Application of Radial-Splitters for Improved Wide-Angle Diffuser Performance in a Blowdown Tunnel

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Severe flow separation in the 15:1 area-ratio, 38° total angle conical diffuser preceding the settling-chamber of an intermittent blowdown wind tunnel was eliminated by the use of a novel radial-splitter arrangement. As a consequence, the operating life of settling-chamber screens was greatly extended and test-section flow steadiness improved, with no penalty in the tunnel running time.

I. Introduction

TO attain desirable level of flow steadiness in the test-section of blowdown tunnels operating from stored compressed air requires particularly effective upstream flow conditioning. The design criteria for the flow conditioning system must take into account two distinct phases: 1) the compressible throttling process involving complex multiple shock-viscous interactions in the supersonic jet developing downstream of the choked valve,[1] followed by 2) diffusion of the high-velocity subsonic flow appearing at the end of the first phase into a relatively uniform, low-speed stream in the settling chamber for final processing by the anti-turbulence screens. The entire flow conditioning must be carried out within the shortest length possible for economy of space, and also in order to limit the tunnel volume between the valve and nozzle throat for minimizing pressure establishment time, not only to avoid air wastage but also to alleviate transient shock loads on the model in supersonic testing.

This paper is concerned with stage (2) of the flow conditioning process, which calls for effective flow-spreading through a large area-ratio (typically 10-15), short conical expansion with minimum energy loss so as not to significantly compromise the performance envelope of a blowdown facility, particularly one that operates from a relatively low-pressure air source. The successful application of radial splitters, a new flow-spreader concept for wide-angle diffusers[2] to improve the operational features and flow quality of the NAL 1-ft blowdown tunnel is described.

II. Description of the Facility

The NAL 1-ft intermittent blowdown tunnel having a Mach No. range of 0.2-3.5 is operated from a 150 psig maximum pressure air-storage. A 12-in. diam feedback servo-controlled, vertical axis rotating-plug valve is used for automatic regulation of the tunnel stagnation pressure (Fig. 1). The valve discharges through a cylindrical duct 5.5 diam long into a 15:1 area-ratio conical diffuser of 38° total angle. The conical diffuser connects to a 4.5-ft long, 4.5-ft internal diameter settling chamber containing anti-turbulence screens, followed by a fiberglass-molded contraction whose cross-section shape transforms smoothly from circular to a 12×13 in. rectangular section. The flow is then further accelerated either through a slotted-wall or a two-dimensional nozzle for transonic and supersonic testing respectively.

A 55% open-area perforated baffle plate was originally provided at two-thirds the diffuser length from entry for obtaining a measure of control over flow separation. As the tunnel was commissioned for shakedown and calibration tests, a parallel investigation on model scale was undertaken with the object of developing an effective diffuser flow-spreader having better energy efficiency than possible with baffles. The outcome of this investigation was the radial-splitter concept,[2] a brief description of which follows.

III. Radial Splitters as Flow Spreaders

As shown in Fig. 2, eight radial vanes divide the conical diffuser (up to the baffle) into an axisymmetric cluster of identical triangular expanding passages. These splitters do not function in the conventional sense of promoting attached flow through diffuser passages of reduced effective expansion angle; rather, a separation bubble generated along the inner corner of each passage is crucial to the flow-spreading action in this case. This is conveniently achieved by placing a disc on the forward apex of the splitter assembly. The collective outward displacement effect of the corner bubbles ensures attached flow on the diffuser wall; intense turbulent mixing of the retarded flows emerging from the individual passages enables a relatively flat velocity profile to be achieved within a very short distance downstream of the diffuser exit.

In experiments with a one-quarter scale model of the conical diffuser,[2] an optimized radial splitter arrangement yielded a uniform velocity distribution to better than ±5% in a downstream plane corresponding to the first screen position. This performance compares favorably with that of conical diffusers having considerably smaller area-ratio and expansion angle.[3] The flow-spreading effectiveness combined with relatively low pressure loss of the radial splitter concept has been subsequently confirmed elsewhere.[4]

IV. Diffuser Flow Measurements before Installation of Radial Splitters

Total and static pressures were measured in the diffuser entry and exit planes, using a pitot rake at each location connected to mercury manometers. Several meridional planes were covered in successive runs by rotating the rake about the diffuser axis.

At any instant during a blowdown, the rotating-plug valve is at some partly open position, discharging an asymmetric, supersonic jet. The discharge flow spreads by mixing into the constant diameter duct provided immediately downstream, before entering the conical diffuser. Total pressure surveys in the diffuser entry plane showed that although the duct was essentially running full in all cases, asymmetry in the velocity profile persisted at the smaller valve opening in particular (Fig. 3). This inlet flow asymmetry is reflected in the diffuser exit velocity profiles (Fig. 4). While the exit profiles indicate the diffuser flow to remain well-separated (pointing to the ineffectiveness of the perforated baffle), the velocity peak is found to shift closer to the axis as the inlet asymmetry reduces

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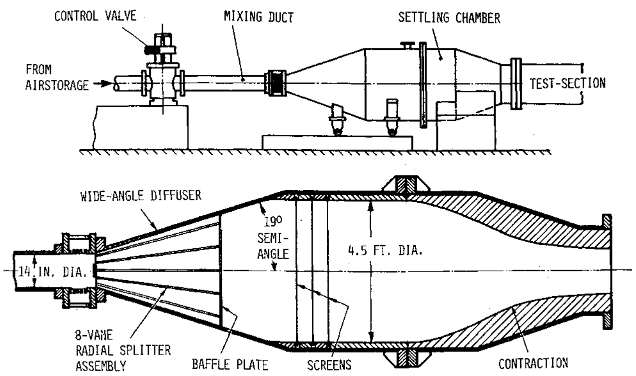

Fig. 1 NAL 1-ft blowdown tunnel settling chamber assembly showing location of baffle and splitters in wide-angle diffusers.

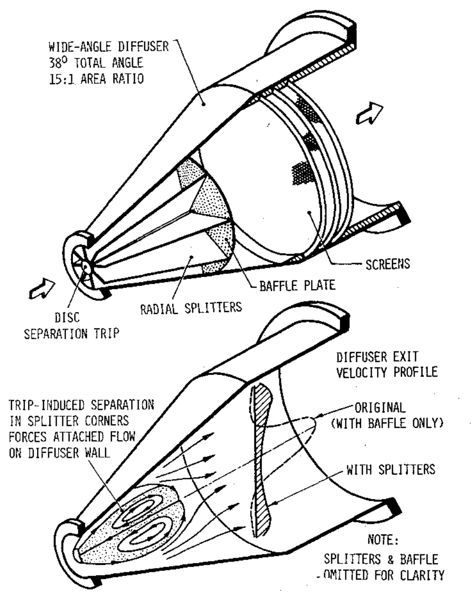

Fig. 2 (Top) Pictorial view of splitter installation. (Bottom) Schematic of corner separation bubble promotion flow-spreading in wide-angle diffuser.

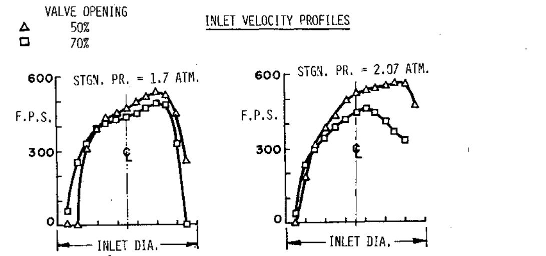

Fig. 3 Typical velocity profiles along vertical meridian in diffuser inlet plane.

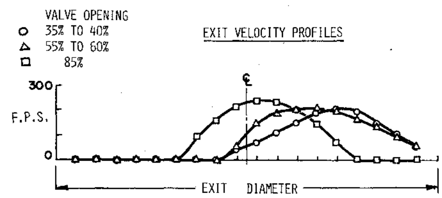

Fig. 4 Velocity profiles along vertical meridian in diffuser exit plane with baffle only.

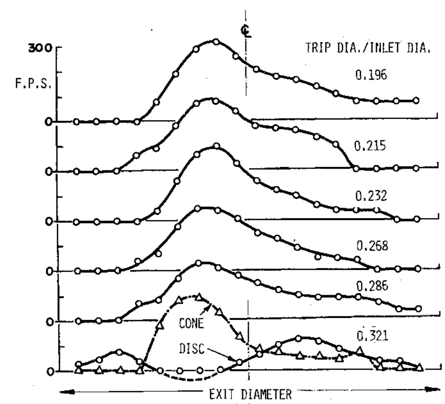

Fig. 5 Vertical meridian velocity profiles in diffuser exit plane with splitters showing effect of increasing separation trip size.

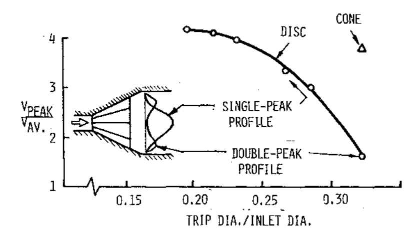

Fig. 6 Exit flow peak velocity alleviation with increasing size of splitter separation trip.

with increasing valve opening. (The asymmetry of the flow in the diffuser exit plane is well indicated in Fig. 7A).

V. Results with Radial Splitters

After the installation of the splitter assembly between the diffuser entry and the baffle (Fig. 1),‡ total pressure measurements in the exit plane showed the still-separated flow now emerging as a nearly axisymmetric free-jet (Fig. 7B), the peak velocity not being appreciably reduced. This corroborates the observations of Ref. 2 that the radial splitters by themselves (i.e. without a separation-trip) were not effective as flow-spreaders.

Separation trips in the form of discs of increasing diameter were tested on the splitter apex, and their effectiveness monitored via the velocity distribution along the vertical diameter in the diffuser exit plane (Fig. 5). A progressive reduction of $V_{(peak)}/V_{(ave)}$, a measure of velocity profile distortion, is observed with increasing disc diameter, (Fig. 6). When the disc diameter was increased from 0.29 to 0.32 of inlet diameter, the exit profile changed qualitatively from single-peak to double-peak type, indicating the establishment of properly-developed corner separation in the splitter passages.[2] This was accompanied by a rapid drop of $V_{(peak)}/V_{(peak)}$. With the largest disk the peak velocity at exit was reduced to about 1.5 times the average velocity. Interestingly, a 90° cone having the same base diameter ratio, viz. 0.32, was not successful in provoking the flow-spreading action. As shown in Fig. 7C, the flow leaving the diffuser is relatively well spread out. From these results, the optimum disc diameter ratio would appear to lie between 0.28 and 0.32, a considerably larger size than anticipated from the data of Ref. 2. This is believed to be the consequence of prevailing asymmetry in the diffuser inlet flow.

VI. Operational Benefits

A. Alleviation of Screen Loading

Prior to the installation of the radial splitters, failure of the settling chamber screens occurred rather frequently, not surprisingly in view of the high velocity peak associated with the separated flow leaving the conical diffuser. A history of the

‡The baffle, retained as a safety barrier in order to protect the screens downstream in the event of a structural failure of the splitters, is thought not to have played a significant role in the flow-spreading function.

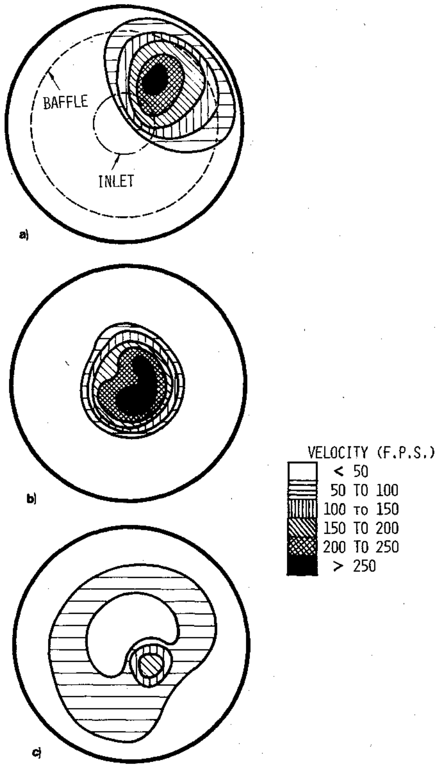

Fig. 7 Iso-velocity contours in diffuser exit plane: a) with baffle only; b) with radial splitters (but no trip); c) radial splitters with 0.321 diam ratio trip.

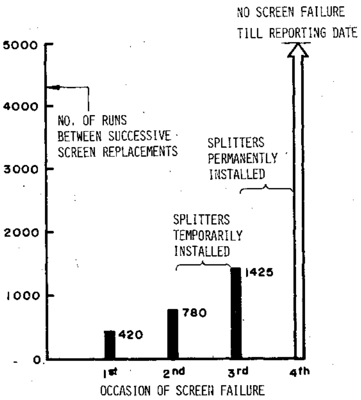

Fig. 8 Settling chamber screens life improvement due to installation of diffuser splitters.

screen replacements in this facility is depicted in Fig. 8. The first instance of failure occured 420 blowdowns after tunnel commissioning. A modification of the screen attachment in order to alleviate stress concentrations at the rim permitted a further 780 blowdowns before the second failure. About 750 blowdowns following the second replacement of screens, the splitter assembly was installed temporarily (for about 250 runs) and then removed for minor modifications. The temporary presence of the splitters is believed to have contributed towards a further increase in screen life to 1425 blowdowns attained before the third failure. The splitter assembly was then permanently installed, and at this reporting (i.e. 5000 blowdowns after the third replacement) the screens were found to be in perfect order. It is concluded that the effective flow spreading in the conical diffuser achieved by the radial splitters was responsible for the dramatic improvement in the operating life of the screens.

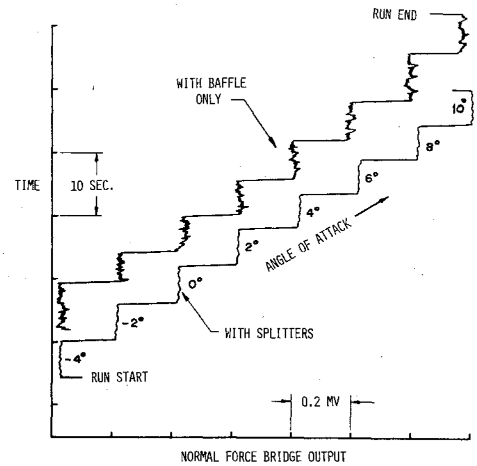

Fig. 9 Normal force signal noise before and after installation of diffuser splitters.

B. Improvement in Test-Section Flow Steadiness

Force tests on an AGARD B calibration model mounted on an internal strain-gage sting balance were carried out at $M = 1.8$. Before the installation of splitters, the analog output of the strain-gage bridges was found to be highly unsteady. A typical trace of normal-force output during a stepped angle-of-attack test program is shown in Fig. 9. The noise level in the balance output was high enough originally to prevent on-line digital data recording. After the splitters were installed, a marked reduction in output fluctuations was noted and, for the first time digital data acquisition was made possible with this tunnel. Simultaneously, small but distinct shifts in the mean level of the output signal at a fixed model angle of attack (believed to be associated with variation in the flow inclination during blowdown[1]) existing before the introduction of the splitters were eliminated.

VII. Conclusions

The installation of a radial-splitter system in the upstream wide angle conical diffuser of a blowdown tunnel greatly improved the uniformity and steadiness of the flow leaving the diffuser. The resulting aerodynamic load alleviation led to substantial enhancement in the operating life of the settling chamber screens, and also improved the test-section flow steadiness. These benefits were derived with no perceptible loss in the tunnel running time, indicating that the radial splitters provided an efficient as well as powerful means of flow spreading in large area-ratio, wide-angle conical diffusers. The large available surface area offers the possibility of acoustic treatment of the radial splitters to achieve an even quieter tunnel flow. The results presented here should be of general interest in applications involving length and volume constrained diffusers.

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