

16. JET-EXIT AND AIRFRAME INTERFERENCE STUDIES ON TWIN-ENGINE-FUSELAGE

AIRCRAFT INSTALLATIONS

By Jack F. Runckel
NASA Langley Research Center

SUMMARY

Jet interference effects on the drag and on the nozzle-afterbody performance of twin-engine-fuselage aircraft configured for a Mach number 1.2 mission are discussed. A detailed tailoring of the afterbody with the nozzles is required to obtain the best afterbody thrust-minus-drag performance. Performance improvements were obtained for a model of an aircraft under development by increasing the afterbody length relative to the jet exits by the addition of volume between and around the jet exhausts.

INTRODUCTION

In paper no. 15, Corson and Schmeer presented the off-design problems of isolated nozzles and indicated that sizable nozzle performance penalties are associated with the installation of the exhaust system in an airplane. The present paper is concerned with the combined nozzle-afterbody performance of twin-engine-fuselage aircraft specifically designed to operate at a Mach number of 1.2; such aircraft might be required for a high-speed sea-level dash.

Jet exits on single-engine-fuselage airplanes are usually located at the end of the afterbody, and jet interference effects are usually confined to a small region near the jet exhaust. Corson and Schmeer in paper no. 15 referred to several jet-airframe interference studies on single-engine airplane models. Twin-engine aircraft can have the jet exits located either at the terminal section of the fuselage (refs. 1 to 6) or forward on the fuselage (refs. 7 to 13). In either instance, the arrangement used to provide aft-end closure of the fuselage ahead of and between the engines determines the magnitude of jet-airframe interference and has an appreciable effect on the configuration drag (refs. 9, 10, and 13 to 15). The jet exhausts can also affect the airplane stability (refs. 8 to 13), the local loading and skin temperatures (refs. 7 to 13), and the base pressures (paper no. 15 and refs. 1 to 3, 6, 8 to 11, and 13).

SYMBOLS

C_p	pressure coefficient
D	drag
D/q	drag coefficient based on unit wing area
d_e	diameter of nozzle shroud exit
d_p	diameter of primary nozzle
F	total gross thrust force
$\frac{F - D}{F_i}$	ratio of total gross thrust minus drag aft of separation line to ideal thrust of both primary nozzles
F_i	ideal isentropic thrust of both primary nozzles
M	free-stream Mach number
$P_{t,j}$	jet total pressure
p_∞	free-stream static pressure
q	free-stream dynamic pressure
x	distance from primary-nozzle or shroud exit

DISCUSSION

Afterbody Drag

It is known that a large amount of the total drag can occur on the afterbody (ref. 16). This situation is particularly serious at transonic speeds where the boattail drag and base drag coefficients are usually maximum (refs. 2, 6, and 17 to 21). Two examples of twin-engine configurations will be discussed to illustrate the magnitude of afterbody drag on this type of aircraft.

A technique for measuring the afterbody drag of aircraft models with jet-power simulation was developed in the Langley 16-foot transonic tunnel (ref. 22). The main features of this system can be examined in figure 1. The photograph shows a research model supported by an underneath sting and a thin strut attached to the forebody to minimize support-system interference. The forebody and wings, which were swept back 108° , provided the correct simulated flow field over the afterbody and propulsion system. The wing tips overlapped but did not touch the afterbody. The model was separated just ahead of the horizontal tails (66-percent-length station) and sealed, and the rear section including the tails

was attached to an internal strain-gage balance. The long engine interfairing was designed to improve the area progression at the rear of the model (refs. 13, 14, and 23).

A powered model of an aircraft under development, which was supported in a similar manner, is shown in figure 2. The wings were swept back 72.5° , and the engine interfairing terminated near the jet exits. Horizontal-tail fairings were located adjacent to both engine nozzles. The separation line was again directly ahead of the horizontal tails at 74 percent of the model length. Force and pressure measurements were obtained on the rear section of the model, with primary and secondary flows in the ejector nozzles and bleed flow at a step exit on the afterbody boattail being controlled variables. Nozzle-afterbody thrust-minus-drag performance will be presented in a subsequent section. It should be noted that the performance ratio used in this paper includes the drag of the afterbody, tails, and nozzle surfaces; therefore, the values of the performance parameter in the present paper are lower than those presented by Corson and Schmeer in paper no. 15.

Both the research and the development models had the inlets faired over. Separate investigations were conducted to determine the effect of fairing over the inlets (ref. 22, for example), and the interference on the afterbody was found to be negligible. The engine exhausts were simulated with hot jets by using the technique described in reference 24.

Comparisons of the afterbody drag of the two configurations (figs. 1 and 2) relative to the drag coefficient of the complete models are presented in figure 3 for a Mach number of 1.2 at sea level and adjusted for full-scale Reynolds numbers. The afterbody of the research model, shown crosshatched, comprised about one-third of the body length and contained about 36 percent of the total wetted area. The bar next to this model represents the drag coefficient of the entire configuration based on unit area. With the jets operating at a typical turbofan pressure ratio at a Mach number of 1.2, the afterbody drag was 41 percent of the total drag.

The afterbody of the development model comprised only one-fourth of the complete model length but had about 39 percent of the total wetted area. The afterbody drag, for the same operating conditions, was 46 percent of the complete model drag. These results show that a large percentage of the total drag occurs on a relatively small portion of the afterbody of twin-engine aircraft configurations.

Afterbody Closure

Several areas on twin-engine-fuselage airplanes are known to be sensitive to jet interference effects. Among these are the afterbody boattail (refs. 9 and 13), tail surfaces (refs. 10 and 11), and fuselage bases (refs. 2, 5, 6, and 10). Inasmuch as the afterbody of an aircraft may be a region of high local drag, an examination of the afterbody of a twin-engine aircraft was made to determine whether detailed tailoring would render better performance. A basic difference in the two configurations of figures 1 and 2 is the way the body

between the engine nozzles is designed. This terminal section is called the engine interfairing.

Pressure distributions on the interfairings of the two configurations are shown in figure 4. The nozzle exits, indicated by the diameter d_e , are located at the reference station 0 on the abscissa. The axial distance x from the exit is given in exit diameters. Pressure measurements are shown for the row of orifices closest to the center line of the exhaust nozzles.

The research model had a long interfairing extending downstream of the jet exits. The results obtained with the jets off indicate a gradual pressure recovery from low pressures near the engine base region. With the jets on, the interference was generally favorable, increasing the pressures to a positive value and causing thrust on part of the interfairing (ref. 22).

The wedge-shape interfairing on the development model was mostly ahead of the jet exit station. The interfairing pressures of this model were lower than those of the research model with the jets off. Jet operation produced a relatively small increase in pressure, an indication that the region between the engines remains an effective base drag area.

These results prompted an investigation of the flow field behind the aft end of the development model. An axial static probe was extended downstream of the model along the center line to measure pressures behind the model. The results are given in figure 5. The pressures obtained with the jets both off and on again show low pressures on the interfairing; however, an abrupt rise which occurred in pressure directly behind the model indicates that extending the fuselage volume into this greater-than-free-stream pressure field would probably reduce afterbody drag.

Engine-Interfairing Studies

Past work has shown that configurations with jets exhausting alongside aft-sloping fuselage surfaces have had favorable jet interference effects on drag; that is, jet operation increased the local pressures in the regions adjacent to and downstream of the jet exits (paper no. 15 and refs. 8 to 13). Usually, excess low-energy internal air is available near the nozzle, and this dumped air can provide a cooling film between the hot exhaust and the fuselage skin (refs. 5 and 10). The results of reference 15 indicate that axial-force reduction by interference between a jet and a neighboring afterbody would be large at supersonic speeds. In addition, an extension of the interfairing would improve the area progression (refs. 4, 14, and 23) and probably would reduce the wave drag.

The rest of this paper will be concerned with only the development model, and the discussion will be confined to performance at a Mach number of 1.2. The first attempt to improve the afterbody performance involved an increase in interfairing length and a volume addition, as is shown in figure 6. A blow-in-door nozzle which had the doors closed next to the interfairing and tail fairings was utilized to allow for maximum volume between the nozzles. The

nozzle-afterbody performance parameter $\frac{F - D}{F_1}$ is the ratio of the total gross thrust minus the drag aft of the line of separation to the ideal thrust of the two primary nozzles. This ratio includes changes in both nozzle performance and afterbody drag due to interfairing differences and jet interference effects. The performance of the two configurations is plotted as a function of jet pressure ratio for identical internal and external flow conditions. These and all subsequent data are presented for zero secondary airflow and a corrected bleed-flow ratio of about 8 percent.

The gain in performance for the configuration with the extended interfairing is about 5 percent. This performance gain is equivalent to about a 30-count decrease in drag coefficient for the airplane model. It is apparent that major gains in performance are possible by working on the nozzle-afterbody region of twin-engine-fuselage aircraft.

The initial improvement in performance obtained with an extended interfairing led to further work to explore this concept. An investigation was conducted to determine the effect of engine interfairing and aft-end changes on the performance of the model with a short, small-diameter nozzle shroud. The results are presented in figure 7. Incremental nozzle-afterbody performance gains are plotted as a function of interfairing length in primary-nozzle diameters. The primary-nozzle diameter was constant for these and subsequent data and corresponded to the scaled nozzle area required for the 1.2 Mach number sea-level dash. The jet pressure ratio was about 3.4 for all configurations. Shown in figure 7 are interfairings of short (① and ⑥), medium (② and ④), and long (③ and ⑤) extensions.

The interfairing-length differences are shown in the photographs in figure 8. The basic short interfairing is shown in the picture on the left, the medium extension of the interfairing is presented in the center photograph, and the long interfairing is shown on the right. The performance of these configurations (fig. 7), indicated by numbers ①, ②, and ③, respectively, shows that a medium extension of the interfairing (configuration ②) produced a performance gain of over 2 percent. A further increase in length to the long interfairing (configuration ③) gave an additional gain of 1 percent. The increase in performance with increasing interfairing length indicates that adding length downstream of the jet exits can provide performance improvements due to better closure, a more favorable flow field, and more favorable jet interference effects.

The numbers ④ and ⑤ in figure 7 represent configurations having the same medium and long interfairings as those indicated by the numbers ② and ③, respectively. The differences in these configurations are shown in the photographs in figure 9. Additional volume was added around the nozzles by installing larger tail fairings which house the horizontal-tail mechanism. The small tail fairings on the medium- and long-interfairing configurations are shown in the bottom pictures and the large tail fairings on the same configurations are shown in the photographs at the top.

The larger tail fairings provided further substantial increases in performance, as shown by the data points for configurations ④ and ⑤ in figure 7.

The use of tail fairings to reduce transonic drag through favorable jet interference and application of the area rule are discussed in reference 14.

A different approach was also tried by using a concave-base interfairing concept based on the concave-base plug nozzle (ref. 25). Figure 10 shows the concave-base interfairing concept. The long interfairing shown on the left was cut-off at about the same length as the basic interfairing (right photograph), and the base was recessed, as shown in the center (configuration ⑥). The cut-off interfairing is essentially a volume addition relative to the basic interfairing since it brings the interfairing surfaces closer to the jet exits. The performance of this configuration, shown by the number ⑥ in figure 7, was equal to that of the model with the long interfairing (configuration ③). Although the cut-off configuration was about the same length as the basic configuration, the pressure coefficients on the sides and base of the concave-base interfairing (configuration ⑥) were higher than those of the wedge-shape interfairing (configuration ①) and, therefore, the effective base drag of the cut-off configuration was lower.

The results presented in figure 7 indicate that adding length to and/or volume between the short, small-diameter nozzles provided performance improvements relative to the model with the basic interfairing. The main benefits are believed to be caused by more favorable jet interference effects and lower slopes on the afterbody between the engines for the altered configurations. Of course, there are compensating problems, such as weight and balance, added skin friction, and high local skin temperatures, which must be considered in making aft-end changes.

Nozzle-Afterbody Integration

Other work on nozzle sizing indicated that nozzles having larger diameters than those previously discussed would provide better performance. Models designed to integrate a large-diameter shroud with a long interfairing were investigated and the results are compared in figure 11. The performance and length parameters are the same as those of figure 7. The reference level of performance is again that of the short, small-diameter nozzle with the basic interfairing, indicated by the solid circle (configuration ①). The open symbols represent the large-diameter shrouds. The squares represent configurations with long, large-diameter nozzles, such as those shown in figure 2.

Some of the large-diameter nozzle-afterbody combinations are shown in figure 12. The long nozzle with the basic interfairing is shown in the left picture. This configuration had almost 2-percent better performance than the reference nozzle, as indicated by the square directly above the solid symbol in figure 11.

The addition of a long interfairing to the long nozzle (square symbol at $x/d_p = 3.25$) provided a gain in performance of about 1 percent. Shortening the nozzle with the same long interfairing provided an additional gain, as indicated by the diamond-shape symbol. This configuration is shown in the center photograph of figure 12. These results are consistent with those shown in figure 7

since shortening the nozzle with the same length interfairing exposes a greater portion of the interfairing to favorable jet interference effects.

The terminal-fairing nozzle shown in the right photograph in figure 12 represents a more complete integration of the nozzle with the afterbody. This concept (ref. 26) has been discussed by Corson and Schmeer in paper no. 15. The terminal-fairing nozzle maintained the diameters and blow-in-door features of the large nozzle, but had a short, fixed shroud. A photograph of the terminal-fairing nozzle configuration is presented on the right-hand side of figure 12. This nozzle-afterbody combination had a large-volume interfairing and utilized the interfairing (refs. 27 and 28) and tail fairing (ref. 14) as part of the nozzle surface. The nozzle had eight terminal bodies, and the open spaces between the terminal fairings allowed ventilation between the jet and the free stream.

The performance of the terminal-fairing configuration is shown by the triangle-shape symbol in figure 11. This combination produced the highest nozzle-afterbody performance at Mach 1.2 of the large-shroud-nozzle-afterbody models investigated. The data presented by Corson and Schmeer in paper no. 15 and the results of reference 15, which indicate favorable jet interference effects at supersonic speeds, indicate that the supersonic performance of this configuration would also be good. (See ref. 27.)

CONCLUDING REMARKS

The results presented indicate that a relatively large amount of the total drag, of the order of 40 to 50 percent, occurs on the aft end of twin-engine-fuselage aircraft at transonic speeds. The performance of configurations with jet exits at the rear of the afterbody may be improved by increasing the afterbody length relative to the jet exits by the addition of volume between and around the jet exhausts. A detailed tailoring of the afterbody with the nozzles is required to obtain the best afterbody thrust-minus-drag performance. Of course, there are compensating problems, such as weight and balance, added skin friction, and high local skin temperatures, which must be considered in making aft-end changes. The cutoff large-volume interfairing represents a possible compromise.

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RESEARCH MODEL

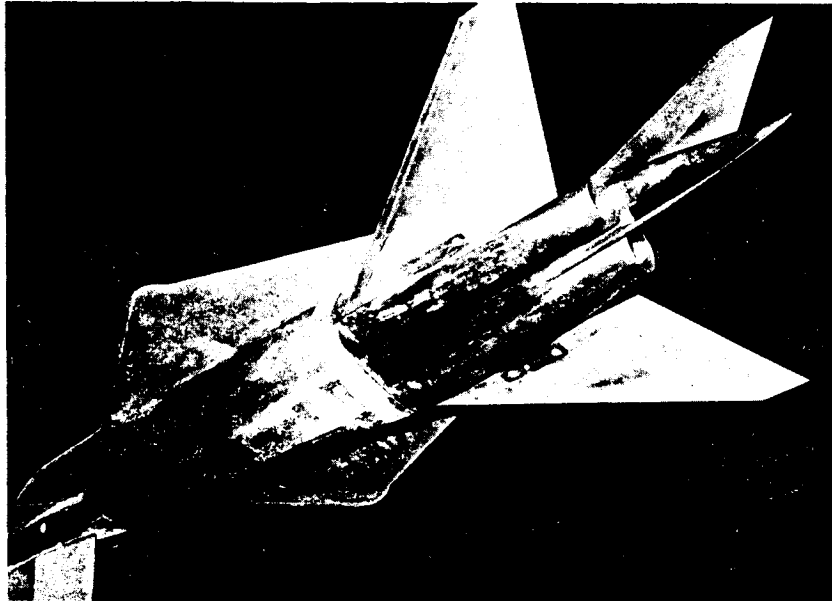


Figure 1

L-2681-1

DEVELOPMENT MODEL

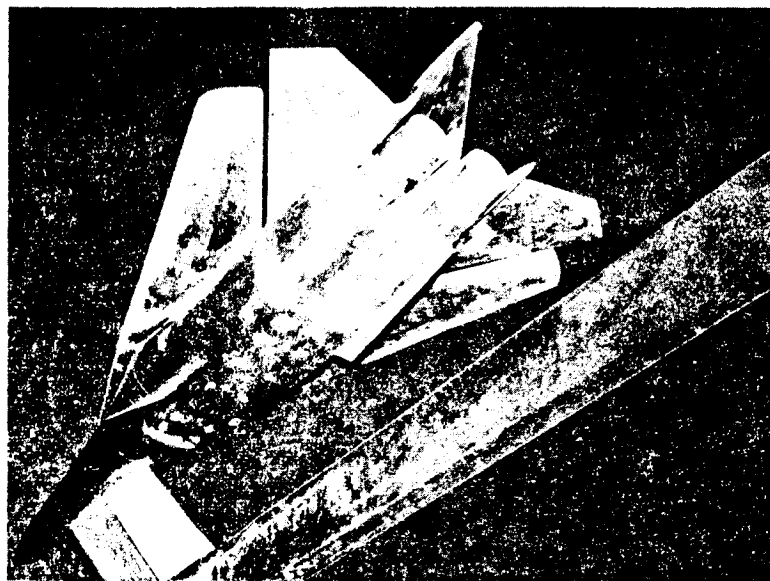


Figure 2

L-2681-2

COMPARISON OF TOTAL AND AFT-END DRAG

M = 1.2 AT SEA LEVEL

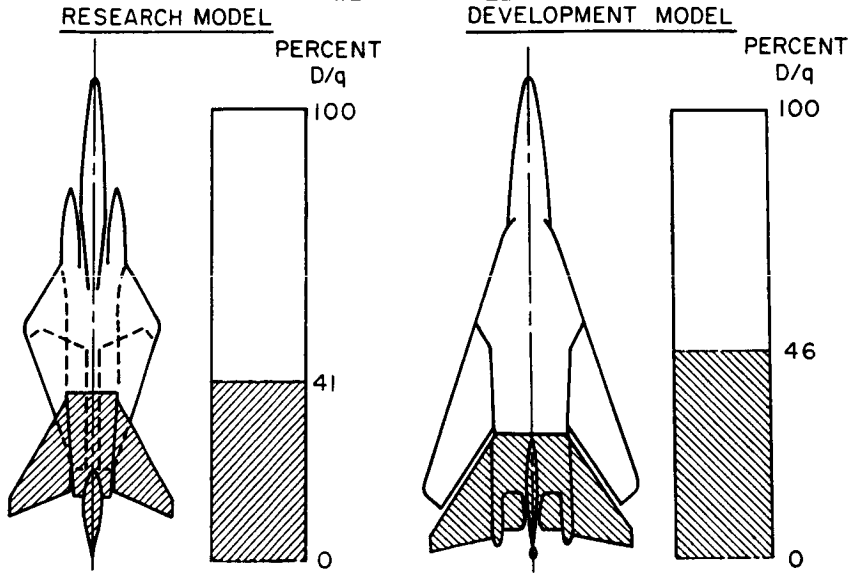


Figure 3

ENGINE INTERFAIRING PRESSURE DISTRIBUTIONS

M = 1.2

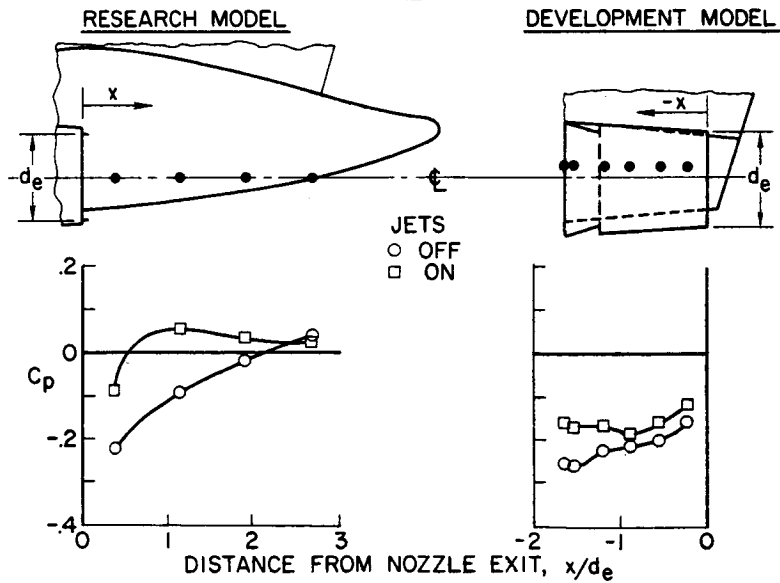


Figure 4

FLOW-FIELD STATIC-PRESSURE DISTRIBUTIONS
M = 1.2

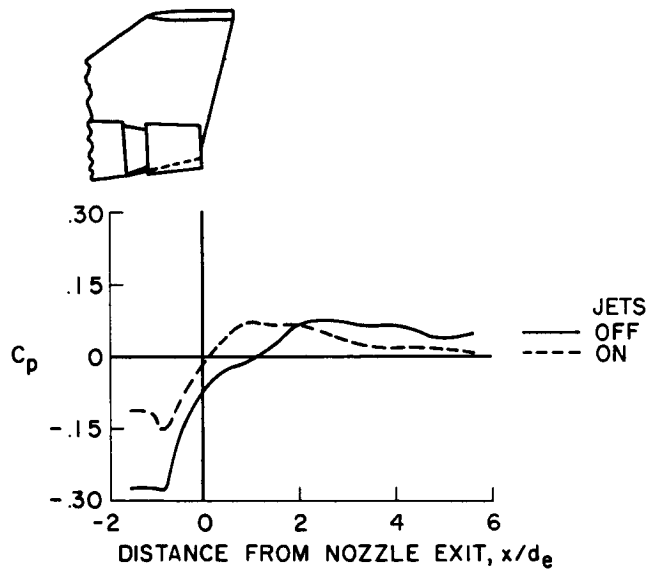


Figure 5

PERFORMANCE OF
BASIC- AND EXTENDED-INTERFAIRING CONFIGURATIONS
M=1.2

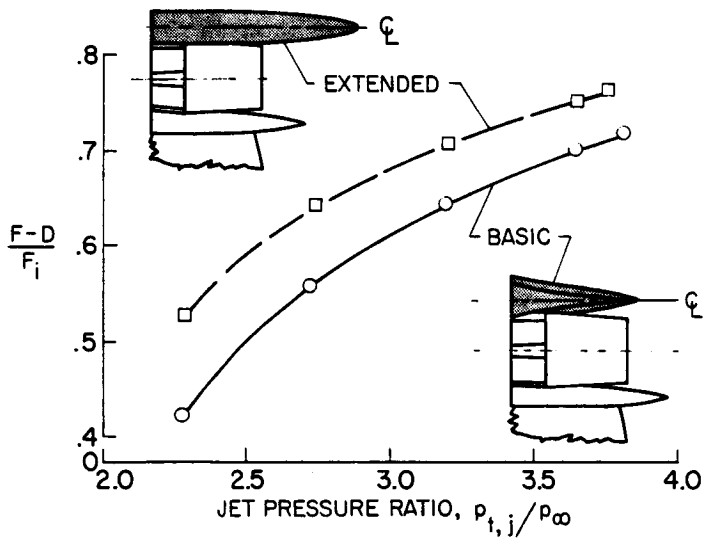


Figure 6

EFFECT OF AFTERBODY LENGTH AND VOLUME
M=1.2; SHORT SMALL-DIAMETER NOZZLE SHROUD

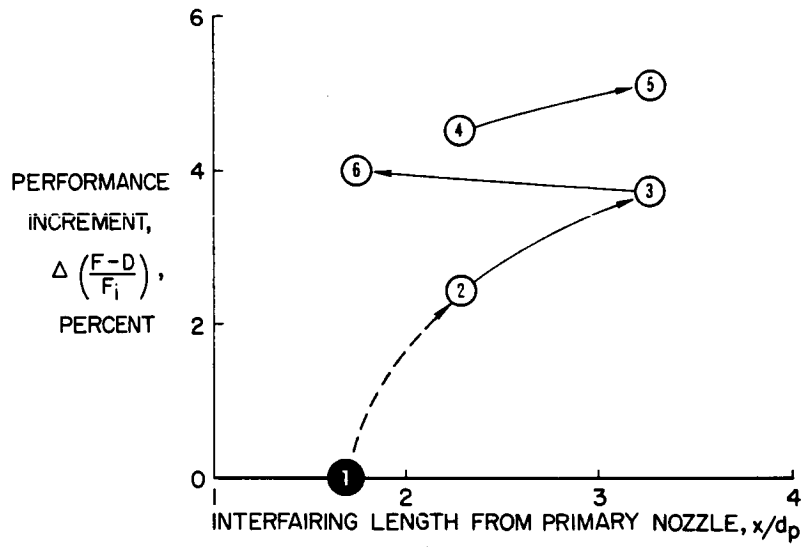


Figure 7

INTERFAIRING EXTENSIONS

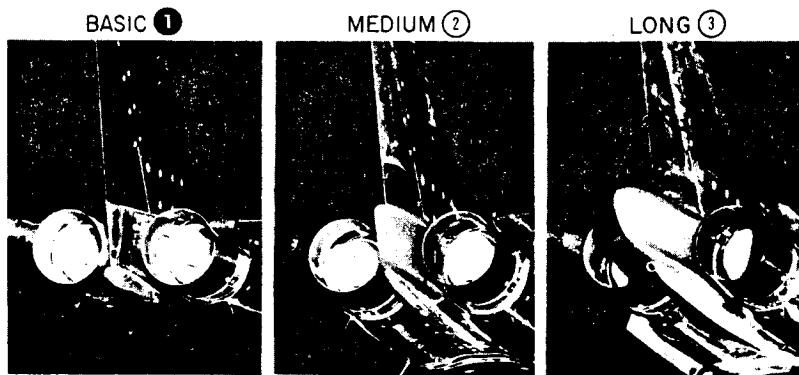
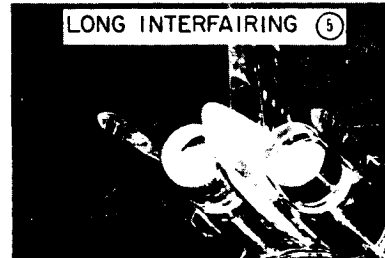
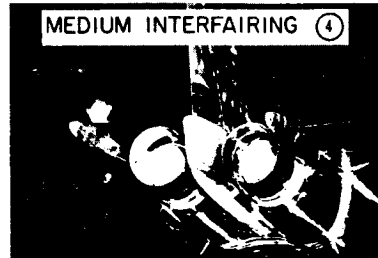


Figure 8

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TAIL FAIRINGS

LARGE



SMALL

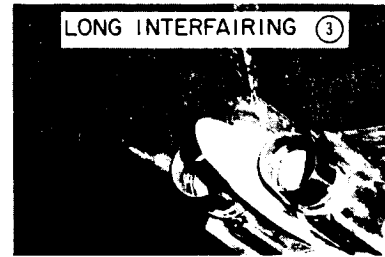
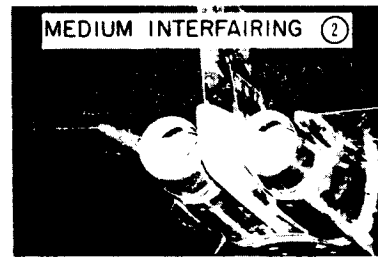


Figure 9

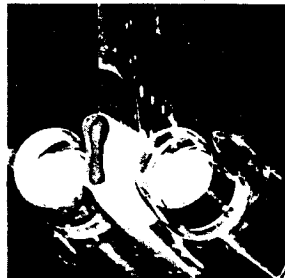
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INTERFAIRINGS

LONG ③



CUT-OFF ⑥



BASIC ①

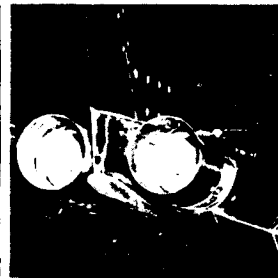


Figure 10

L-2681-10

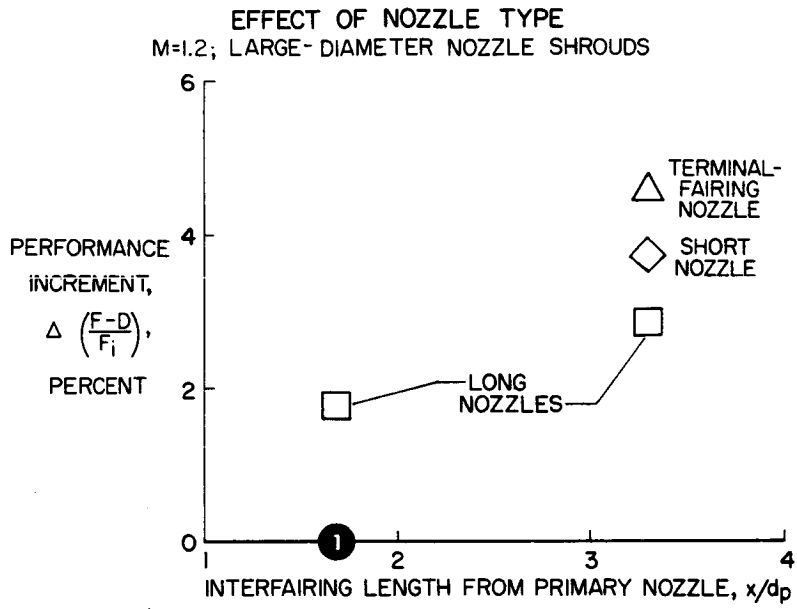


Figure 11

LARGE-DIAMETER NOZZLE SHROUDS

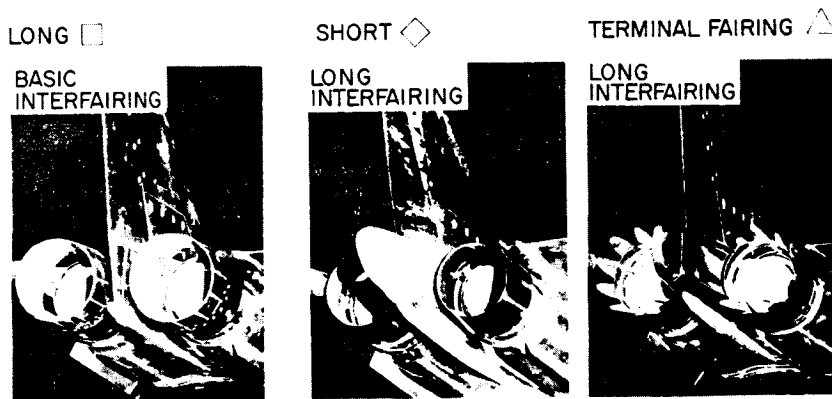


Figure 12

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