THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
345 E. 47 St., New York, N.Y. 10017

83-GT-43

The Society shall not be responsible for statements or opinions advanced in papers or in discussion at meetings of the Society or of its Divisions or Sections, or printed in its publications. Discussion is printed only if the paper is published in an ASME Journal. Released for general publication upon presentation. Full credit should be given to ASME, the Technical Division, and the author(s). Papers are available from ASME for nine months after the meeting.
Printed in USA.

Copyright © 1983 by ASME

Check for updates

A COMPACT DIFFUSER SYSTEM FOR ANNULAR COMBUSTORS

Adkins, R.C.
Principal Research Officer
School of Mechanical Engineering
Cranfield Institute of Technology
Cranfield, Bedford MK43 OAL, England

Yost, J.O.
Chief Aerodynamicist (Turbomachinery)
Rolls-Royce Ltd.
Filton, Bristol, England

ABSTRACT

Airflow tests have been conducted on an aerodynamic simulation of a combustor with pre-diffuser of compact configuration. The inlet Mach number throughout the tests was 0.35. The configuration was successful because of the attainment of a high pressure recovery, (C_p = 0.80), coupled with an exceptionally low total pressure loss (λ = 0.04). A useful analytical relationship is derived between the aerodynamic performance of combustor, compressor exit Mach number and diffuser performance.

NOMENCLATURE

- A cross-sectional area
- B fraction of flow bled-off through diffuser
- C_B static pressure recovery of bled air
- C_L coefficient of total pressure loss (cold) for combustor per-diffuser combination
- C_p coefficient of static pressure recovery between pre-diffuser inlet and combustor supply annulus.
- d diameter of jet
- F approach factor to air admission hole
- I fraction of combustor air flowing to inner annulus
- L axial length of diffuser; measurement location
- Mn Mach number
- $\dot{m}$ mass flow rate
- O inlet measuring station
- P total pressure
- p static pressure
- ΔP combustor cold pressure loss
- S dump gap (distance between combustor dome and pre-diffuser)
- u ultimate depth of penetration of air admission jet
- v velocity
- y radial gap between fence and pre-diffuser exit
- Z dump gap (distance between combustor dome and back-plate
- α coefficient of kinetic energy
- η diffuser effectiveness (measured pressure recovery/ideal pressure recovery)
- ϕ angle made between vortex chamber aperture and major axis
- θ angle between outer wall of post diffuser and major axis
- δ jet entry angle
- ρ density

Subscripts

- c combustor
- i inner
- o outer
- 1 compressor exit plane
- 2 annulus
- j jet

Note All dimensions have been normalized by division by the annulus height at pre-combustor inlet.

INTRODUCTION

The development of axial compressors using fewer stages for a given pressure ratio has been achieved by substantial increases in blade speed and axial velocity, and by modest increases in blade row gas deflection.

Traditionally the back stages of high pressure compressors have been constrained in axial velocity by combustor requirements. This could be relaxed if a more effective pre-combustor diffuser was available.

Short length, effective Hybrid diffusers have been described in recent research and have prompted the present investigation to examine their suitability for pre-combustor application.

This Cranfield investigation was initiated and sponsored by Rolls-Royce Limited.

ROLE OF THE PRE-COMBUSTOR DIFFUSER

Most of the air for combustion is delivered along the annular passageways formed between the combustor casings and liners, and from here it enters the combustion region as jets which pass through air admission holes in the liner walls. For efficient combustion these jets must penetrate directly to the centre of the combustor, with sufficient momentum to generate recirculating flow of the products of combustion and to promote rapid mixing. The ability of these jets to

Downloaded from http://asmedigitalcollection.asme.org/GT/proceedings-pdf/GT1983/79511/V001T01A021/4453643/v001t01a021-83-gt-43.pdf by guest on 20 August 2022

accomplish their tasks can be directly related both to the Mach number at compressor exit and to the performance of the pre-combustor diffuser. The relationship can be illustrated most conveniently by considering a liner with plain holes, as shown in figure 1, and by use of the following non-dimensional parameters given below it.

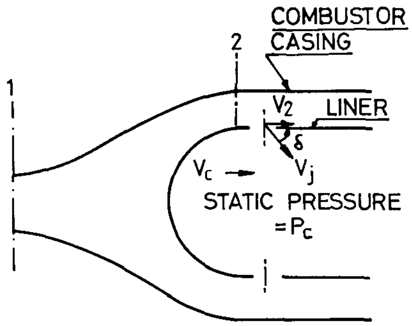


FIG. 1 AIR INJECTION THROUGH LINER HOLES

Coefficient of diffuser static pressure recovery, $$C_p = \frac{P_2 - P_1}{P_1 - p_1} \quad (1)$$

Coefficient of diffuser total pressure loss, $$\lambda = \frac{P_1 - P_2}{P_1 - p_1} \quad (2)$$

Combustor 'cold loss' coefficient, $$C_L = \frac{P_1 - p_c}{P_1 - p_1} \quad (3)$$

Combustor pressure loss fraction, $$\frac{\Delta P}{P_1} = \frac{P_1 - P_c}{P_1} \quad (4)$$

Approach factor, $$F = \frac{P_2 - p_c}{P_2 - p_2} \quad (5)$$

Expressions (3) and (4) can be directly related by compressibility considerations such that rearrangement of (3) gives:-

$$C_L = \frac{(P_1 - P_c)}{P_1} \cdot \frac{P_1}{(P_1 - P_1)}$$

$$\text{i.e: } C_L = \frac{\Delta P}{P_1} \cdot \left[1 - (P/P_1)^{-1}\right]^{-1}$$

$$\text{or: } C_L = \frac{\Delta P}{P_1} \cdot \left[1 - (1 + Mn_1{}^2/5)^{-3.5}\right] \quad (6)$$

A further useful relationship is obtained by direct substitution of expressions (1), (2) and (3) into (5) giving:

$$F = \frac{C_L - \lambda}{1 - \lambda - C_p} \quad (7)$$

Injection Through Liner Wall

For plain holes, the angle of injection, δ, can be derived directly from the velocity vectors shown in figure 1 where:

$$\delta = \cos^{-1} (v_2/v_j)$$

$$\text{or: } \delta = \cos^{-1} \left[(P_2 - p_2)/(P_2 - P_c)\right]^{\frac{1}{2}}$$

$$\text{i.e: } \delta = \cos^{-1} (F^{-\frac{1}{2}}) \quad (8)$$

Expressions (6), (7) and (8) were used to compute the curves in figure 2 which illustrate the variation in jet angle, δ, with compressor exit Mach number and diffuser performance when the combustor pressure loss fraction is held constant at 5%. Figure 2 shows that the jet angle can be improved either by increasing the loss coefficient, λ, or the pressure recovery coefficient, C_p. If λ is increased by too much, however, experience then dictates that its effect could be more than offset by a decrease in C_p which can take on a negative value.

It follows that satisfactory high injection angles at increased Mach numbers are best obtained by using a diffuser with a high pressure recovery; otherwise the alternatives are to either increase the liner pressure loss or to use mechanically vulnerable chutes in order to guide the jets into the combustion region.

The coefficients of discharge, C_d, of air admission holes were investigated in (1) where it was found that they are dependent on the approach factor F. The data given in this reference has been used, for present purposes, to derive the follows approximate empirical equation where:

$$C_d = 0.61 \ (1 - F^{-1.15}) \quad (9)$$

Use was then made of expressions (6), (7) and (9) to compute the curves presented in figure 3; similar conclusions can be drawn from these curves as for those shown in figure 2.

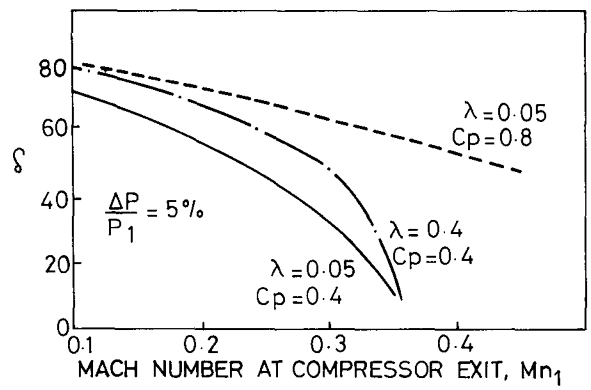


FIG. 2 INJECTION ANGLE THROUGH LINER

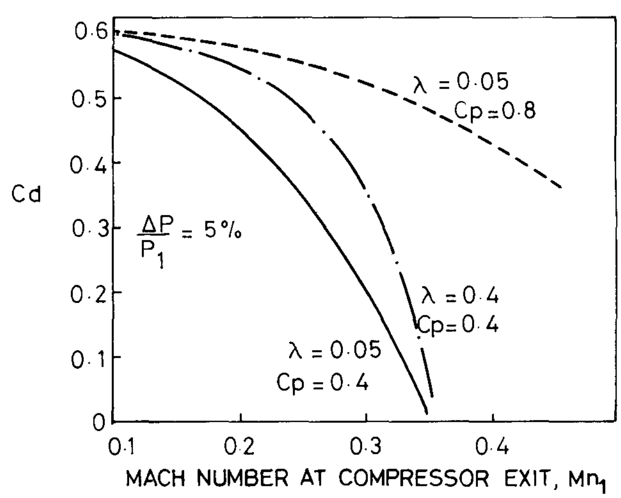


FIG. 3 COEFFICIENT OF DISCHARGE OF PLAIN HOLES

Downloaded from http://asmedigitalcollection.asme.org/GT/proceedings-pdf/GT1983/79511/V001T01A021/4453643/v001t01a021-83-gt-43.pdf by guest on 20 August 2022

Penetration of Jets into Combustion Region

An expression for the ultimate penetration of air admission jets was given in (2) as:

$$\frac{u}{d} = 1.15 \sqrt{\frac{\rho_j \, v_j^2}{\rho_c \, v_c^2}} \, . \sin \delta \qquad (10)$$

In the downstream region of the combustor it can be deduced, from (10), that the adequate penetration of dilution jets is difficult to obtain. The difficulty arises because a large proportion of airflow has entered the liner, making the gas velocity, v_c, high and hence tending to reduce the penetration ratio, u/d.

Fortuitously in this region, since the massflow outside the liner is low, the approach factor F is high and it then follows from (8) that sin δ will be close to unity.

Consequently the only component of (10) directly influenced by external flow is $\rho_j . v_j^2$ and because of its dependence on diffuser performance, it has led to the introduction of a penetration parameter.

$$K = \sqrt{\frac{\rho_j . v_j^2}{P_1}}$$

Use of equations (2), (3), (4) and (6) enables this parameter to be expressed as:

$$K = \sqrt{\frac{\Delta P}{P_1} - \lambda . \left[1 - \left(1 + \frac{Mn^2}{5}\right)^{-3.5} \right]}$$

It is noteworthy that K is independent of Cp but IS dependent on λ as illustrated in figure 4; this indicates that only diffusers having low pressure loss will ensure sufficient penetration of dilution jets in combustors operating at high Mn.

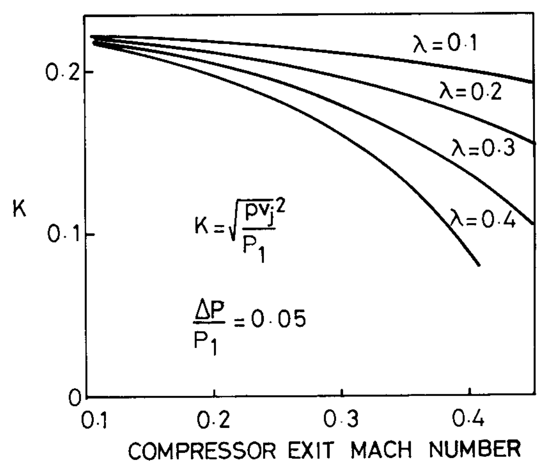


FIG. 4 VARIATION OF PENETRATION PARAMETER

CHOICE OF DIFFUSER CONFIGRATION

Basically there are two types of configuration, the 'Faired' diffuser and the 'Dump' diffuser, figures 5a and 5b. The known sensitivity of faired diffusers to variations in inlet profile, particularly at high inlet Mach numbers (3), makes them unsuitable for the present purpose.

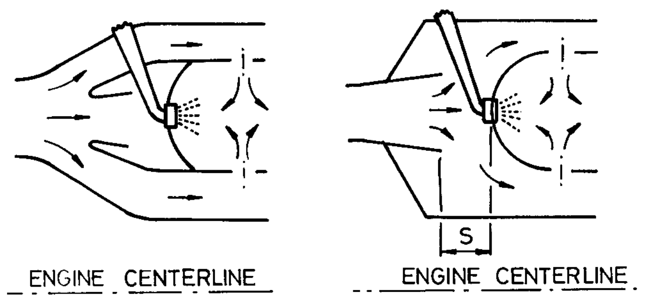


FIG. 5 (a) FAIRED DIFFUSER (b) DUMP DIFFUSER

The dump diffuser configuration, therefore, is a more obvious choice for high Mach number operation since the air is diffused down to a low velocity before division into the separate flow streams around the combustor dome. In this way the fraction of air flowing into each stream remains more nearly constant. It is largely controlled by the pressure drop through the liner walls rather than by the inertial forces in the approaching flow.

SOME PREVIOUS TESTS ON DUMP DIFFUSER CONFIGURATIONS

Tests on a dump diffuser were described in (4) in which the performance was assessed by the pressure lost between the diffuser inlet and the annular passages. Minimum values of pressure loss coefficient, λ, were in the order of 0.4, the losses could vary considerably between inner and outer passages and were sensitive to the dump gap, s, between pre-diffuser exit and combustor dome (fig. 5b). It has already been shown in figure 4 that a large value of λ, such as 0.4, would not be suitable for combustors operating with a high inlet Mach number.

An explanation for the high pressure loss, however, could be that the pre-diffuser area ratio of 1.23:1 was insufficient to adequately decelerate the flow. The velocity at pre-diffuser exit would still have been large enough to incurr high turning losses around the combustor dome. In fact, tests reported in (5) showed that losses can be reduced by increasing the pre-diffuser area ratio, although the conventional design of the pre-diffuser then added to the overall length.

A short length annular diffuser was first reported in (6). Here, bled vortices were used to guide the flow smoothly over a sudden step in the diffuser wall, as sketch in figure 6. The pressure recovery, achieved by

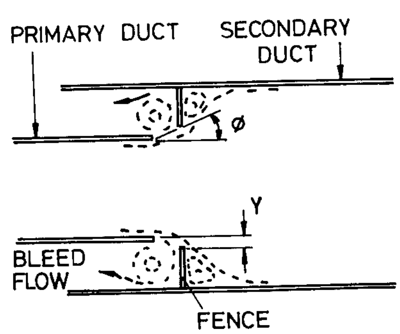


FIG. 6 VORTEX CONTROLLED DIFFUSER

Downloaded from http://asmedigitalcollection.asme.org/GT/proceedings-pdf/GT1983/79511/V001T01A021/4453643/v001t01a021-83-gt-43.pdf by guest on 20 August 2022

this arrangement, was so close to the ideal that total pressure losses were presumed to have been negligible. Furthermore, the new diffuser was only one-third the length of an optimum conventional diffuser of the same area ratio.

Two potential disadvantages were discovered. Firstly the practicable area ratio was limited by the level of flow non-uniformity at inlet. When this area ratio was exceeded, there was a reduction in pressure recovery and the flow became unstable, the situation could not be restored by an increase in bleed-off; a point later confirmed in (7). The second disadvantage, the need to stabilize the vortices by bleeding air off them, has already been mentioned. The quantity of bleed required is related to the area increase over the vortex controlled step. For an annular diffuser, suitable for pre-combustor application, this bleed would have amounted to around 10% of the mainstream flow. One suggested use of this bleed air, for turbine cooling purposes, would be difficult to achieve since it is extracted at a pressure level slightly lower than the static pressure at diffuser inlet.

A partial solution to both problems is to diffuse part-way, using a conventional pre-diffuser, located just upstream of the step. Air can then be bled off at a higher pressure and the area increase over the step is reduced. This technique was used in tests on an aerodynamic simulation of a combustor and later reported in (8). The diffuser was found to be insensitive to inlet Mach number over the range of tests ($0.3<Mn<0.5$) and the static pressure rise coefficient, C_p, was found to be in excess of 0.8. When the diffuser was operated with a total bleed rate of 8%, the pressure loss became 71% less than that of a conventional diffuser system. However, data presented leads to the conclusion that λ was still around 0.15. One very useful advantage was demonstrated, in that it was possible to balance the pressure losses between the outer and inner combustor annuli by adjustment to the individual air bleeds.

More recently, a short-length diffuser requiring smaller bleed flows was reported in (9) and (10). Even without bleed the new diffuser outperformed conventional diffusers of the same area ratio, optimised for maximum C_p, and requiring twice the length. The new arrangement was referred to as the 'Hybrid Diffuser', since a small vortex controlled step was combined with a conventional diffusing cone located immediately downstream, figure 7.

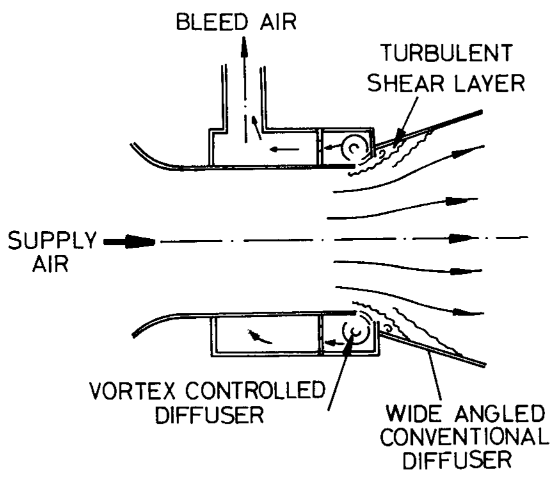


FIG. 7 A HYBRID DIFFUSER ARRANGEMENT

It was postulated that the cavity and fence arrangement at the step generated a highly turbulent shear layer which rapidly adhered to the wall of the conical diffuser, this condition enabled the use of wide angled cones without the onset of flow instability. Further derivatives of this diffuser are described in (11).

In the present investigation a preliminary study has been made of the suitability of the Hybrid diffuser to pre-combustor application.

Test Model

Due to its exploratory nature the test program was designed to a low budget. Tests were to be conducted at near ambient pressures using the laboratory air supply, and the inlet Mach number was to be limited to around 0.35.

Details of the test rig are shown in figure 8 where all dimensions have been normalized by division with the annulus height at inlet. The model was constructed mainly from sheet steel, machined surfaces being restricted to regions where dimensions were critical. The 'combustor dome' was turned from wood. No air admission holes, whatsoever, were made through either the dome or the liner. The diffuser was supplied via a settling chamber fitted with a contraction leading into the diffuser approach annulus, here the ratio of inner casing to outer casing diameters was 0.893:1. The length of this parallel inlet was 9.5.

The diffuser system began with a pre-diffuser with similar dimensions to those described in (5), having an area ratio of 1.28:1 and a length of 2.33. This pre-diffuser was incorporated in order to raise the pressure level of any air that may be bled off from the following vortex controlled step. As explained previously, in an engine situation, this increased pressure level would render the bled air more useful for tasks such as turbine cooling.

Design of the vortex controlled steps on both the inner and outer walls of the diffuser was based upon data given in (10). The steps were of equal height and they increased the cross-sectional area by 20%. Three sets of fences were manufactured so that the radial height, y, of the vortex aperture could be varied. The angle ϕ, made between the vortex aperture and the diffuser major axis (see figure 8), was maintained at 15 degrees by fitting spacing rings whose thickness had been pre-determined by the fence height. Provision was made to extract bleed uniformly from around the circumferences of both vortex chambers, these bleed streams could then be either metered individually or after combining them together. The bleed system was designed to cope with a total bleed-off of 5% of the mainstream flow.

Further variation to the model was achieved by the selection of post diffuser length. Three sets of post diffusers were provided, each producing an overall area ratio of 2.5:1, and in each set the inner and outer cone lengths were equal. The angles made between the outer cones and the diffuser major axis were 7.5, 15 and 22.5 degrees.

The combined areas of the outer and inner combustor supply annuli equalled 2.5 times the diffuser inlet area, and the inner annulus accounted for 39.7% of the total flow around the combustor liner. Both the combustor and the diffuser were designed about the same mean radius and three thin sheet metal support struts were used to suspend the liner assembly from the combustor outer

Downloaded from http://asmedigitalcollection.asme.org/GT/proceedings-pdf/GT1983/79511/V001T01A021/4453643/v001t01a021-83-gt-43.pdf by guest on 20 August 2022

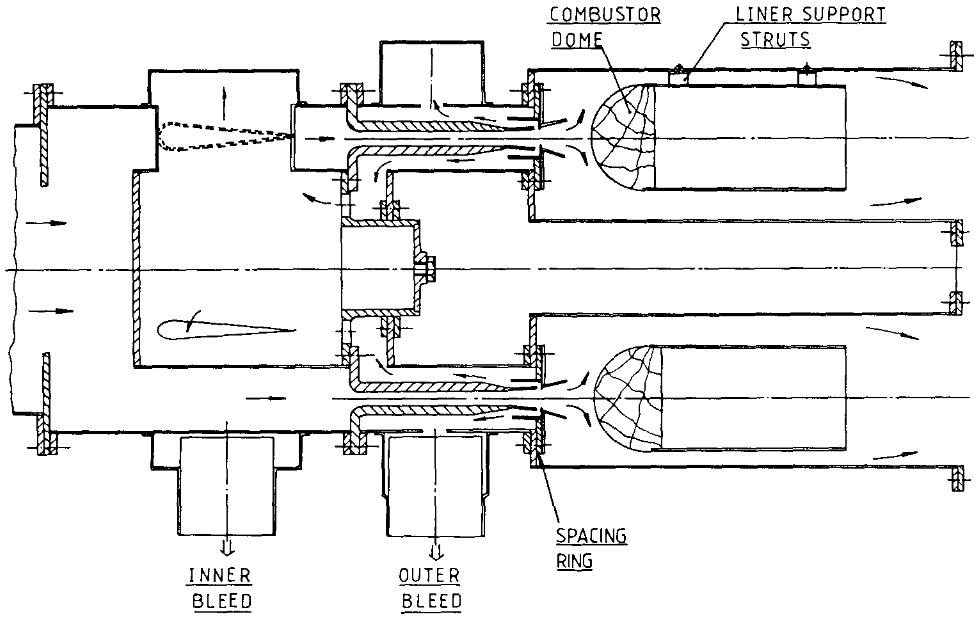
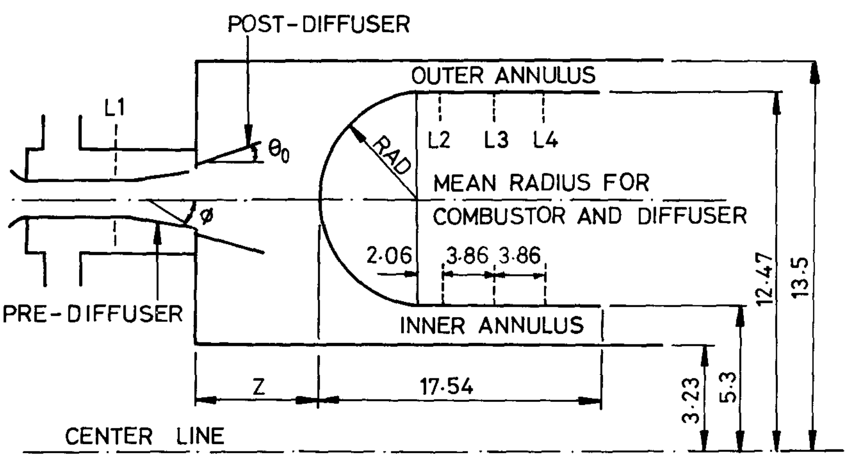


FIG 8 AXIAL SECTION THROUGH MODEL



$\theta_0 = 7.5^0; 15^0; 22.5^0$

NOTE ALL DIMENSIONS ARE DIVIDED BY ANNULUS HEIGHT AT INLET

FIG. 9 LEADING DIMENSIONS

casing. The liner could be supported in different axial locations relative to the diffuser, and in this way the dump gap could be increased from its minimum setting of 1.035. This minimum setting had previously been derived from data given in (5).

Instrumentation

Mass flow measurements were made using sharp edged orifices. In the main air supply, the orifice was specially calibrated and any error would have been less than ± 1%. The orifice plates in the two bleed-off pipes were installed according to British Standards and any error was less than ± 1.5%. Four static pressure measurements were taken at plane L1 (see figure 9), which was located at a distance of one annulus height upstream of the pre-diffuser. Here two tappings were made, spaced at 120 degrees circumferentially apart, in both the inner and outer walls of the approach annulus. Numerous static pressure tappings were made on both the inner and outer combustor casings but the main assessment of static pressure recovery was taken from pressure tappings on the combustor liner walls. These tappings were arranged in two rows, parallel to the major axis and 90 degrees circumferentially apart, on each liner wall. Measuring stations were at locations L2, L3 and L4, as shown in figure 9 and these refer to both inner and outer passages Total pressures were assessed in both of the combustor supply annuli from rakes located radially at planes L2 and L4. The rake at L4 was displaced by 90 degrees circumferentially from that at L2 in order to prevent interference. The pressure probes were mounted at radial locations representative of five equal portions of cross-sectional area.

Downloaded from http://asmedigitalcollection.asme.org/GT/proceedings-pdf/GT1983/79511/V001T01A021/4453643/v001t01a021-83-gt-43.pdf by guest on 20 August 2022

Provision was made for traversing the flow at pre-diffuser inlet and exit. This was accomplished after removal of the combustor assembly and by mounting a total pressure probe of suitable length on the end of a radius arm which could be swivelled about the major axis. A micrometer adjustment mechanism was included in order to give accurate radial location of the probe.

Data Reduction

During testing of the fully assembled model there were no total pressure probes located in the diffuser inlet because of the danger of interference from their wakes. Accordingly, both total and dynamic pressures at inlet were derived using compressible flow relationships together with measurements of mass flow rate, temperature, and the arithmetic mean of the four static pressures measured at plane L1.

The performances of the outer and inner annular passages were assessed independently. The arithmetic mean of the six pressures measured from the liner walls was used to calculate values of static pressure recovery coefficient.

This procedure was justified by preliminary tests which had shown that the pressures agreed to within 1% and that they also closely agreed with corresponding measurements taken from the casing walls. The data is presented in the form of static pressure recovery coefficients, C_p as defined earlier.

The total pressure readings measured from the rakes at location, L2 were mass flow weighted and then used to calculate the total pressure loss coefficients for the two passages. However, because of a more uniform flow distribution, the rakes at L4 were used to calculate the fraction of air, I, entering the inner passage.

Static pressure of the bleed air streams was measured just upstream of their metering orifices and these pressures were used to calculate a coefficient of bleed air pressue recovery, C_B, defined as:

$$C_B = \frac{\text{bleed air static pressure} - p_1}{P_1 - p_1}$$

The dimensions 'Z', between vortex controlled step and combustor dome has been introduced in some of the later figures in order to afford a comparison between overall diffuser lengths which is independent of the lengths of the post diffusers.

Preliminary Tests

Two preliminary tests are noteworthy. The first was with the combustor assembly removed so that the nature of the inlet flow and the performance of the pre-diffuser could be assessed. Figure 10 shows two typical radial profiles of velocity in plane L1, one taken directly downstream of a settling chamber support strut and the other from mid-way between two struts. The survey showed that the boundary layers on both walls were well developed and that there were low energy wakes from the three support struts. The distribution was considered to be acceptable, however, since support strut wakes are often more severe in engines. In spite of these flow conditions, the pre-diffuser was found to be 84% effective.

During the second phase of preliminary tests, the combustor assembly was attached without any post diffuser cones and the dump gap, S, between pre-diffuser exit and

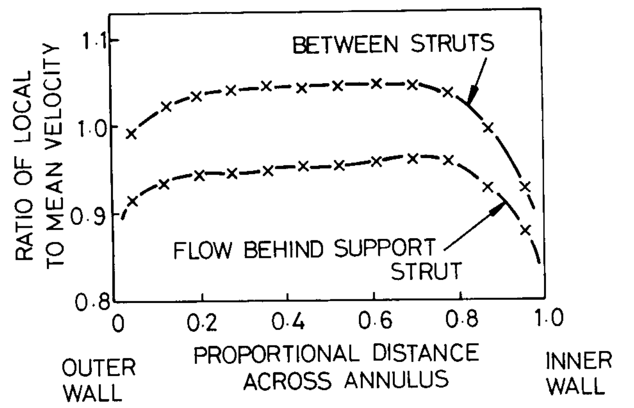


FIG. 10 RADIAL VELOCITY DISTRIBUTION AT DIFFUSER INLET

combustor dome, adjusted to 1.035. In this formation the system closely resembled the optimum configuration reported in (5), and so formed a datum for the present investigation. Pressure loss coefficients of 0.359 and 0.419 were obtained from the outer and inner annuli respectively and the corresponding coefficients of static pressure rise were 0.429 and 0.423. As such the pressure loss coefficients were very similar to those given by the previous investigators (c.f. the value $\lambda = 0.4$ given in (4)). The low value of C_p confirmed that this configuration would not be suitable for a combustor with high inlet Mach number.

Test on the Complete Model

A comprehensive matrix of tests was conducted on 36 geometric configurations, this encompassed three sets of fence geometries, three post diffusers and four dump gaps. Each test was at the maximum inlet Mach number obtainable from the air supply (0.35) and a range of bleed flows was covered from zero up to 5% of the main-stream flow. This total bleed flow was taken equally from the two vortex chambers.

From the data collected it was possible to identify the most favourable vortex chamber geometry for each particular combination of post diffuser, dump gap and bleed rate. As an example, the variation in aerodynamic performance with diffuser bleed rate for one optimised combination is given in figure 11. This combination was selected because of its short overall length, the total distance between pre-diffuser inlet and the combustor dome was 4.73, of which the pre-diffuser occupied a distance of 2.33.

A particularly important feature for annular combustors is the similarity in performance obtained by the outer and inner flow paths, as shown both by the pressure loss and recovery curves. Furthermore, the fraction of air, I, flowing to the inner annulus remained close to the design value (based on flow area) of 0.397 over the full range of bleed flows.

The improvements in static pressure recovery and the reductions in total pressure loss, when compared to the datum configuration, are immediately apparent, even at the zero bleed condition. Still further improvements were obtained as the bleed-off was increased up to 4%. At this condition the pressure recovery coefficient, C_B, of the bleed air was above 0.3 and this value indicates that, in an engine, the bleed air would have sufficient pressure for use as a turbine coolant. Also of interest is the fact that the sum of C_p and λ was almost invariant to bleed rate, at a value of about 0.85. Next,

Downloaded from http://asmedigitalcollection.asme.org/GT/proceedings-pdf/GT1983/79511/V001T01A021/4453643/v001t01a021-83-gt-43.pdf by guest on 20 August 2022

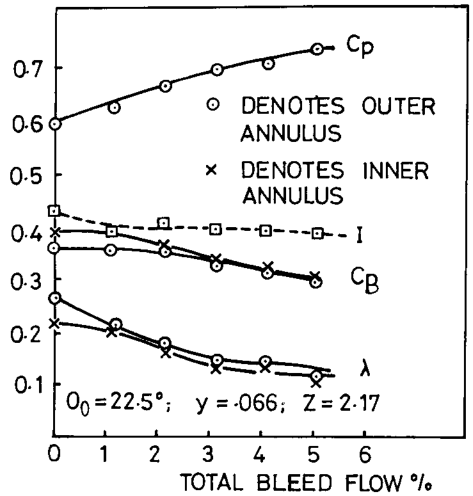


FIG. 11 SHORT-LENGTH HYBRID PERFORMANCE

if follows, from equation (7), that if the cold loss coefficient is close to unity, then the approach factor of the air admission holes would also be sensibly independent of bleed rate. The only benefit then to be gained by introducing vortex chamber bleed would be to increase the penetration of the air jets through the liner. A situation can be envisaged when diffuser bleed is only extracted at peak operating conditions when the need for a more uniform distribution of temperature becomes critical and when extra turbine cooling air would be beneficial.

Figure 12 summarises performance with optimised vortex step geometries at zero bleed. Here, similarity between inner and outer passage was so close that only data taken from the outer annulus is presented. An insensitivity to dimensions z is apparent for the two extremes of post diffuser, namely θ_o = 7.5 and 22.5 degrees; however, when θ_o was 15 degrees, the curves display a distinct step.

An explanation for this behaviour is that there are two loss mechanisms, namely diffuser loss and turning loss which is a function of velocity as diffuser exit and of the angle through which the flow must turn.

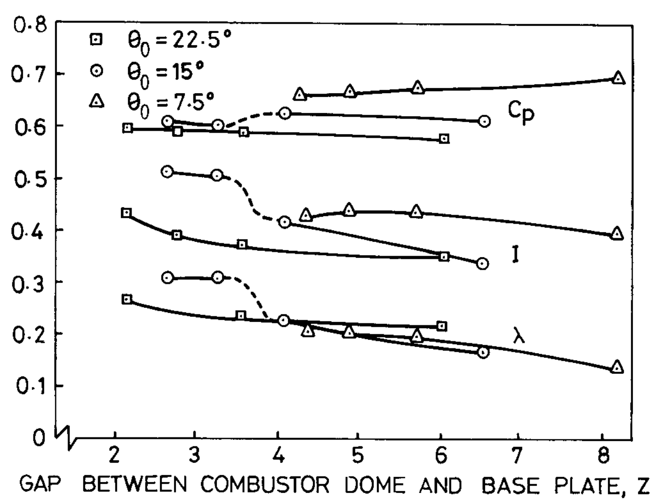


FIG. 12 PERFORMANCE OF OUTER PASSAGE (0% BLEED)

In the case when θ_o was 7.5 degrees the post diffuser would have incurred very little loss, and furthermore, the air velocity at its exit would have been very low. The major source of loss would have been due to the large angle through which the flow had to turn about the combustor dome. On the other hand, overall loss in the case of the post diffuser having θ_o = 22.5 degrees was kept modest solely due to the reduced angle of turning about the combustor dome. In the intermediate case, when θ_o was 15 degrees, the diffuser was more sensitive to combustor dome proximity than was the first diffuser, and effective diffusion was not achieved until dimension 'Z' exceeded about 3.8. At smaller dimensions, then pressure loss was higher because of a combination of excessive velocities at diffuser exit and because of the significant angle of turning.

When bleed was extracted from the vortex controlled step, all three diffuser combinations operated so effectively that the low velocities at exit did not permit the generation of any significant turning losses. As a result, the aerodynamic performance became virtually independent of dump gap over the range of gaps tested. This is illustrated by figure 13 which summarises the performance of preferred geometries while operating with a total bleed of 4.1%

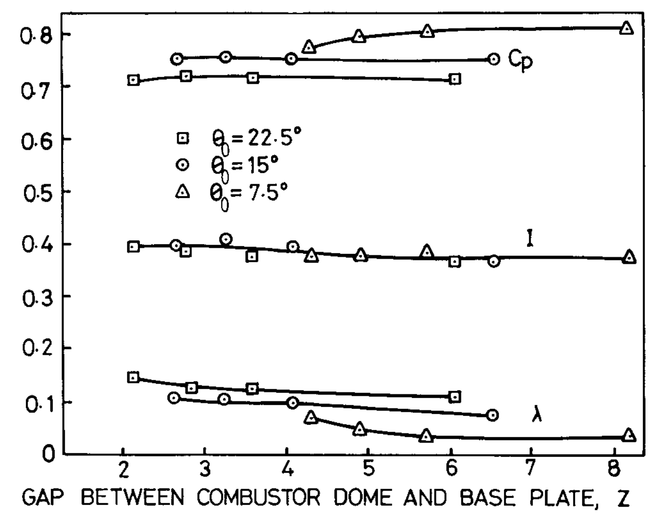


FIG. 13 PERFORMANCE OF OUTER PASSAGE (41% BLEED)

A comparison between figures 12 and 13 clearly indicates the further benefits which can be obtained by both extracting bleed from the vortex controlled steps and by permitting some increase in diffuser length. It is significant that a pressure loss coefficient of less than 0.04 was achieved together with a pressure recovery coefficient, C_p of 0.8. It is thought to be unlikely when the level of flow distortion at diffuser inlet and the severity of the redirection of the flow about the combustor dome are taken into account, that this high level of performance can be exceeded.

Figure 14 is included to give a direct comparison between the Hybrid system and the dump diffusers described in (4) and (5). For this task, performance parameters are plotted against the total diffusing length which includes the dump gap, S. The discontinuities in the Hybrid curves were produced by changes in the post-diffuser angle.

The figure shows that the Hybrid configuration outperformed the Dump arrangement. It had a superior

Downloaded from http://asmedigitalcollection.asme.org/GT/proceedings-pdf/GT1983/79511/V001T01A021/4453643/v001t01a021-83-gt-43.pdf by guest on 20 August 2022

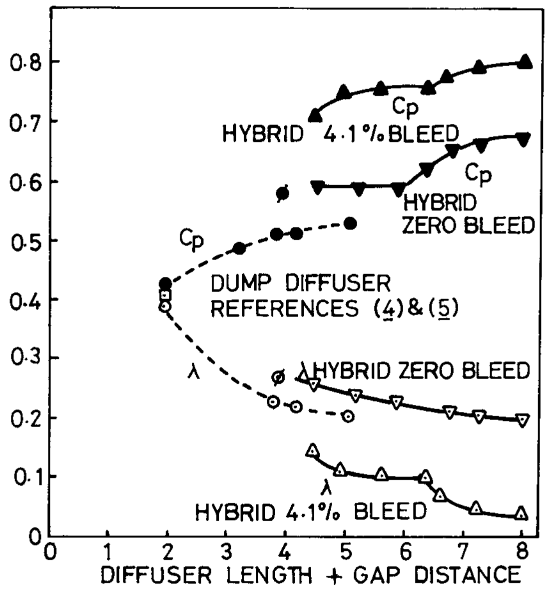


FIG. 14 COMPARISON OF HYBRID AND DUMP DIFFUSERS

pressure recovery, and when, 4.1% bleed was extracted, it gave a substantially lower loss in total pressure. Furthermore, the length advantage of the Dump diffuser was mainly due to the disproportionate pre-diffuser length of the Hybrid arrangement. Here, a length of 2.33 annulus heights was taken to produce an area ratio of 1.28:1. Indeed, without bleed-off, there is no requirement for a pre-diffuser in the Hybrid arrangement.

Reference to figures 2, 3 and 4, however, suggests that bleed-off is necessary in order to generate good aerodynamic conditions for high Mach number combustors.

CONCLUSIONS

1) A useful method for relating combustor aerodynamic performance to diffuser performance and compressor exit Mach number has been devised.

2) Requisites for operation of a pre-combustor diffuser at high inlet Mach numbers are shown to be both a high static pressure recovery and a low total pressure loss.

3) Model tests have shown that a 'Hybrid' diffuser operating with a 4.1% bleed-off, meets the requisites for high Mach number operation. Furthermore, the pressure level of the bled air makes it useable for turbine cooling.

4) If moderate inlet Mach numbers are used, then the Hybrid arrangement, operating without bleed-off, could provide higher pressure recoveries than the equivalent Dump diffuser.

5) The distribution of airflow between the inner and outer combustor passages remained almost constant, and in direct proportion to flow areas, throughout the tests.

6) A good pressure balance between the inner and outer combustor passages was achieved from most of the configurations tested. It is suggested that should an imbalance occur, due to radial distortion of the inflow, then equilibrium could be restored by differential variation of the bleed-off from the two diffuser walls.

The tests have shown that the Hybrid arrangment offers a compact and efficient diffuser system for annular combustors.

REFERENCES

1. Dittrich, R.T., & Graves, C.C. "Discharge Coefficients for Combustor-Liner Air-Entry-Holes", NACA TN 3663, April, 1956.

2. Norster, E.R. "Second Report on Jet Penetration and Mixing", C.I.T., Department of Aircraft Propulsion Report No. PD/JP2.

3. Adkins, R.C. "The Effect of Compressor Exit Flow Distribution on Air Placement in Annular Combustors", Trans ASME, J. of Eng. for Power, Vol. 100, No. 3, July 1978, pp. 444 to 451.

4. Klein, A., Rohlffs, M., & Pucher, P. "The Effects of Blade-Wakes on the Performance of Short Dump-Diffuser Type Combustor Inlets", Proc. of Joint ASME Symposium on Design and Operation of Fluid Machinery, Fort Collins, Colorado, June, 1978.

5. Fishenden, C.R., & Stevens, S.J. "The Performance of Annular Combustor-Dump Diffusers", AIAA Paper No. 74-1097.

6. Adkins, R.C., "A Short Diffuser With Low Pressure Loss", Trans. ASME J. of Fluids Eng., Sept. 1975, pp. 297-302.

7. Juhasz, A., & Smith, J. "Performance of High-Area-Ratio Annular Dump-Diffuser Using Suction-Stabilized-Vortex Flow Control", NACA Lewis, Jan. 1977.

8. Verdouw, A. "Performance of the Vortex -Controlled Diffuser (VCD) in an Annular Combustor Flowpath", Proc. Combustion Institute, Gas Turbine Session, Purdue University, April 1978.

9. Adkins, R.C., & Yost, J.O. "A Combined Diffuser Arrangement", Turbo & Jet Engine Technology Part I, I.G.T.A., 1980.

10. Adkins, R.C., Matharu, D., & Yost, J.O. "The Hybrid Diffuser", Trans. ASME J. of Eng. for Power, Vol. 103, No. 1, pp. 299-236.

11. Adkins, R., & Yost, J.O. "Diffusion Apparatus", European Patent Application 0035838. Published Sept. 1981.

Downloaded from http://asmedigitalcollection.asme.org/GT/proceedings-pdf/GT1983/79511/V001T01A021/4453643/v001t01a021-83-gt-43.pdf by guest on 20 August 2022