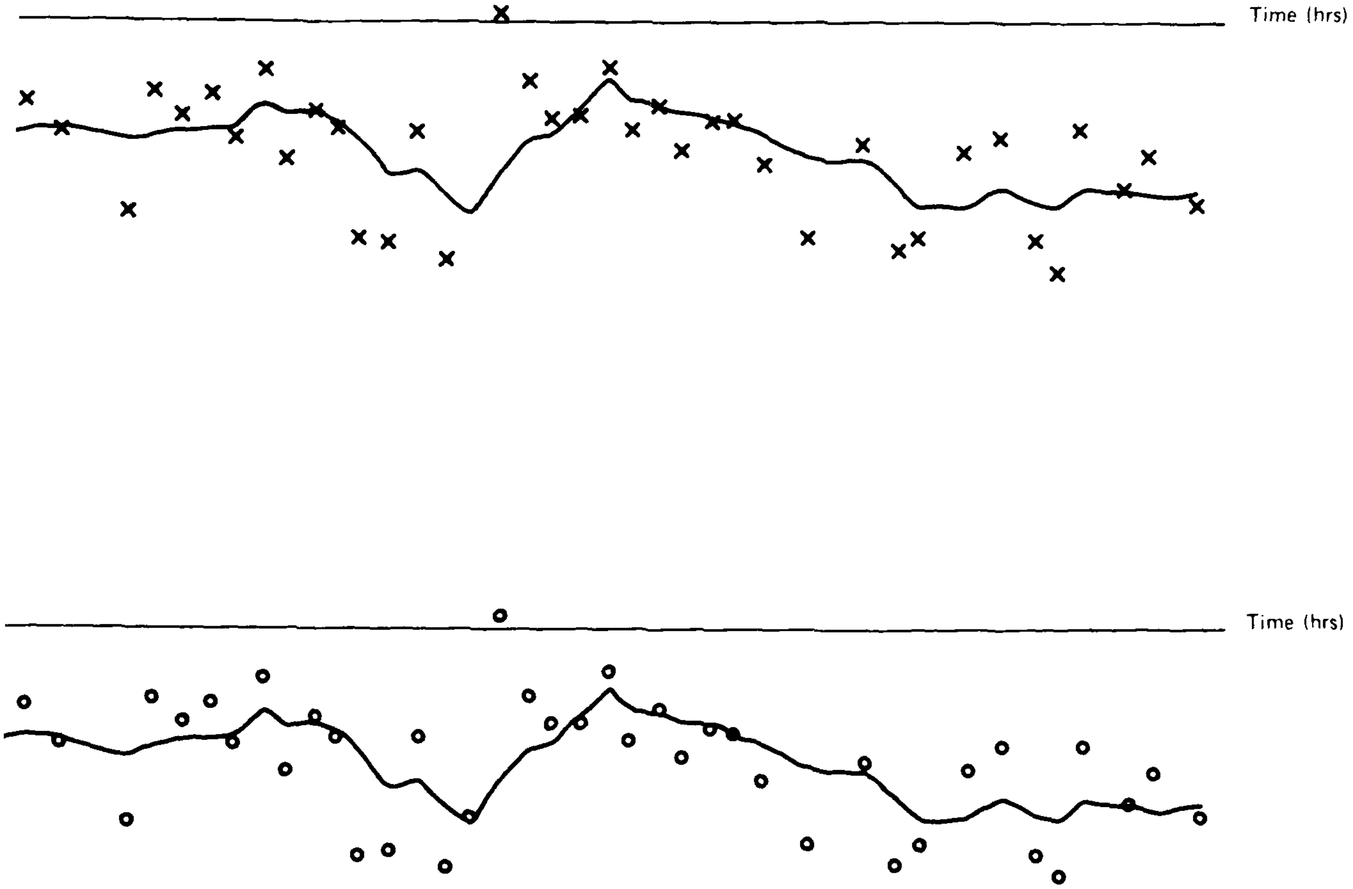
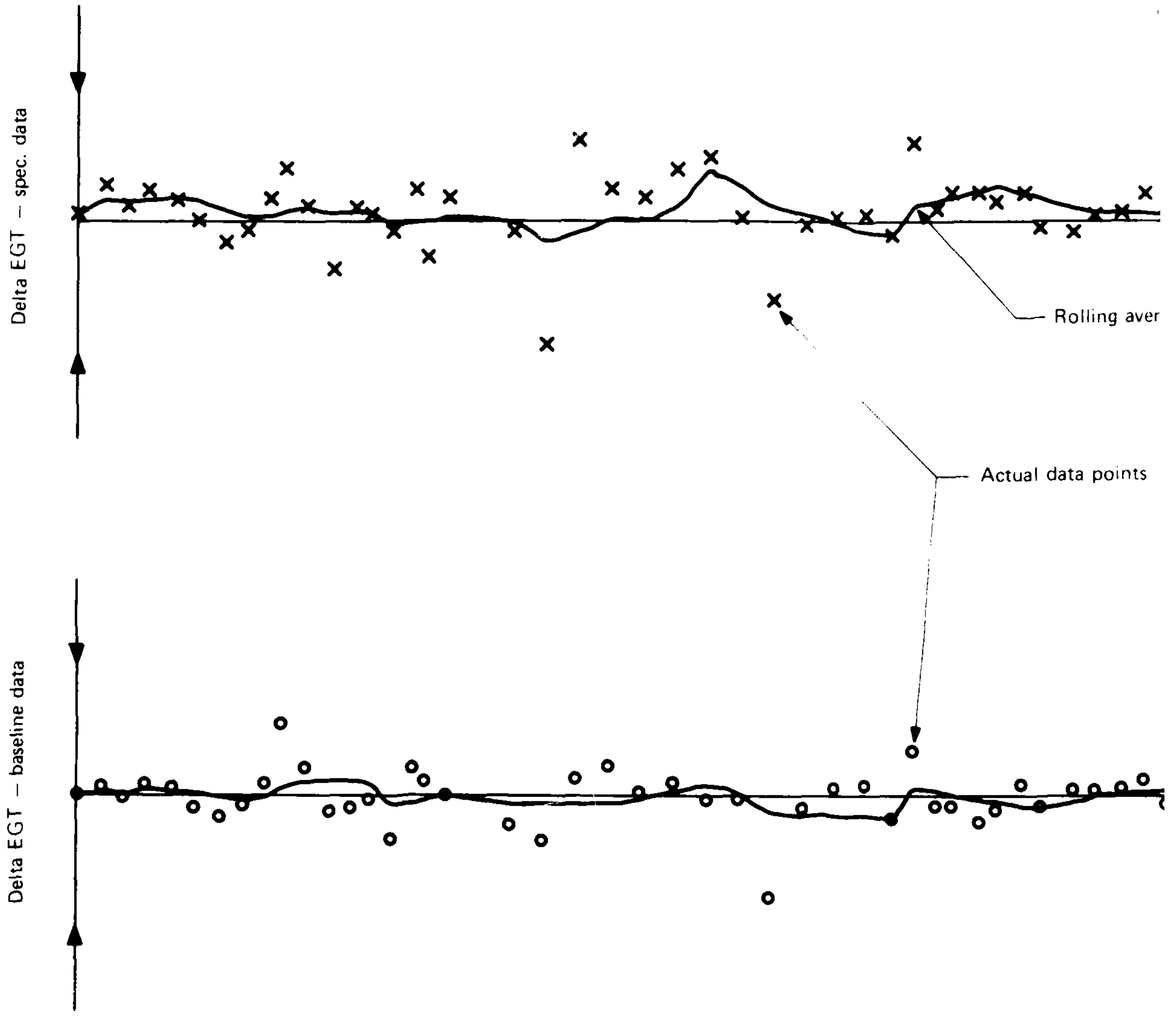


FIG. 3(c) DEVIATION OF OBSERVED TORQUE FROM BOTH SPECIFICATION AND ACTUAL BASELINE ENGINE PERFORMANCE

3


Delta EGT – spec. data
Rolling aver
Actual data points
Delta EGT – baseline data

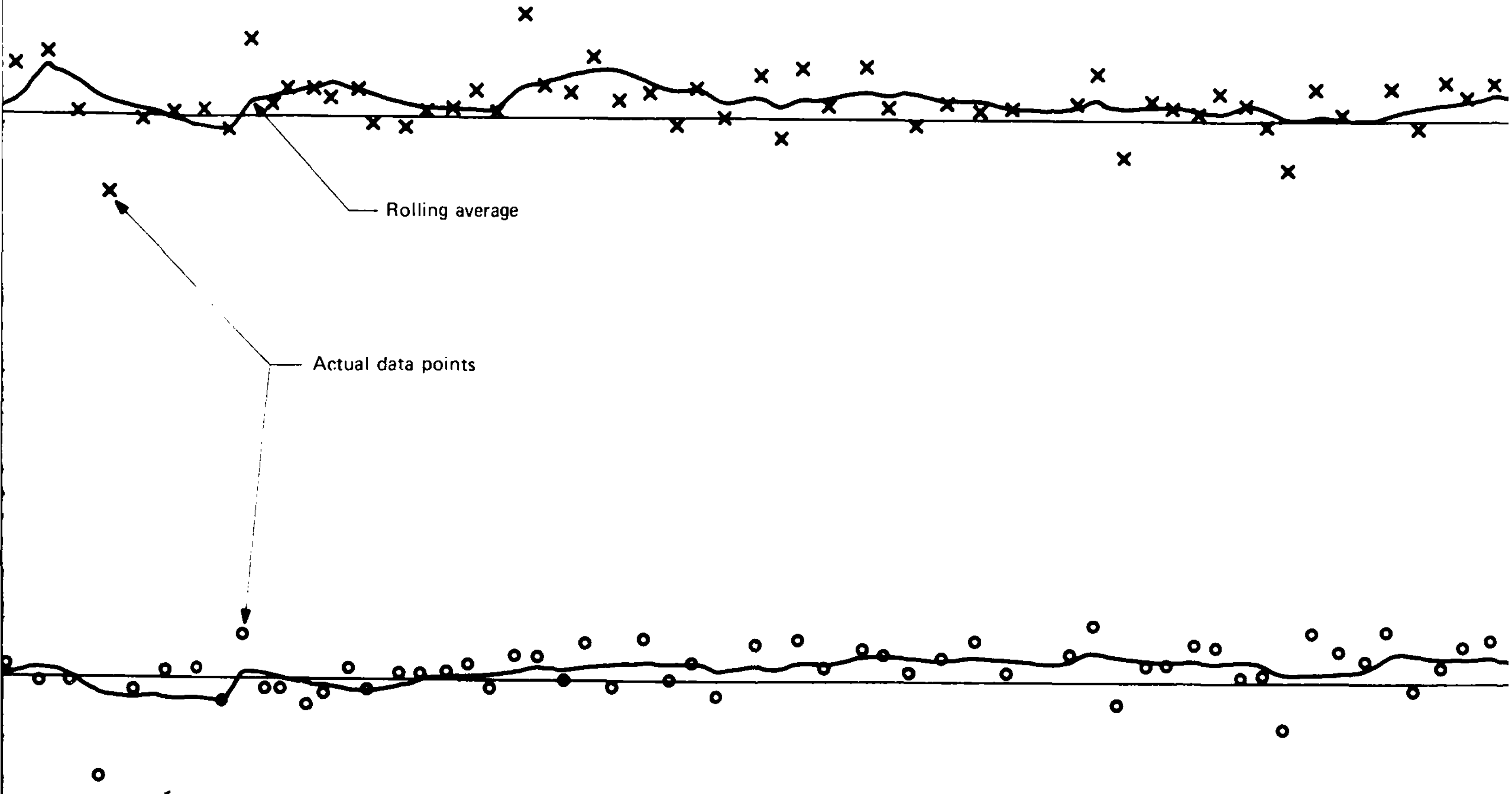


FIG. 3(d) DEVIATION
BASELINE E

Lydat 308. daily inflight monitoring eng. no. LE L13/16125

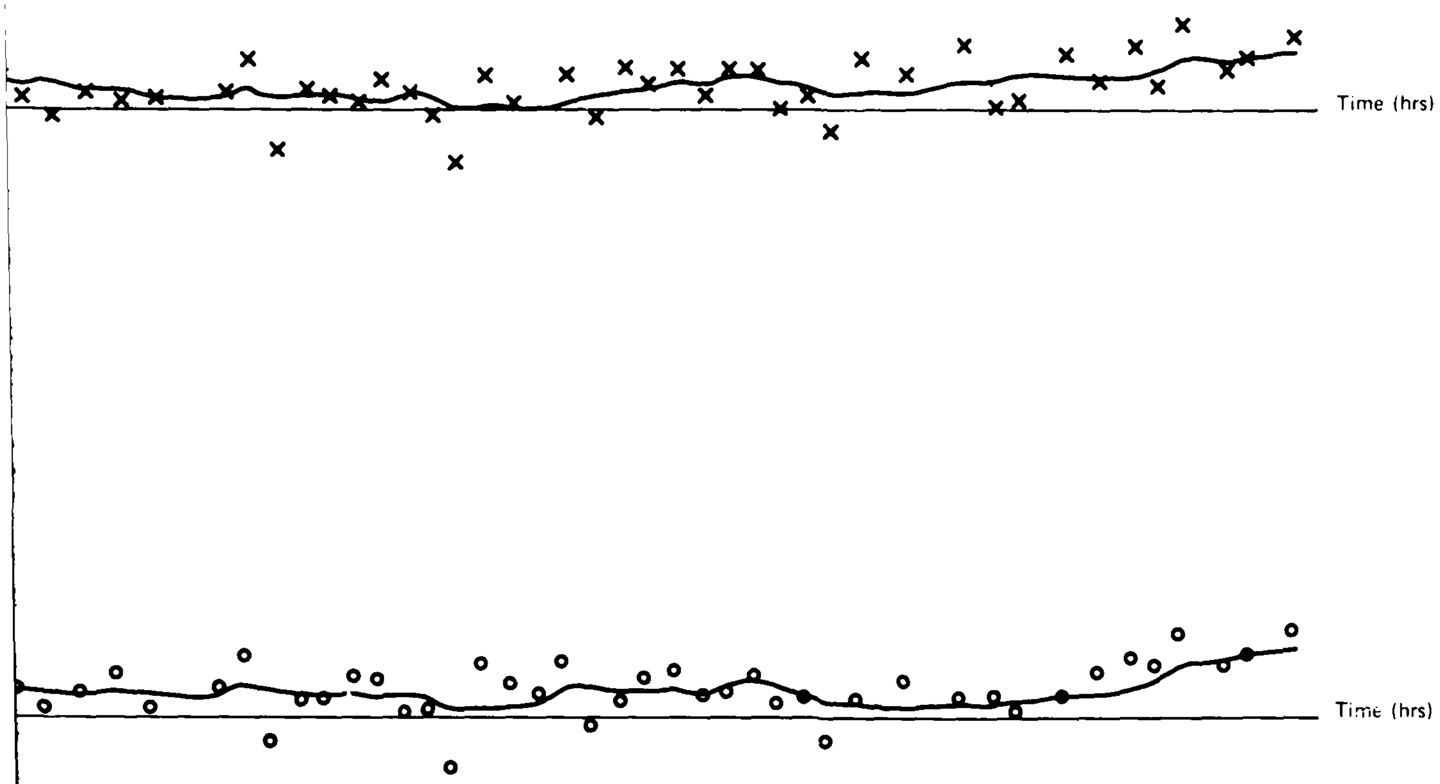


FIG. 3(d) DEVIATION OF OBSERVED EGT FROM BOTH SPECIFICATION AND ACTUAL BASELINE ENGINE PERFORMANCE

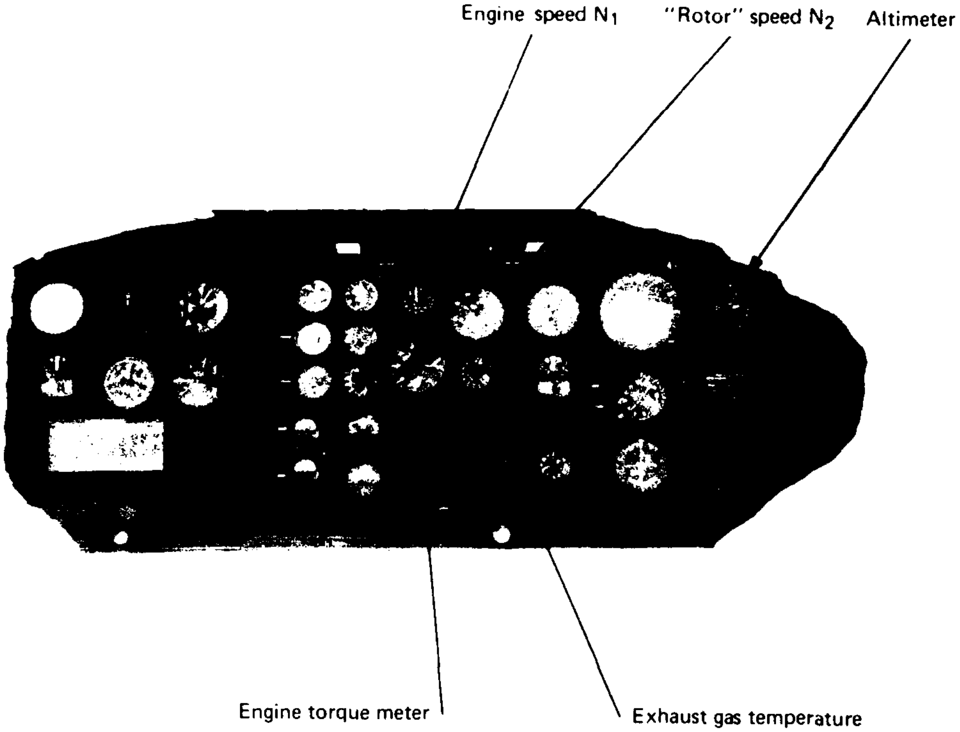
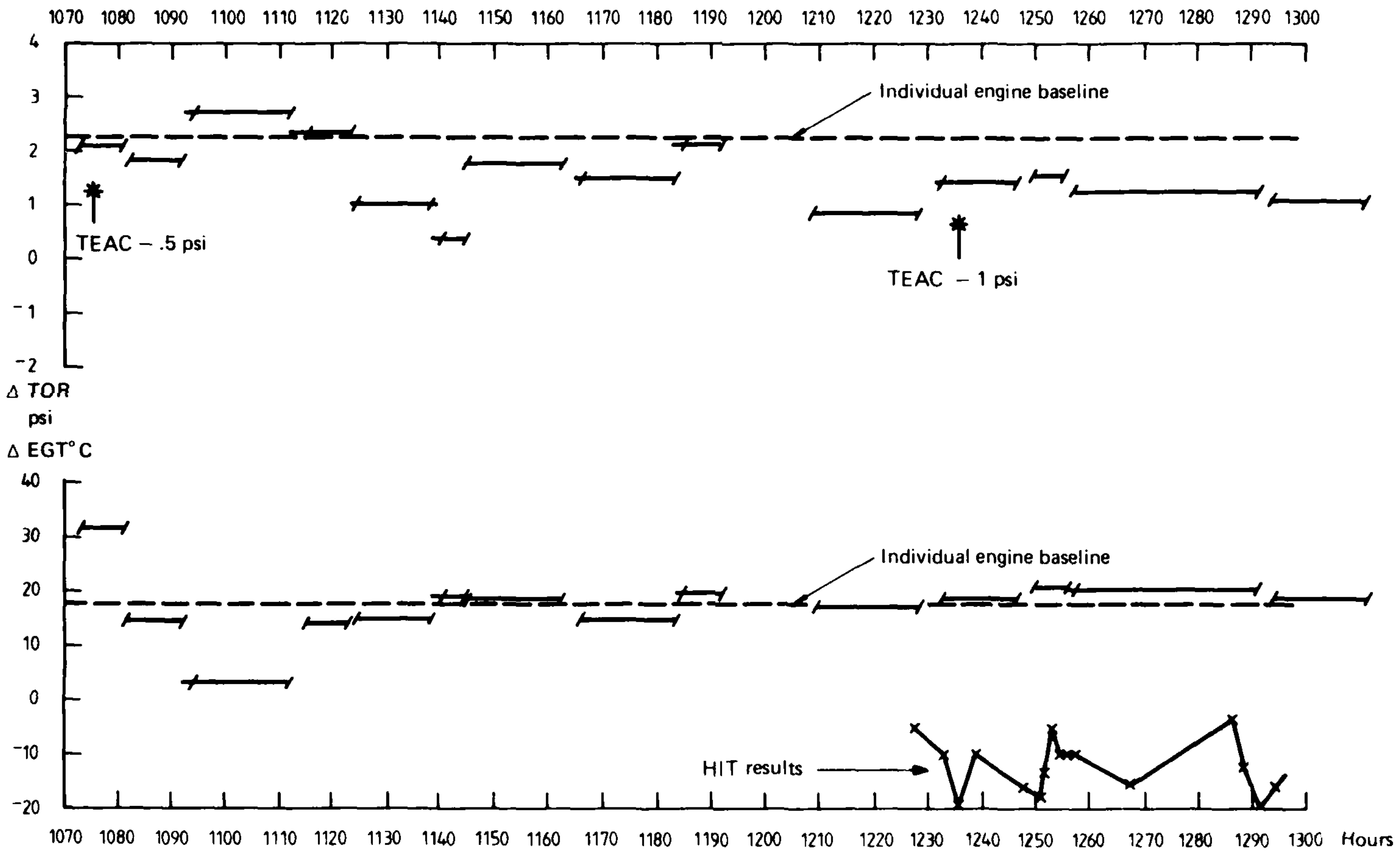


FIG. 4 INSTRUMENT PANEL IROQUOIS HELICOPTER



(⟝——⟞ Simple average of each group of five data points)

FIG. 5(a) IFM T53–L13 Δ TOR AND Δ EGT v TIME

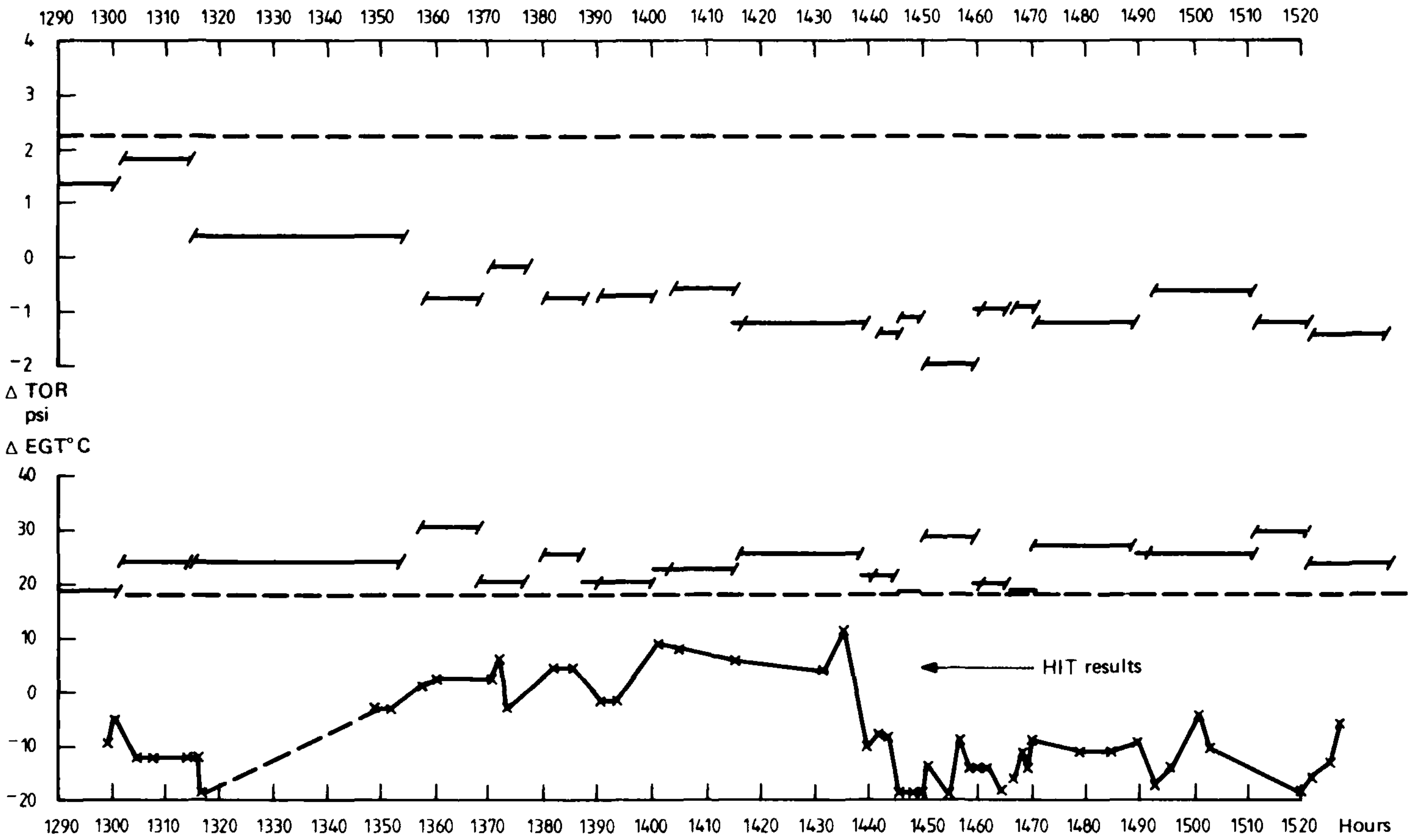


FIG. 5(b) IFM T53−L13 Δ TOR AND Δ EGT v TIME

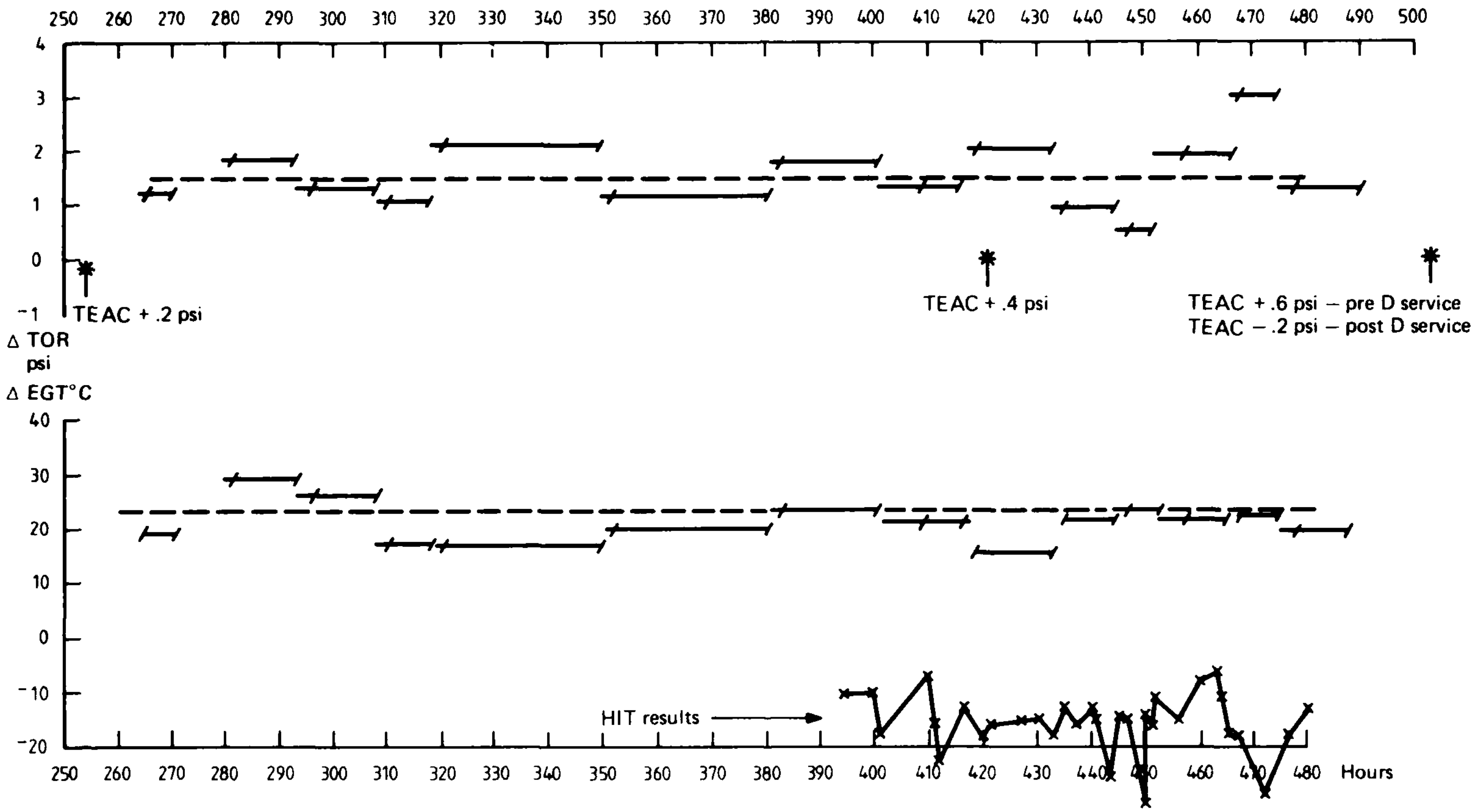


FIG. 6(a) IFM T53–L13 Δ TOR AND Δ EGT v TIME

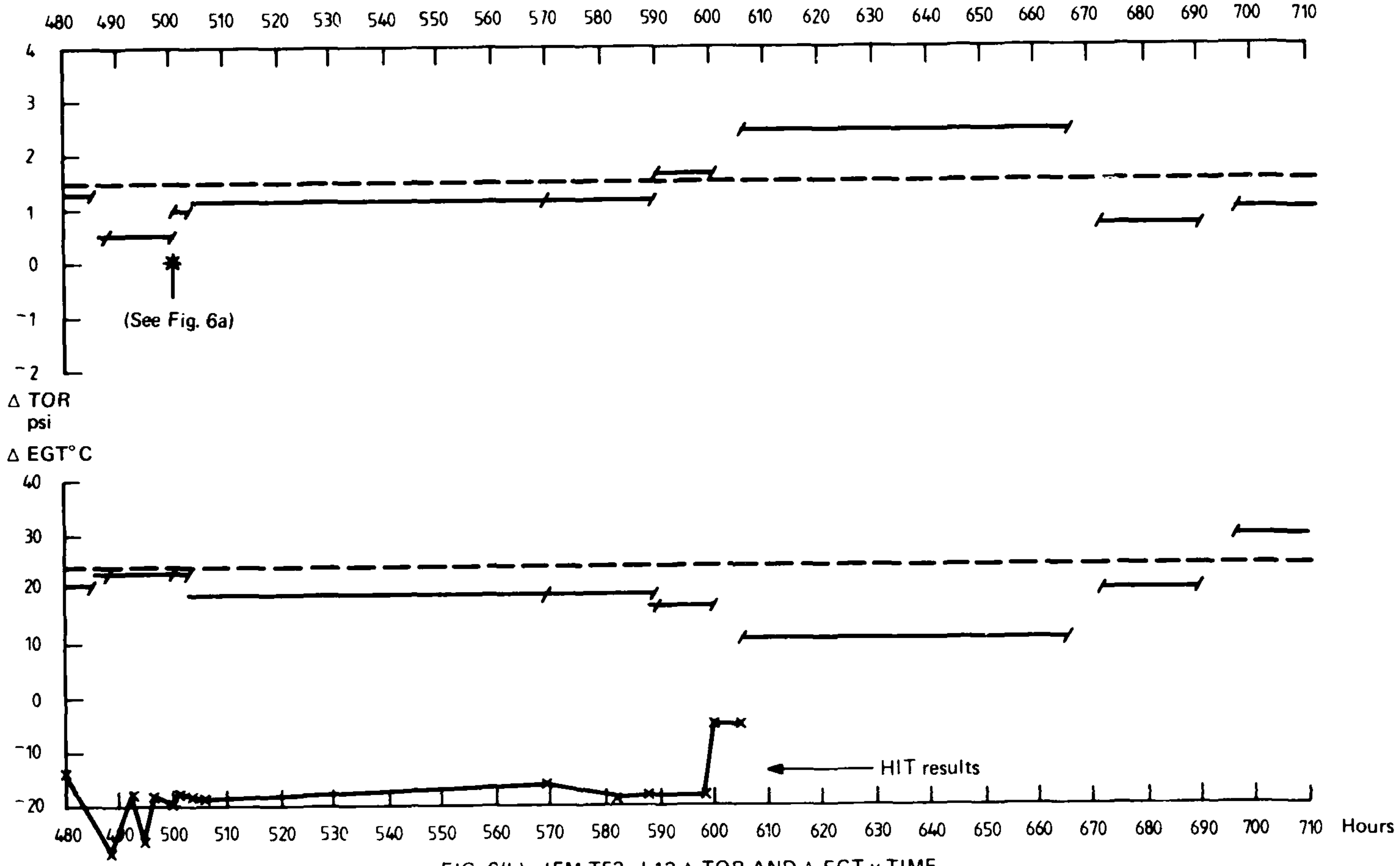


FIG. 6(b) IFM T53–L13 Δ TOR AND Δ EGT v TIME

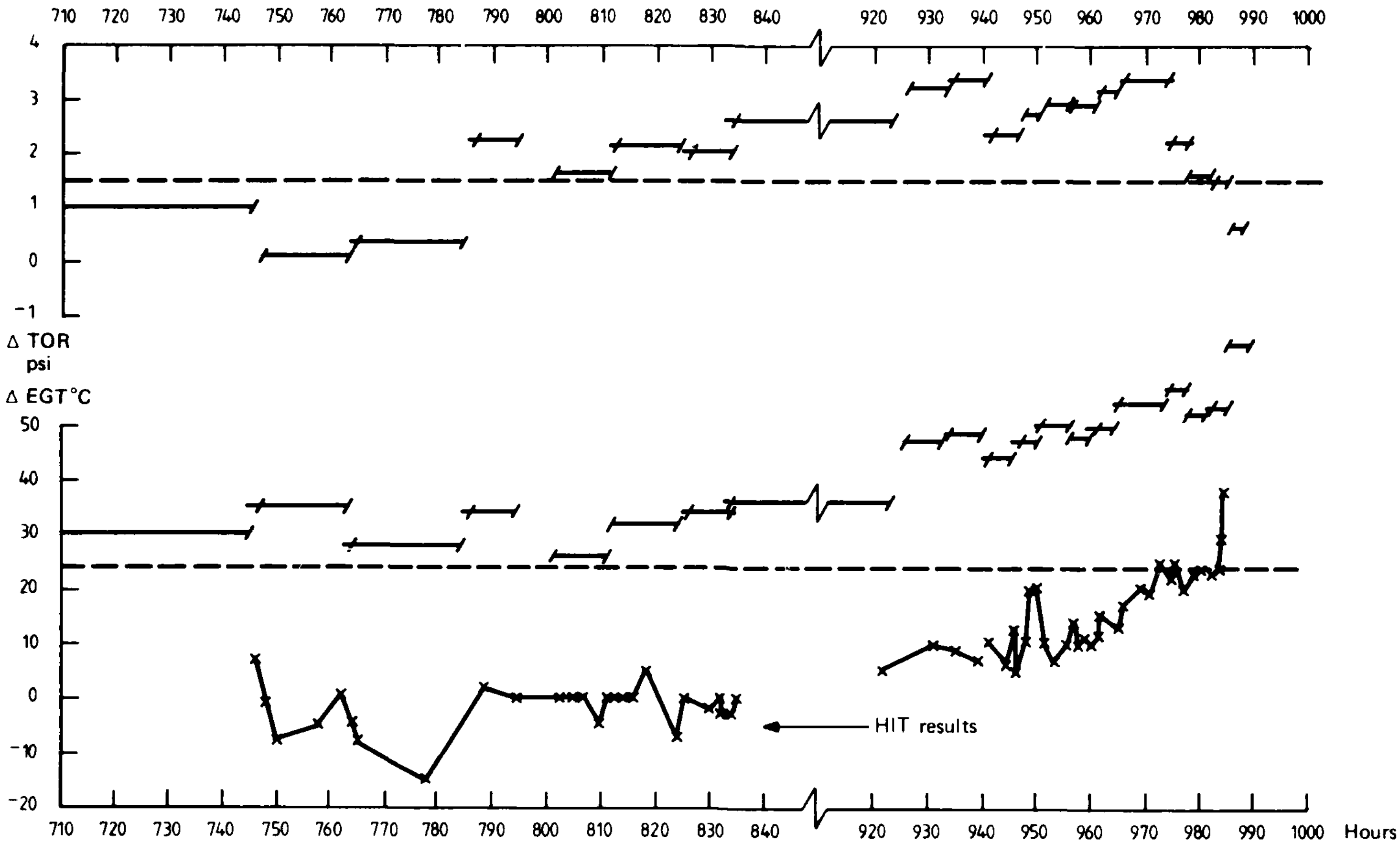


FIG. 6(c) IFM T53–L13 ΔTOR AND Δ EGT v TIME

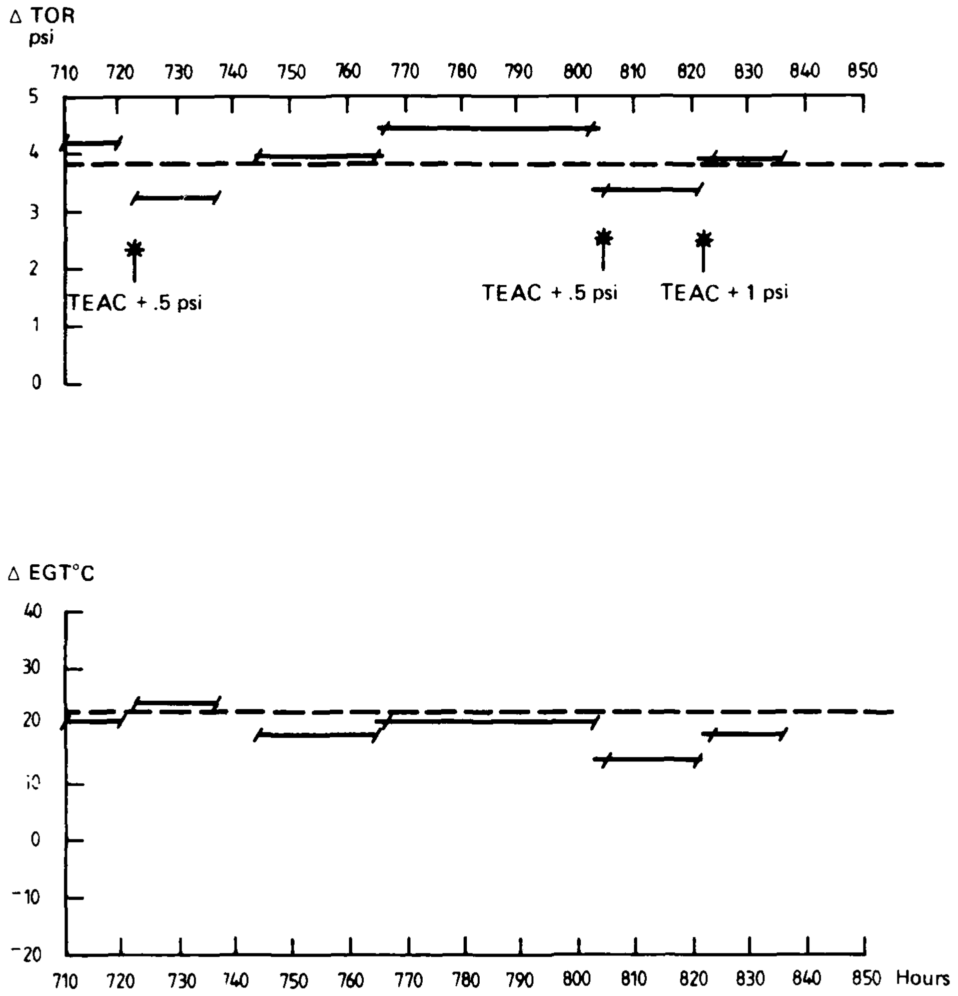


FIG. 7 IFM T53–L11 Δ TOR AND Δ EGT v TIME

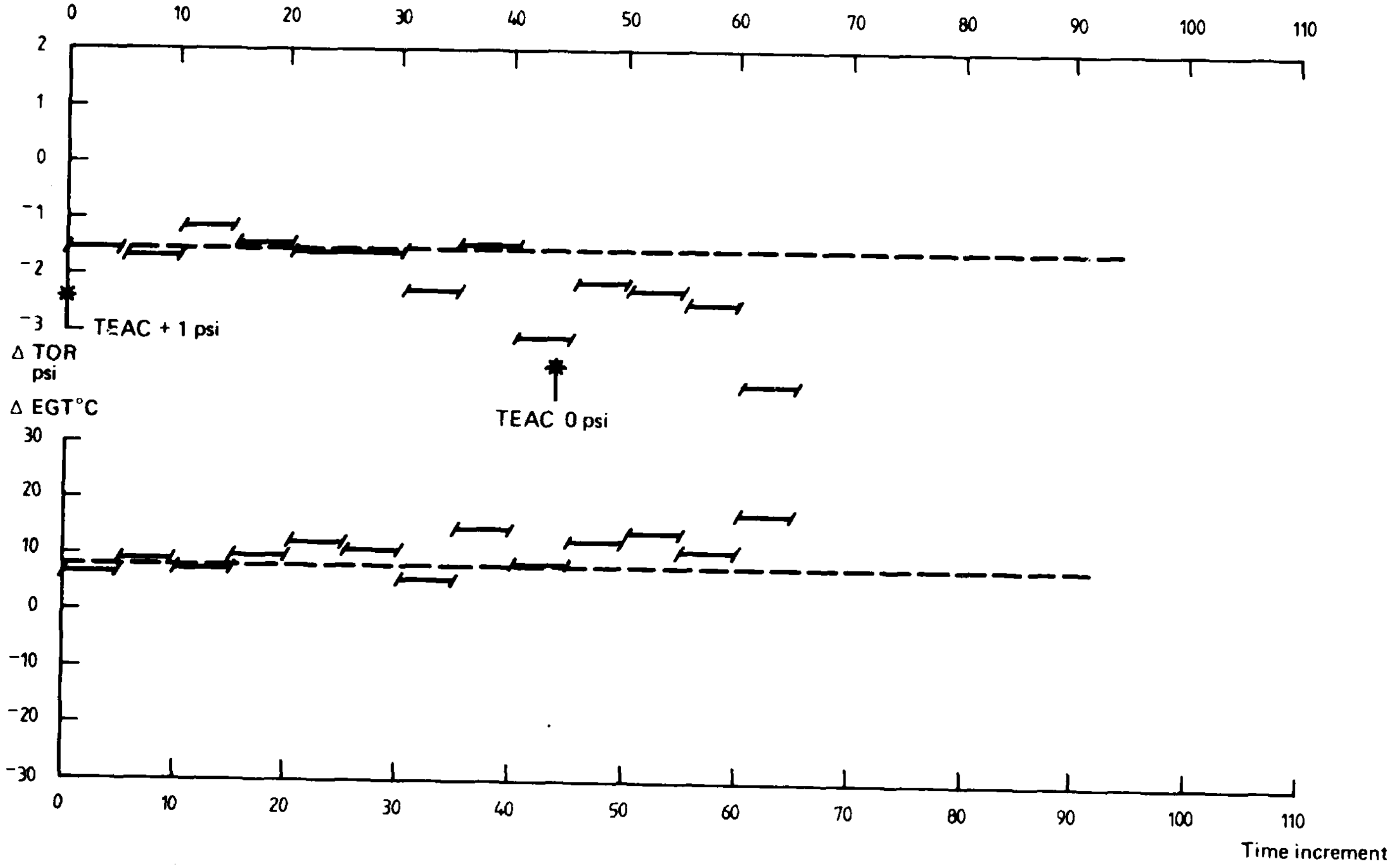


FIG. 8 IFM T53–L13 Δ TOR AND Δ EGT v TIME

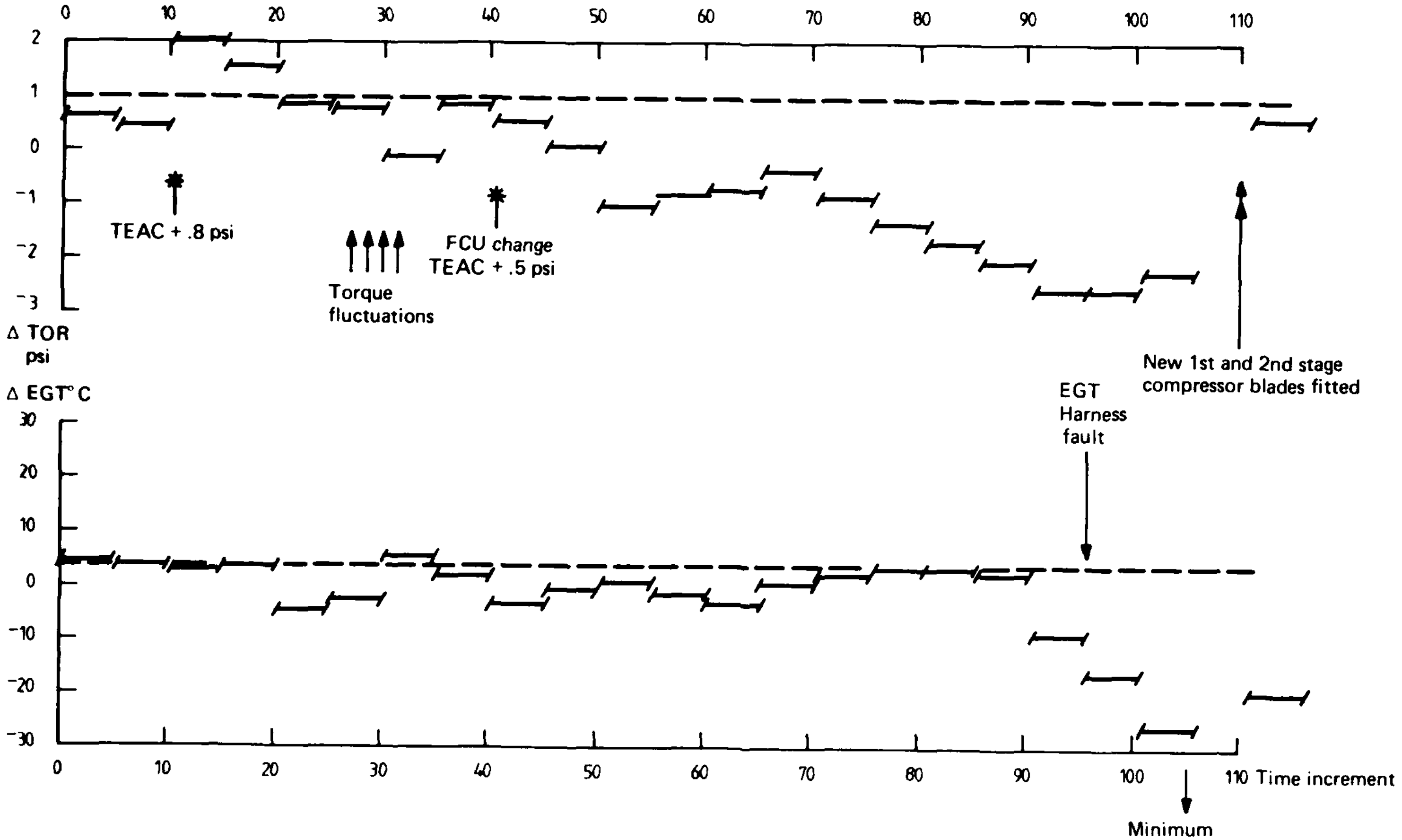


FIG. 9 IFM T53–L13 Δ TOR AND Δ EGT v TIME

APPENDIX A

T53—In Flight Monitoring Principles and Data Analysis

Background

1. In a turboshaft engine, the variation of Torque, EGT and CPR with N_1, for a given N_2 can be represented by simple curves provided the respective parameters have been corrected for variations in ambient conditions.

i.e. $N_{1C} = N_1/\sqrt{\theta}$ (1)

$TOR_C = TOR/\delta\sqrt{\theta}$ (2)

$EGT_C = EGT/\theta$ (3)

$CPR = p_3/P_1$ (4)

where θ = Ambient Pressure/14·7 (5)

δ = (Ambient Temperature + 273)/288 (6)

In the case of the Lycoming T53-L11 and L13 turboshaft engines, it can be shown that in the speed range $85\% < N_{1C} < 101 \cdot 5\%$ the above mentioned curves can be represented by straight lines,

i.e. $N_{1C} = M_T(TOR_C \times N_2) + C_T$ (where $6400 < N_2 < 6600$) (7)

$N_{1C} = M_E \times EGT_C + C_E$ (8)

$N_{1C} = M_C \times CPR + C_C$ (9)

where M_T, M_E, M_C are gradients, and

C_T, C_E, C_C are intercepts of the lines.

2. It is to be noted that engine power output is usually defined in terms of N_{1C} versus SHP_C

i.e. $N_{1C} = M_S \times SHP_C + C_S$ (10)

However in the Iroquois power is displayed in the form of a torque pressure. For a given engine the relationship between torque pressure and SHP (or torque itself) is determined subsequent to manufacture or overhaul of the engine and is defined in terms as that torque pressure achieved at a torque of *1125 lb ft* (875 lb ft for T53-L11) at a specified N_2 speed (6600 rpm). The torque pressure achieved is known as the Data Plate Torque Value (DPTV). In mathematical terms the following general relationship can be defined relating SHP, TOR and DPTV.

$$SHP_C = \frac{1125 \times (N_2 \times TOR_C)}{K \times DPTV} \qquad \left(K = 5252 = \frac{60 \times 550}{2\pi}\right) \tag{11}$$

This can be substituted into (10) to give

$$N_{1C} = \frac{M_S \times 1125 \times (N_2 \times TOR_C)}{K \times DPTV} + C_S \tag{12}$$

In the T53-L13 engine* the values of DPTV can vary from 58 psi to 64 psi, depending on the engine build and torque meter characteristics. For simplicity a mean value of 61 is assumed to apply for all engines, thus equation (12) can be rewritten and compared with (7).

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* For T53-L11 engines DPTV varies from 45–51.

i.e. $$N_{1C} = \frac{M_S \times 1125\,(N_2 \times TOR_C)}{K \times 61} + C_S$$

$$M_T(TOR_C \times N_2) + C_T$$

where $$M_T = \frac{M_S \times 1125}{K \times 61}$$

$$C_T = C_S$$

3. Typical examples of curves for SHP_C, EGT_C and CPR are given in Figures A1, A2 and A3. It should be noted that the relationships between N_{1C} and SHP_C, etc. are not the same for all engines, the slopes and intercepts can vary. However, for a given engine, once the relationship is established, at manufacture or overhaul, then its shape and position will only change if the engine configuration changes, i.e. if the engine performance is degraded due to wear or the gas path components are damaged. This property of engine performance is the basis on which the In Flight Monitoring procedures have been formulated.

IFM Procedures and Data Analysis for Determining Trends in ΔTOR, ΔEGT and ΔCPR

4. From the basic engine aircraft instrumentation the following information can be found

H_p	Pressure Altitude
OAT	Outside Air Temperature
N_1	Engine Speed Gas Generator
N_2	Engine Speed Power Turbine
TOR	Engine Torque
EGT	Exhaust Gas Temperature
CPR	Compressor Pressure Ratio

Using this data and equations 1 6 the corrected actual engine operating parameters may be calculated. These results can be compared with the corrected specification (baseline) engine operating parameters of TOR, EGT and CPR derived from equations 7 9 for the same operating conditions. The differences between the actual and specification values, i.e. ΔTOR, ΔEGT and ΔCPR, can be used in trend graphs to assess the engine performance and hence determine engine condition or degradation.

5. A simple data analysis program to calculate values of ΔTOR, ΔEGT, ΔCPR using equation[illegible] 10 is given in Tables A1 and A2. The program as written is configured for the HP34C [illegible] held programmable electronic calculator. Using the output from the calculator, changes in the gas path condition of the engine can be determined and hence the degree of engine degradation.

Note. In Tables A1 and A2 specific values for M_T, M_E, M_C, C_T, C_E and C_C have not been entered. Precise values can be determined from either the actual engine operating condition or from the specification performance. Typical values of the respective constants are given below for both the T53-L11 and L13 engines.

	T53-L11	T53-L13
M_T	0·000078	0·0004[illegible]79
M_E	0·10985	0·09434
M_C	N.A.	17·3467
C_T	74·50	83·51
C_E	0·03742	20·34
C_C	N.A.	10·2163

TABLE A1

Lycoming T53 Inflight Monitoring Program Instructions for HP 34C Calculator

Step	Instructions	Input Data Units	Keys	Output Data Units
	Set to PRGM			
	Key in Programme	Table A2		
	Set to RUN			
	Store Data	273·0	STO 0	
		288·0	STO 1	
		145454·54	STO 3	
		5·2545	STO 4	
		C_T	STO 6	
		M_T	STO 7	
		C_E	STO 8	
		M_E	STO 9	
		C_C	STO · 0	
		M_C	STO · 1	
	Check Data H_p	3500	A	
	OAT	10·0	R/S	
	N_1	95·0	R/S	
	N_2	6400	R/S	
	Torque	38	R/S	
	ΔTOR		——→	0·4975
	EGT	550	R/S	
	ΔEGT		——→	36·6436
	CPR	6·2	R/S	
	ΔCPR		——→	0·0863

TABLE A1 (*Continued*)

Step	Instructions	Input Data-Units	Keys	Output Data-Units
	Real Data (1) H_p		A	
	OAT		R/S	
	N_1		R/S	
	N_2		R/S	
	Torque		R/S	
	ΔTOR		——→	Δ Torque
	EGT		R/S	
	ΔEGT		——→	ΔEGT
	CPR		R/S	
	ΔCPR		——→	ΔCPR
	Real Data (2) H_p		A	
	OAT		R/S	
	N_1		R/S	

TABLE A2

Lycoming T53-IFM—Program Listing—HP34C

Display		Key Entry	X	Y	Z	T	Comments	Registers
Line	Code							
00		f CL PRGM						R_0 273
01		h LBL A						
02		R/S						
03		RCL O						R_1 288
04		+						
05		RCL 1						
06		÷						R_2 θ
07		STO 2						
08		⇄						
09		RCL 3						R_3 145454·54
10		÷						
11		1						
12		⇄						R_4 5·2545
13		—						
14		RCL 4						
15		h y^x						R_5 $N_1/\sqrt{\theta}$
16		⇄						
17		f $\sqrt{x}$						
18		R/S						R_6 C_T
19		⇄						
20		÷						
21		STO 5						R_7 M_T
22		RCL 6						
23		—						
24		RCL 7						R_8 C_E
25		÷						
26		×						

TABLE A2 (*Continued*)

Display Line	Display Code	Key Entry	X	Y	Z	T	Comments	Registers
27		RCL 2						R_9 M_E
28		f $\sqrt{x}$						
29		×						
30		R/S						$R_{.0}$ C_E
31		÷						
32		R/S						
33		🔄						$R_{.1}$ M_C
34		—						
35		R/S						
36		RCL 5						
37		RCL 8						
38		—						
39		RCL 9						
40		÷						
41		RCL 2						
42		×						
43		RCL 0						
44		—						
45		—						
46		R/S						
47		RCL 5						
48		RCL .0						
49		—						
50		RCL. 1						
51		÷						
52		—						
53		h RTN						

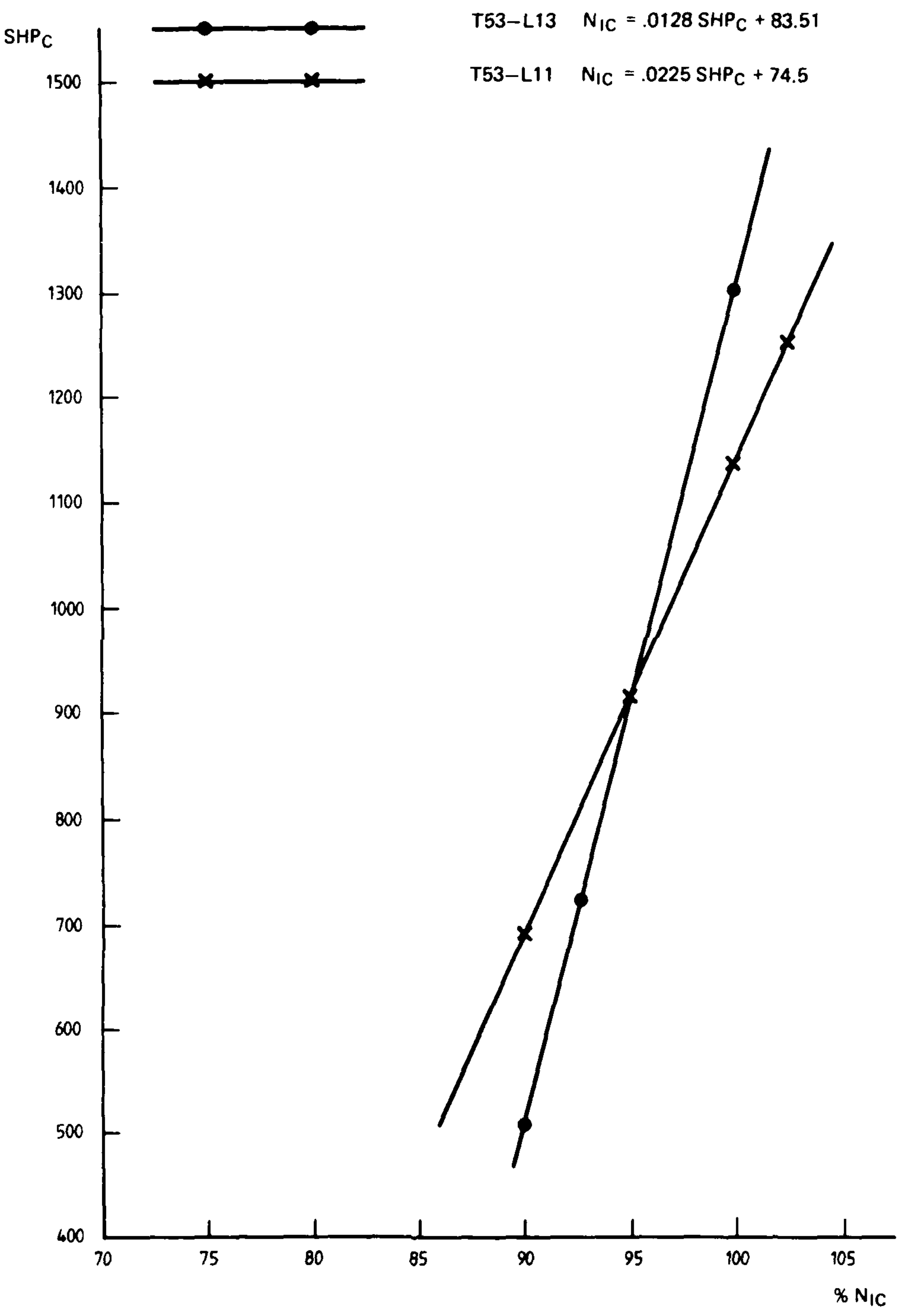

FIG. A1 SHAFT HORSE POWER vs ENGINE SPEED

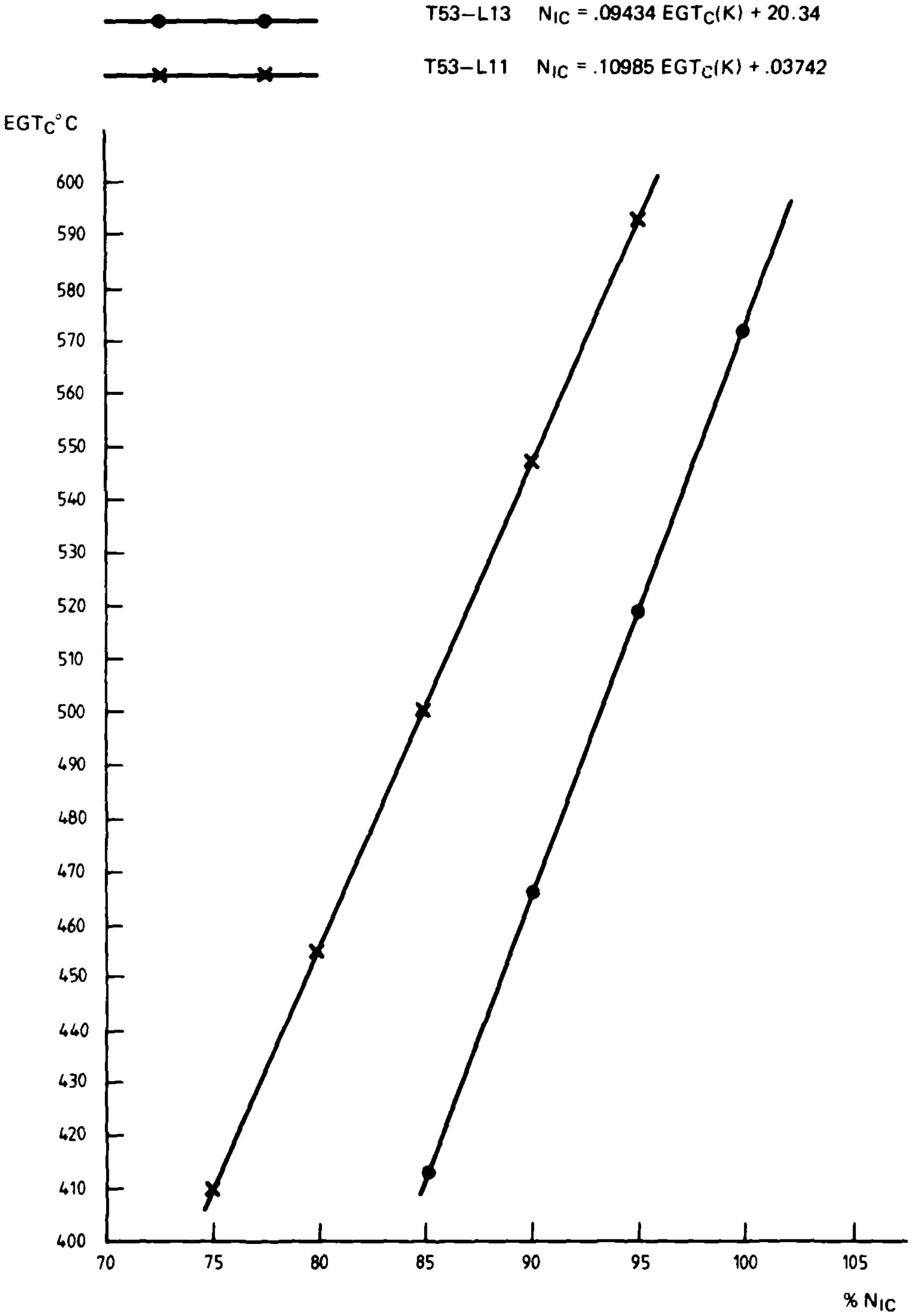

FIG. A2 EXHAUST GAS TEMPERATURE vs ENGINE SPEED

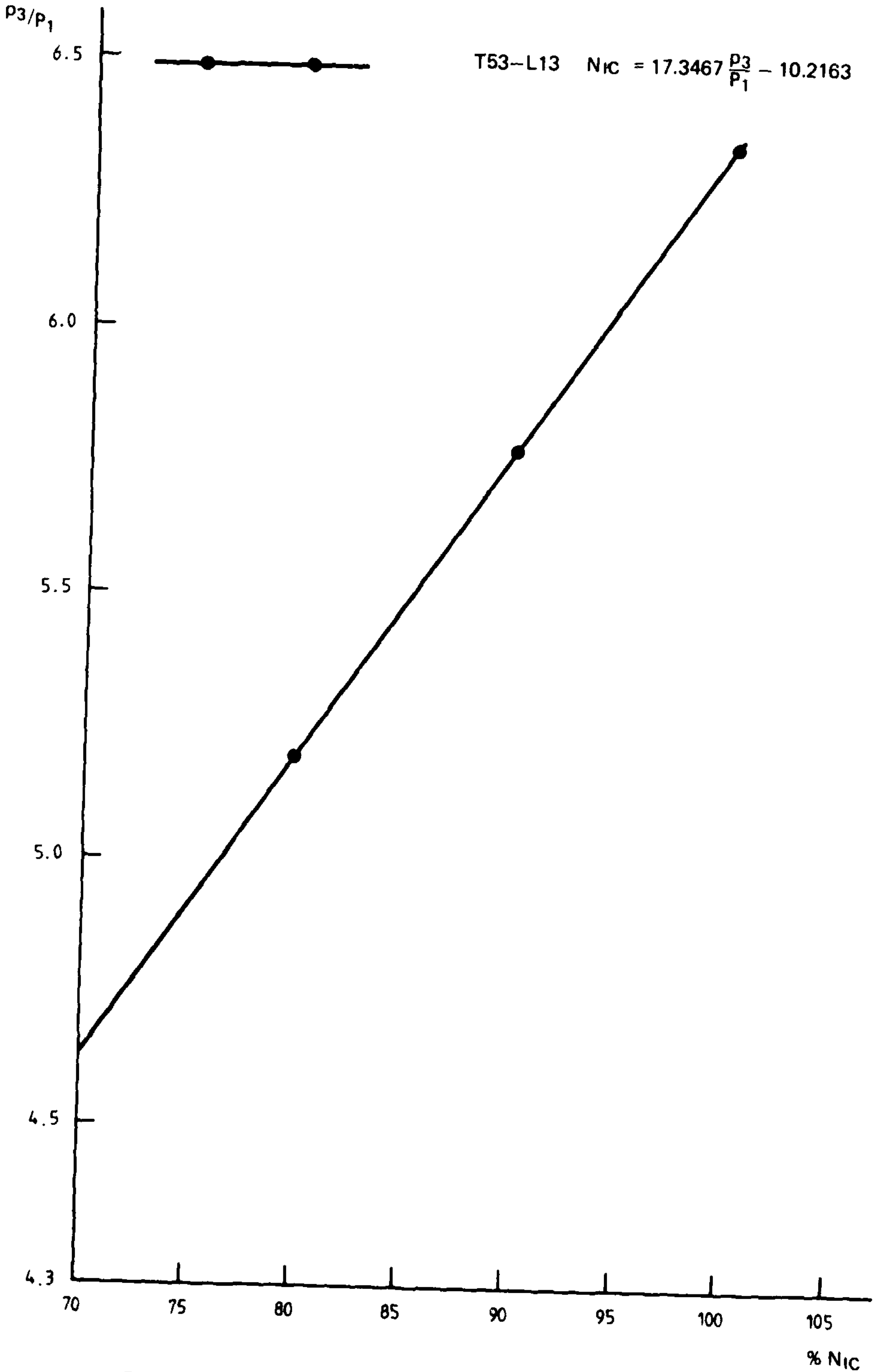

FIG. A3 COMPRESSOR PRESSURE RATIO vs ENGINE SPEED

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