NASA TECHNICAL MEMORANDUM

ADVANCED AUGMENTOR-WING RESEARCH

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SUMMARY

Results of research on advanced augmentors are discussed. Research concerned with performance has indicated that: (1) Augmentors with lobe-type nozzles give higher thrust augmentation than those with slot-type primary nozzles, (2) the thrust of augmentor wings at forward speed is greater than that of internally blown flaps for the speed range of interest, and (3) the optimum augmentor geometry at forward speed may be different from the optimum static geometry. Analysis of augmentor-wing data has shown that the data may be correlated by accounting for the augmentation and entrainment in defining a net thrust coefficient.

INTRODUCTION

Research programs have been conducted both by contractors and by NASA to improve augmentor performance and reduce the noise of the augmentor. This paper will cover only the performance aspects of these studies; however, noise reduction was the major driving force of the study. Specifically, the topics to be covered in this paper are thrust augmentation performance of augmentors designed to be quiet, a comparison of thrust available from conventional jet flaps and the augmentor wing, and thrust correlating parameters.

SYMBOLS

C_D drag coefficient

$C_{D,i}$ induced drag coefficient

$C_{D,o}$ profile drag coefficient

C_J nozzle jet thrust coefficient, $\dfrac{\text{Nozzle thrust}}{q_\infty S}$

$C_{J,net}$ net jet thrust coefficient, $\phi C_J - 2C_q$

C_L lift coefficient

C_q	secondary mass flow coefficient, $\dfrac{\text{Secondary mass flow}}{\rho_\infty V_\infty S}$
h	average nozzle height, cm (in.)
ℓ	flap length, cm (in.)
$\dot{m}$	mass flow rate, kg/sec (lbm/sec)
q_{JET}	nozzle jet dynamic pressure, N/m^2 (lb/ft^2)
q_∞	free-stream dynamic pressure, N/m^2 (lb/ft^2)
S	wing reference area, m^2 (ft^2)
V	velocity, m/sec (ft/sec)
ϕ	thrust augmentation ratio, $\dfrac{\text{Augmentor thrust}}{\text{Nozzle thrust}}$
ρ	density, kg/m^3 $(slugs/ft^3)$

Subscripts:

primary	nozzle
secondary	free-stream air entrained by augmentor
∞	free stream

RESULTS AND DISCUSSION

Development of the slot-type augmentor, shown in figure 1, was begun in the early 1960's by the Canadian Defence Research Board and De Havilland Aircraft of Canada. During the latter part of the 1960's, research on a large scale was conducted at the Ames Research Center with joint Canadian-NASA sponsorship. This work produced an effective augmentor that was appropriate for flight testing but, with the growing emphasis on noise, was too noisy. Research to reduce noise led to studies of multielement nozzles.

Static Performance

At Ames Research Center the performance of multielement nozzles has been studied. This effort led to the nozzle depicted in figure 2. This nozzle has a small continuous slot as well as discrete vertical lobes. Other multielement nozzles may have vertical lobes alone and may have different height and spacing values. The basic difference between the characteristics of the nozzles in figures 1 and 2 is that the lobe nozzle improves mixing by distributing the primary flow over much of the inlet, whereas the slot nozzle is limited to mixing obtained by natural jet spreading.

The maximum static thrust augmentation for the two types of nozzles is shown plotted against the nondimensional mixing length in figure 3. Data for the upper curve were obtained from references 1 to 4 and the present investigation. The lower curve was extracted from some unpublished data. The figure shows that lobe nozzle augmentors give higher thrust augmentation than slot nozzle augmentors at a given value of mixing length.

System studies reported in references 1 to 4 indicate that a typical, quiet, 150-passenger, augmentor-wing STOL would have as much thrust as possible in the nozzles and a resultant nondimensional mixing length of about 50. At that value, figure 3 shows that lobe nozzles give a 50-percent increase in augmentation or a 10-percent increase in thrust compared with slot nozzles.

The manner in which the lobe nozzles increase the thrust augmentation is shown in figure 4, a plot of the exit velocity profiles for the two types of nozzles. Both nozzles are canted 30° so that there is no turning within the augmentor. The primary momentum is approximately the same for each nozzle.

An integration of the two curves would show that the lobe nozzle has greater momentum and mass flow, hence greater thrust augmentation and secondary flow entrainment, than the slot nozzle. Also, because the profile for the lobe nozzle is more uniform, the lobe is more efficient than the slot nozzle and gives greater thrust augmentation per entrained flow.

The static noise characteristics of lobe nozzles are better than those of slot nozzles and are shown in detail in paper no. 31 by Falarski, Aoyagi, and Koenig.

Forward Speed

At forward speed, the augmentor wing is basically an internally blown flap (IBF), hence one would expect their characteristics to be similar. There are, however, two basic differences. First, the augmentor wing lacks strong boundary-layer control on the upper shroud surface, which may lead to shroud flow separation at high flap angles.

Second, the addition of a shroud causes thrust augmentation and secondary flow entrainment much like a propulsive device.

The effect of this last difference is shown in figure 5. This is a plot of nondimensional thrust as a function of nondimensional forward speed for an augmentor wing and an internally blown flap at identical conditions. The data are from references 1 to 4. The shroud forms an ejector and thereby increases thrust at low forward speeds. This thrust due to the augmentor falls off with forward speed due to secondary flow momentum drag. However, for the range of forward speeds from static to takeoff, the augmentor wing has greater net thrust than the internally blown flap. This would result in a smaller required installed thrust for a given mission.

The effect of adding a shroud is also shown in figure 6. The figure shows drag polars from references 1 to 4. All the polars are at the same nozzle thrust coefficient C_J but are at different forward speeds and pressure ratios (PR). The figure indicates that C_J is a reasonable correlating parameter at low forward speeds and pressure ratios, but fails at the higher values of each.

The drag characteristics of the augmentor wing are dependent on the net thrust or the gross augmented thrust minus the secondary flow inlet momentum. The momentum drag can be calculated if it is assumed that the augmentation and entrainment do not change with forward speed, only with pressure ratio, so that the static values may be used. Values of static augmentation and entrainment as a function of pressure ratio are shown in figure 7 for the data in figure 6.

Figure 8 shows the drag equation for the augmentor wing; $C_{D,o}$ and $C_{D,i}$ are the profile and induced drag coefficients, respectively. If the assumptions are correct, subtracting the effects of the augmentor, $-\phi C_J + 2C_q$, from the data of figure 6 should collapse the data to a single line since they have identical profile and induced drags. The right-hand plot of figure 8 indicates that the assumptions were correct. The drag polars are nearly identical; thus, the difference in the drag polars of figure 6 was due to the differences in $\phi C_J - 2C_q$ or $C_{J,net}$ caused by changes in augmentation and entrainment with pressure ratio.

These results indicate that static augmentor results can be used to adjust data for the effect of pressure ratio if $C_{J,net}$ is used for the correlating parameter. This, of course, applies only to data from the same augmentor configuration.

Turning now to lift characteristics, figure 9 shows the effect of some geometry changes on the lift of an augmentor wing at a high flap angle. The normal configuration is similar to the augmentor of reference 5, but with a lobe nozzle. Both lowering the shroud (moving it rearward relative to the flap) and closing the lower gap (practical only

with a lobe nozzle) improve the lift characteristics. Closing the lower gap also improves the lift at low flap angles. Static augmentation is reduced with both these changes.

CONCLUSIONS

From the results and discussion contained in this paper, the following conclusions can be made:

1. Lobe nozzles give higher augmentation than slot nozzles.

2. The thrust of an augmentor wing at forward speed is greater than that of an internally blown flap for the range of interest of thrust coefficients.

3. Augmentor wing drag data should be correlated with a net jet thrust coefficient to account for the augmentation and entrainment.

4. Optimum augmentor geometry at forward speed may be different from optimum static geometry.

REFERENCES

1. O'Keefe, J. V.; and Kelley, G. S.: Design Integration and Noise Studies for Jet STOL Aircraft. Vol. I – Program Summary. D6-40552-1 (Contract NAS2-6344), Boeing Co., May 1972. (Available as NASA CR-114471.)

2. Roepcke, F. A.; and Kelley, G. S.: Design Integration and Noise Studies for Jet STOL Aircraft. Vol. II – System Design and Evaluation Studies. D6-40552-2 (Contract NAS2-6344), Boeing Co., May 1972. (Available as NASA CR-114472.)

3. Campbell, J. M.; Lawrence, R. L.; and O'Keefe, J. V.: Design Integration and Noise Studies for Jet STOL Aircraft. Vol. III – Static Test Program. D6-40552-3 (Contract NAS2-6344), Boeing Co., May 1972. (Available as NASA CR-114473.)

4. Wang, T.; Wright, F.; and Mahal, A.: Design Integration and Noise Studies for Jet STOL Aircraft. Vol. IV – Wind Tunnel Test Program. D6-40552-4 (Contract NAS2-6344), Boeing Co., May 1972. (Available as NASA CR-114474.)

5. Falarski, M. D.; and Koenig, D. G.: Longitudinal and Lateral Stability and Control Characteristics of a Large-Scale Model With a Swept Wing and Augmented Jet Flap. NASA TM X-62,145, 1972.

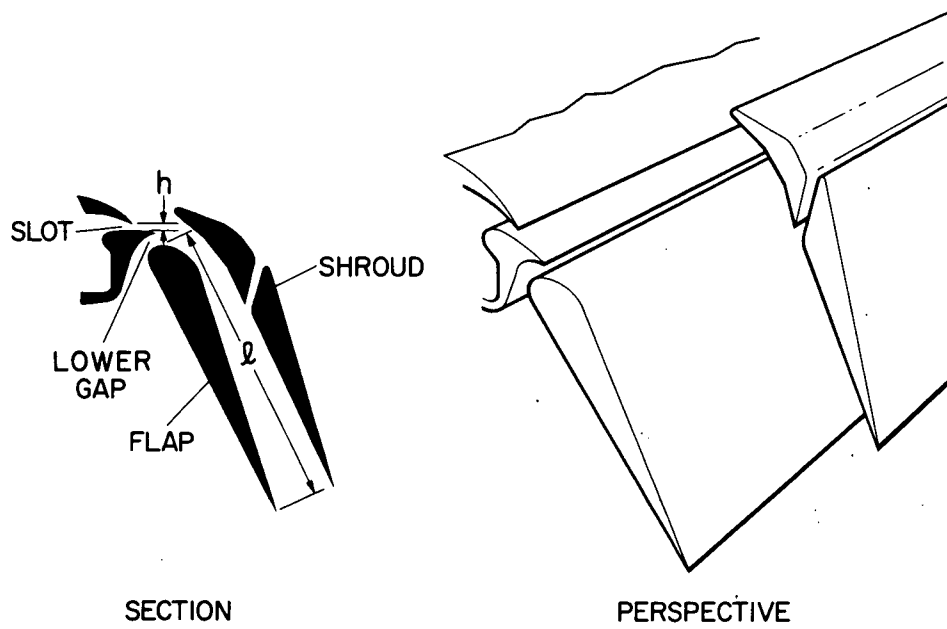# VIEWS OF SLOT NOZZLE AUGMENTOR WING
AMES 40 x 80 SWEPT WING MODEL

SECTION

PERSPECTIVE

Figure 1

VIEWS OF LOBE NOZZLE AUGMENTOR WING
AMES 7 x 10 QUASI 2-D MODEL
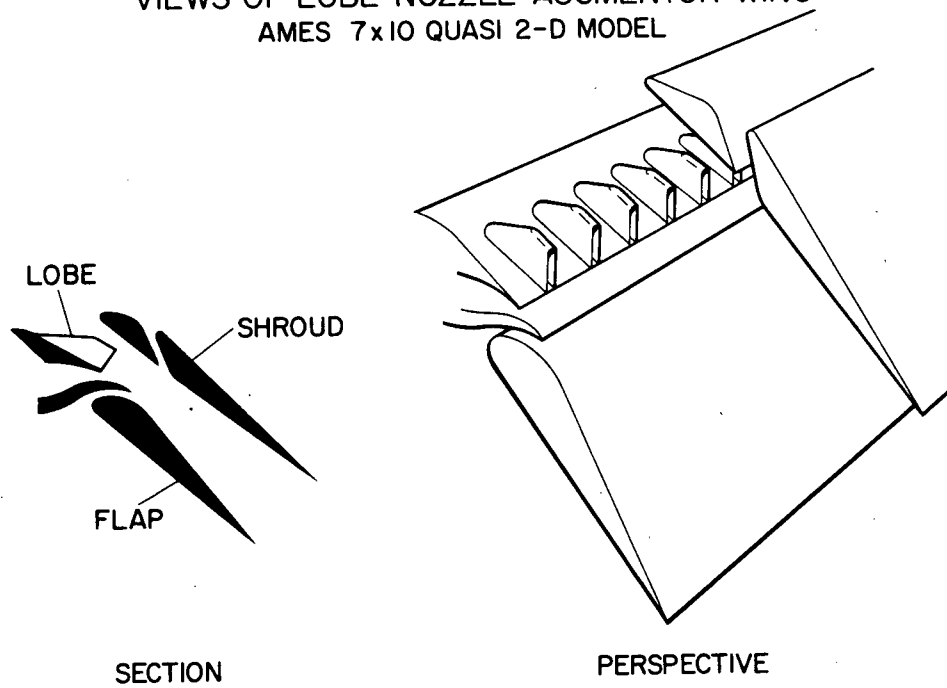

SECTION

PERSPECTIVE

Figure 2

EFFECT OF MIXING LENGTH ON THE MAXIMUM STATIC THRUST AUGMENTATION OF TWO NOZZLE TYPES
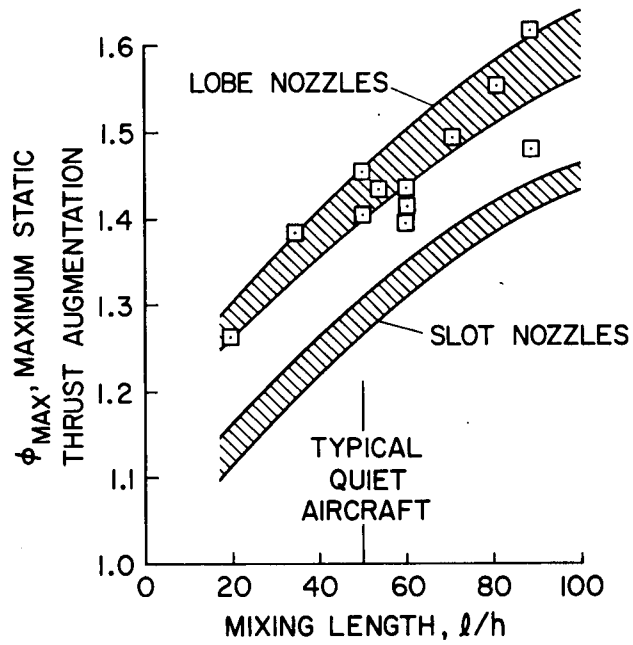

Figure 3

EXIT VELOCITY PROFILES FOR TWO NOZZLES
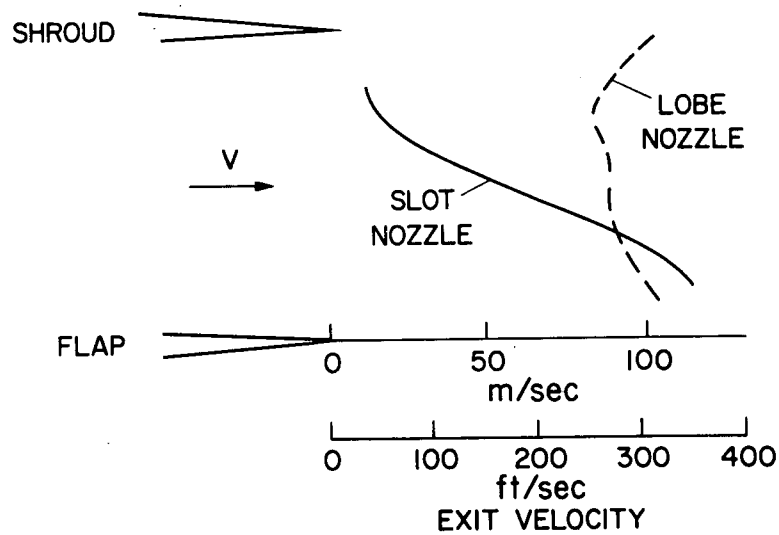### FLAP ANGLE = 30°

Figure 4

COMPARISON OF THRUST LAPSE FOR AUGMENTOR WING AND IBF

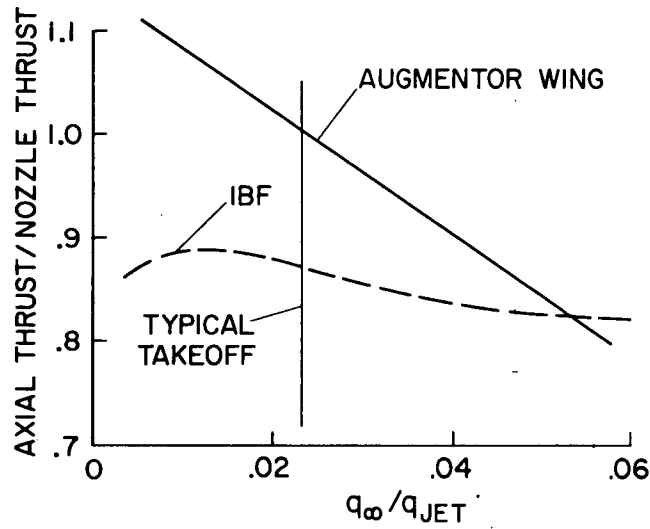$C_L = 3$, FLAP ANGLE = 30°, NOZZLE PRESSURE RATIO = 2.3

Figure 5

DRAG POLARS OF AN AUGMENTOR WING AT SEVERAL FORWARD SPEEDS AND PRESSURE RATIOS
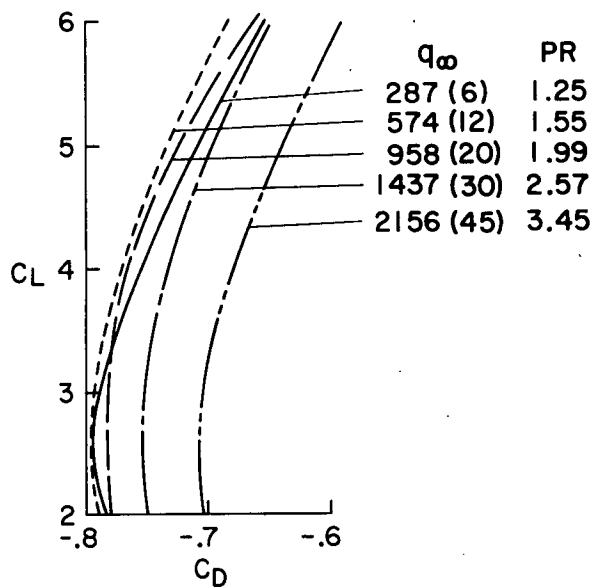
SLOT NOZZLE, FLAP ANGLE = 30°, $C_J = 0.8$

q_∞	PR
287 (6)	1.25
574 (12)	1.55
958 (20)	1.99
1437 (30)	2.57
2156 (45)	3.45

Figure 6

STATIC AUGMENTATION AND ENTRAINMENT CHARACTERISTIC OF SLOT NOZZLE AUGMENTOR WING

FLAP ANGLE = 30°

STATIC THRUST AUGMENTATION RATIO, ϕ

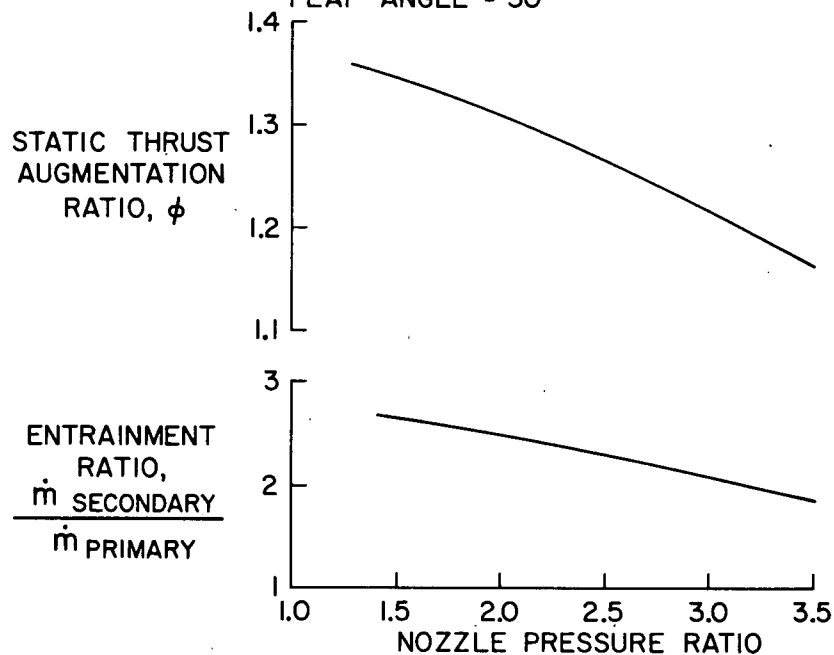ENTRAINMENT RATIO, $\dfrac{\dot{m}\ \text{SECONDARY}}{\dot{m}\ \text{PRIMARY}}$

NOZZLE PRESSURE RATIO

Figure 7

DRAG EQUATION OF AUGMENTOR WING

$$C_D = -\phi C_J + 2C_q + C_{D,o} + C_{D,i}$$

$$2C_q = \frac{V_\infty\ (\text{SECONDARY MASS FLOW})}{q_\infty\ S}$$

ϕ, C_q ARE COMPUTED USING STATIC DATA

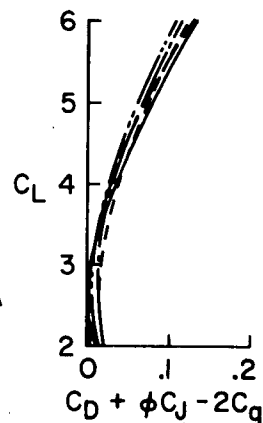## CORRELATION OF DRAG POLARS

C_L

$C_D + \phi C_J - 2C_q$

Figure 8

EFFECT OF GEOMETRY CHANGES ON LIFT
CHARACTERISTICS OF AUGMENTOR WING
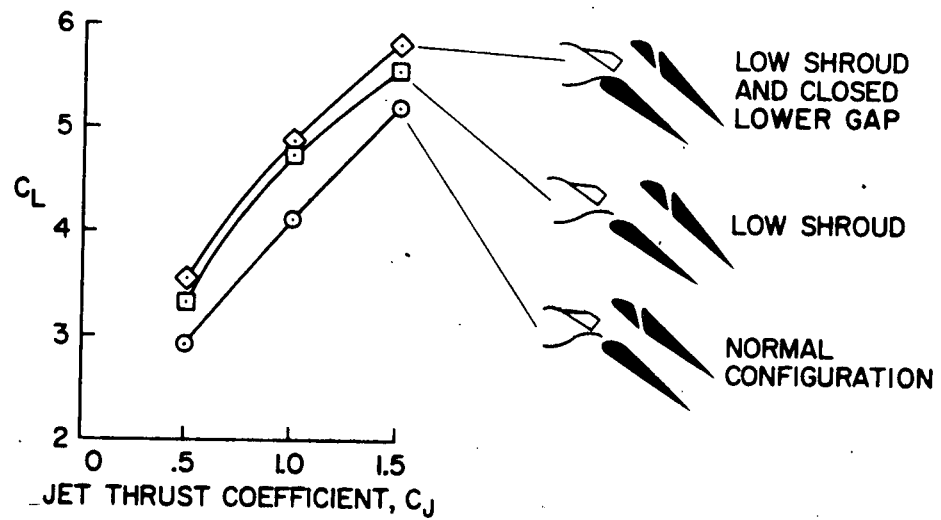LOBE NOZZLE, FLAP ANGLE = 60°, ANGLE OF ATTACK = 0°

Figure 9