RESEARCH MEMORANDUM

BYPASS-DUCT DESIGN FOR USE WITH SUPERSONIC INLETS

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SUMMARY

A successful method for designing bypass ducting for use with supersonic inlets has been developed experimentally. The design is shown to be satisfactory in all aspects of performance. Further refinement will be possible in detailed development for specific applications.

INTRODUCTION

Figure 1 is a sketch illustrating the use of an engine bypass ducting system in conjunction with a supersonic inlet. The inlet is followed by a subsonic diffuser. Near the exit of the subsonic diffuser, the flow is divided into two parallel streams – the bypassed air and the air consumed by the engine. The problems associated with matching inlet performance with engine requirements and the use of the bypass duct as a solution to these problems are referred to in references 1 and 2. In brief, with a bypass-ducting system, the inlet would be sized to pass a flow which always would be equal to or greater than that demanded by the engine. For conditions where the engine demands less flow, the excess air would be bypassed around the engine and discharged from the airplane at the most convenient location.

This paper is concerned with the detail design of the subsonic ducting in the region where the bypass air is removed from the total flow passed by the inlet. In particular, the effects of bypassing the air on the engine-face velocity distributions and on the total-pressure losses are to be evaluated in order that the designer may have more specific information on which to base his designs and analyses.

SYMBOLS

H_B mean total pressure at bypass

H_E mean total pressure at engine-face station

H_{MAX} maximum total pressure

H_{MIN} minimum total pressure

H_R mean total pressure at reference station

M Mach number

M_E Mach number at engine-face station

U maximum velocity

IDEAL BYPASS-DUCT DESIGN

The ideal bypass-duct design would consist of an arrangement which removes the bypass flow uniformly from the entire periphery of the duct. Such a ducting design would bleed off uniformly all the boundary layer or low energy air, which is generally the source of flow distribution distortions. However, wrapping annular ducting around the entire periphery of the main duct introduces so many design complications that in most cases it would be impractical. For this reason, the experimental investigations to be described were confined to designs where all the bypass air was removed from one wall or a limited sector of the duct. The subsonic diffuser was supplied with air flow by an inlet bell, and the various effects of the supersonic inlet operation were simulated by varying the supply pressure.

RESULTS

Model I

The first configurations investigated are shown in figure 2. In model Ia, a conventional 6° diffuser designed for the maximum engine air-flow condition was altered by cutting a hole in one side and adding a scoop to obtain high recovery in the bypass flow. Four scoop projections were tested ranging from the full scoop of model Ia to the flush scoop of model Ib. Only results for models Ia and Ib will be presented since the performance is bracketed by these two configurations. The inlet area of the extended scoop was designed to intercept about a third of the air flow at a scoop inlet velocity ratio of 1.0. For ease of fabrication and test measurement, rectangular ducting was used; however, the general principles indicated by the test data should be applicable to any cross-sectional shape.

Figure 3 summarizes the performance of models Ia and Ib for the case where the diffuser was operating at a point just below the choke condition. The diagrams are velocity distributions in which velocity is plotted horizontally against distance across the duct vertically. The center of the maximum velocity region is indicated by the arrow. The shaded areas, then, represent retarded velocity regions. The bottom line corresponds to the wall on the bypass side, and the top line to the wall opposite to the bypass. Stations R and E are the reference and engine-face stations, respectively. The two distributions on the left side of figure 3, which were measured with no scoop in place and with the opening sealed and faired, are normal for this type of diffuser. The performance for model Ia with the scoop in place is given at the top of figure 3, where the percent of bypass flow is given on the top line, the total-pressure-recovery ratio for the engine-face station on the second line, and the bypass duct recovery on the third line. Total-pressure recovery is given in terms of the mean total pressure at station R.

The large region of retarded velocity and the accompanying low pressure recovery obtained with no bypass flow resulted from the high angle of attack on the scoop for this condition and the high expansion angle on the downstream face of the scoop. With the design bypass flow of 32 percent, the angle of attack was eliminated and the boundary layer bypassed; thus, the bad flow on the bypass side was eliminated. However, a large retarded velocity region was obtained on the side opposite the scoop because of the alteration to the diffuser pressure gradients caused by bypassing about a third of the air. Bypassing this amount of air is equivalent to a sudden area increase in the diffuser of about 50 percent, which produces a rapid rate of boundary-layer growth. The engine-face total-pressure recovery with 32 percent bypass was fairly high, 98.6 percent, because of the reduced air flow (and thus dynamic pressure) in the engine duct and because the velocity distribution was somewhat better than with no bypass flow.

Eliminating the scoop extension by using a flush scoop, model Ib, considerably improved the velocity distribution and engine recovery with no bypass flow. With the design bypass flow of 32 percent, the distribution was again distorted as in model Ia because of the increased diffuser pressure gradient. Eliminating the scoop extension reduced the bypass recovery from 98 to 96.8 percent.

The performance of these two configurations and the other scoop designs not discussed here was not considered to be satisfactory from either the flow distribution or loss standpoint. The data showed that the design approach of cutting a hole in the wall of a diffuser and adding a scoop is oversimplified and that the basic diffuser lines ought to be laid out with specific consideration for the bypass operation.

Model II

Model II, shown sketched in figure 4, was designed using the information derived from the tests of model I; model Ib is also shown in this figure for comparison. In model II, the adverse effects of the extended scoop were eliminated by moving the bypass inlet back to the diffuser exit and by increasing the diffuser exit area by an amount sufficient to include the bypass inlet area. Thus, the bypass design became a splitter-type configuration, which, of course, retains the ability to recover ram pressure in the bypass duct. For the same diffuser angle, the model II type of design would be longer than model I. For model II, two diffuser area ratios were tested which, with no bypass flow, produced at the engine-face station Mach numbers of about 0.4 and 0.7. These two conditions were desired in order to bracket the current turbojet-compressor-inlet Mach number values of 0.5 to 0.6.

Figure 5 presents the performance of model II for the ducting for a Mach number of 0.4, and the corresponding performance of model Ib is included for comparison. With or without bypass flow, substantially more uniform velocity distributions were obtained at the engine face with model II than with model Ib. The improvement without bypass flow is directly due to the contraction which the flow experiences between the reference station and station E with no flow through the bypass. With the design bypass flow of 32 percent, the improved velocity distribution and engine total-pressure recovery of model II were due to the fact that the diffuser pressure gradients in the region of the bypass for model II correspond to those for a 6° diffuser; whereas, in model Ib, the bypass flow sets up gradients appreciably higher than those for the basic 6° diffuser.

The data for model II presented in figure 5 are for the condition where the diffuser was operating just below the choke point, and a Mach number of about 0.4 existed at station E with no bypass flow. As noted previously, data for the same condition were taken for a Mach number at station E of about 0.7. The performance at the higher Mach number level was nearly identical to the data for a Mach number of 0.4 and will not be presented here.

The velocity distribution for model II depreciated some on the opposite wall with increasing bypass flow. In laying out the duct design, this effect could be reduced by taking most of the area expansion on the diffuser wall containing the bypass, thus favoring the boundary layer development on the opposite wall. An alternative design would be to include an area contraction just upstream from the engine on the opposite wall.

Distorted Inlet Flow, Model II

In order to determine the effectiveness of the model II design for off-design inlet operating conditions, the diffuser was tested in the choked condition with a normal shock standing in the diffuser and in some cases with various types of spoilers mounted on the diffuser wall. Data for one of the most extreme conditions have been selected for presentation here. A diagram for the diffuser flow pattern is shown in figure 6. The normal shock occurred at a Mach number of 1.52. The diffuser area ratio for this case normally produced a Mach number of about 0.4 at station E with no bypass flow. For the flow conditions illustrated, however, the engine-face Mach number was about 0.6 due to the total-pressure losses incurred in the shock and in the subsequent separated flow region. As generally occurs in cases of this type, the flow always separated from the same wall – in this case, the bypass wall.

The amount of flow distortion produced by the shock—boundary-layer interaction is readily apparent from the reference station measurement. The installation of the bypass splitter and varying the amount of bypass flow did not alter the reference-station total-pressure distribution appreciably. The velocity distributions obtained at the engine face are not appreciably different from those obtained when the diffuser was operating just below the choke condition. The outstanding conclusion to be derived is that even with a flow distortion at the reference station of the magnitude indicated, the model II design produced fairly uniform distributions at the engine face. The total-pressure recovery in the engine duct was high because it received the high total-pressure portion of the entire flow. Conversely, the bypass recovery was low. Other tests with the higher Mach number ducting and with separated flow on the opposite wall produced essentially the same performance and, therefore, these results may be considered typical.

Total-Pressure Distortions

The total-pressure distortions obtained at the engine face are summarized for several models in figure 7. In obtaining the distortion factor, 5 percent of the cross-sectional area adjacent to each duct wall was ignored; in other words, this amount of area was assigned to the low energy part of the boundary layer. The distortion factor is defined as the difference between the maximum and minimum total pressure divided by the mean total pressure at the engine-face station. The abscissa is the percent of bypass flow. The plot on the left side of figure 7 is for the diffuser operating just below the choked condition. For this case, model Ia with the extended scoop produced distortions as high as 50 percent. The flush scoop of model Ib reduced the 50-percent value to about 11 percent with no bypass. At high bypass flows, both models Ia and Ib produced a distortion of about 9 percent. This relatively low value was obtained in spite of bad velocity distributions because of the low engine-face Mach number level of the tests of about 0.2. At low Mach numbers, the dynamic pressure is very small relative to the total pressure and, therefore, large variations in velocity distribution do not affect the total-pressure distortion appreciably. For model II, the distortions for the bypass system for Mach numbers of 0.4 and 0.7 were on the order of 4 and 7 percent, respectively, the difference between the two values being due almost entirely to the change in Mach number rather than a change in velocity distribution. The model II results are considered to be within the range of values acceptable for engine operation.

The right-hand plot of figure 7 summarizes the data for the tests where the diffuser flow was distorted by shock—boundary-layer interaction. The lower Mach number ducting for model II, which produced a Mach number of about 0.6 at the engine with no bypass, had distortions on the order of 9 percent, which is probably on the borderline of being acceptable. Model Ib had prohibitive distortions. It is evident that model II resisted the effects of distorted flow upstream from the bypass much more successfully than model I.

CONCLUDING REMARKS

A successful method for designing bypass ducting for use with supersonic inlets has been developed in this preliminary investigation. The design has been shown to be satisfactory in all aspects of performance. Further refinement should be possible in detailed development for specific applications.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 1, 1955.

REFERENCES

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2. Wilcox, Fred A., and Perchonok, Eugene: Aerodynamic Control of Supersonic Inlets for Optimum Performance. NACA RM E55L14, 1956.

SUPERSONIC INLET WITH BYPASS

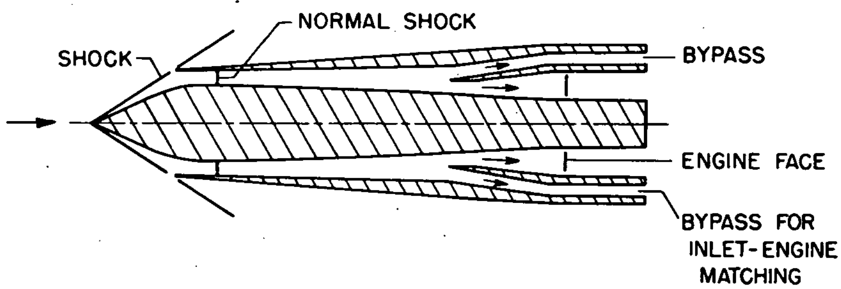

Figure 1

MODEL I DESIGN

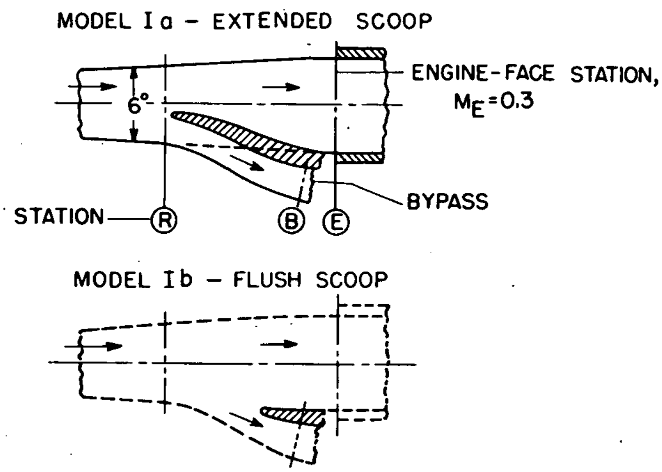

Figure 2

MODEL I VELOCITY PROFILES

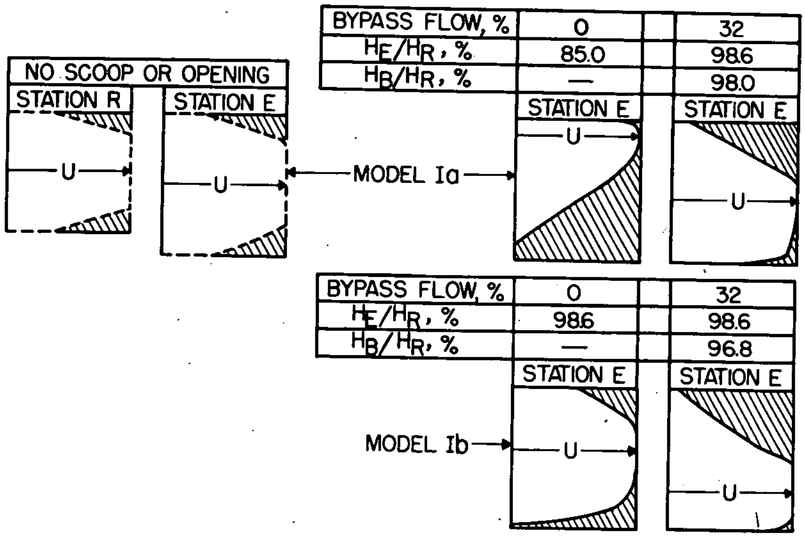

Figure 3

MODEL II DESIGN

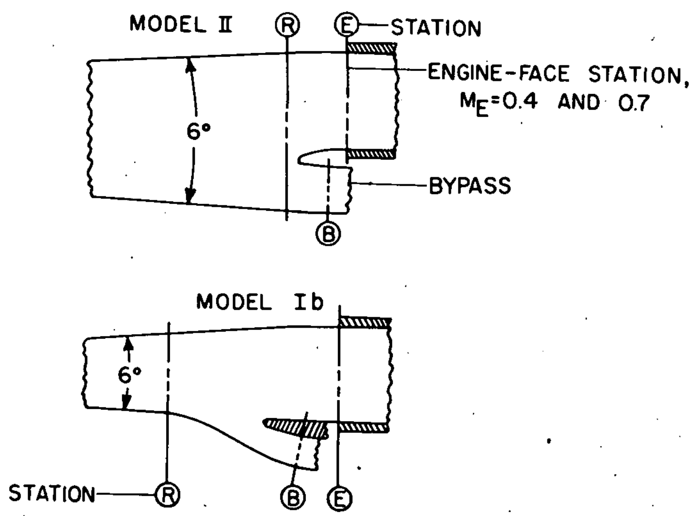

Figure 4

MODEL II VELOCITY PROFILES

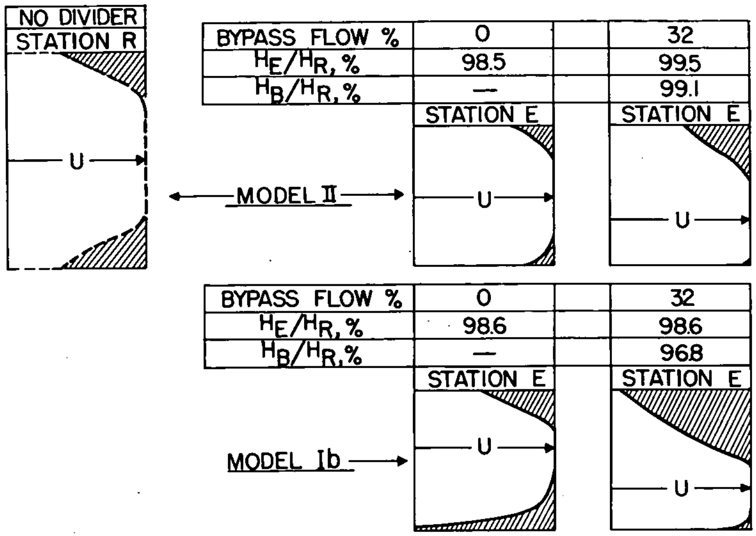

Figure 5

MODEL II VELOCITY PROFILES

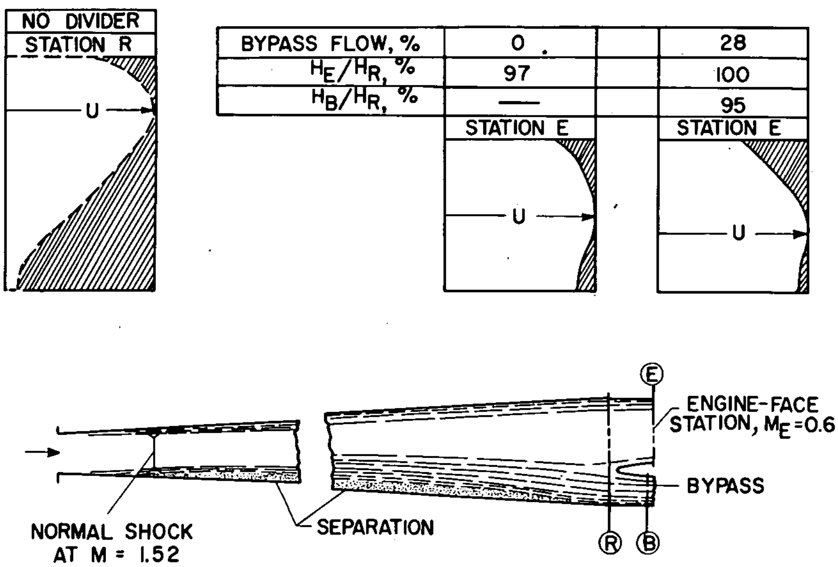

Figure 6

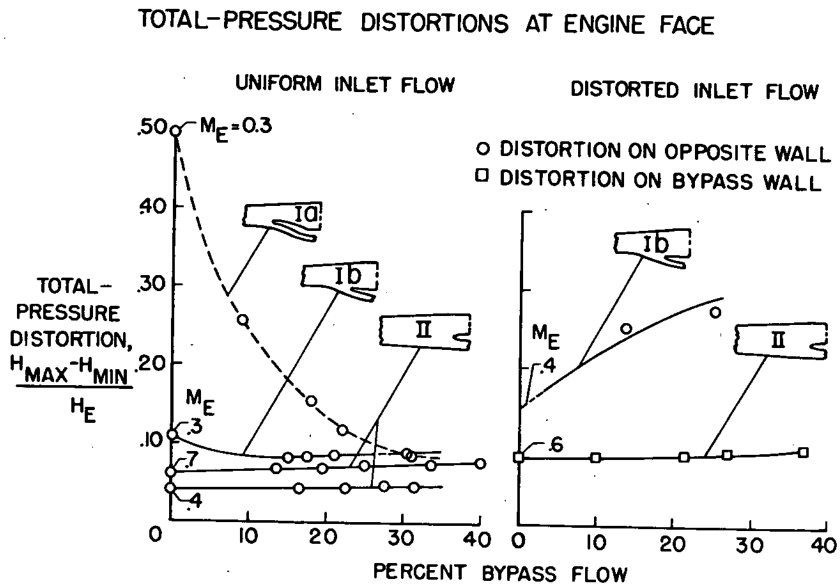
TOTAL-PRESSURE DISTORTIONS AT ENGINE FACE
UNIFORM INLET FLOW
DISTORTED INLET FLOW
O DISTORTION ON OPPOSITE WALL
□ DISTORTION ON BYPASS WALL
TOTAL-PRESSURE DISTORTION, $\frac{H_{MAX}-H_{MIN}}{H_E}$
PERCENT BYPASS FLOW
$M_E = 0.3$
M_E
.3
.7
.4
.6
Ia
Ib
II
0
.10
.20
.30
.40
.50
10
20
30
40

Figure 7