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Aero Propulsion Technical Memorandum 444

THE VARIATION IN AIRFLOW COEFFICIENT FOR ALLISON T56 COMBUSTOR LINERS (U)

by

F.W. Skidmore
and
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THE VARIATION IN AIRFLOW COEFFICIENT FOR ALLISON T56 COMBUSTOR LINERS

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SUMMARY

It is shown that it is possible to have a circumferential turbine inlet temperature variation in excess of 90°C in a correctly assembled T56 Series III engine. A significant part of this variation is due to differences in airflow into the liner caused by the variations in airflow area associated with manufacturing tolerances. A simple technique is described that will enable matched sets of liners to be selected to build engines and thus avoid excessive temperature maldistributions. Preliminary experimental results are described.

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1. INTRODUCTION

Allison T56 engines operated by the RAAF are used to power the Hercules and Orion aircraft. These engines currently suffer hot section failures, particularly, turbine nozzle guide vanes and first stage turbine blades. In an effort to gain a better understanding of the likely cause of the problem, the RAAF has decided to run a T56 engine on a mobile engine test stand in various builds and measure each of the 18 individual turbine inlet temperatures separately. Three engine builds will be investigated; an unmodified condition; fitted with a matched set of fuel atomisers and rebuilt using the matched set of atomisers and a matched set of combustor liners.

This memorandum describes some initial work for this program. A technique and the equipment necessary to calibrate the airflow of a combustor liner is described and some preliminary results carried out on liners drawn from various T56 engines is reported.

2. THE ALLISON T56 TURBOPROP ENGINE

The Allison T56 turboprop engine has a 14 stage axial flow compressor with a pressure ratio of 9.5:1, six canannular type combustors and a 4 stage axial turbine. The engine is designed to operate at a constant speed of 13820 RPM and drive a propeller through a reduction gearbox. The RAAF operate 3 models of the Allison T56 engine, details of which are listed in Table 1.

TABLE 1

ALLISON T56 ENGINES OPERATED BY THE RAAF

SERIES	ENGINE MODEL	AIRCRAFT
SERIES II	T56-A-7	C130E
SERIES III	T56-A-14	P3 ORION
SERIES III	T56-A-15	C130H

From a combustion system viewpoint the two Series III engines are identical. However, there are significant differences between the Series II and III engines, particularly in the airflow distribution through the combustors. A Series II combustor liner is shown in Figure 1a and a Series III combustor liner in Figure 1b.

FIG. 1(a) ALLISON T56 SERIES II COMBUSTOR LINER

FIG. 1(b) ALLISON T56 SERIES III COMBUSTOR LINER

In an engine six of these liners are installed within an annular pressure casing and linked together with interconnector tubes. Two of the combustors, located at the top and bottom of the engine, have high energy igniters.

As seen in Figure 1a and 1b there are several important differences in the design of the Series II and Series III liners; in particular the location of air holes in the liner midsection and the variations in the outlet sections that are necessary to accommodate the particular turbine configuration.

Figures 2a and 2b indicate the distribution of air entering into the Series II and III engine liners respectively. These flows were estimated from measured areas using the coefficients of discharge for combustion systems described in Knight and Walter (1953) and Adkins and Gueroui (1986).

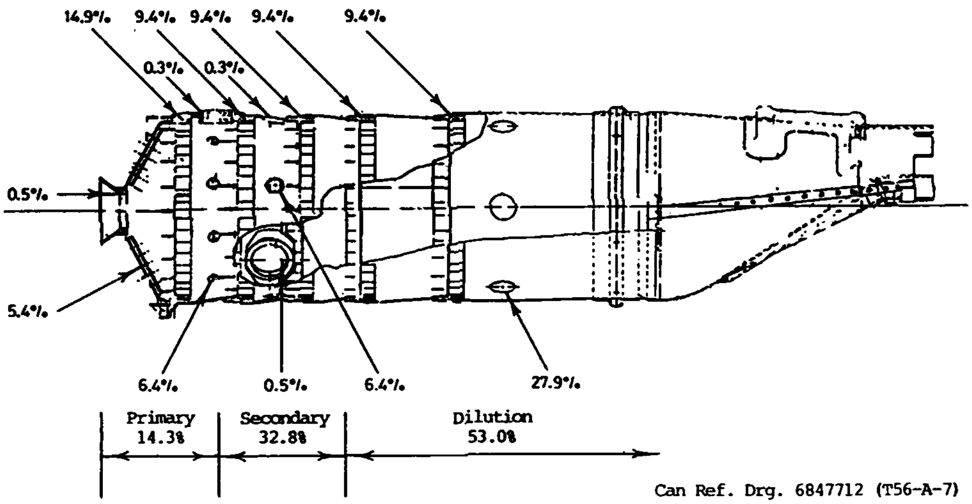

FIG. 2(a) AIRFLOW DISTRIBUTION OF T56 SERIES II COMBUSTOR LINER

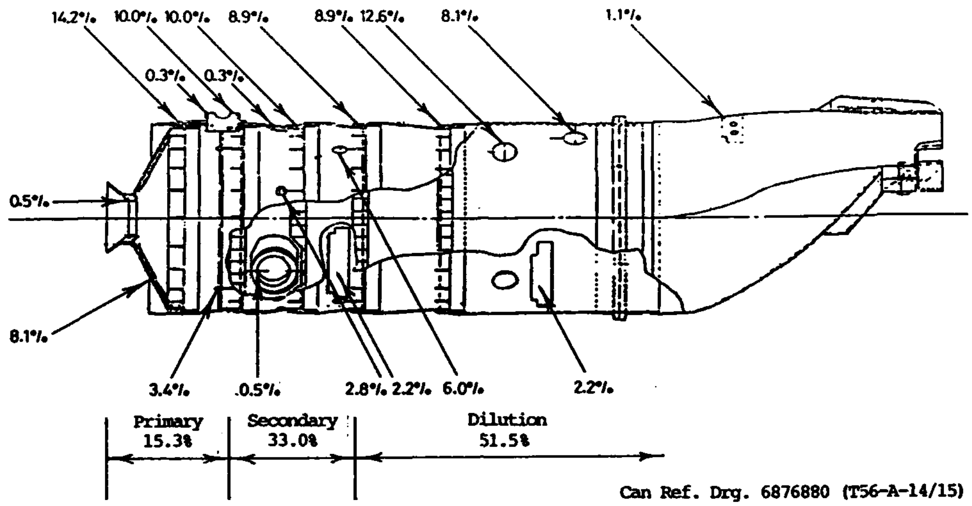

FIG. 2(b) AIRFLOW DISTRIBUTION OF T56 SERIES III COMBUSTOR LINER

Following the usual practice of dividing the liner into primary, secondary and dilution zones it was assumed that the primary zone included one third of the air that enters the first cooling corrugation around the dome plus half of the air that enters the first set of holes. The remaining part of these flows then forms part of the airflow for the secondary zone where combustion should be completed. Similarly the secondary zone includes half of the air entering the holes in the third segment of the liner and one third of the air entering the third cooling corrugation with the remaining part of these flows becoming dilution air. This method was used by Detroit Diesel Allisons (1985) to assign and divide airflows between different zones in a similar liner.

Fuel is injected into the dome of the liner via a duplex or twin orifice type atomiser shown in Figure 3.

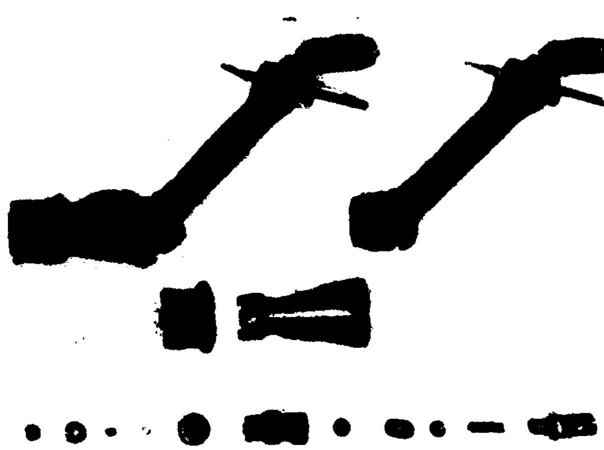

FIG. 3 ALLISON T56 ATOMISER-ASSEMBLED AND UNASSEMBLED

The secondary stage of the atomiser has a pressure operated variable orifice in the fuel passage to enable fuel to be shut off and also to provide an approximate linear flow versus pressure characteristic. A typical flow calibration curve is shown in Figure 4.

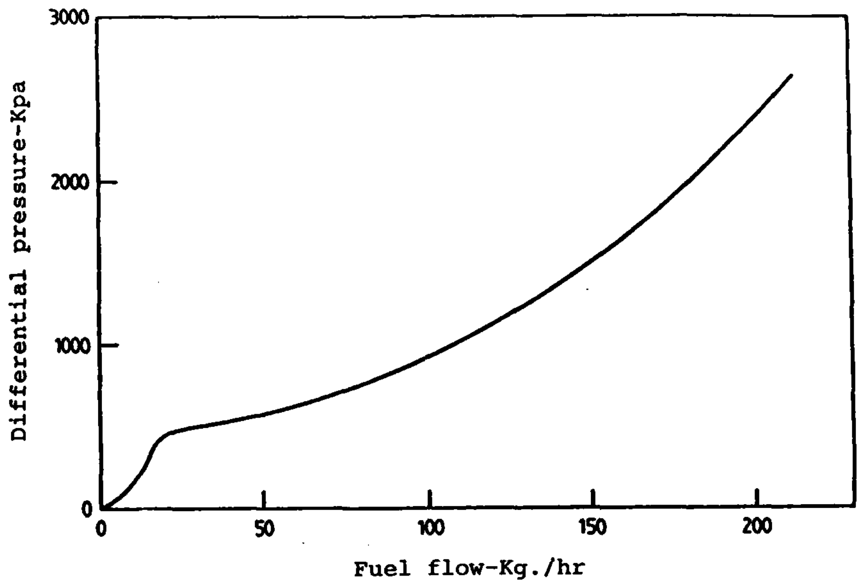

FIG. 4 ALLISON T56 ATOMISER FLOW CHARACTERISTIC

3. THE EFFECT OF LINER MANUFACTURING TOLERANCE

Analysis of Allisons Drawing No 6876080 for manufacturing Series III combustor liners shows that there is a maximum possible variation in flow area from (approximately) 4820 mm^2 to 5140 mm^2 at the extremes of the manufacturing tolerances.

For a combustor liner with exactly the nominal airflow areas at sea level take off and a turbine inlet temperature of 1077°C, the fuel/air ratio is 0.0212[1]. For a combustor liner on the lower airflow area limit of 4820 mm^2, the fuel/air ratio is increased to 0.0219 which implies a turbine inlet temperature of 1097°C. Alternatively for the combustor liner on the higher limit of flow area the fuel air ratio is decreased to 0.0205 which implies a turbine inlet temperature of 1055°C.

This analysis assumes that each atomiser admits the same amount of fuel to each liner which in practice does not occur. Allisons allow for variations under sea level take off conditions in atomiser calibrations of ± 11 kg/hr in fuel flow. If this variation is applied to a matched set of liners, each with the same airflow area then the implied turbine inlet temperature will vary from 1051°C to 1101°C[2]. If, to take the worst cases, a liner with minimum flow area was fitted with an atomiser with the highest fuel flow and a maximum air flow liner is fitted with a minumum fuel flow atomiser then the outlet temperatures from these liners would vary from 1123°C to 1032°C. From this analysis it was decided to develop a procedure to calibrate the air flow of T56 liners so that each engine could be assembled with a matched set of liners to minimise the circumferential temperature variation.

4. COMBUSTOR LINER CALIBRATION

4.1 Test Equipment

A schematic layout of the test equipment used to calibrate the T56 combustors for airflow coefficient is shown in Figure 5 and photographed in Figure 6. The equipment consists of a wooden box which has a cut out shaped to accept a liner. All joints are sealed to prevent air leaking into the system except through the liner. The box is connected to a centrifugal blower via a section of 100 mm tubing incorporating a venturi meter. Pressure drop across the venturi is measured using an aircraft airspeed indicator. This is used to set the airflow being drawn through the liner to the same value for each test. Airflow is controlled by a butterfly valve on the outlet of the blower. The pressure drop across the liner is measured using an inclined water manometer. The pressure inside the combustor is tapped using a rubber stopper, that has been drilled through to accept an 8 mm tube, inserted into the atomiser boss in the dome of the liner. Both the interconnector tubes in the combustor liner and the igniter boss are sealed with rubber stoppers.

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[1] Temperatures and fuel air ratios were determined from NGTE produced charts of combustor temperature rise at constant pressure versus fuel/air ratio.

[2] Rheaume (1987) discusses the practical problems of the T56 atomisers in detail.

4.2 Operation

The liner to be tested is inserted into the box and sealed at a point just below the last dilution hole as shown in Figure 5. The blower is then started and the butterfly valve adjusted to give a predetermined reading on the airspeed indicator. After the airflow has stabilized, the pressure drop across the liner is measured on the inclined manometer.

Care is required to ensure that no extraneous leaks are present and that the same setting is used on the airspeed indicator at each change.

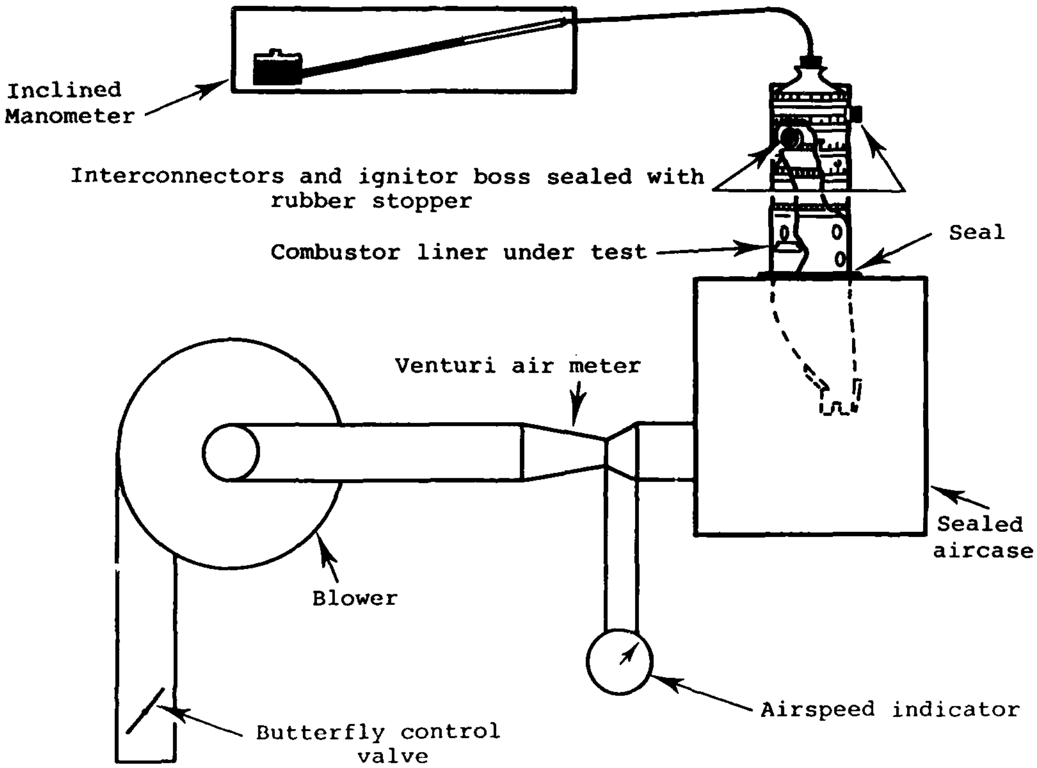

FIG. 5 SCHEMATIC LAYOUT OF LINER CALIBRATING EQUIPMENT

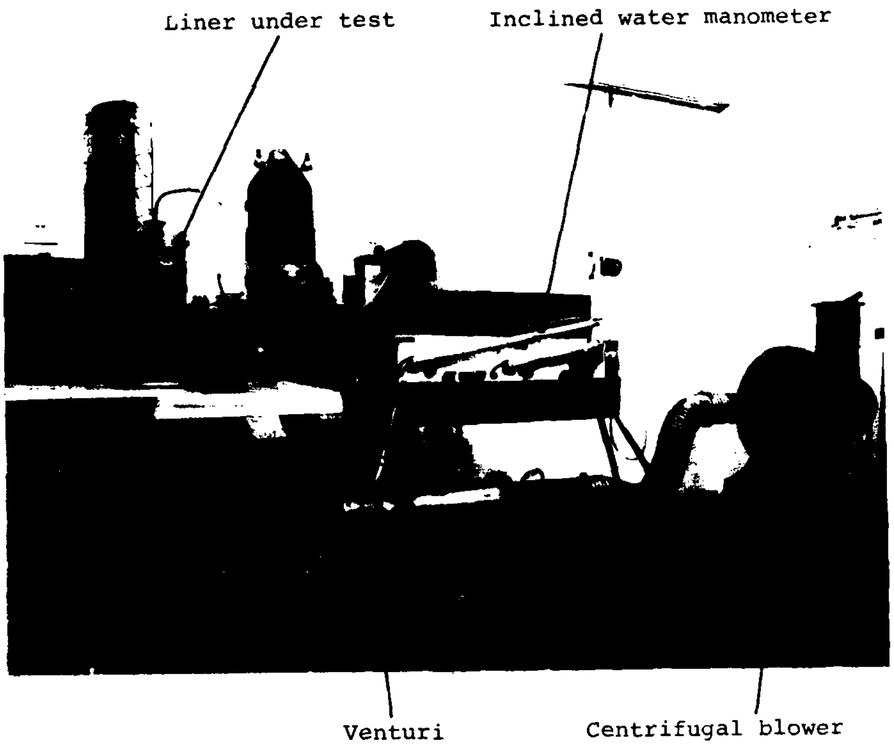

FIG. 6. LINER CALIBRATION RIG

4.3 Theoretical Considerations

The mass flow through a combustor liner in the equipment shown in Figure 5 will be given by

$$\dot{m}_T = \sum_{n=1}^{N} \rho A_n V_n$$

where $\dot{m}_T$ is the total mass flow

ρ is the air density

A_n is the effective flow area of each of the holes 1 to N and

V_n is the velocity through each of the holes 1 to N.

For convenience we write

$$\dot{m}_T = \rho A_T V_T \qquad (1)$$

where A_T is a total effective flow area through the liner as a whole and V_T is the equivalent velocity through that effective flow area.

The pressure drop across the liner caused by the airflow induced through the liner can be written

$$\Delta p_L = C_1 \frac{1}{2} \rho V_T^2$$

where again C_1 is an *effective* or overall drag coefficient *of* the liner holes. Replacing Δp_L with h, the pressure measured with the inclined manometer we have

$$h = C_2 \rho V_T^2 \qquad (2)$$

In comparing a set of liners from an engine, we are primarily interested in the percentage variation in airflow around the engine.

Equation (2) can be written

$$V_T = \sqrt{\frac{h}{\rho C_2}}$$

which when substituted into (1) gives

$$\dot{m}_T = \rho A_T \sqrt{\frac{h}{\rho C_2}} \qquad (3)$$

or $$A_T \propto \sqrt{\frac{1}{\rho h}}$$

if the mass flow is held constant

$$\text{or} \quad \frac{A_T}{A_{T_{av}}} = \sqrt{\frac{h_{av}}{h}} \tag{4}$$

which gives the required variation from the average.

5. RESULTS

ARL had six combustor liners from an Allison T56-A-11 engine. These liners were similar to the liners from a T56-A-7 engine used in the C130E aircraft and were in good condition. They were tested using the equipment and procedure described in Section 4.1 and 4.2. The results are presented in Table II.

ARL also had 2 Series III liners out of the T56-A-14/15 engines. These liners were unserviceable due to cracks and buckling but were also tested. The results for these liners are presented in Table III.

Liner Serial No.	h Scale Reading	$\sqrt{\frac{h_{av}}{h}} \times 100$	Fuel/Air Ratio[3]	T.I.T. °C
3655	15.9	99.7	0.02126	1078
1669	15.4	101.3	0.02093	1068
3554	15.7	100.3	0.02114	1074
6573	16.7	97.3	0.02179	1094
3662	15.6	100.6	0.02107	1072
1671	15.5	101.0	0.02099	1069
AVERAGE	15.8	100	0.02120	1076

TABLE II. SERIES II LINER CALIBRATION AND PREDICTION OF TURBINE INLET TEMPERATURE FOR EACH

Liner Serial No.	h Scale Reading	$\sqrt{\frac{h_{av}}{h}} \times 100$	Fuel/Air Ratio	T.I.T. °C
AA5904	16.2	100.6	0.02107	1072
KH2148E	16.6	99.4	0.02126	1078

TABLE III. SERIES III LINER RESULTS

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3. Actual airflow into each liner is reduced or increased from the average by the percentage $\sqrt{\frac{hav}{\Delta h}}$ x 100. Liner fuel/air ratio is therefore calculated from the overall engine fuel air ratio of 0.02120 x $\sqrt{\frac{hav.}{\Delta h}}$ Turbine inlet temperature was determined from NGTE charts of Combustor Temperature rise at constant pressure versus fuel/air ratio.

6. DISCUSSION

6.1 Airflow Calibration

The airflow tests carried out on the liners from the T56-A-11 engine show that there can be a considerable variation in mass flow induced through a combustor liner (Table II) and if this variation was applied to the Series III maximum operating turbine inlet temperature of 1077°C with a perfectly matched set of atomisers, then the circumferential variation of temperatures around the six liners would range from 1068°C to 1094°C. It must be stressed, however, that the sample of liners tested was small, and that it is likely that a larger sample would show a greater variation. In addition, variations in atomiser flow rates would increase the circumferential temperature variation.

The results for the Series III liners show that temperature variations can be expected in this case also. However, with a sample of two liners no conclusions can be drawn.

6.2 Further Work

In order to establish the full extent of airflow variation for T56 liners a large number of liners will need to be tested. With the variation established, liners should be grouped into 4 or 5 ranges of mass flow to enable engines to be built with a more uniform fuel/air ratio between combustion chambers. If this is carried out with selective fitment of atomisers, as discussed by Rheaume (1987), then a minimal circumferential temperature maldistribution in Allison T56 engines will be realised. This procedure should contribute to the extension of life of hot end components such as the turbine nozzle guide vanes and first stage turbine blades.

7. CONCLUSIONS

A simple technique has been developed to enable matched sets of T56 combustor liners to be fitted to engines. Preliminary calculations and tests show that a circumferential temperature variation of at least 90°C is possible. It is anticipated that a greater variation than this will exist in the present RAAF inventory of T56 engines. Circumferential temperature variations in engines will be minimised if the technique described in this memorandum is adopted and is combined with selective fitment of atomisers.

ACKNOWLEDGEMENT

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