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P-3C On-Wing Trial of a Data Logger for T56 Turbine Inlet Temperature Monitoring System

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Airframes and Engines Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

Following successful ground based on-wing trials on a C-130H aircraft, a commercial data acquisition system, the DataTaker DT220, was tested at RAAF Base Edinburgh on a P-3C on the ground to determine its suitability as a flight demonstrator for a T56 engine individual turbine inlet temperature monitoring system.

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Executive Summary

The RAAF-operated C-130 Hercules and P-3C Orion are both fitted with Allison T56 turboprop engines. Each engine has eighteen thermocouples measuring the turbine inlet temperature. The thermocouples are electrically averaged to provide both a cockpit indication and an input for the engine control system. If individual thermocouples become unserviceable, the average temperature measured decreases and the control system adds additional fuel to correct the temperature. This leads to increased actual inlet temperatures with resulting increases in failures of various components.

AMRL successfully demonstrated, in an engine test cell, that by monitoring the eighteen thermocouples individually it was possible to determine unserviceable thermocouples and other faults such as those which might originate in fuel nozzles.

A commercial data acquisition system (DataTaker DT220), which is used in many industrial applications, is being investigated to determine its suitability as an inflight demonstrator for an individual thermocouple turbine inlet temperature monitoring system.

A successful ground trial of the DataTaker for this task has been previously completed on a C-130H Hercules. A second ground-based on-wing trial of this equipment on a P-3C was conducted with two main objectives: firstly to investigate the susceptibility of the system to various emitting avionics, prevalent in the P-3C, and secondly to collect data fully autonomously over a *simulated multi flight* time period for comparison of normal flight-to-flight variations in temperature profiles.

It was discovered that the flight-to-flight variations of each thermocouple output were significant, and therefore the techniques so far developed for determining early failure of the thermocouples may need further investigation.

It was concluded that the DataTaker is capable of being utilised as an airborne demonstrator of this system but will require careful consideration of the mounting options so that the environmental specifications of the device are not exceeded, whilst still allowing the minimum of cabling to be installed. Installation of the equipment at a test cell would also be advantageous to allow the normal variation in temperature distributions to be determined.

Contents

1. Introduction

Under a proposal by Skidmore [1], AMRL has been testing a commercial data acquisition system to determine its suitability as a flight demonstrator to measure individual turbine inlet temperatures (TIT) on a T56 engine to allow early diagnosis of common thermocouple and fuel nozzle faults.

The proposal involves a system that monitors all eighteen turbine inlet thermocouples of the T56 engine. Once the engine is operating at a predetermined steady state condition, a record of the thermocouple temperatures is taken. This data is then analysed, post-flight, to determine if any fault conditions exist by comparing with previous data taken during either a Mobile Engine Test Stand (METS) run or post maintenance test flight.

The aim of the trial, conducted at RAAF Base Edinburgh, was to validate the operation of the DataTaker DT220 on an airframe in an unattended mode and to investigate any problems which might be associated with airframe installation. The system had earlier been successfully demonstrated on a T56 engine both at the engine test cell at the QANTAS Jet Base[2] in Sydney, and on-wing on a RAAF C-130H Hercules.

This document discusses the trial and its results, addresses some of the points raised by the author on the C-130H trial[3], and discusses the suitability of the DataTaker data acquisition system for application as a flight demonstrator for an individual TIT monitoring system.

2. Trial Configuration

The system tested was the DataTaker DT220, which had been previously trialed at the QANTAS Jet Base and at RAAF Base Richmond on-wing on a C-130H. The DT220 is an older and larger version of the DataTaker DT500 (referred to by Mooney[4]). The DataTaker is a commercial data logger which contains interface instrumentation to allow direct connection of various signals likely to be found in industry (eg. Temperature, Voltage, Current etc). The system samples at varying rates as determined by a schedule input by the engineer. It records its data directly in engineering units, which can be down-loaded to either a PC or credit card RAM storage.

A thermocouple test loom was placed on the starboard inboard engine (Allison T56-A-14) of a P-3C Orion aircraft (Tail Number 658) in parallel with the manufacturer's thermocouple loom and connected to the Turbine Inlet Temperature (TIT) indication thermocouples. Seven inputs were made to the DT220. For trial purposes, inputs were taken from six of the eighteen individual thermocouples on the engine. The loom was connected to the six thermocouples on two adjacent combustors (thermocouple position numbers 1 through 3 on combustor 1 and thermocouple position numbers 16 through 18 on combustor 6). The top two combustors were selected for ease of access. The seventh thermocouple connection was made in parallel to the averaged TIT signal at the thermocouple terminal block on the engine. This signal is the basis for the cockpit TIT indicator, which is fully described by Fraser [5].

The loom was brought out through an access panel on top of the engine and taped along the nacelle, along the leading edge of the wing and fuselage into the starboard over-wing escape hatch where it was terminated at the DT220 via thermocouple connectors. The DT220 was powered from the aircraft supply (115V AC 400Hz) via a stepdown isolation transformer. This method of powering the system is likely to be adopted for in-flight tests although power from the aircraft DC supply may also be used. Powering from the 115 Volt supply allowed investigation of generator-induced noise in the system.

A battery-operated laptop computer was used to download, via a serial interface, the DT220 control program and for uploading of the DT220-acquired data. This function would be replaced in an in-flight version by a credit card type storage medium.

3. Trial Procedure

The engine was operated at six conditions;

- Low Speed Ground Idle
- Flight Speed Ground Idle
- 877 ^{o}C TIT
- 932 ^{o}C TIT
- 960 ^{o}C TIT
- 1010 ^{o}C TIT

The engine condition was set according to cockpit TIT indication and allowed to stabilise for three minutes. The DT220 was then used to acquire data on all seven channels at its maximum rate of thirty samples/second for thirty seconds followed by a statistical scan for thirty seconds. The statistical scan acquires data on each of the channels but only records the desired statistical data for each channel. The statistical data can comprise any combination of average, standard deviation, minimum and maximum signal levels. This is the most likely method of operation as it allows numerous flights to be recorded, if desired, prior to having to download the data, and significantly decreases the processing requirement of the downloaded data. This procedure is identical to that used on the C-130 on-wing trial and was used to allow a comparison of acquired data.

After the six engine conditions were completed the system was tested for susceptibility of onboard electronic systems. The engine was set at two conditions, 932 ^{o}C TIT and

960 ^{o}C TIT, and onboard avionics were energised. Avionics energised included HF radios (1 & 2), TACAN and RADAR (Mode 3 into a dummy load) as well as all cockpit and sensor operator avionics. The data was acquired as above for comparison with the conditions when minimum avionics were energised. The signals were also examined using an oscilloscope.

The DT220 was also tested in an unattended role in which it monitored the temperature of the averaged TIT signal, waited for it to fall within the band 960 ± 10^{o}C and to remain there for three minutes, and then performed a statistical scan of each of the thermocouples. The engine was then brought back to the start condition, allowed to cool, and the procedure repeated for a total of four times. This procedure was repeated on the subsequent morning for a further three times. This test was performed to simulate the operational use of the equipment on subsequent flights to determine the expected "flight to flight" variation

4. Results

The acquired data were analysed primarily using statistical techniques.

The signals referred in this discussion are as follows:

Report Nomenclature	Actual Signal	Comment
Thermocouple 1	Engine Thermocouple 3	Combustor 1
Thermocouple 2	Engine Thermocouple 2	Combustor 1
Thermocouple 3	Engine Thermocouple 1	Combustor 1
Thermocouple 4	Engine Thermocouple 18	Combustor 6
Thermocouple 5	Engine Thermocouple 17	Combustor 6
Thermocouple 6	Engine Thermocouple 16	Combustor 6
TIT	Averaged TIT Thermocouple	Engine Terminal Block

Figure 1 shows a comparison of the average data taken on each of the seven inputs for the six engine conditions. The six combustor thermocouple inputs and the averaged TIT thermocouple input are shown. Thermocouples 4, 5 and 6 (combustor 6) generally had higher temperature readings than those for combustor 1, indicating a possible problem. The data collected from the six individual thermocouples showed good correlation with the averaged TIT signal and when these were averaged the result was within 1% of the measured TIT signal.

The DT220 whilst acquiring data was simultaneously calculating the standard deviation of the sample. This was subsequently normalised against the mean reading (the coefficient of variation) for each of the seven channels (Figure 2).

Figure 2 shows a trend in the measured temperature variation between successive data samples, in that the first and last of the three thermocouples (1&3, 4&6) in a combustor have significantly more temperature variation than the centre thermocouple (2&5). This phenomenon had been noted elsewhere, including the trial at the QANTAS Jet Base, the C-130H trial, and in Allison documentation and is most likely due to instabilities in the flame caused by variations in the performance of the fuel nozzle over time.

The coefficients of variation of the data acquired in this trial is lower than data collected by this equipment during the C-130H on-wing trials conducted at Richmond [4] which had coefficients of variation in the range 0.2 to 2.0% (compared with 0.2% to 1.2% for this trial).

Figure 3 shows the result when the onboard electromagnetic equipment was energised at two engine conditions compared with only electrical generators (and normal cockpit instrumentation) running. The difference between coefficients of variation (which represents noise in the system), with electronic systems off and later energised for the same engine condition, for each channel has been plotted against the thermocouple input. Overall for engine condition 932 Degrees TIT and 960 Degrees TIT the average increase in coefficient of variation was 0.007% and 0.01% respectively. This indicates that the system does not appear to be susceptible to onboard electronic emitting devices.

In final operation it is anticipated that the system will monitor the averaged TIT signal, wait for the engine to be at one of the normal operating points, allow time for the engine to stabilise then acquire statistical data which will be logged for trending at base. This requires that, prior to initiating a statistical scan, the Data Logger check that the engine is operating at one of its normal conditions by checking that the temperature falls within a pre-programmed band. Ideally this band should be as small as possible for each condition.

Fully autonomous operation of the system was successfully demonstrated at one engine condition, namely 960^{o}C TIT. The DT220 continually monitored the average TIT signal, waiting for it to fall into the band 960^{o}C ± 10^{o}C. Every sample for a further three minutes had to remain within that band prior to the system accepting that the engine had stabilised and allowing a statistical scan acquisition of all the channels to commence. When this condition was met, a remotely located light connected to the DT220 was illuminated to indicate that it had started acquisition. At the completion of the statistical acquisition a second light was illuminated to signify completion of the sequence. The engine was then brought back to the start condition and allowed to cool. At the completion of acquisition the data were downloaded from the DT220 to the PC as if a flight had been completed. In the proposed flight version this would involve simply removing a credit card memory device for analysis. This procedure was repeated a total of seven times over two days to simulate seven individual flights.

Since the DataTaker, when operating in a fully autonomous mode, waits for the TIT to fall within a band of values before acquiring data it is not unreasonable to expect that on each of the *flights* the actual TIT temperature may have been slightly different (By as much as the band of ± 10°C). To allow a comparison of data between *flights* it is therefore necessary to normalise each of the thermocouple readings as a percentage of the actual TIT value recorded. This also allows judicious comparison of data with data taken at different engine operating points (960 & 1010°C TIT)

The difference between each individual thermocouple, normalised, and the averaged TIT signal was calculated and plotted against channel number (Figure 4) for each of the seven fully autonomous runs undertaken. This forms the basis of the handprint which allows comparison with earlier flights to determine if any thermocouple problems have developed during the last flight.

This *handprint* has been replotted (Figure 5) so that offsets from the TIT for an individual thermocouple over a number of *flights* could be more readily examined. These two figures (Figures 4 and 5) would form the basis of trending software at the base for post flight analysis.

Figure 5 might indicate a possible problem with thermocouples 3, 5 and 6 in that their *handprint* has changed significantly. For *flights* 5, 6 and 7 these thermocouples show a significant increase (Each has changed by approximately 2%) in the values they are reading compared with the average value as measured on the TIT signal. Alternatively this may be a normal flight to flight variation of the actual thermocouples or a variation introduced by the method in which the fully autonomous system operates. *Flights* 5, 6 and 7 were all conducted on a subsequent day to the earlier runs.

5. Concluding Remarks and Recommendations

The results of this trial, and the preceding C-130 trial, indicate that the DataTaker does not appear to be susceptible to electrical interference either from either aircraft power generating equipment or electromagnetic radiating equipment.

Only limited simulation could be achieved of the temperature variations which would occur flight-to-flight, and then only with supposedly healthy thermocouples. The data obtained should be further analysed to determine whether the proposed statistical techniques for determining when a thermocouple fault exists hold valid with the measured variation in acquired data. A number of factors could have contributed to the variation. Firstly there is the noise on the signals, whether it be electrical interference or actual thermal noise producing variations between each sample. Secondly the system must look for an average to fall within a certain band before it determines that data should be acquired. It is unlikely that for any two flights that the pilot will have set the engine on exactly the same indicated TIT, even if it was his desire to do so. The validity of normalising this data to the actual measured average TIT for comparison of handprints should also be further considered. Variations are likely to exist simply due to the engine operating at differing times of days and altitudes, for example. The *normal* flight to flight variation therefore needs to be explored more thoroughly.

The DataTaker has been demonstrated to be capable of being utilised as an airborne demonstrator of this system but will require careful consideration on the mounting options so that the environmental specifications of the device are not exceeded whilst still allowing the minimum of cabling to be installed.

It would be beneficial to install this system, in the short term, into the test cell at QANTAS Jet Base and allow it to run in a fully autonomous mode for a period of time to increase the size of the sample for run to run variations that may be expected across a fleet of engines. This would allow better determination of the best statistical techniques to be applied prior to installing flight hardware.

6. References

1. Skidmore F.W. and Parslow D.R.; *A Temperature Monitoring System for the Allison T56 Turbo-Prop Engine*, ARL Technical Report 12, December 92.

2. Dutton S.A.; *Test Cell Trial of a Data Logger for T56 Individual Turbine Inlet Temperature Monitoring System*, ARL Airframes and Engines Division Propulsion Note No 2/93, February 93.

3. Dutton S.A.; *C-130 On-Wing Trial of a Data Logger for T56 Turbine Inlet Temperature Monitoring System*, ARL Technical Note 55 (ARL-TN-55), November 93.

4. Mooney D.I.; *A Demonstrator for a Special Turbine Inlet Monitoring System for Allison T56 Engines*, ARL Propulsion Note 9/92, December 92.

5. Fraser, K.F ; *Characteristics of the Turbine Inlet Temperature Sensing Circuit for the T56 Turbo-Prop Engine*, DSTO Technical Report 95 (DSTO-TR-0095), November 94.

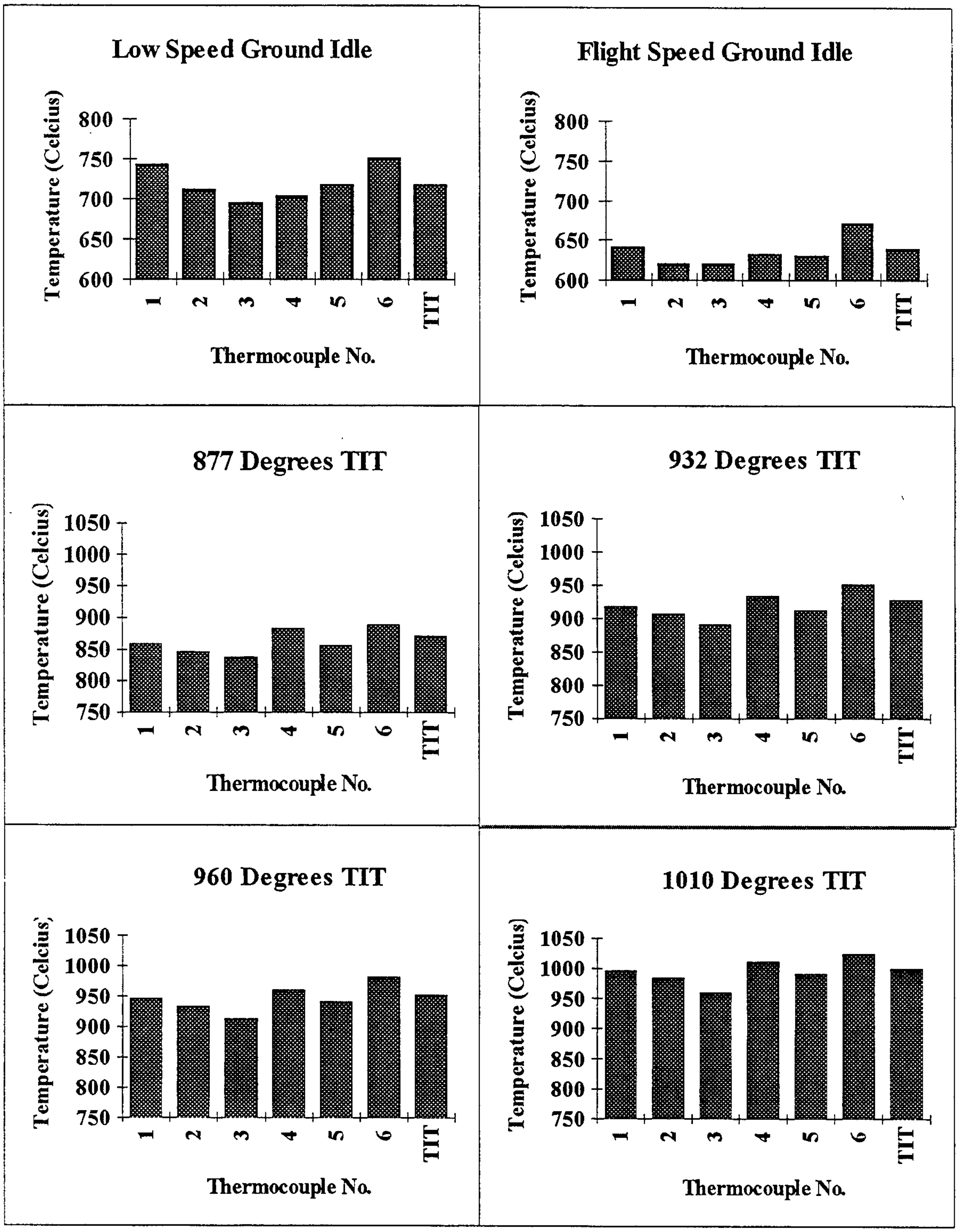

Low Speed Ground Idle
Temperature (Celcius)
800
750
700
650
600
1
2
3
4
5
6
TIT
Thermocouple No.
Flight Speed Ground Idle
Temperature (Celcius)
800
750
700
650
600
1
2
3
4
5
6
TIT
Thermocouple No.
877 Degrees TIT
Temperature (Celcius)
1050
1000
950
900
850
800
750
1
2
3
4
5
6
TIT
Thermocouple No.
932 Degrees TIT
Temperature (Celcius)
1050
1000
950
900
850
800
750
1
2
3
4
5
6
TIT
Thermocouple No.
960 Degrees TIT
Temperature (Celcius)
1050
1000
950
900
850
800
750
1
2
3
4
5
6
TIT
Thermocouple No.
1010 Degrees TIT
Temperature (Celcius)
1050
1000
950
900
850
800
750
1
2
3
4
5
6
TIT
Thermocouple No.

Figure 1

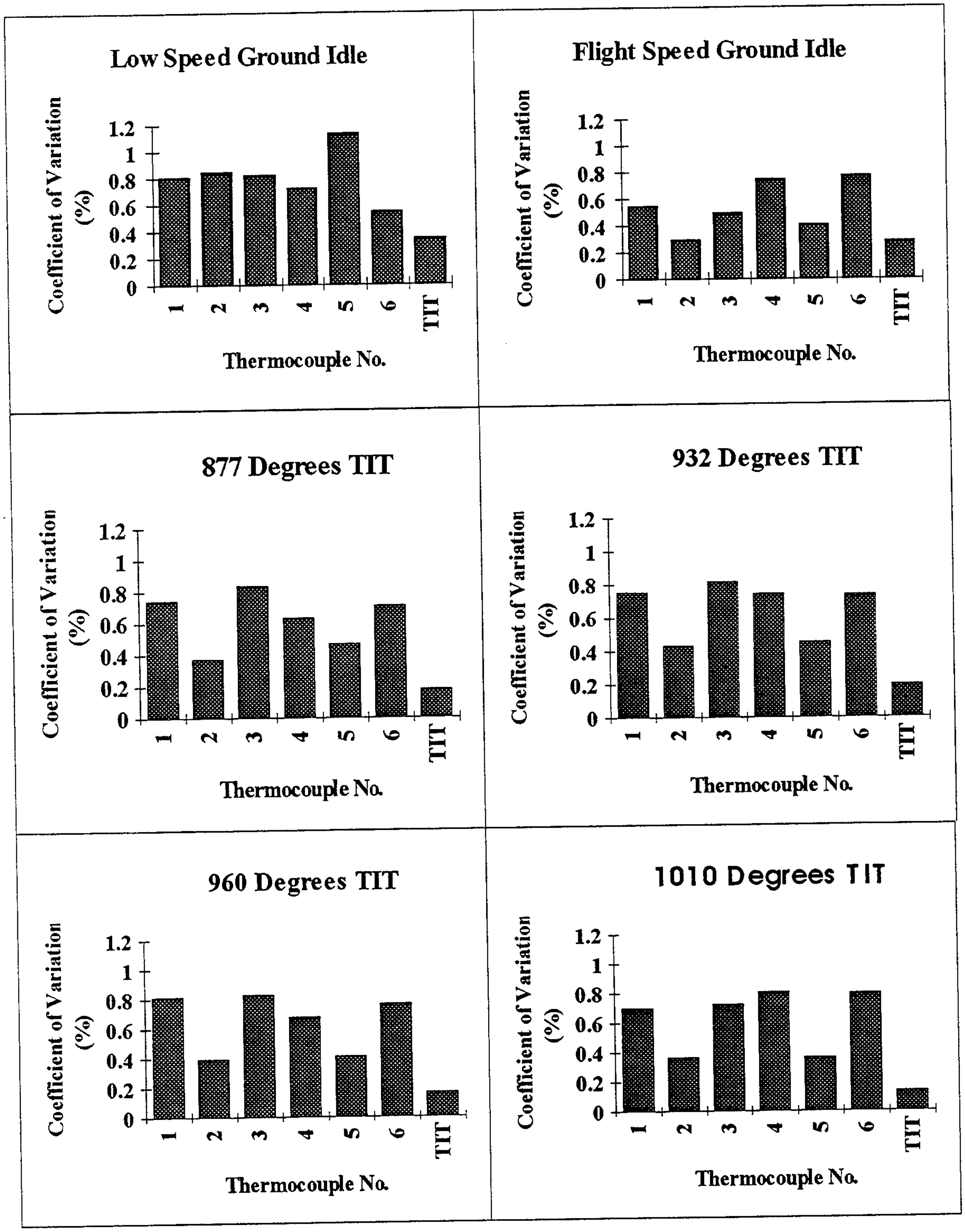
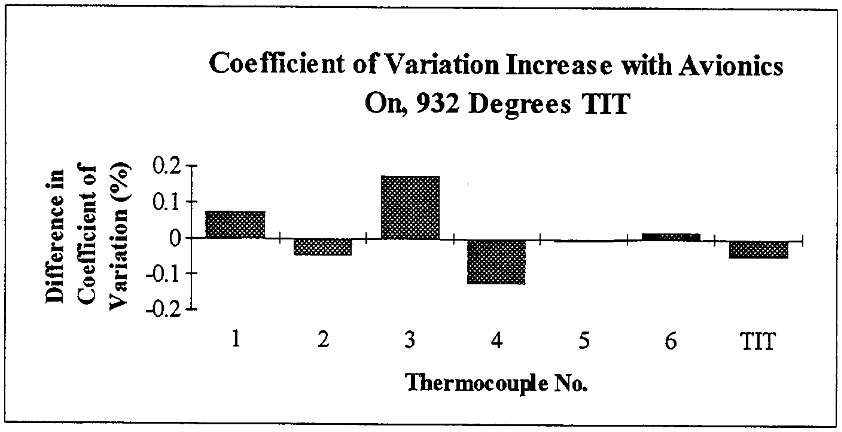

Low Speed Ground Idle
Flight Speed Ground Idle
877 Degrees TIT
932 Degrees TIT
960 Degrees TIT
1010 Degrees TIT
Coefficient of Variation (%)
0
0.2
0.4
0.6
0.8
1
1.2
1
2
3
4
5
6
TIT
Thermocouple No.

Figure 2


Coefficient of Variation Increase with Avionics On, 932 Degrees TIT
Difference in Coefficient of Variation (%)
0.2
0.1
0
-0.1
-0.2
1
2
3
4
5
6
TIT
Thermocouple No.

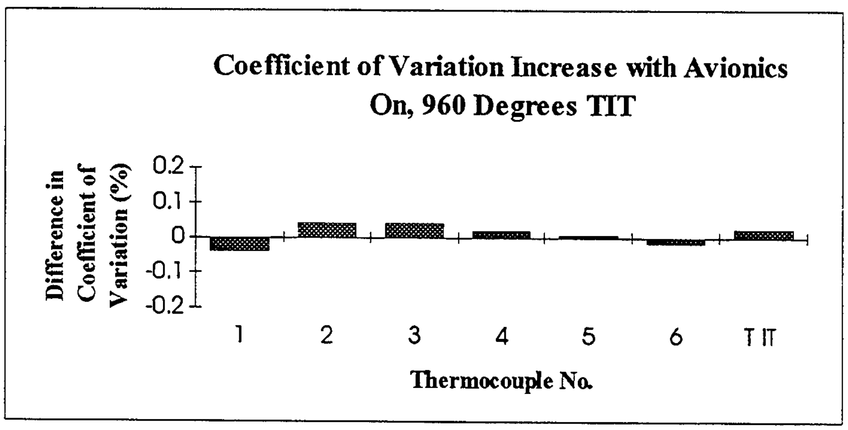

Coefficient of Variation Increase with Avionics On, 960 Degrees TIT
Difference in Coefficient of Variation (%)
0.2
0.1
0
-0.1
-0.2
1
2
3
4
5
6
TIT
Thermocouple No.

Figure 3

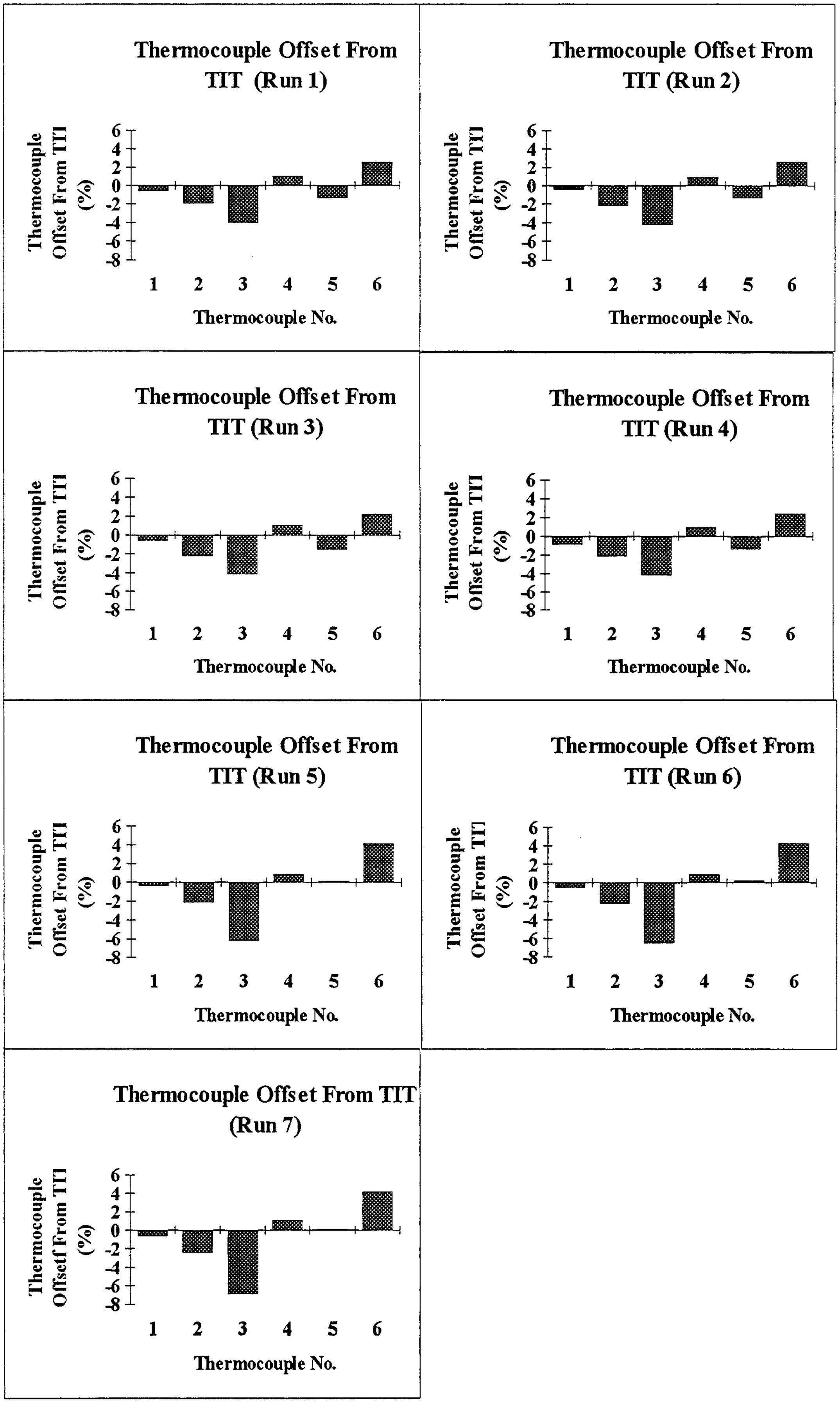

Thermocouple Offset From TIT (Run 1)
Thermocouple Offset From TIT (%)
6
4
2
0
-2
-4
-6
-8
1
2
3
4
5
6
Thermocouple No.
Thermocouple Offset From TIT (Run 2)
Thermocouple Offset From TIT (Run 3)
Thermocouple Offset From TIT (Run 4)
Thermocouple Offset From TIT (Run 5)
Thermocouple Offset From TIT (Run 6)
Thermocouple Offset From TIT (Run 7)

Figure 4

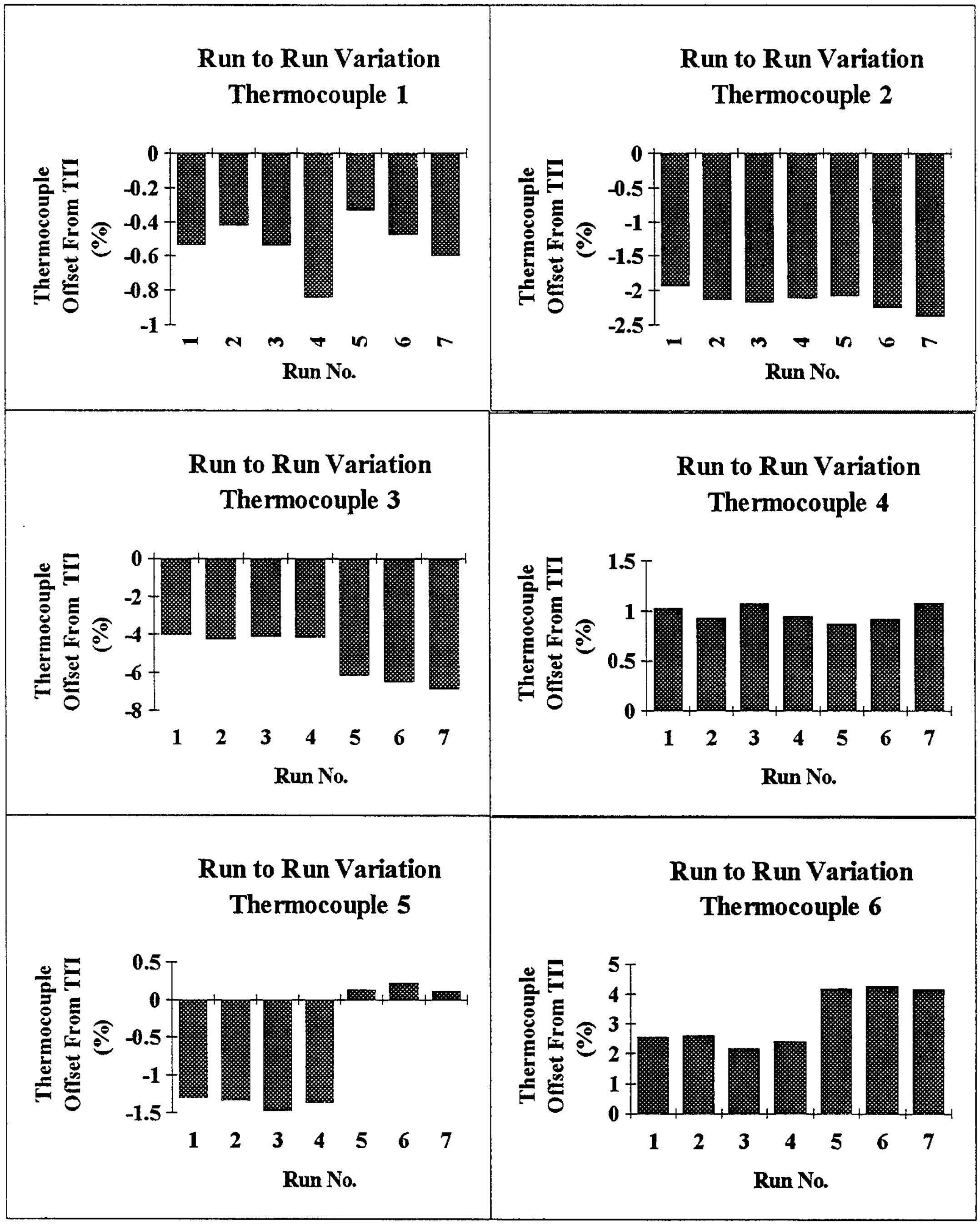

Run to Run Variation
Thermocouple 1
Thermocouple Offset From TTI (%)
0
-0.2
-0.4
-0.6
-0.8
-1
1 2 3 4 5 6 7
Run No.
Run to Run Variation
Thermocouple 2
Thermocouple Offset From TTI (%)
0
-0.5
-1
-1.5
-2
-2.5
1 2 3 4 5 6 7
Run No.
Run to Run Variation
Thermocouple 3
Thermocouple Offset From TTI (%)
0
-2
-4
-6
-8
1 2 3 4 5 6 7
Run No.
Run to Run Variation
Thermocouple 4
Thermocouple Offset From TTI (%)
1.5
1
0.5
0
1 2 3 4 5 6 7
Run No.
Run to Run Variation
Thermocouple 5
Thermocouple Offset From TTI (%)
0.5
0
-0.5
-1
-1.5
1 2 3 4 5 6 7
Run No.
Run to Run Variation
Thermocouple 6
Thermocouple Offset From TTI (%)
5
4
3
2
1
0
1 2 3 4 5 6 7
Run No.

Figure 5

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S.A. Dutton

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19. ABSTRACT

Following successful ground based on-wing trials on a C-130H aircraft, a commercial data acquisition system, the DataTaker DT220, was tested at RAAF Base Edinburgh on a P-3C on the ground to determine its suitability as a flight demonstrator for a T56 engine individual turbine inlet temperature monitoring system.

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