Preliminary Tests on an Annular Hybrid Diffuser

by

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ABSTRACT

Tests have been conducted on an annular, Hybrid Diffuser, of short length while operating in isolation. The purpose was to ascertain whether such a diffuser could operate efficiently without the downstream influence of the combustor dome which had been a feature of previous tests. The diffuser was fitted with a pre-diffuser in order to raise the static pressure level of the bleed air. A series of exit cones was used as the final stage of diffusion, covering a range of included angle from 15 to 45 degrees.

Results obtained demonstrate that this configuration of Hybrid diffuser operates efficiently, that performance is improved if pressures inside the inner and outer vortex chambers are balanced, and that larger quantities of bleed must be extracted in order to maintain a high pressure recovery as the exit included angle is increased.

INTRODUCTION

The potential of Hybrid Diffusers to reduce the considerable length required for diffusion inside the Gas Turbine Engine has already been established in references (1), (2), and (3). However, publications to date have centered either on tubular diffuser configurations or on diffuser/combustor combinations.

From the previous success has stemmed an interest for the application of this short lengthened diffuser to other applications, such as between compressor spools or for use in inter-turbine ducts. In fact there are numerous applications where a short lengthed, efficient diffuser would be an advantage.

Information is therefore required on the performance of an annular, Hybrid, diffuser without the downstream effects of a combustor which could have provided some of the stability previously attributed to the Hybrid diffuser.

TEST MODEL AND APPARATUS

The diffuser used for the present tests was the one previously used in conjunction with a simulated combustor and which was described fully in ref. (2). Details of the test diffuser and supply plenum chamber are given in figs. 1 and 2.

As described in (2), the Hybrid diffuser was preceded by a pre-diffuser, having an area ratio of 1.278 : 1. The purpose of this was to raise the level of static pressure at the vortex chamber location. By these means, any air bled-off from it would be at a suitably high static pressure level for re-injection into the engine, if so required. The overall area ratio of the diffuser system was 2.5 : 1, and the area ratio over the vortex controlled
Three sets of fences were manufactured so that the dimension, $y$, at the vortex chamber, could be made equal to 0.51, 1.02, or 1.52 mm, at both the inner and outer walls. Furthermore, the dimension, $x$, could be varied by inserting spacers between the fences and their mounting flanges.

The diffuser inlet was supplied with air through a smoothly contoured transition piece, designed so as to give a near uniform distribution of flow. The transition piece

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FIG. 1 ANNULAR HYBRID DIFFUSER

FIG. 2 LEADING DIMENSIONS OF ANNULAR HYBRID DIFFUSER
connected the diffuser inlet to an annular plenum chamber which had a hollow centerbody, suspended concentrically from three hollow struts. The centerbody and struts served the dual purpose of supporting the inner assembly of the diffuser and providing a passage for bleed air to be extracted from the inner vortex chamber.

A second plenum chamber was located around the outside of the vortex chamber serving the outer diffuser wall. Both the inner and outer plenums contained metering plates designed so as to ensure the circumferential uniformity of bleed extraction.

The diffuser model was intended to operate with an inlet Mach number of 0.25 and so a low pressure ratio fan was adequate for the purpose of air supply. The diffuser discharged directly into the test house. Bleed air removal, when required, was drawn out through two ducts which were linked to the inner and outer diffuser plenum chambers. A possibility was foreseen for improving diffuser performance by balancing the two plenum chamber static pressures. Accordingly, a branch pipe with control valve (the so-called intermediate valve), was inserted between the two extraction ducts so that its deployment could be made optional.

INSTRUMENTATION

Sharp edged orifice plates were installed to measure mass flow rates in the model supply pipe and in the two bleed extractor ducts. The orifice plates were installed according to British Standards Specification No. 1042, and as such, ensured that the mass flows would be measured to an accuracy of better than 1.5%

The measurement station at diffuser inlet was actually located in the inlet duct, upstream of the commencement of diffusion, by a distance equal to one annulus height. This location was selected in order to avoid the strong static pressure gradients which normally occur due to streamline curvature at the start of diffusion. Three static pressure tappings, equispaced around the circumference, were made through both the inner and outer diffuser walls. No pressure tappings were necessary at diffuser exit since it exhausted directly into the test house, the diffuser pressure rise could therefore be assessed directly from the mean value of depression measured at pre-diffuser inlet. A sensitive micromanometer which could discriminate to 0.1 mm of water was used for measuring static pressures.

Dynamic pressure at diffuser inlet was derived from the measured mass flow, the cross sectional area, and the local static pressure and temperature. This method avoided the use of total pressure probes which would otherwise have disturbed the flow at inlet, and so have influenced diffuser performance.

PERFORMANCE PARAMETERS

Aerodynamic performance was assessed by the level of pressure recovery, the total bleed-off quantity expressed as a percentage of flow entering the diffuser, and the pressure level of the bleed air. The data is presented using the following non-dimensional parameters which are accurate to 2.2%.

Pressure recovery was assessed in two ways:

a). By the coefficient of static pressure recovery, $C_p$, where:

$$C_p = \frac{(P_{exit} - P_{inlet})}{(P - P_{inlet})}$$

b). By the diffuser effectiveness, $\eta$, expressed as a percentage, where:

$$\eta = \frac{\text{measured } C_p}{\text{ideal } C_p}$$

This parameter was included because it gives a direct comparison between the pressure recovery achieved by the diffuser and that which would ideally be obtained for isentropic diffusion over the same area ratio as the test diffuser.

The pressure level of the bleed air was quantified by use of the so called Vortex Chamber Depression, VCD. This parameter expresses the pressure drop normally encountered between diffuser inlet and the bleed air duct as a fraction of the dynamic pressure at diffuser inlet. It is interesting to note that, due to the presence of the pre-diffuser, the static pressure of the bleed air was greater than at diffuser inlet and so the term VCD appears as a negative quantity.

SCOPE OF TESTS

The means for varying the vortex chamber geometry has already been described. In general, these variations have been quantified by giving the radial gap dimension, $y$, and the included angle, $\alpha$, made over the vortex chamber aperture. Where is defined by:

$$\alpha = \tan^{-1}(y/x)$$

Three sets of conical diffusing ducts (the post diffusers), were provided for direct location immediately downstream of the step. Each cone gave provision for an overall area ratio, including pre-diffuser, of 2.5 : 1. Selection of post diffuser comes gave a choice of the following included angles, 15, 30 and 45 degrees.

The suction pump, used for drawing off the bleed air, had the capability of extracting up to 7% of the mass flow entering the diffuser.

RESULTS AND DISCUSSION

The first set of tests were conducted with the intermediate valve, in the balance pipe, closed. Equal mass flows were bleed-off from the inner and outer steps. Data taken from configurations using the 15 and 45 degree (total angle), post diffusers are presented as figures 3 and 4, respectively.
In figure 3, data is given from a wide range of fence configurations which, it is shown, produce very little variation with respect to pressure recovery. The level of pressure recovery was very high throughout these tests. A greater variation, however, is to be observed in the values of vortex chamber depression, VCD.

The insensitivity of pressure recovery to fence geometry and, to a lesser extent, to bleed is probably due to the modest angle of the conical outlets and to the presence of the pre-diffuser. This pre-diffuser would have generated a higher level of turbulence than if the approach to the vortex step had been a parallel duct, and presumably this was sufficient to trigger-off the generation of turbulent eddies downstream of the fence. In ref (1), it was hypothesised that these turbulent eddies formed a stream which reattached to the wall of the conical outlet, so promoting energisation of the boundary layer and thereby inhibiting flow separation in the post diffuser.

It follows that bleed extraction would only lead to a minor improvement arising from two mechanisms. Firstly, as bleed extraction removes the lesser energetic portion of the flow the mean energy level of the remaining fluid increases. Secondly, the mainstream has now to fill an increased cross-sectional area due to the extraction of the bleed, and so the effective area ratio of the diffuser is increased.

On the other hand, the value of the vortex chamber depression, VCD, was influenced to a greater extent because flow entering into the vortex chamber is directly influenced by the size of the aperture, and more particularly, by the angle at which it is facing.

In figure 4 the same trends are present but are amplified by the use of the wider angled exit cone, the reasons are twofold:
Firstly, the mainstream flow has to be turned through a greater angle and so would produce a more severe static pressure gradient transversely across the duct. This in turn would create a deeper depression above the vortex chamber aperture. Greater suction has then to be applied in order to draw bleed flow through the aperture and so the geometry in this region will be more critical.

Secondly, the wider exit cone angle gives rise to a greater static pressure gradient along the diffusing cone and so the task of diffusion is made more difficult. The turbulence created in the pre-diffuser and amplified by the vortex chamber, is no longer adequate for this higher rate of diffusion and, without bleed, the diffuser is not very efficient. A high level of effectiveness, however, was restored by increasing the bleed rate so that the energy deficient fluid was removed and the turbulent eddies were generated from fluid streams having a higher velocity.

A further important observation can be drawn from fig. 4, where there is a substantial difference in VCD values between the two vortex chambers. The lower negative values of the inner vortex chamber indicate that losses are higher than on the outer wall. One explanation could be that the perimeter of the inner vortex chamber aperture is smaller than the outer one, the bleed quantities were however, extracted equally. Blood flow would therefore originate from a greater distance away from the inner vortex chamber and so a more intense depression would manifest above it’s aperture.

In order to overcome the difficulty described above, the intermediate valve was opened in order to balance the static pressures in the inner and outer bleed extraction plenums. The differences between operating with and without the intermediate valve open are shown in figure 5. Data for this figure were taken while using the 30 degree post diffuser configuration. This figure clearly illustrates that a beneficial effect of balancing the vortex chamber depressions can be a further rise in static pressure recovery.

CONCLUSION

Tests have been conducted on an annular Hybrid Diffuser, operating in isolation and without the possibility of any assistance from downstream components, such as a combustor dome. The Hybrid diffuser encompassed a pre-diffuser in order to raise the static pressure level of the bleed air. A range of included angles of the exit conical portion, from 15 up to 45 degrees, were investigated.

Results demonstrated that this configuration of Hybrid diffuser operated efficiently.

Performance is improved if pressures inside the inner and outer vortex chambers are balanced.

Larger quantities of bleed must be extracted in order to maintain a high level of pressure recovery as the exit included angle is increased.

REFERENCES

