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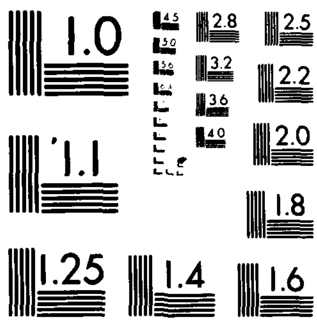

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AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

Mechanical Engineering Technical Memorandum 409

RESULTS OF T56 ENGINE PERFORMANCE MONITORING TRIAL
IN HERCULES AIRCRAFT, FEBRUARY-JULY 1977

D.E. GLENNY

Approved for Public Release.

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RESULTS OF T56 ENGINE PERFORMANCE MONITORING TRIAL IN HERCULES AIRCRAFT, FEBRUARY-JULY 1977

D.E. GLENNY

SUMMARY

An analysis of results from a T56 Engine Performance Monitoring Trial is given together with operating instructions for aircrew and maintenance personnel. This memorandum should be used in conjunction with Part B of Reference 1.

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16. ABSTRACT:

An analysis of results from a T56 Engine Performance Monitoring Trial is given together with operating instructions for aircrew and maintenance personnel. This memorandum should be used in conjunction with Part B of Reference 1.

CONTENTS

1. INTRODUCTION

This memorandum records details of the results of an Engine Performance Monitoring Trial carried out on the Hercules Aircraft of the RAAF during February-July 1977. The engine monitoring procedures were developed as an aid to the Flight Engineer and the Maintenance Section, so that the performance of the Allison T56 engines could be monitored more closely than is currently specified in RAAF Squadron operating procedures, thus enabling engine operation and maintenance action to be carried out more effectively. The trial was conducted on all Hercules aircraft operated by Nos. 36 and 37 Squadrons, and the initial analysis of results was carried out by personnel from No. 486 Squadron, who are responsible for maintenance of these aircrafts.

The memorandum is divided into two sections:

a. Operating Instructions for Aircrew and Maintenance Personnel, and

b. Results of Trial.

Details of the rationale behind the monitoring procedures and overall conclusions on the trial are given in Reference 1, Part B.

2. OPERATING INSTRUCTIONS FOR AIRCREW AND MAINTENANCE PERSONNEL

Prior to undertaking the engine performance monitoring trial on the Allison T56 engines installed in the Hercules aircraft, discussions were held between HQSC project staff, and aircrew and maintenance personnel of Nos. 36, 37 and 486 Squadrons to define procedures for the implementation of the trial. From these discussions it was agreed that the flight engineer would record engine data from all Hercules aircraft operated by the RAAF whilst personnel from the Maintenance Control Section (MCS) of 486 squadron would have the responsibility for producing engine trend plots for torque and fuel flow deviations. The procedures agreed upon are given in Appendix 1: these instructions were issued as an Annex to a RAAF, HQSC letter to operators, Reference 2.

3. ANALYSIS OF RESULTS OF TRIAL

As stated in Reference 1, the results of the trial were analysed in two ways. In the first case, the monthly (engine) service reports for the aircraft were examined to determine the number of engines removed or rejected and to ascertain the cause; in those cases in which performance monitoring could have been expected to reflect the fault, the appropriate engine performance trend plots were scanned to locate any significant deviation in either the torque or fuel flow.

In the second case, the remaining trend plots were examined to locate deviations in torque and/or fuel flow outside the specified limits. Where major deviations had occurred, these were investigated in conjunction with the appropriate EE 500. (This form is used by aircrew and maintenance personnel to record any aircraft/ engine fault and its subsequent rectification).

The results obtained from an analysis of engine removals are given in section 3.1, entitled "Engine Removals/Rejections", whilst the results obtained from the second case are given in section 3.2 under the heading "Faults not Associated with Engine Removals". In both cases the results are presented as synopses of:

a. engine fault and/or information obtained from trend graphs, and

b. assessment of trend plot deviations (torque and fuel flow), and their relevance to the particular fault, either inferred or specified.

3.1 Engine Removals/Rejections

In the course of the trial a total of 37 engines was removed from service. Of these removals:

- 12 were because the engines were time expired,
- 9 were for oil leaks or low oil pressure,
- 2 were for metal contamination,
- 2 were for worn stator splines.
- 1 was for a bird strike,
- 1 was for a cracked gearbox assembly,
- 1 was for a cracked inlet housing,
- 5 were for compressor damage,
- 3 were for turbine damage,
- 1 was for blue harness replacement, and
- 1 was for high torque, low fuel flow and low turbine inlet temperature (TIT).

From this list it was assessed that only the latter 10 removals/ rejections warranted further investigation because they could be expected to modify thermodynamic performance of the engine, and hence the trend plots for torque or fuel flow.

A synopsis of the 10 engine removals is given below together with references to the appropriate trend plots. Details of engine histories and their associated defect reports are given in Table 1.

A97-160

According to the defect report for this aircraft, the compressor of the number four engine was seriously damaged when parts of the propeller cuff broke up and were ingested during a post D service* test flight. The nature of this event would require the engine to be shut down immediately, preventing any use of the trend plots.

A97-177

The number 4 engine on this aircraft was consistently reported for high levels of torque and fuel flow in comparison with the other three engines; this fact is confirmed by the trend plots given in Fig. 1, which consistently show low levels of torque for engines 1, 2, 3 (and fuel flow - not given), indicating high torque values for engine number four. The results of the defect investigation for this engine are not known, but the problem is most probably associated with the temperature indicating system.

A97-180

In this defect report, several compressor blades, from a number of blade rows of engine number 1, were found damaged during a post flight engine check. As this damage would have occurred during the previous flight there is little chance that the effects of the damage would have been indicated on the trend plots. A perusal of the relevant trend graphs provides confirmation.

A97-207

On engine number 2, one (only) turbine nozzle guide vane was found cracked and eroded during a scheduled C service check. Even though the damage was sufficient to reject the engine from service, the degree of damage would not have been of sufficient magnitude to have affected the gas path performance. Inspection of the relevant trend plots also indicates no marked changes in either the torque or fuel flow levels.

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* A "D service" on a Hercules aircraft is carried out every 1000 hours and requires the removal of the aircraft from service, a "C service" is performed at 250 hour intervals and is normally carried out at the operational level.

A97-208

During a scheduled D servicing on engine number four, several 1st stage compressor blades were observed to be damaged, this appeared to be the result of ingestion of a "foreign object". The degree of damage was assessed to be sufficient to have modified the gas path performance, and would have been expected to have had an effect on either the torque or fuel flow trends. Inspection of the trend plots failed to reveal the effects of this damage, indicating, to date, the lack of experience in relating observed damage and changes in performance.

A97-210

This defect, reported subsequent to a post flight check on engine number 4, indicated that a single first stage compressor blade was twisted (from the normal). This relatively minor damage would not have been expected to modify either the torque or fuel flow trends.

A97-211

On engine number 4 a number of nozzle guide vanes and combustor flame tubes were found cracked during a C service. From the degree of damage, it was considered that marked changes in the gas path performance should have been indicated on the trend plots. Analysis of both the torque and fuel flow trend graphs shows that only six readings had been taken before the engine was removed; consequently no change in performance would have been observed.

A97-212

Foreign object damage or the failure of an internal component of engine number 2 had caused numerous nicks and dents in the fourth stage turbine blades. The damage, found on a C servicing, was considered to be sufficient to have modified the engine performance. Inspection of the relevant trend graphs, prior to the discovery of the fault, failed to indicate any change in engine performance.

A97-213

In comparison to the performance of engine number 4, high levels of torque and fuel flow were continually being reported on engines 1, 2 and 3. Maintenance action on engine 4, subsequent to its removal from the aircraft, indicated that a faulty harness leading to the Temperature Datum amplifier was giving an over reading of the turbine inlet temperature. This fault would result in low indicated torque and fuel flow values for that engine, or conversely the apparent high trend values for the performance of engines numbers 1, 2 and 3. Examination of the torque trends for this aircraft, given in Fig. 2, indicates a sudden increase in torque level at point 46; the original torque level is restored at point 88, after the faulty harness had been replaced and the engine reinstalled. It should be noted that the original failure was indicated a considerable time before maintenance action had been initiated. (Also shown in Fig. 2 are the effects of a torque mis-reading at point 60, the corrected trend line is shown dotted).

A97-214

On a C service a single turbine nozzle guide vane was found cracked on engine number 4. As in the case of aircraft A97-207, given above, even though the blade damage was sufficient to reject the engine from service, the degree of damage was too small and localised to have had a measurable effect on either the torque or fuel flow trend plots.

3.1.1 Resume

From the examination of 10 engine faults described above, it can be stated that:

a. Five of the failures would not have been indicated by the trend monitoring because the damage was too small and localised to have had a significant effect on the trend plots, or occurred on a flight closely related to a schedule servicing.

b. Two were not identified on the trend plots when it was considered that a deviation should have occurred.

c. One engine was removed before any significant monitoring had occurred.

d. Two were identified on the plots.

In the latter cases (d), the trend plots show that significant indications of the fault were apparent prior to maintenance being initiated. In-flight trending of the engine performance would have given a much more rapid response to these engine malfunctions.

3.2 Faults not Associated with Engine Removals

From a general examination of the remaining trend plots it was only possible to identify 13 other deviations (in either torque or fuel flow) which were of sufficient magnitude for further investigations to be undertaken with respect to the respective EE 500 maintenance form.

Of these general faults:

- **six** were identified on the EE 500 as being actual faults,
- four were not identified on the EE 500 but are believed to be associated with an incipient fault, and
- three were the result of either a plotting or misreading error.

A synopsis of the observed trends and the associated causes for the deviations are given below, whilst details of the aircraft, engine position, and type of deviation are summarized in Table 2.

A97-178

An extract from the torque trend plots for this aircraft is given in Fig. 3 which shows that at point 30 there is a distinct change in the torque levels for engines 1, 2 and 3, indicating a malfunction or change in the operation of the fourth engine. (Similar indications are present on the fuel flow trends). Examination of the flight engineer's raw data prior to point 30 shows that the TIT of the fourth engine had been suppressed by 20-30°C below the value of the other 3, thus maintaining the torque and fuel flow levels of all 4 engines at approximately the same value. Corrected trend plots for the 3 engines obtained by "artificially" increasing the TIT* of the fourth engine are given by the dotted line, which shows that "correct" torque level for engines 1-3 should have been at least 800 in. lb. below that of engine number 4.

Reference to the EE 500 shows that at point 30 the TIT harness had been changed in an endeavour to correct for the difference in temperature/torque levels. During subsequent engine operation, all TIT's were held at a common value with the result that the torque level of the No. 4 engine is now only 300 in. lb. greater than the average of engines 1, 2 and 3; this difference in levels could be the result of thermocouple deterioration.

A97-180

Examination of the torque trends for aircraft 180 given in Fig. 4 shows that between points 37 and 44 there is a sudden drop in torque level for engines 1, 2 and 3, indicating a rise in the output of the fourth engine. Scrutiny of the EE 500's failed to indicate any malfunction associated with the reference engine,

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* At cruise power,
10°C is equivalent to 250 in. lb. of torque.
10°C is equivalent to 20 lb. fuel/hr.

It should be noted that Imperial based units have been adhered to in this Memorandum as they are still used, operationally, by the RAAF and the US manufacturers.

however cross checking the raw data showed that points 38-43 were in fact applicable to aircraft A97-190 and had been inserted in error. Replotting the data with points 37 and 44 sequentially shows that there is no engine fault or change in performance: analysis and plotting of the trends in flight would obviate this error.

A97-190

A general survey of the torque plot in Fig. 5 for engine 1 on aircraft 190 indicates that the torque level had been gradually falling, over a period of 6 weeks, until at about point 81 the lower limit line was encountered. At point 83, there is a sudden increase in torque and the 'normal" mean level is re-established. Reference to the EE 500's shows that the torque gauge was replaced between points 82 and 83: it is not known how long the flight engineer had been aware of the problem before reporting this malfunction.

A97-205

Reference to the fuel flow and torque trends given in Figs. 6a and b for aircraft 205 shows marked deviations in these values between points 106 and 110 on all three engines: this behaviour is symptomatic of an indicating or control problem on the fourth engine. The diagnosis was confirmed by reference to the EE 500 which showed that the Temperature Datum amplifier and indicator were changed between points 109 and 110 on the No. 4 engine. Special note should be made of the dashed lines between points 107 and 111, examination of the raw data showed that these 3 points were associated with a different aircraft.

A97-206

Examination of the trend plots for this aircraft, (no figures given) indicates a sudden rise and fall in both fuel flow and torque levels for all three engines, suggesting a possible malfunction of the fourth, reference engine. Cross reference to the EE 500's did not substantiate the observed deviation; subsequent investigation attributed the deviation to a reading error.

A97-208

The torque and fuel flow trends given in Figs. 7a and 7b, for aircraft 208, show that there are at least four distinct changes in trend levels between points 5 and 45. On reference to the original data recorded by the flight engineer it was determined that the deviations at points 11-12 and at 26 in Fig. 7a were a direct result of a gauge reading error for the No. 4 and No. 2 engines respectively. The deviation at point 15 was attributed to a misrepresentation of recorded data by personnel in the MCS. Corrected trend curves are indicated by the dashed lines in Fig. 7a. At this stage it must be stated that direct analysis and plotting of data in flight would obviate these problems. The other deviation observed between points 41 and 45 in Fig. 7b, was shown to be, on examination of the EE 500, a direct result of an unserviceable fuel gauge.

A97-209

Reference to Figs. 8a and 8b, for aircraft 209 shows that between points 1 and 146 when the monitoring trial was discontinued, there had been a gradual rise in the fuel flow for engine number 2 (a similar result was apparent for the torque trends) and from point 100 the trend lines were above the upper limit line. Analysis of these results suggests a serious deterioration of the thermocouples in the Turbine Inlet Temperature indicating system; examination of the EE 500 gives no reported indication of this malfunction. Further investigation, in an endeavour to isolate the cause has revealed that the aircraft and the engine had been withdrawn from service prior to disposal.

A97-210

No particular change or deviation occurred in the trend plots throughout the recording period for this aircraft other than a consistently large difference in power levels between engines 1 and 3. A total difference in torque of 1000 in. lb. (+600 and -400 for Nos. 1 and 3, respectively) could always be observed. Reference to the flight engineer's reports indicates that the aircraft would consistently yaw under normal flight conditions (i.e. when the TIT was set to the same nominal value)· to equalize the power levels, the TIT of one of the engines would have to be changed by up to 40°C. Comparison of the fuel flow levels for engines 1 and 3 indicated little variation from the accepted value; consequently it can only be concluded that one engine was down, and the other one up on power with respect to the engine specification; under these circumstances little can be done to alleviate the operational problem other than matching and relocating the engines to equalize the power on each wing.

A97-212

The torque trends for this aircraft show a slight but consistent rise in value for engines 1, 2 and 3, indicating an incipient fault in the reference engine, No. 4. Cross checking, with the EE 500's failed to give any indication of the problem; with the discontinuation of the monitoring trial no further information on the current torque level was available.

A97-214

Reference to Fig. 9, shows that a sudden increase in torque level, for engine number 2 , occurs at point 45, this increase is maintained up to point 58 after which the torque trend returns to its previous level. Analysis of the EE 500's shows that the torque indicator and TIT system was modified between points 56 and 58. It is perhaps relevant to note that this particular fault was indicated by the trend plots some four weeks before maintenance action was initiated.

A97-215

The torque trend for engine number 3, as given in Fig. 10, shows a sudden increase in levels at point 17, which was maintained until the monitoring of performance trends was discontinued. No explanation for the changes in levels can be ascertained from the EE 500's and it is thought that, as with A97-214, it could be an unrecognised fault in the torque or TIT indicating system.

A97-216

For this aircraft, the torque levels for engines 1, 2 and 3 have shown a gradual but consistent rise, reflecting a change in the reference, fourth engine. The rise in torque levels was not reflected in the fuel flow trends. Examination of the EE 500's again failed to indicate a cause for this behaviour, which is thought to be associated with either the torque or temperature indicating system on the reference engine.

NOTATION

FF	Fuel Flow lb./hr.
LLL	Lower Limit Line.
MCS	Maintenance Control Section.
N	Engine Speed - rpm.
OAT	Outside Air Temperature, $^{\circ}C$
rpm	revolutions per minute.
TIT	Turbine Inlet Temperature, $^{\circ}C$
ULL	Upper Limit Line.
Δ	Increment or Decrement in a given parameter.

REFERENCES

1. GLENNY, D.E.
Engine Performance Monitoring:-
Rolls Royce Dart and Allison T56 Turbo-prop Engines,
ARL-MECH-ENG-NOTE-382.

2. RAAF HQSC
Allison T56 Engine Performance Monitoring
RAAF HQSC 2602/75/76.

TABLE 1

	DEFECT		AIRCRAFT	ENGINE		Operating Hrs Since	
	DATE	NUMBER	NUMBER	NUMBER	POSITION	NEW	O/H
+	25/3/77	486/55/77	160	105589	4	6433	1459
*	22/9/77	486/155/77	177	106187	4	4709	2228
+	14/4/77	486/70/77	180	106173	1	6202	1182
+	15/7/77	486/111/77	207	100907	2	6204	2137
O	13/5/77	486/67/77	208	100896	4	8183	1316
+	29/3/77	486/57/77	210	101593	4	7807	609
O	23/2/77	486/27/77	211	101600	4	7177	1173
O	18/5/77	486/84/77	212	101667	2	9356	2168
*		Not Raised	213	101610	4	7543	376
+	6/6/77	486/102/77	214	101580	1	6992	1528

* Engine removals as identified by trend plots.

\+ Damage which would not be identified by trend plots.

O Damage which should have been identified by the trend plots.

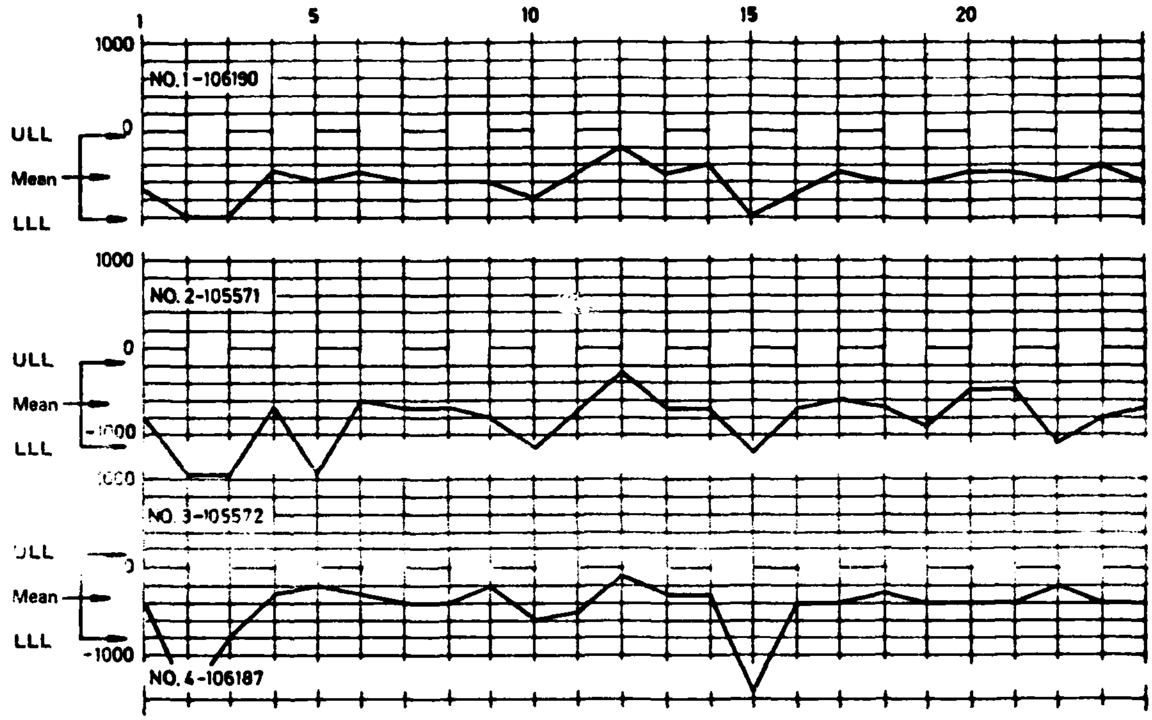
TABLE 2

	AIRCRAFT NUMBER	ENGINE		FIGURE		
		NUMBER	POSITION	NO.	TYPE	POSITION
*	178	106177	4	3	Torque	30
?	180	106198	4	4	Torque	37-45
*	190	106208	1	5	Torque	82
*	205	101602	4	6	Torque/F.F.	100-110
?	206	101605	4	-	-	-
?	208	-	1,2,3 &4	7	Torque	10-27
*	208	101578	2	7	Fuel Flow	40-45
O	209	100906	2	8	Fuel Flow	1-145
*	210	101660	1	-	-	-
	210	101579	3			
O	212	101616	4	-	-	-
*	214	101663	2	9	Torque	44-57
O	215	101608	1	10	Torque	16 →
O	216	100904	1	-	-	-
	216	101662	2			

* (6) identified on EE500 as being actual faults.

O (4) not identified on the EE500 but believed to be associated with an incipient fault.

? (3) plotting or reading errors.



Hercules aircraft A97 – 177
T56 – engine performance monitoring
Δ Torque (in lbs) ~ Time

Consistently low values of torque (and fuel flow) for engines 1, 2 and 3 during the total period of the monitoring trial. Engine No. 4 periodically reported for high torque and high fuel flow with low TIT indication. *Finally rejected and returned to Qantas.*

FIG. 1 TORQUE TRENDS

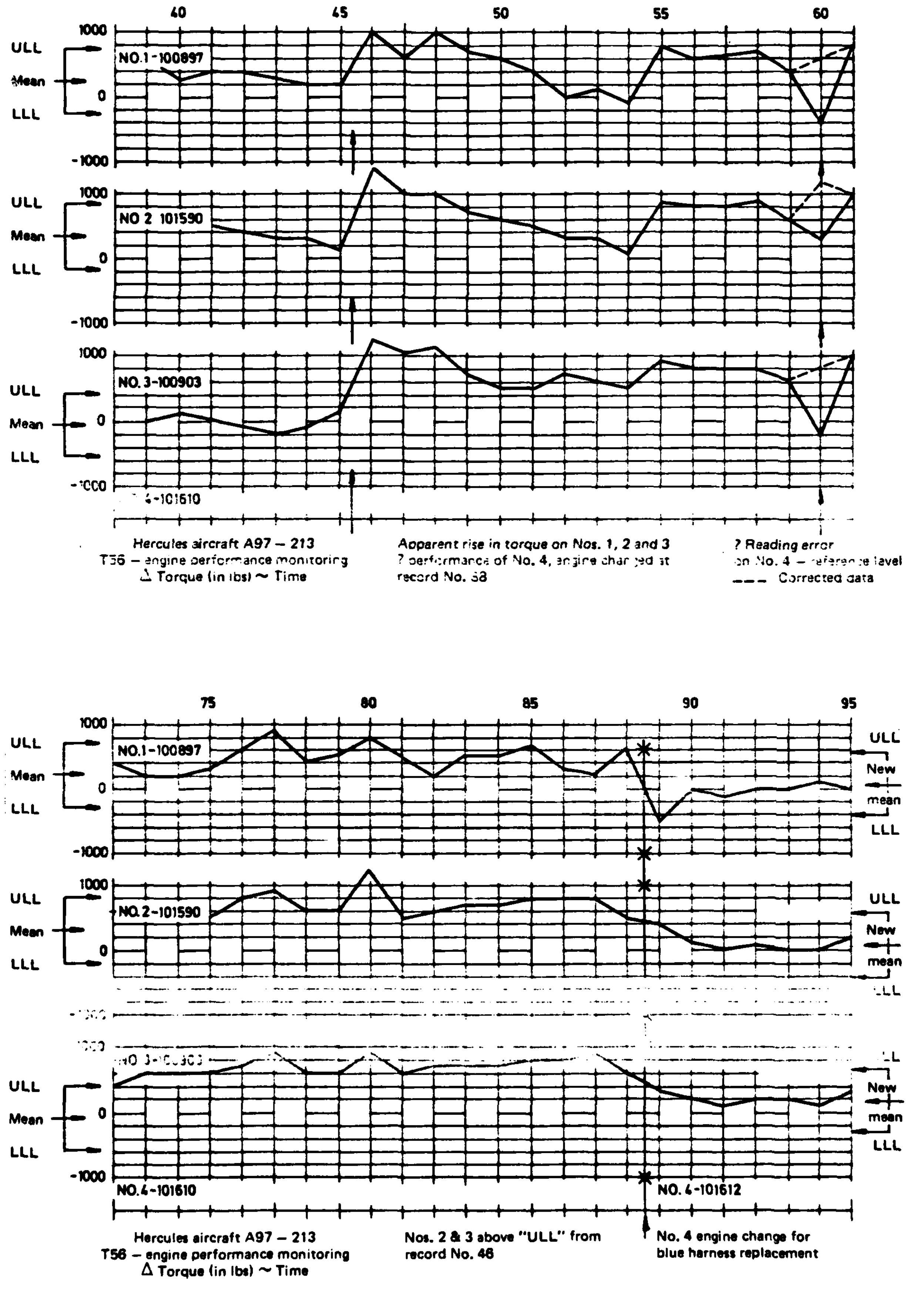


FIG. 2 TORQUE TRENDS

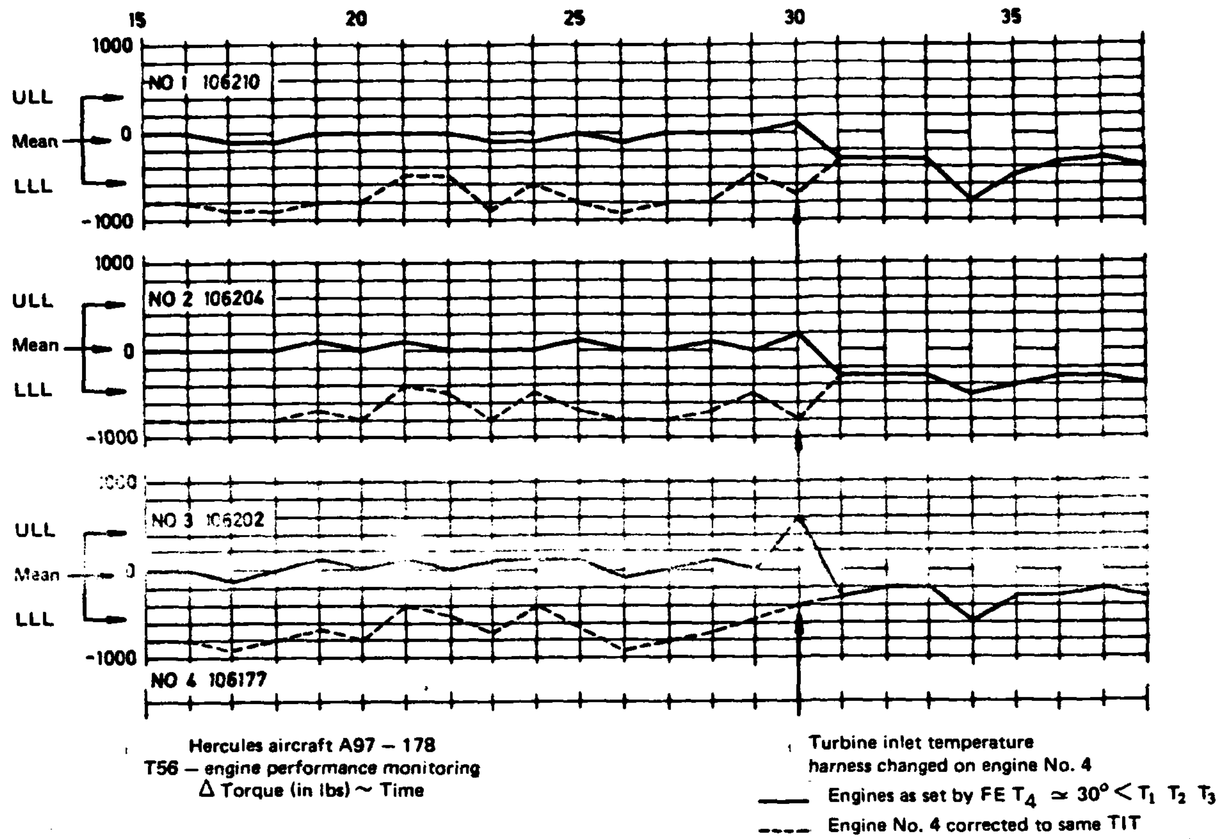
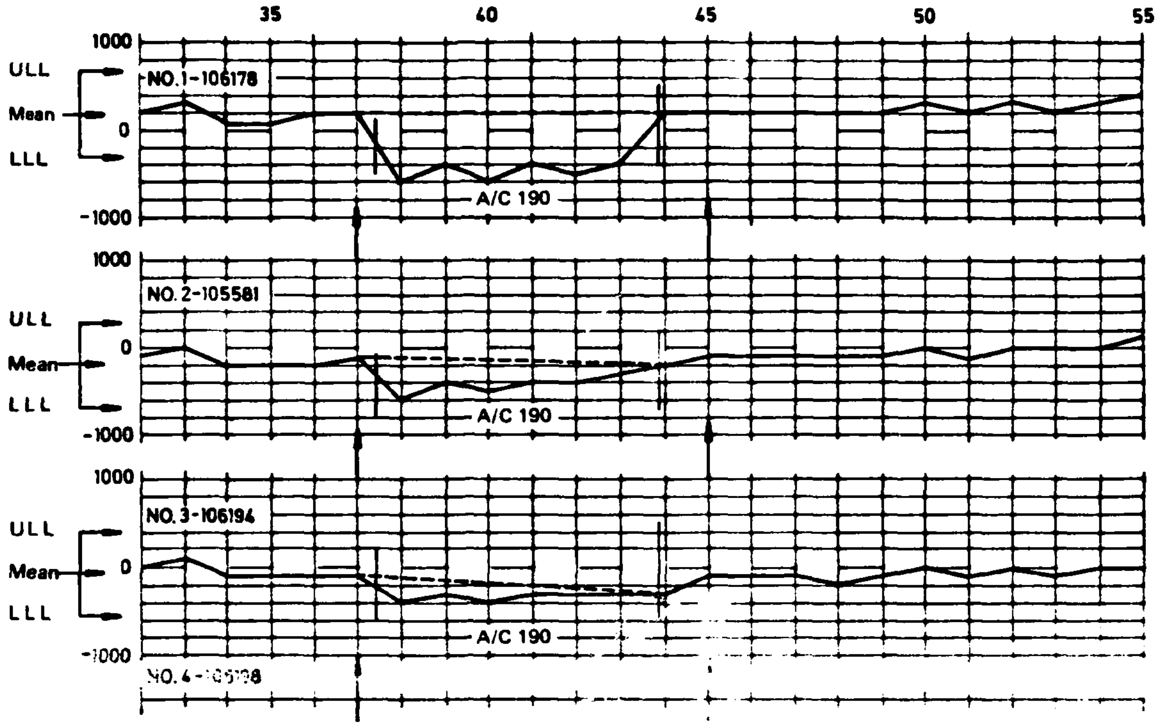


FIG. 3 TORQUE TRENDS

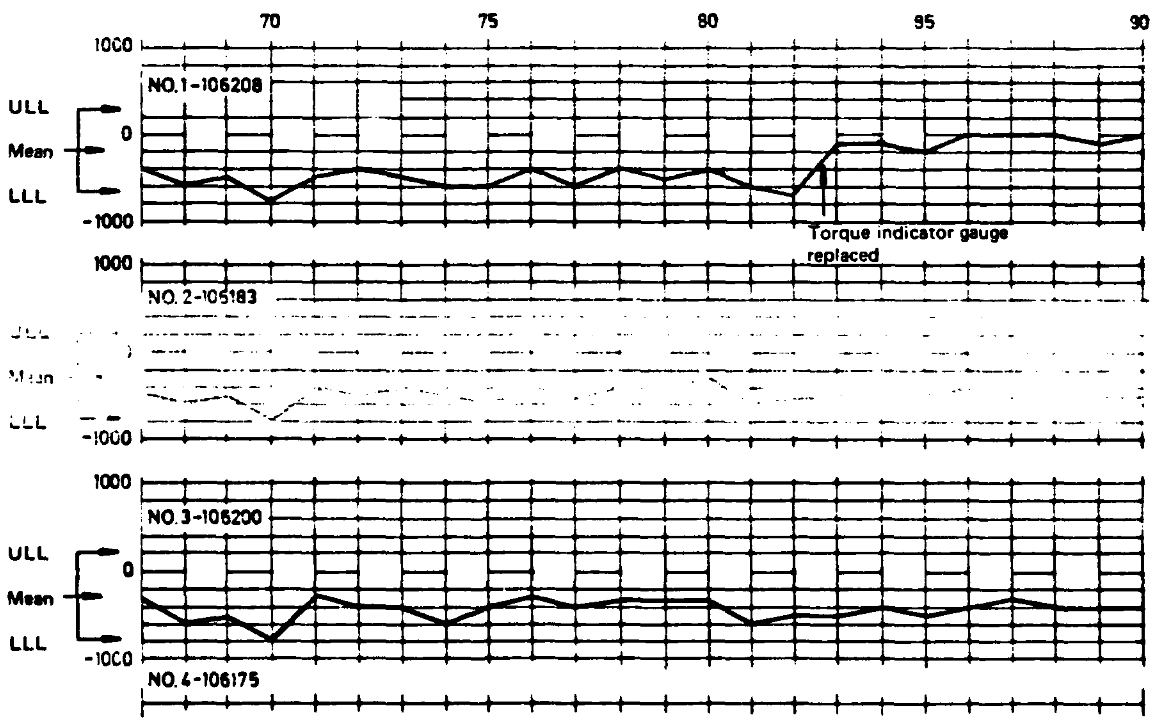


(1) Fall in torque & fuel flow on 1, 2 and 3 possible fault in No. 4 [illegible] or thermocouple.

(2) On checking data for A/C-180 it was found that results for A/C-190 had been inserted by error. Therefore readings 37-44 should be deleted.

Hercules A97 — 180
T56 — engine performance monitoring
Δ Torque (in lbs) ~ Time

FIG. 4 TORQUE TRENDS



Hercules aircraft A97 — 190
T56 — engine performance monitoring
Δ Torque (in lbs) ~ Time

FIG. 5 TORQUE TRENDS

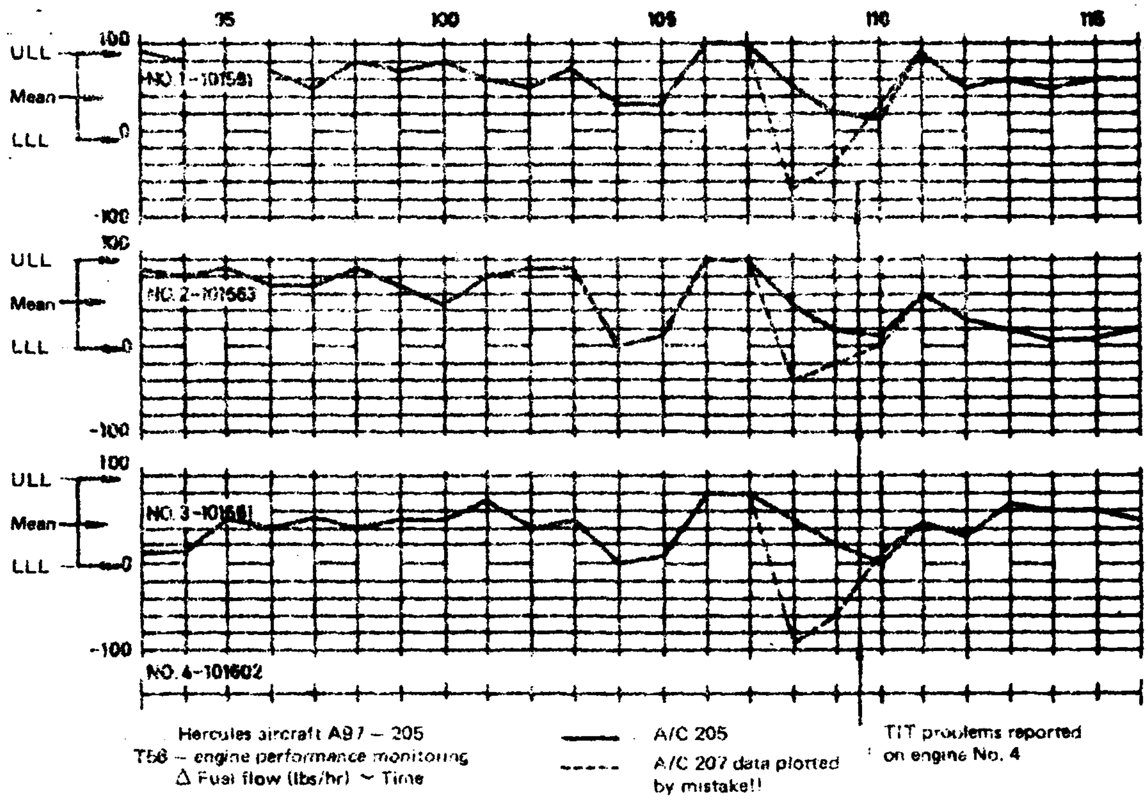


FIG. 6(a) FUEL FLOW TRENDS

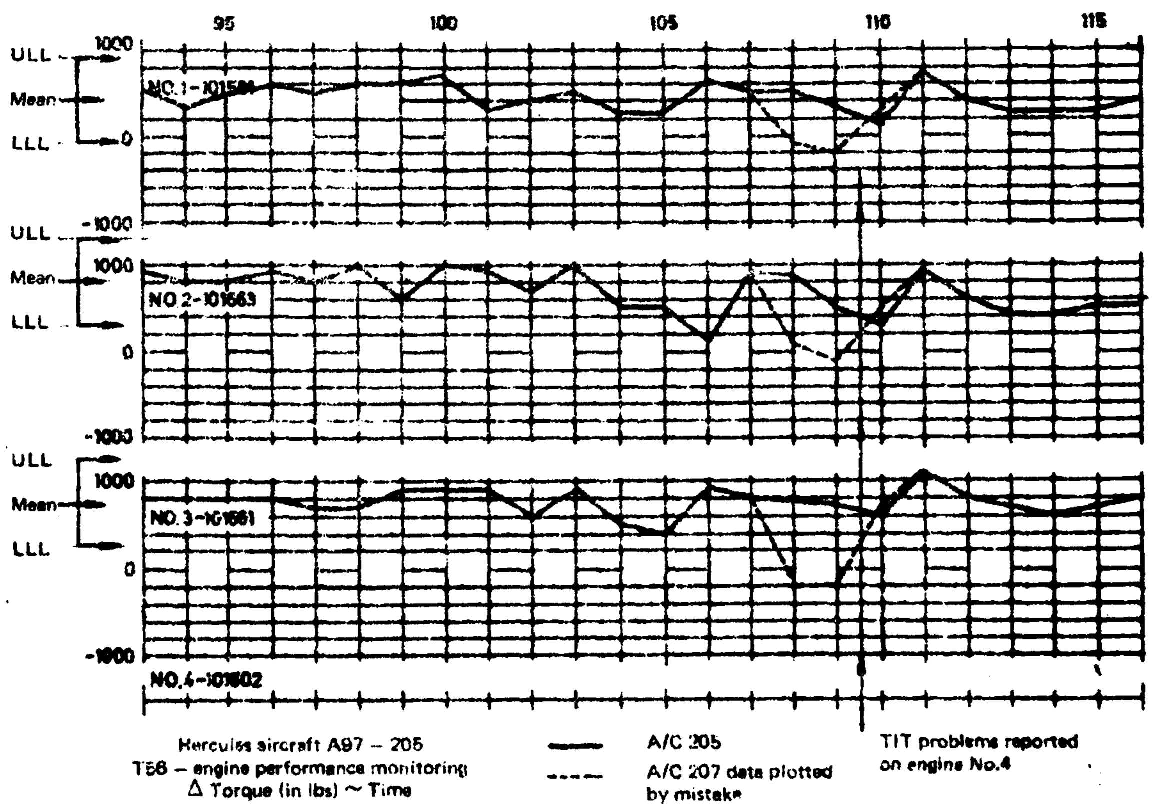


FIG. 6(b) TORQUE TRENDS

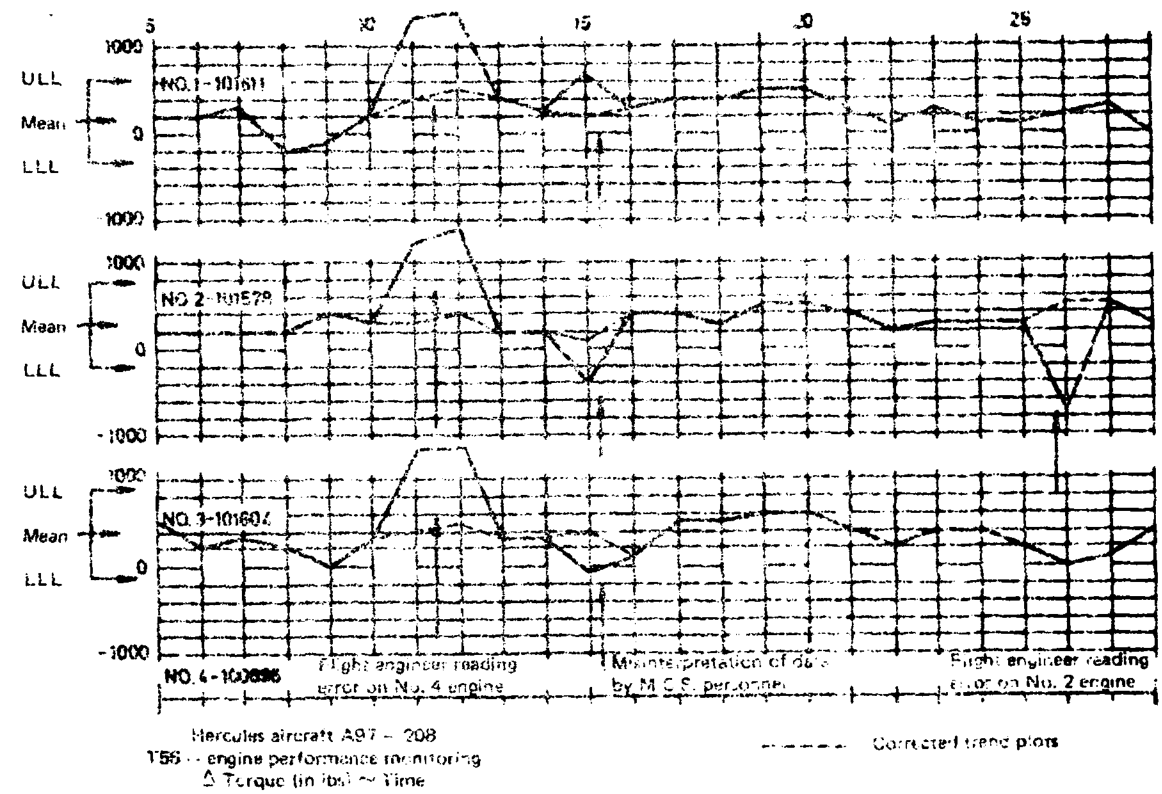


FIG. 7(a) TORQUE TRENDS

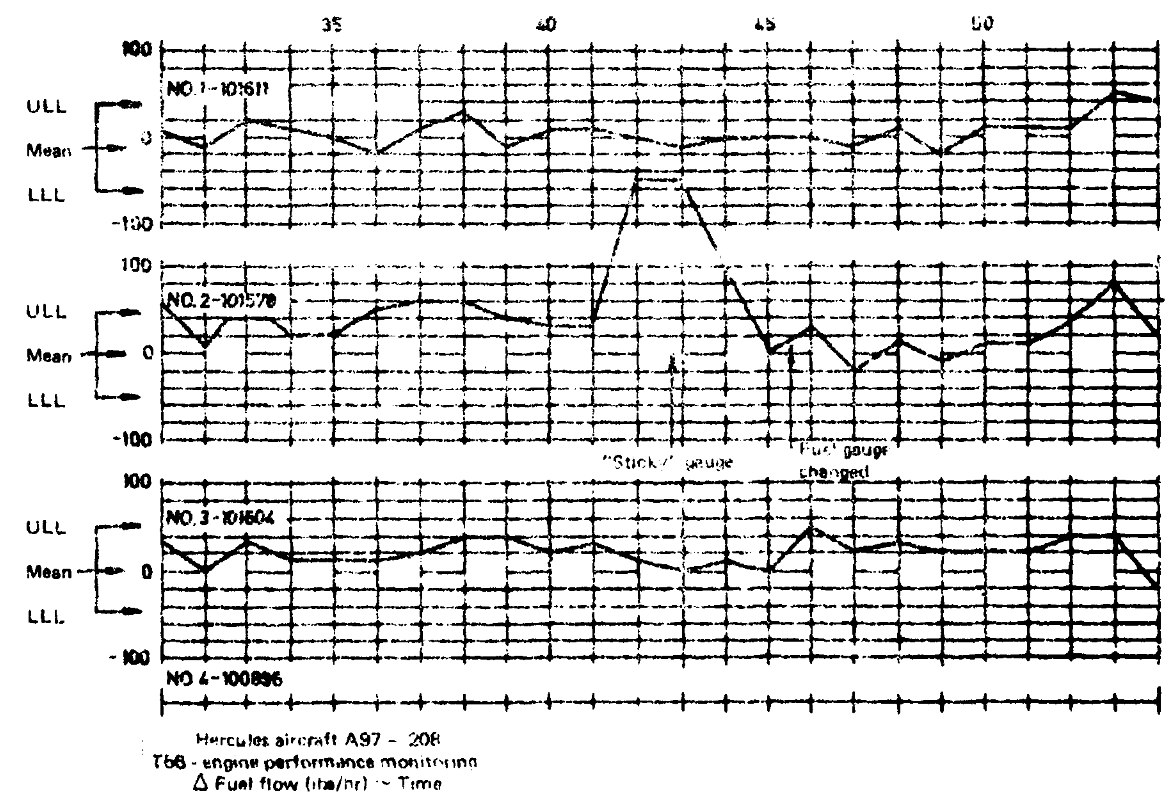


FIG. 7(b) FUEL FLOW TRENDS

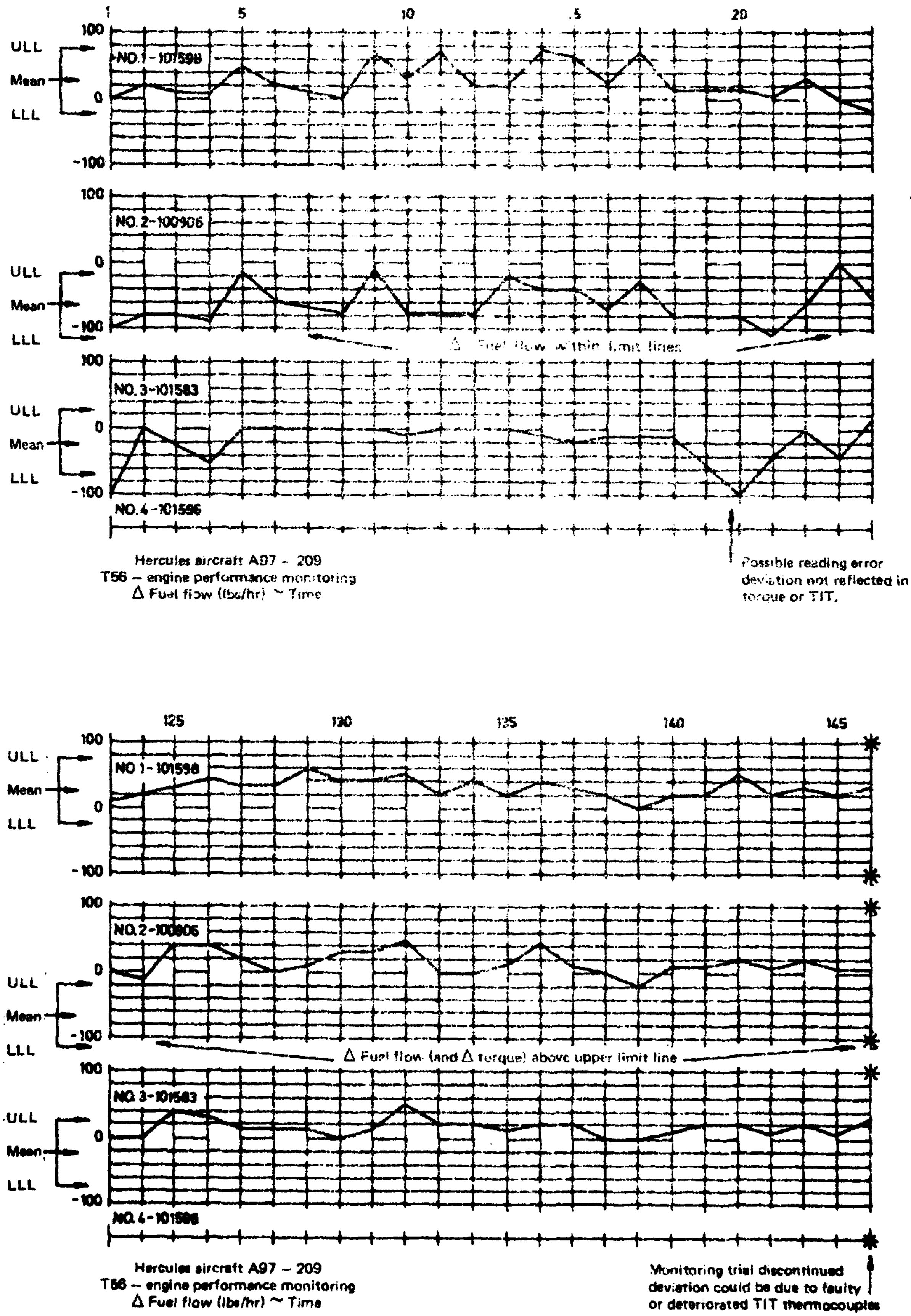


FIG. 8(a) & 8(b) FUEL FLOW TRENDS

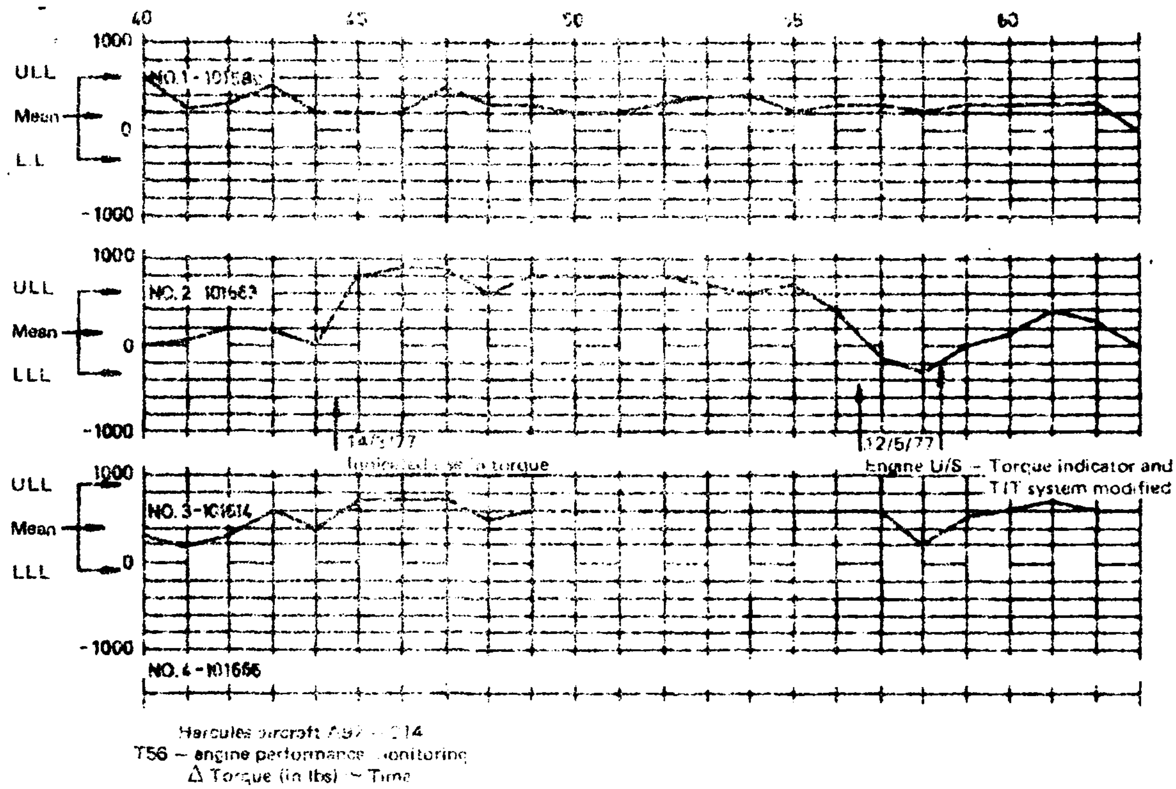


FIG. 9 TORQUE TRENDS

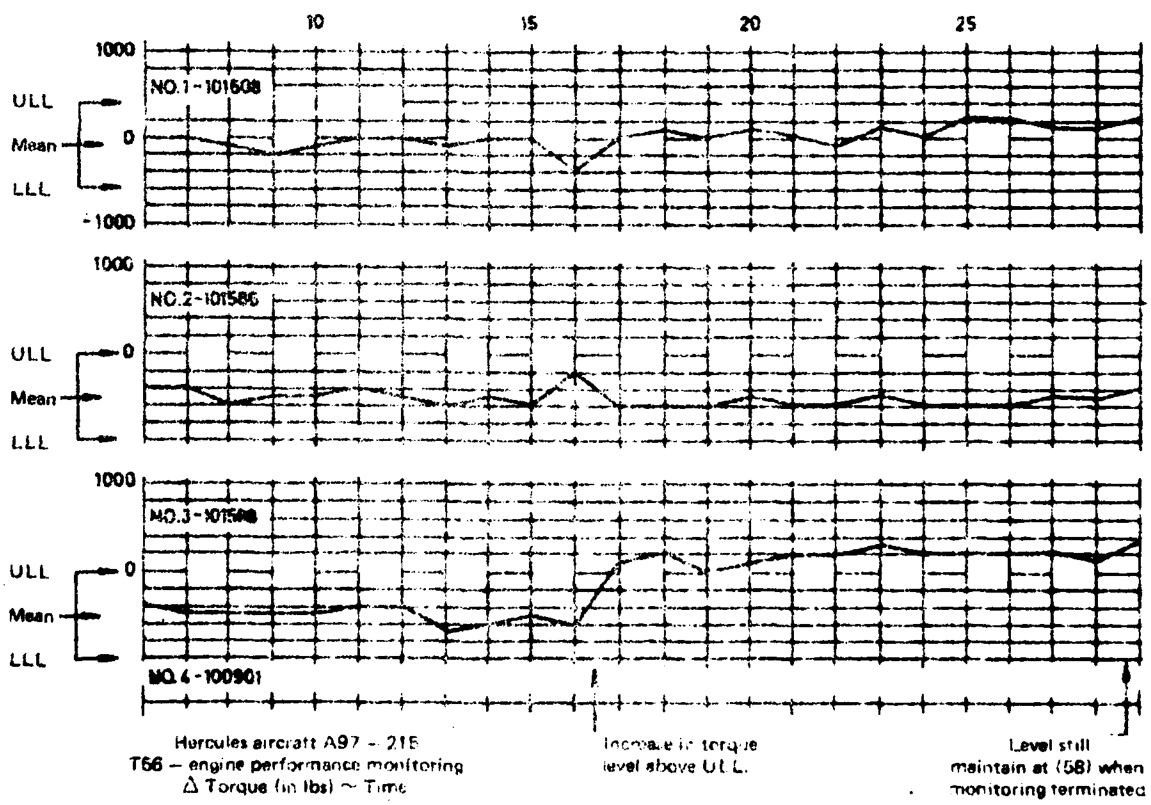


FIG. 10 TORQUE TRENDS

APPENDIX 1

ANNEX A TO HQSC 2602/75/76

ENGINE PERFORMANCE MONITORING PROCEDURES FOR ALLISON T56 ENGINES IN THE C130A AND E AIRCRAFT

References:

A. RAAF AAP 7211.011-1-1 Flight Manual Performance Data Hercules C130A.

B. RAAF AAP 7211.012-1-1 Flight Manual C130E Appendix 1 Performance Data.

The inflight and ground engine monitoring procedures detailed in the following sections should enable aircrew and maintenance personnel to assess more readily the day to day performance of the aircraft engines so enhancing aircraft safety and providing guidelines for maintenance action.

2. Ground Performance/Monitoring Check:

a. On any occasion following engine installation or rectification when a ground power check is carried out the following engine/aircraft parameters are to be recorded:

(1) Time and date of check.

(2) Indicated Outside Air Temperature.

(3) Pressure Altitude.

(4) Increment of observed torque over that given in Figures 1 and 2 or Figure A3-3 of References A and B for C130A and C130E aircraft respectively.

(5) Increment or decrement in fuel flow in comparison to that given in Figures 1 and 2 of this Annex for C130A and C130E aircraft respectively.

The changes in torque and fuel flows given above may be used to re-establish trending levels subsequent to change of engine configuration; detailed procedures are given in Section 6 and Figure 3 of this Annex.

b. On the first flight of the day, in the course of carrying out pre-flight checks, with normal bleed air and auxiliaries operating, TIT and N set to 850 C and 13820 rpm (100%) respectively record the following engine/aircraft data on the EE10-Flight Engineers Log C130 form:

(1) Time and date of check.

(2) Indicated Outside Air Temperature preferably as given by the control tower.

(3) Pressure Altitude.

(4) Prevailing wind conditions relative to the aircraft.

(5) Observed Torque, Engines 1-4.

(6) Observed Fuel Flow, Engines 1-4.

3. Inflight Monitoring Check:

a. Procedures. For meaningful trends to be obtained from performance monitoring it is desirable to record data on each and every flight; it is appreciated however that whilst the aeroplane is being operated in a training role it may not be possible for sufficiently stabilized engine operating conditions to be obtained which would allow accurate data to be recorded, consequently, whilst operating in a training role readings should be taken on an opportunity basis and the engineers flight log appropriately annotated. When cruise conditions prevail it is required that engine/aircraft data are recorded for stabilized operating conditions existing at the top of climb and thereafter at 2 hourly intervals, if the flight is not of sufficient duration, data at the top of climb and just prior to descent should be recorded.

b. Data Required. With all 4 engines operating at 100% N1 and the TIT's set to a common value the following information is to be recorded once the engine instrumentation has stabilized:

(1) Time and date of check.

(2) Indicated Outside Air Temperature.

(3) Calibrated airspeed or sufficient data to obtain the same.

(4) Pressure altitude and cabin altitude.

(5) Observed Torque, Engines 1-4.

(6) Observed Fuel Flow, Engines 1-4.

(7) Engine rpm (%).

(8) Engine TIT.

(9) Bleed and or auxiliaries operating.

The above data when recorded on the EE10 Flight Engineers Log, should be annotated Data Engine Performance Monitoring (DEPM) results.

4. The information recorded in Sections 2 and 3 is to be returned to the Maintenance Squadron as soon as possible after each flight to enable performance trends to be determined and any maintenance action deemed necessary to be carried out.

5. Trend Plotting:

a. In determining performance trends for a given engine it is normally mandatory to correct the observed data for variations in ambient conditions. In the case of a multi-engined aircraft a much more simple method has been evolved which uses one engine as a reference against which the remaining engines are compared, as such no data correction is required. The major problem with this system is that if the specified reference engine is adjusted or changed then new trends have to be commenced, however if a ground power check is undertaken subsequent to installation then the trending may be made continuous by determining the differences in performance level between the 'new' and 'old' reference engines.

b. Trend plots may be determined as follows: using engine number 4 as a reference calculate for engines Nos. 1, 2 and 3 the following increments (decrements) in torque and fuel flow:

Δ 14 Torque = Torque No. 1 - Torque No. 4

Δ 24 Torque = Torque No. 2 - Torque No. 4

Δ 34 Torque = Torque No. 3 - Torque No. 4

Δ 14 FF = Fuel Flow No. 1 - Fuel Flow No. 4

Δ 24 FF = Fuel Flow No. 2 - Fuel Flow No. 4

Δ 34 FF = Fuel Flow No. 3 - Fuel Flow No. 4

c. Plot increments (decrements) in torque and fuel flow once per flight in the manner indicated in Figure 4a. and 4b. respectively: on flights of long duration more than one trend plot may be determined thus minimizing errors in instrument readings.

d. Using the first 10 calculated-plotted points establish a mean value of Δ torque and Δ fuel flow for each engine, then draw limit lines representing a deviation of ±500 in. lb. of torque and ±50 lb/hr of fuel flow on each trend plot as shown.

e. If during subsequent performance trending of a particular engine or engines a consistent deviation in Δ torque and or Δ fuel flow outside these limits occur (i.e. 3-5 consecutive readings) then an analysis of the trends should be initiated in line with the following criteria:

(1) If only one engine deviates outside the limit lines then maintenance investigation should be initiated around that engine.

(2) If 3 engines consistently deviate outside the limit lines the fourth engine should be investigated.

f. The following general guidelines may be applied in investigating a suspected engine malfunction:

(1) Low Torque - High Fuel Flow indication: inspect for turbine/ combustor damage.

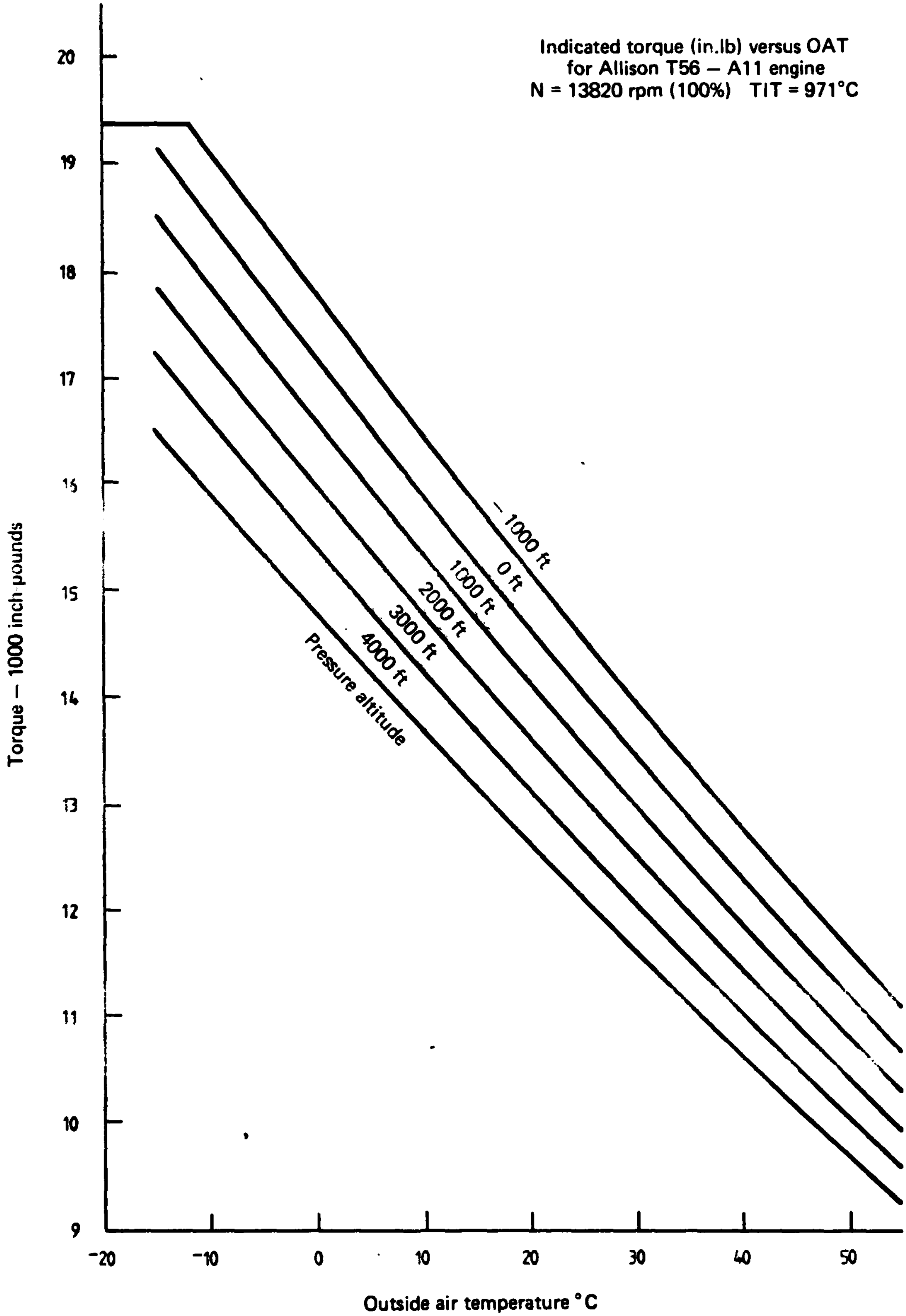
(2) Low Torque - Low Fuel Flow indication: inspect for compressor contamination or damage.

(3) High Torque - High Fuel Flow indication: suspect a thermocouple deterioration.

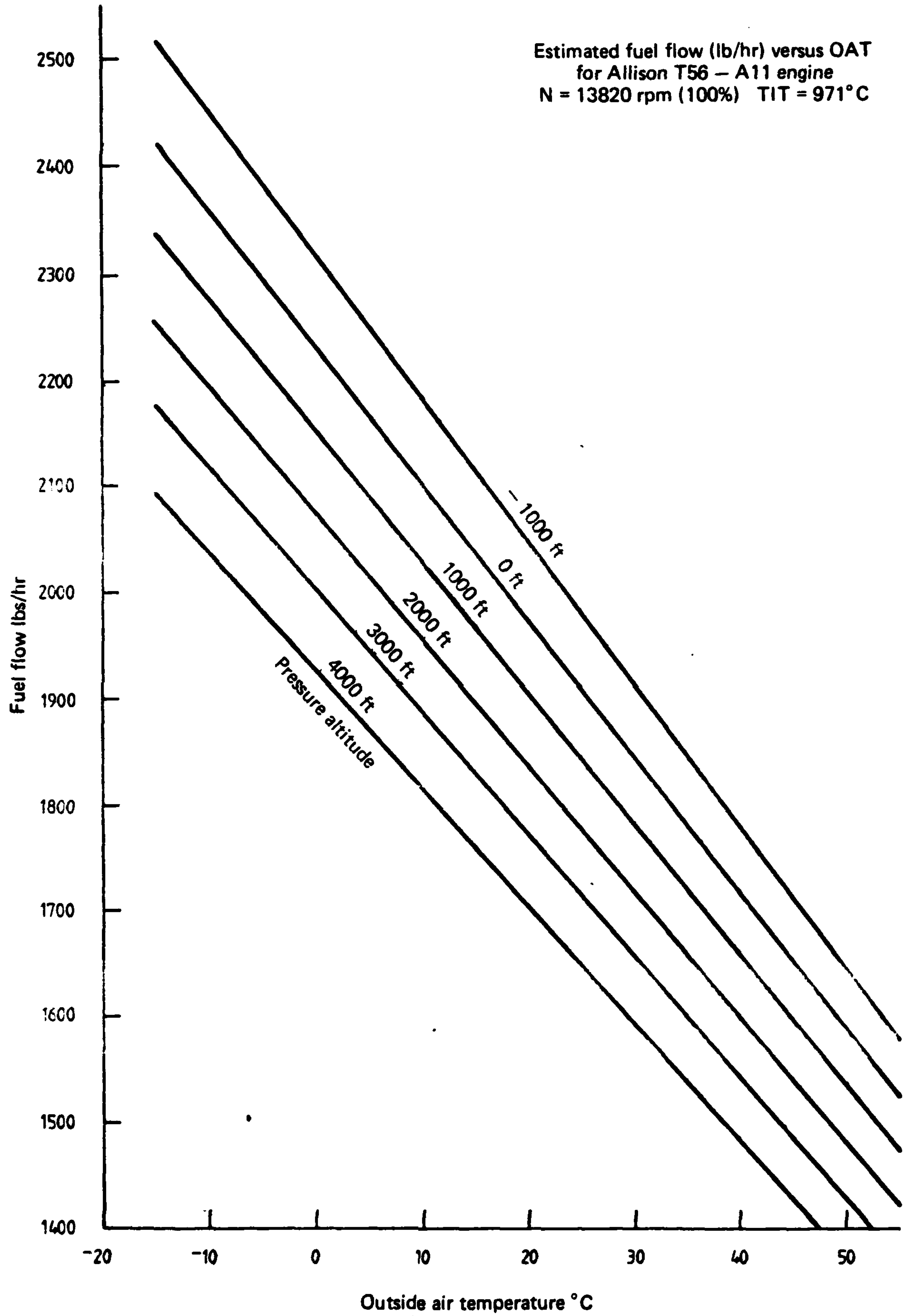
6. As mentioned in Section 5 once a change or adjustment has been made to the reference engine (No. 4) the trend plots have to be 'corrected' to account for changes in performance (torque and fuel flow) for that engine. An indication of the new mean levels can be obtained using installation ground power check data along the lines indicated in Figure 3. It should be noted however that as the installation ground power check is carried out at maximum power (as against the part load power checks carried out prior to and in flight) the increments in levels calculated in Figure 3 can only be used as a guide to the direction and maximum amount of movement of the new mean trend lines. In practice new mean levels will have to be re-established using up to 10 plotted points, subsequent to engine adjustment, in the manner described in Section 5d. for each of the 3 engines. If at any time engines 1, 2 or 3 are changed then new mean values of torque and fuel flow should be calculated for that engine irrespective of any results of a ground performance check.

7. If in the course of trending the performance of the four engines it is required to determine the performance of the reference (No. 4) engine or one or more of the other 3 engines then this can be achieved by comparing the indicated power and fuel flow for the reference engine with that obtained from Figures A2-1 and A2-2 of References A and B for C130A and C130E aircraft respectively. (These graphs define the inflight power and fuel flow available for a specification engine operating with normal bleed flows and at 100% rpm.) Simple addition or subtraction of deviations determined in Section 5b. will give the absolute performance of the remaining three engines.

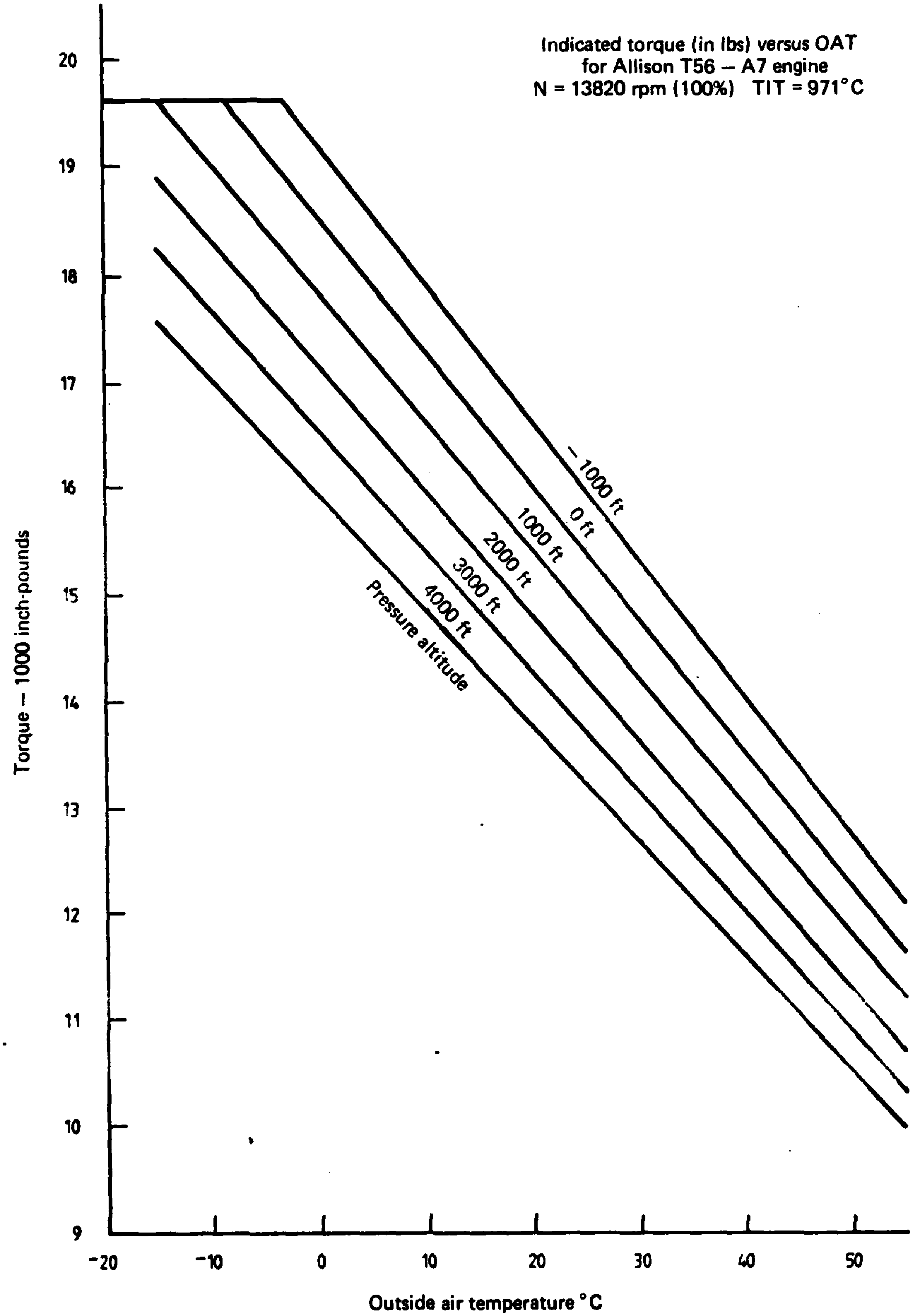
8. Caution. During the initial introduction of the monitoring procedures caution should be exhibited in over reacting to, and drawing conclusions from, single abrupt parameter changes. if there is any doubt about the validity of a trend point obtained, the data recording and calculations should be repeated. It cannot be stressed often enough that in any manual monitoring procedure the engine should be allowed to stabilize sufficiently for the instruments to take up their true readings, in addition any specified conditions such as constant TIT and N for all engines should be strictly observed. Additional safeguards may be achieved by restricting the trending analysis to records obtained within a particular altitude range and engine power setting: at present no criteria or instructions in this regard are envisaged but these may become necessary depending upon the progress of the trial.



ANNEX A FIG. 1(a) T56 – A11 TORQUE VS OAT

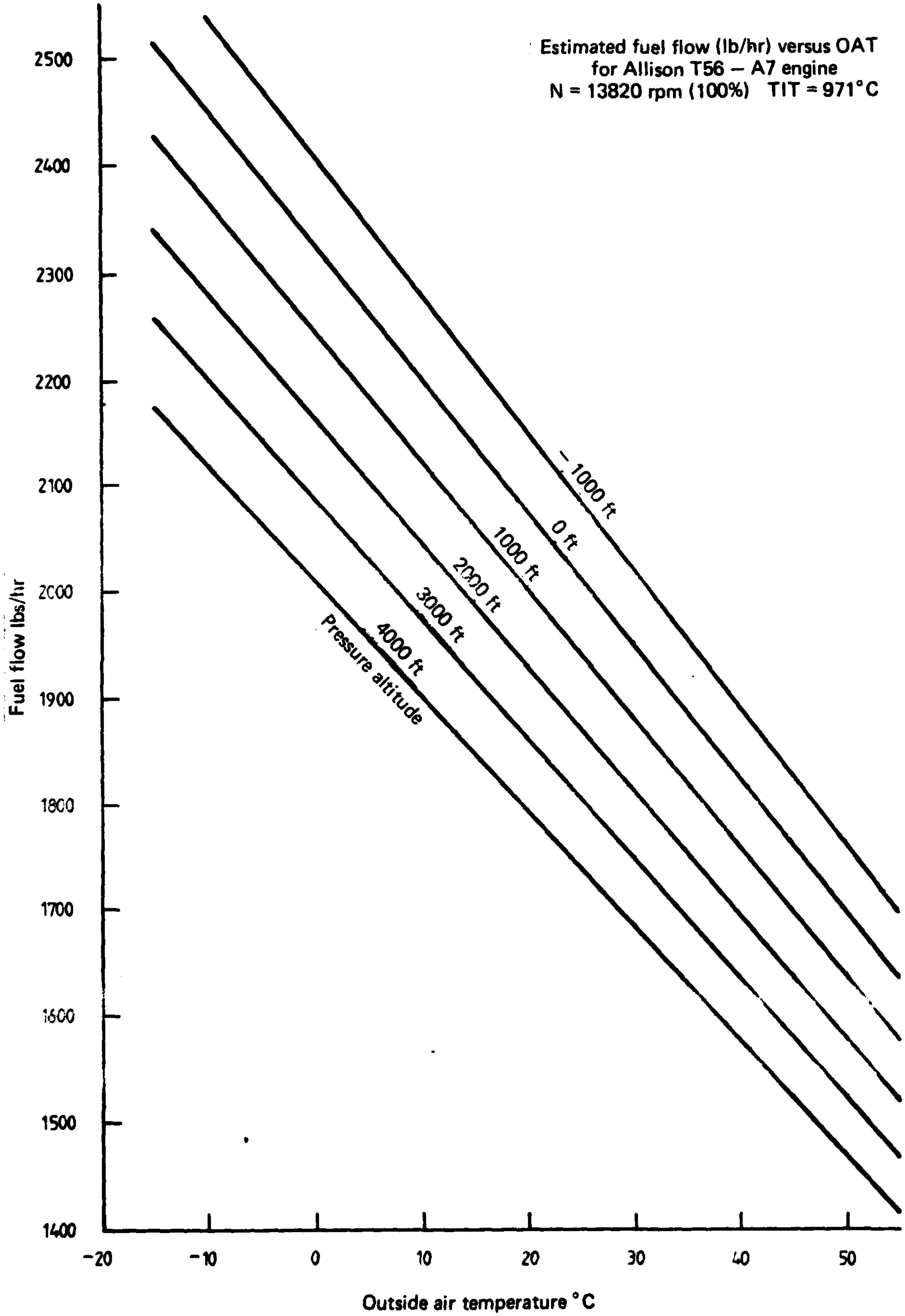


ANNEX A FIG. 1(b) T56 – A11 F.F. VS OAT



ANNEX A

FIG. 2(a) T56 – A7 TORQUE VS OAT



ANNEX A

FIG. 2(b) T56 – A7 F.F. VS OAT

FIGURE 3

TYPICAL VARIATIONS TO MEAN TORQUE AND FUEL FLOW LINES DUE TO CHANGE IN SETTING OF REFERENCE ENGINE

As an example, consider the following ground performance data obtained subsequent to adjustments made to the No. 4, reference, engine: the data are applicable to a T56-A7 engine.

	PA	OAT	Torque Indicated	Torque Estimated	Fuel Flow Indicated	Fuel Flow Estimated
Initial Installation	0/SL	15	16680	16620	2072	2136
After Adjustment No 1	1000	25	15000	14780	1920	2010
After Adjustment No 2	0/SL	15	16880	16620	2136	2136

Initial Installation

Increment in Torque = $\Delta\ TOR_0$ = IND - EST = 16680 - 16620 = 60
Increment in Fuel Flow = $\Delta\ FF_0$ = IND - EST = 2072 - 2136 = -64

After Adjustment No. 1

Increment in Torque = $\Delta\ TOR_1$ = IND - EST = 15000 - 14780 = 220
Increment in Fuel Flow = $\Delta\ FF_1$ = IND - EST = 1920 - 2010 = -90

Max. change in mean lines for Engines No. 1-3
a. Torque = $\Delta\ TOR_0 - \Delta\ TOR_1$ = 60 - 220 = -160
b. Fuel Flow = $\Delta\ FF_0 - \Delta\ FF_1$ = -64 - (-90) = +26

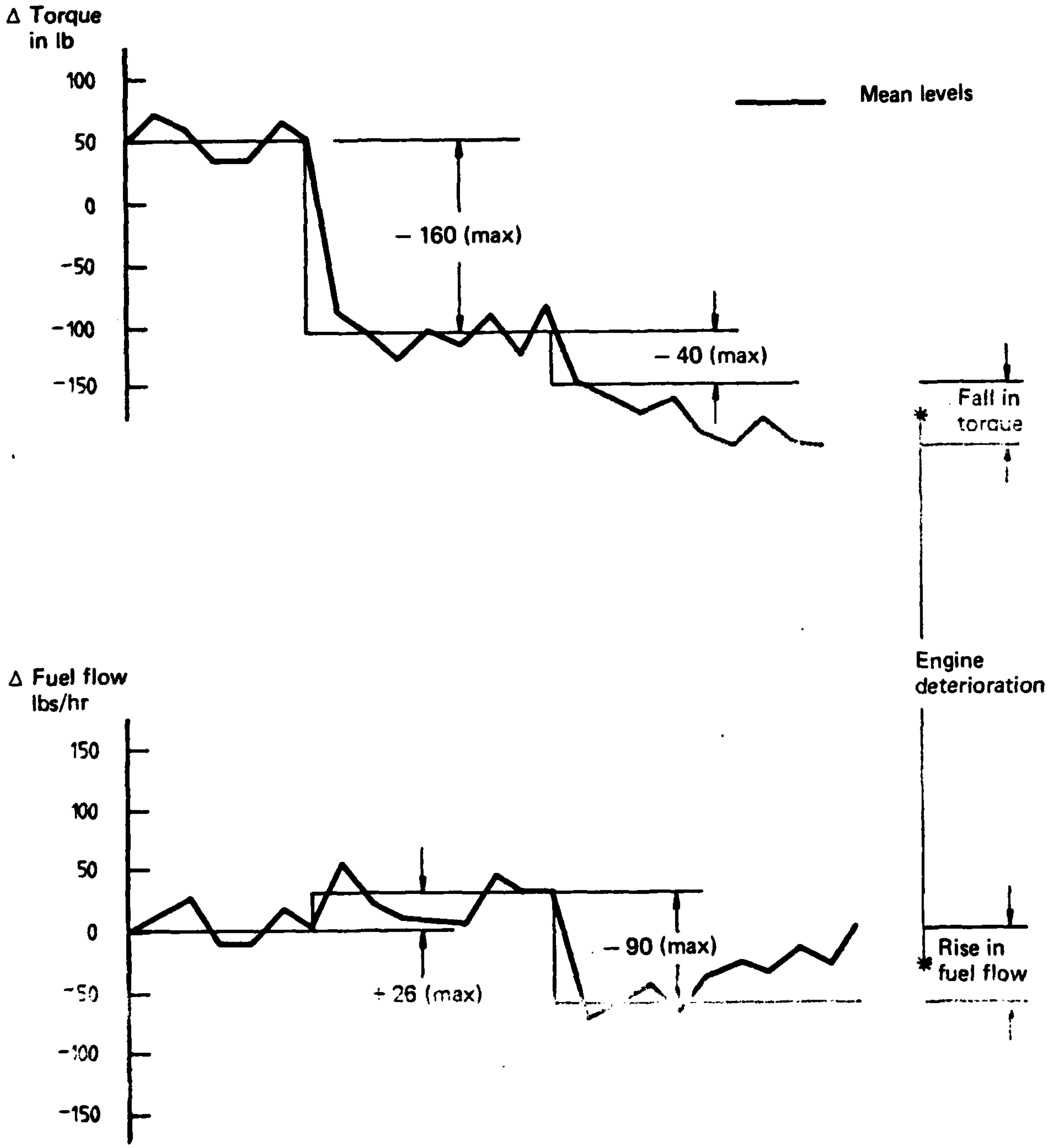
The effect of a. is to lower the mean torque lines of engines 1-3 by a maximum of up to -160 in. lb. of torque whilst that of b. is to raise the mean fuel flow levels by up to 26 lb/hr; the results for a typical installation are shown in the sketch below.

After Adjustment No. 2

Increment in Torque = $\Delta\ TOR_2$ = IND - EST = 16880 - 16620 = 260
Increment in Fuel Flow = $\Delta\ FF_2$ = IND - EST = 2136 - 2136 = 0

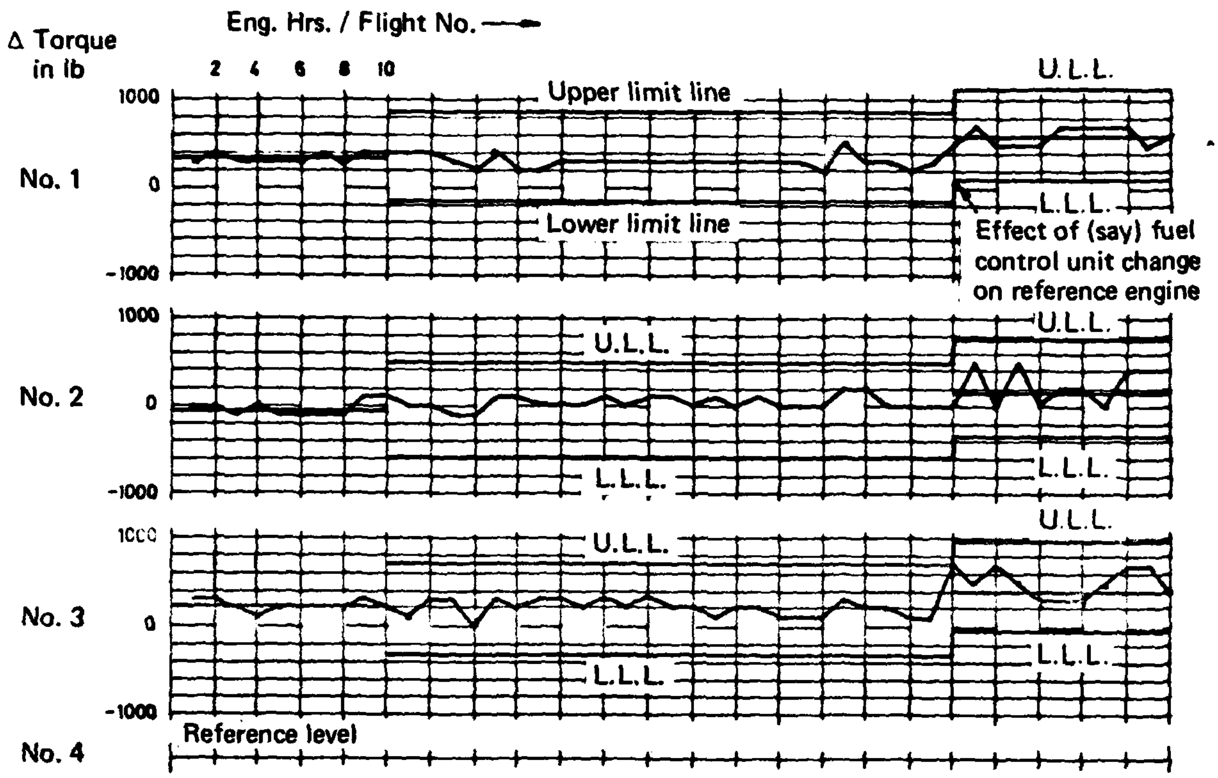
Max. change in mean lines for Engines No. 1 3
a. Torque = $\Delta\ TOR_1 - \Delta\ TOR_2$ = 220 - 260 = -40
b. Fuel Flow = $\Delta\ FF_1 - \Delta\ FF_2$ = -90 -(-0) = -90

In this case the effect of a. and b., as seen in the sketch below, is to lower the mean lines for both torque and fuel by a maximum of -40 in. lb. of torque and -90 lb/hr of fuel flow respectively. These changes are applicable to engines number 1-3. It should be noted however that the changes indicated, for both mean torque and fuel flow levels, are only given to represent trends and should not be taken as denoting the absolute position of the mean lines after an adjustment or change has been made to the number 4 engine.



ANNEX A

FIG. 3 (Cont)

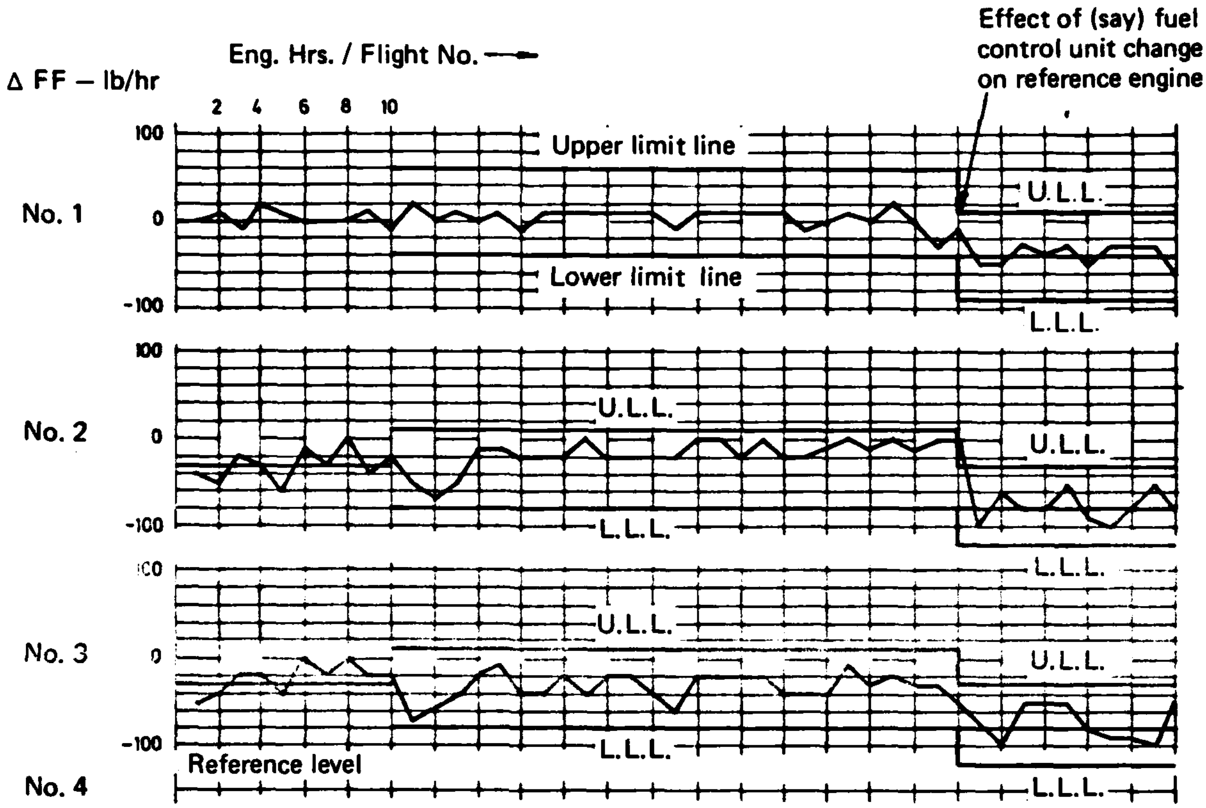


Hercules – Allison T56
Engine performance monitoring – Torque
Aircraft No. A97 –
⊗ Pre-flight × Inflight

	1	2	3	4
Engine No.				
Date installed				
Hours at installation				

ANNEX A

FIG. 4(a)



Hercules — Allison T56
Engine performance monitoring — Fuel flow
Aircraft No. A97 —
⊗ Preflight × Inflight

	1	2	3	4
Engine No.				
Date installed				
Hours at installation				

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