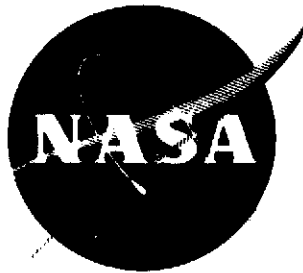


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THE RESULTS OF LOW-SPEED WIND TUNNEL TESTS TO
INVESTIGATE THE EFFECTS OF THE NASA REFAN JT8D
ENGINE NACELLES ON THE STABILITY AND CONTROL

CHARACTERISTICS OF THE BOEING 727-200

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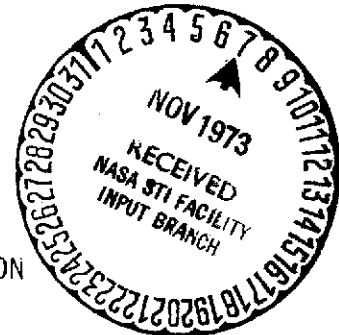
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by M. D. Shirkey

BOEING COMMERCIAL AIRPLANE COMPANY
A DIVISION OF
THE BOEING COMPANY

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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16. Abstract <p>This report presents the results from two low-speed wind tunnel tests of the Boeing 727-200 airplane as configured with the NASA refan JT8D-109 turbofan engines. The tests were conducted by the Flight Controls Technology Staff of the Boeing Commercial Airplane Company in support of Phase I and Phase II of the Program on Ground Test of Modified, Quiet, Clean JT3D and JT8D Turbofan Engines in Their Respective Nacelles. The objective of these tests was to determine the effects of the refan installation on the low-speed stability and control characteristics of the 727 airplane. Four side nacelle locations were tested to insure that aerodynamic interactions of the nacelles and empennage would be optimized. The optimum location was judged to be the same as that of the production JT8D-9 engines; the current production engine mounts can be used for this location. Some small changes in the basic airplane characteristics are attributable to the refan nacelles. The flaps up longitudinal and lateral-directional stability are both slightly increased for low angles of attack and sideslip respectively. The longitudinal stability at stall is improved for both the flaps up and landing flap configurations. The high attitude characteristics of the basic airplane are not significantly altered by the refan nacelle installation. Directional control capability is not affected by the refan nacelles</p>					
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FOREWORD

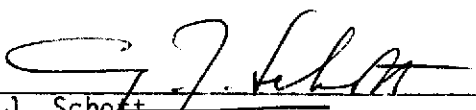
The low-speed wind tunnel tests described in this report were performed by the Flight Controls Technology Staff of the Boeing Commercial Airplane Company, a division of The Boeing Company, Seattle, Washington. The work, sponsored by NASA Lewis Research Center and reported herein, was performed between May and August 1973.

This report has been reviewed and is approved by:



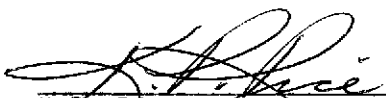
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DATE NOV 27 1973



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1.0 SUMMARY

Two low-speed wind tunnel tests of the Boeing 727 airplane were conducted in support of the NASA Refan Program. The purpose of these tests was to investigate the effects of the larger refan nacelles on the stability and control characteristics of the 727 airplane and to determine an optimum location for the refan side nacelles. Four nacelle locations were tested.

The following were concluded from these tests:

1. The optimum location for the JT8D-109 NASA Refan Nacelle is the same as the production JT8D-9 nacelle location.
2. The small improvement in pre-stall longitudinal stability and the slight degradation at very high angles of attack will not significantly alter the low-speed flying qualities of the basic 727 airplane.
3. The low-speed lateral-directional static stability of the refan airplane will be essentially the same as the basic 727.
4. Low-speed directional control characteristics of the 727 will not be affected by the refan installation.

The Pratt & Whitney Aircraft JT8D-109 engine is a derivative of the basic JT8D-9 turbofan engine, modified to incorporate a new, larger diameter, single-stage fan with a bypass ratio of 2.03 and two supercharging low-pressure compressor stages. The modification gives lower jet noise, increased takeoff and cruise thrust, and lower specific fuel consumption. The use of the JT8D-109 engine on the Boeing 727 airplane will require enlarged side engine nacelles and center engine inlet, referred to as the NASA Refan Configuration.

Previous wind tunnel testing has shown that aft body mounted nacelles on a T-tail transport can have a significant effect on the longitudinal and lateral-directional stability and control characteristics. This effect consists of two parts: aerodynamic forces on the nacelle itself and interference effects between the nacelles and the empennage. The relative magnitude of the effect is a function of nacelle size and the location of the nacelle relative to the vertical and horizontal tails, the body, and wing. It is also a function of both angle of attack and sideslip.

In the pitch axis, larger nacelles tend to increase the stability at low angles of attack. At higher, post-stall α 's the increased interference tends to reduce stabilizer and elevator effectiveness.

In the yaw axis, the larger nacelles and center engine inlet can reduce the effectiveness of the vertical tail and rudder due to increased interference effects .

Due to the complex nature of these effects, wind tunnel testing was required to determine the influence of the larger NASA Refan nacelles on the longitudinal and lateral-directional characteristics of the 727 airplane. The low-speed longitudinal characteristics were evaluated in the 20 x 20 foot (6.10 x 6.10 meter) Boeing Vertol Wind Tunnel (BVWT) during May and June 1973. Four different NASA Refan locations, all on the aft body, were tested and compared with the production JT8D nacelle. The low-speed lateral-directional characteristics were evaluated at the University of Washington Aeronautical Laboratory (UWAL) 8 x 12 foot (2.44 x 3.66 meter) wind tunnel in August 1973.

Only the most favorable NASA Refan location as determined at BVWT was tested and compared with the production JT8D nacelle in the second (UWAL) test.

The effect of the refan nacelles on the low-speed stability and control characteristics of the 727-200 airplane as determined from these tests is the subject of this report.

3.0 NOMENCLATURE

b	Wing span
BVWT	Boeing Vertol Wind Tunnel
\bar{c}	Mean aerodynamic chord of the wing
c.g.	center of gravity
C_L	Airplane lift coefficient, lift/ qS_w
$C_{l\beta}$	Rolling moment coefficient, $\frac{\text{rolling moment}}{qS_w b}$, positive right wing down
$C_{m.25\bar{c}}$	Pitching moment coefficient about the quarter MAC, $\frac{\text{pitching moment}}{qS_w \bar{c}}$, positive airplane nose up
$C_{m\alpha}$	Variation of pitching moment with angle of attack, $\frac{\partial C_m}{\partial \alpha}$
$C_{n.25\bar{c}}$	Yawing moment coefficient about the quarter MAC, $\frac{\text{yawing moment}}{qS_w b}$
C_y	Side force coefficient, $\frac{\text{side force}}{qS_w}$
D_{HI}	Nacelle Highlight Diameter
D_{max}	Nacelle maximum diameter
D_N	Nozzle exit diameter
D_{TH}	Nacelle throat diameter
MAC	Mean aerodynamic chord
N/m^2	Pressure in Newtons per square meter
psf	Pressure in pounds per square foot
q	Freestream dynamic pressure
$\Delta\omega_{cp}$	Horizontal stabilizer position relative to the wing chord plane, degrees - positive trailing edge down
S_w	Wing reference area
UWAL	University of Washington Aeronautical Laboratory

wcp	wing chord plane
X	Length of maximum nacelle section
α	Angle of attack, degrees
α_{wcp}	Wing angle of attack, degrees
β	Angle of sideslip, degrees
δ_e	Elevator deflection, degrees - positive trailing edge down
δ_R	Rudder deflection, degrees - positive trailing edge left
θ	Nacelle boattail angle, degrees.

4.0 MODEL AND TEST DESCRIPTION

4.1 MODEL DESCRIPTION

4.1.1 BASIC MODEL

A 7.5 percent scale model of the Boeing 727-200 airplane was used in low-speed wind tunnel tests of the NASA Refan nacelle configuration. A three-view drawing of the 727-200/NASA Refan configuration is shown in Figure 1.

The model designated TX-549I-1 was sting mounted with an internal strain gauge balance for testing at Boeing Vertol as shown in Figure 2. The model designated TX-549E-34 was strut mounted with an external balance for the University of Washington testing as shown in Figure 3. The basic model was modified to accept the NASA Refan nacelles and center engine inlet.

4.1.2 NACELLE GEOMETRY

The JT8D-109 NASA Refan engine requires a larger nacelle due to its higher bypass ratio. The geometry of the NASA Refan and the basic 727 nacelles as tested is shown in Figure 4. The side nacelles were of the flow-through type and the center engine inlet was plugged. The exit diameter of the side nacelles tested was enlarged from that of the actual nacelles to more correctly simulate the inlet flow field and its interaction with the empennage.

A plugged center engine inlet configuration was tested for two reasons. First, the sting mount at BVWT precluded the use of a flow-through design for the longitudinal testing. Second, previous wind tunnel testing has shown the effects of the inlet plug to be negligible in both pitch and yaw.

4.1.3 NACELLE INSTALLATION COMPARISON

The NASA Refan side nacelles were tested in four different locations. The plugged center engine inlet was tested in one location. A comparison of the four side nacelle locations, (Positions A through D), is shown in Figure 5.

Position A is considered to be the same as the production JT8D engine location and represents a minimum change position. In Position B, the nacelle and strut were moved inboard six inches (15.2 cm) relative to Position A. In Position C, the nacelle and strut were moved 24 inches (61.0 cm) aft of Position A. In Position D, the nacelle and strut were moved 13.3 inches (33.8 cm) outboard of Position A.

4.2 TEST FACILITIES AND MODEL INSTALLATION

The low-speed wind tunnel testing of the NASA Refan nacelles was accomplished in two parts. The first test, which dealt with longitudinal characteristics, was done at the Boeing Vertol Wind Tunnel (BVWT) in May and June 1973. This 20 x 20 foot (6.10 x 6.10 meter) tunnel was required to accommodate the large model at high angles of attack. Lateral-directional characteristics were determined in the 8 x 12 foot (2.44 x 3.66 meter) University of Washington Aeronautical Laboratory (UWAL) wind tunnel in August 1973.

At BVWT the model was installed with the Boeing 635C internal strain gauge balance on the Boeing 935-656 offset sting as shown in Figure 2. At UWAL the model was installed on the UWAL external balance with UWAL single strut No. 1, pitch arm No. 1, and balance fairing No. 3 as shown in Figure 3.

4.3 TEST PROCEDURE

The nominal test dynamic pressure at BVWT was 34 psf (1628 N/m²). The angle of attack pitch series was generally from -4 degrees to 60 degrees. A nominal test dynamic pressure of 35 psf (1676 N/m²) was used at UWAL. The sideslip angle yaw series was -8 degrees to 20 degrees. Six-component force and moment data were recorded in both tests and were corrected by standard methods for tunnel effects. Data repeatability in both tests was good.

5.0 DISCUSSION OF TEST RESULTS

5.1 LONGITUDINAL CHARACTERISTICS

The effect of the NASA Refan nacelles on the longitudinal characteristics of the 727-200 airplane is shown in Figures 6, 7 and 8. The data are presented as angle of attack (α_{wcp}) versus pitching moment coefficient at the quarter chord ($C_{m,25\bar{c}}$). Lift characteristics are not shown since the effect of the large nacelles was negligible.

The effects of nacelle position and size are not easily predictable without wind tunnel investigations due to the complicated nature of the flow field aft of the wing and its interaction with the nacelles. This is of particular importance when the trailing edge flaps are extended and a vortex flow is established at the ends of each flap segment. This swirling flow field has a significant effect on the contribution of the nacelles to total airplane pitching moment. As can be seen in Figure 6, moving the refan side nacelles to a more aft location does not improve the low angle of attack stability in the predictable way a change in the downwash field alone would. Similarly, moving the nacelles both inboard and outboard from the production location does not alter the basic nacelles-on pitching moment characteristics in the pre-stall α range. In fact, all four of the tested refan nacelle locations and the basic nacelle are indistinguishable for $\alpha_{wcp} < 10^\circ$.

As the airplane approaches stall α 's, the vortex flow field begins to curve above the nacelles and the effect of nacelle size and position begin to be more discernible. For α_{wcp} between 10° and 30° , the aerodynamic forces on the nacelles are such that the airplane becomes increasingly more stable as the nacelle size is increased or they are moved aft. In the very high α region above 30° , the separated flow from the nacelles begins to envelop the horizontal tail, significantly decreasing its effectiveness. Since the location and shape of the nacelle wake is a function of nacelle position and geometry, it is to be expected that more of the horizontal tail will be impinged by the refan nacelle wake, resulting in a further decrease in horizontal tail effectiveness. Detail A of Figure 6 shows that all four refan

nacelle locations tested decrease the nose down pitching moment capability of the 727-200, but these changes are not large enough to significantly degrade the capabilities of the basic airplane. It can also be seen in Detail A that the refan nacelle location which will alter the basic-airplane high attitude characteristics the least is Position A. Position A also represents the minimum change to the airplane since it is the same as the production location and utilizes the existing engine mounts. Based on these data, Position A was chosen as the optimum refan nacelle location.

A comparison of the pitching moment characteristics of the 727-200 airplane with the refan nacelles and the basic nacelles in the production location is shown in Figure 7 with the flaps up. In the low angle of attack range, the effect of nacelle size is more easily seen, due largely to the less disturbed flow behind the clean, flaps up wing. In this instance the aerodynamic stiffness ($C_{m\alpha}$) of the 727-200 airplane is increased by 17% as a result of the refan nacelle installation. Although the small aft movement of the stick-fixed neutral point accompanying this improvement is not expected to be particularly noticeable in the airplane handling qualities, the trend will be toward improved basic airplane characteristics. Figure 8 shows no discernible difference between the refan and basic nacelles with the flaps at 40° and $\alpha_{wcp} < 10^\circ$. Near stall, the refan nacelle configuration shows an increase in static longitudinal stability at both flap settings. The observed increase in stability at low α and the improvement near stall are due to increases in the aerodynamic forces acting on the larger refan nacelles. In the post-stall high angle of attack range, both flap settings exhibit a small incremental nose-up pitching moment due to the refan nacelles. Increased aerodynamic interference between the horizontal tail and the wake from the larger nacelles in this α regime causes the pitching moment change.

5.2 LATERAL-DIRECTIONAL CHARACTERISTICS

The effect of the NASA Refan nacelles on the lateral-directional characteristics is shown in Figures 9 through 14. The data are presented in terms of

yawing moment ($C_{n,25} \bar{c}$), rolling moment (C_{l}) and side force (C_y) coefficient versus sideslip angle. Figures 9, 10 and 11 present the lateral-directional characteristics of the 727-200 airplane with the flaps up, vertical and horizontal tails on. Although previous wind tunnel experience with the 727 configuration had shown that enlarging the side nacelles reduces the vertical tail effectiveness, the data from this test show an increase of approximately 10% in static directional stability with the refan nacelles. It is apparent that the increased side area of the refan center inlet more than offsets the expected interference losses due to the large side nacelles.

Figures 12, 13 and 14 show the effect of the refan nacelles in yaw with the flaps at 40°, vertical and horizontal tails on, with rudder deflections of zero and 27.5 degrees. The higher basic stability level of the flaps down configuration and its more complicated flow environment combine to make the small effects of the refan nacelles less noticeable at low β 's. At larger sideslip angles, the slight increase in directional stability is again due to the dorsal fin effect of the larger refan center engine inlet. The refan nacelles show no effect on the directional control characteristics of the 727-200 airplane.

The effect of the JT8D-109 NASA Refan nacelles on the stability and control characteristics of the Boeing 727-200 airplane were evaluated in two low-speed wind tunnel tests. Four potential installations were tested in yaw at UWAL. From these tests it was determined that the optimum location for the NASA Refan nacelles is the same as the production location of the JT8D-9 nacelle. The low-speed stability and control characteristics of the 727-200 with the refan nacelles in the production location are very similar to those of the current airplane.

In the pitch axis, the larger nacelles slightly improve the low alpha stability with the flaps up and show no change with the flaps at 40°. At stall, a small additional nose-down pitch is indicated with the larger nacelles. At high angles of attack the refan nacelles cause an insignificant nose-up pitching moment increment.

In the lateral-directional axes, a slight improvement in static stability was obtained with the refan nacelles in the flaps up configuration. No significant changes in static stability or directional control characteristics were noted with the flaps at 40°.

It may be concluded from these tests that no significant change in the low-speed static stability and control characteristics of the Boeing 727-200 airplane will result from the installation of the JT8D-109 NASA Refan nacelles.

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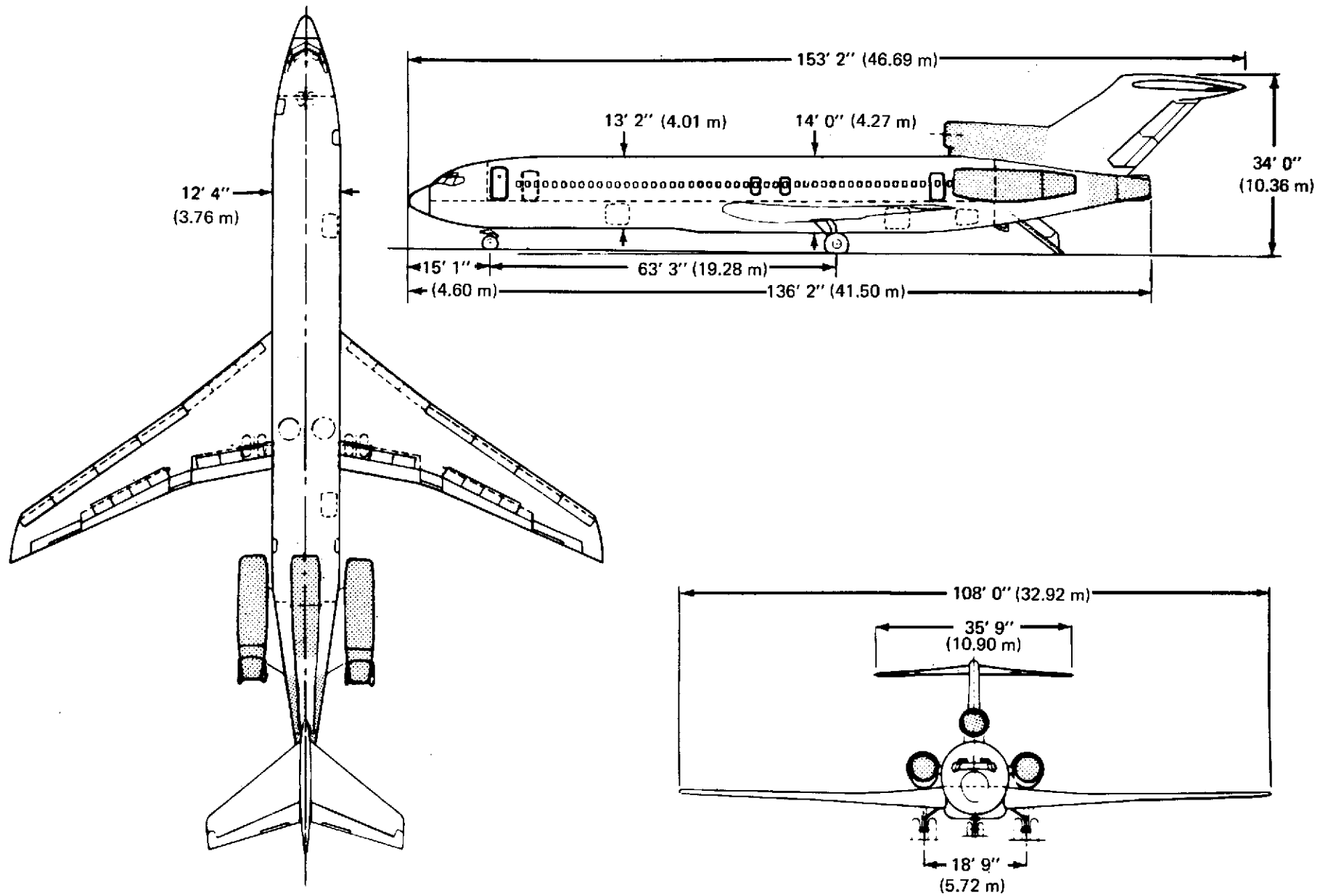
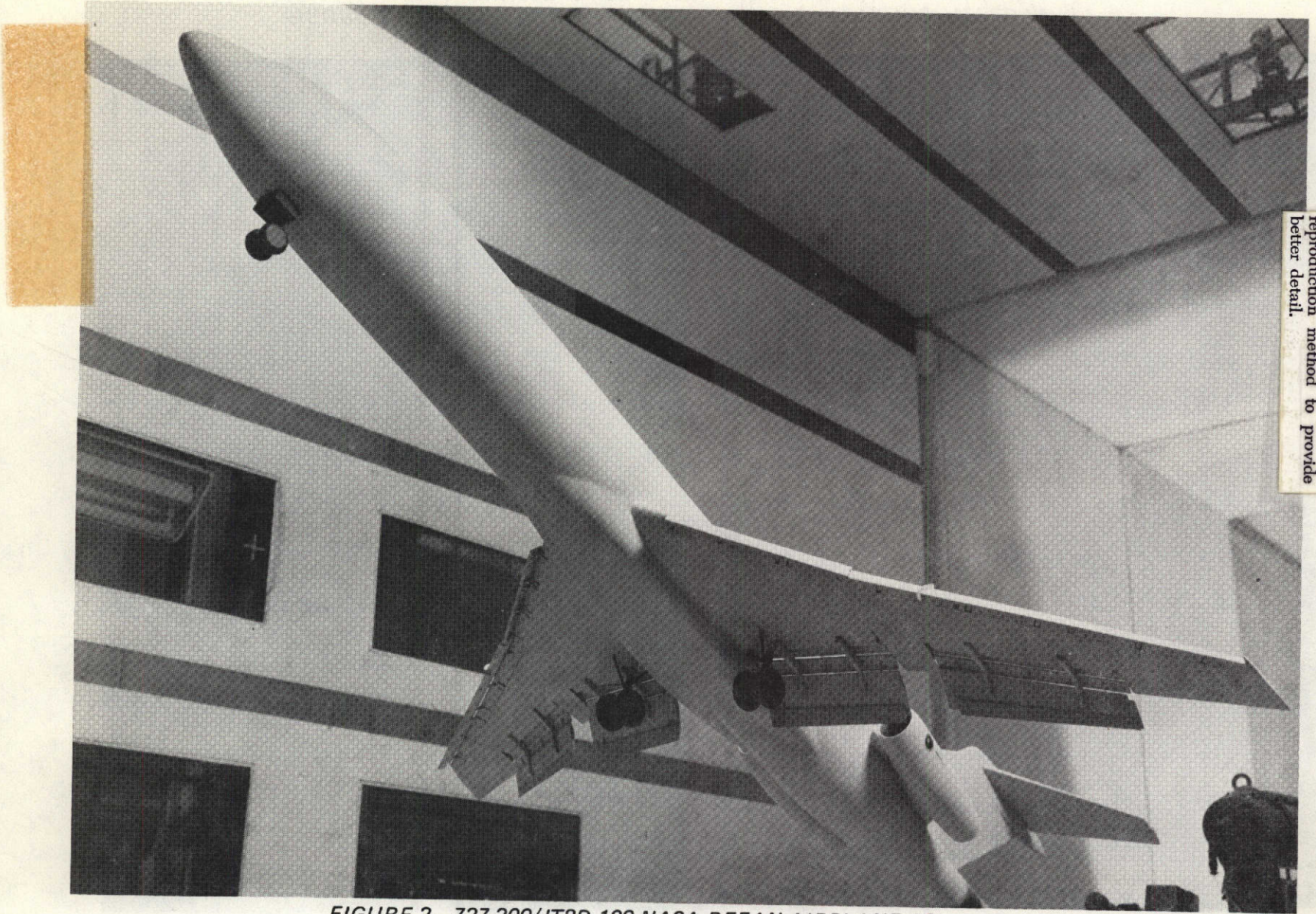
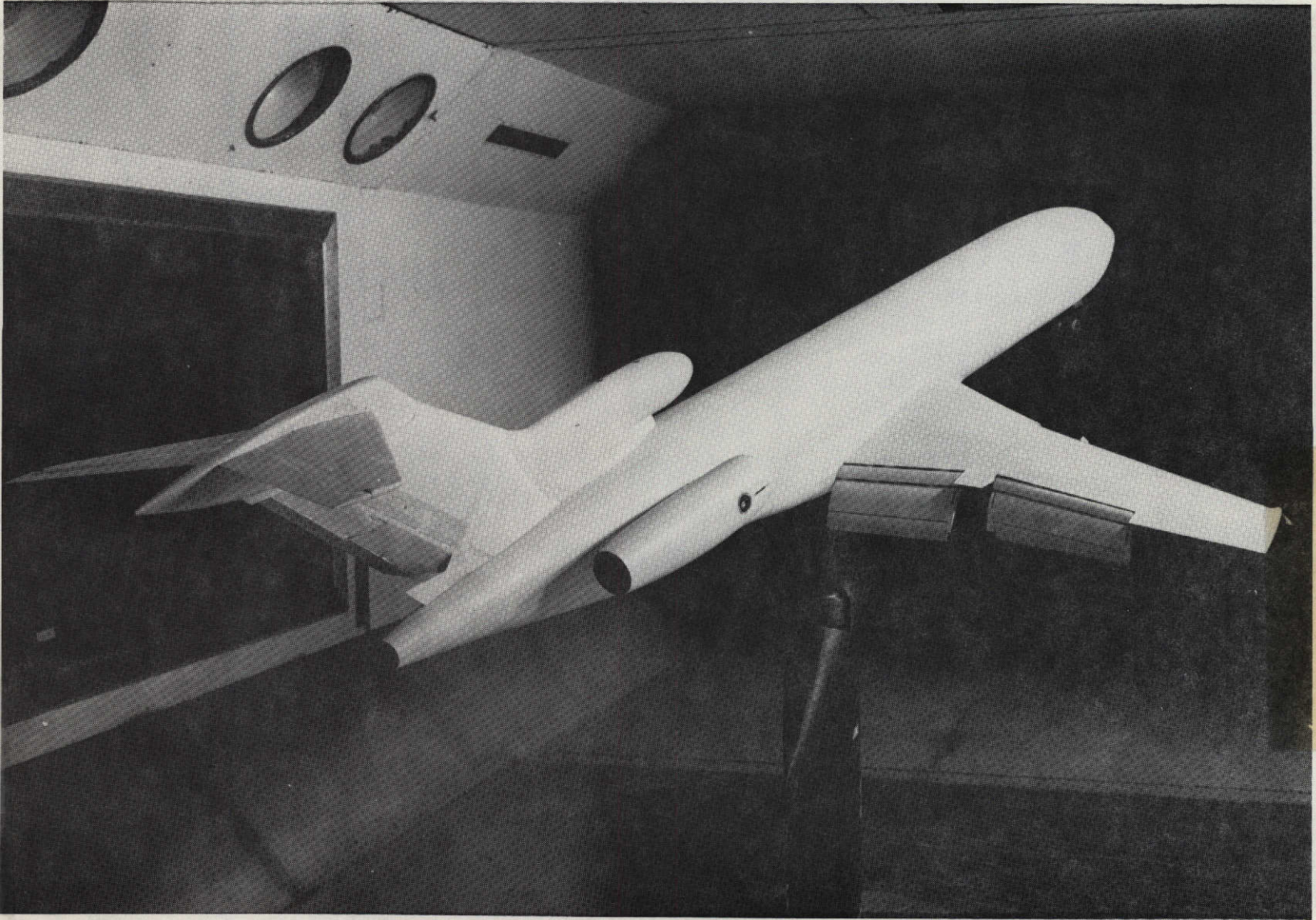


FIGURE 1.—727-200/JT8D-109 NASA REFAN AIRPLANE



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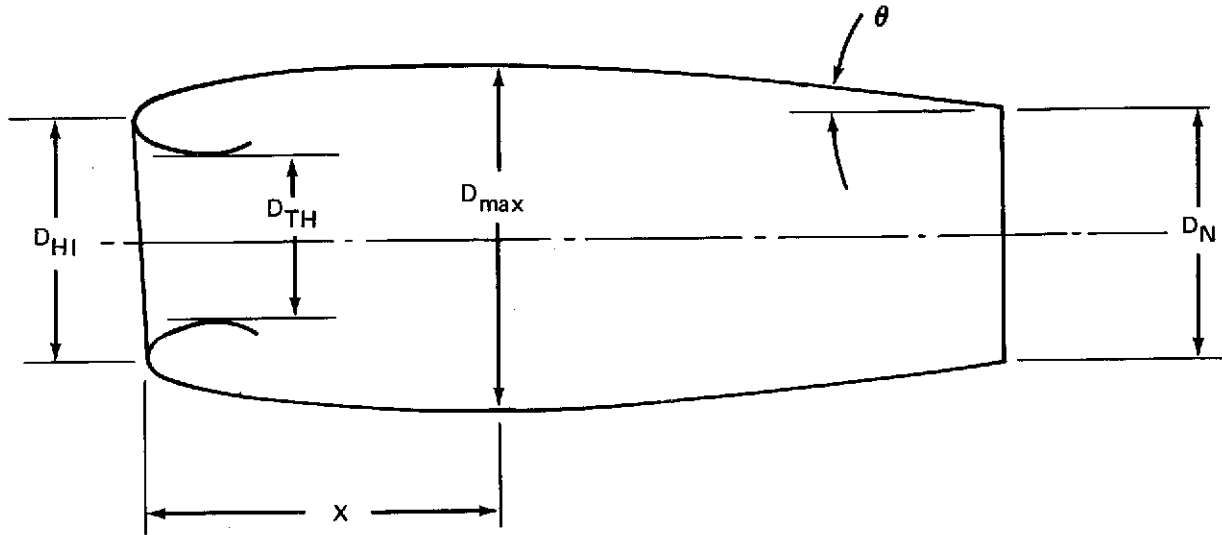
FIGURE 2.—727-200/JT8D-109 NASA REFAN AIRPLANE AS INSTALLED IN THE BOEING VERTOL WIND TUNNEL (BVWT)



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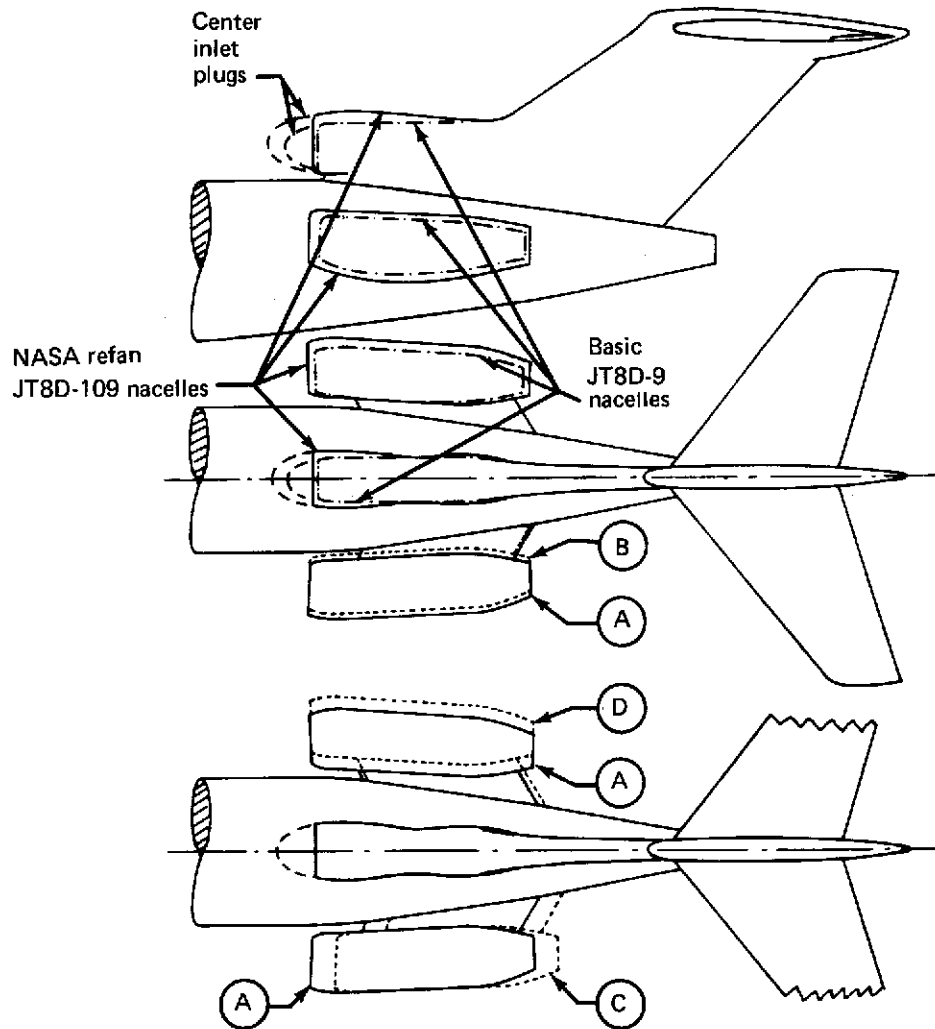
FIGURE 3.—727-200/JT8D-109 NASA REFAN AIRPLANE AS INSTALLED IN THE UNIVERSITY OF WASHINGTON AERONAUTICAL LABORATORY (UWAL) WIND TUNNEL

NACELLE PLAN VIEW



	Production side nacelle JT8D-9	NASA refan side nacelle JT8D-109	Production center inlet JT8D-9	NASA refan center inlet JT8D-109
Nacelle length, in. (cm)	210.0 (533.4)	234.0 (594.4)	—	—
Maximum diameter, D_{max} , in. (cm)	50.0 (127.0)	62.0 (157.5)	45.2 (114.8)	60.0 (152.4)
Nozzle exit diameter, D_N , in. (cm)	30.0 (76.2)	46.7 (118.6)	Plugged	Plugged
Length to maximum section, X , in. (cm)	36.9 (93.7)	27.6 (70.1)	10.0 (25.4)	13.5 (34.3)
Throat diameter, D_{TH} , in. (cm)	37.8 (96.0)	47.0 (119.4)	Plugged	Plugged
Hilite diameter, D_{HI} , in. (cm)	42.3 (107.4)	52.0 (132.1)	Plugged	Plugged
Tail pipe boattail angle, θ , deg (rad)	8.5 (0.148)	9.7 (0.169)	—	—

FIGURE 4.—NACELLE GEOMETRY AS TESTED



Refan position designation	Definition
(A)	Same as production nacelle location
(B)	Nacelle and strut moved 6 in. (15.2 cm) inboard from position (A)
(C)	Nacelle and strut moved 24 in. (61.0 cm) aft from position (A)
(D)	Nacelle and strut moved 13.3 in. (33.8 cm) outboard from position (A)

FIGURE 5.—DEFINITION OF NASA REFAN NACELLE TEST LOCATIONS

727-200

Flaps 40°

Gear down

$\Delta_{wcp} = -4^\circ$

$\delta_e = +17^\circ$

Symbol	Nacelle/location
—○—	Basic/production
- - -□- - -	Refan/(A) (production)
- - -△- - -	Refan/(B) (6-in. (15.2 cm) inboard)
- - -○- - -	Refan/(C) (24 in. (61.0 cm))
- - -□- - -	Refan/(D) (13.3 in. (33.8 cm) outboard)

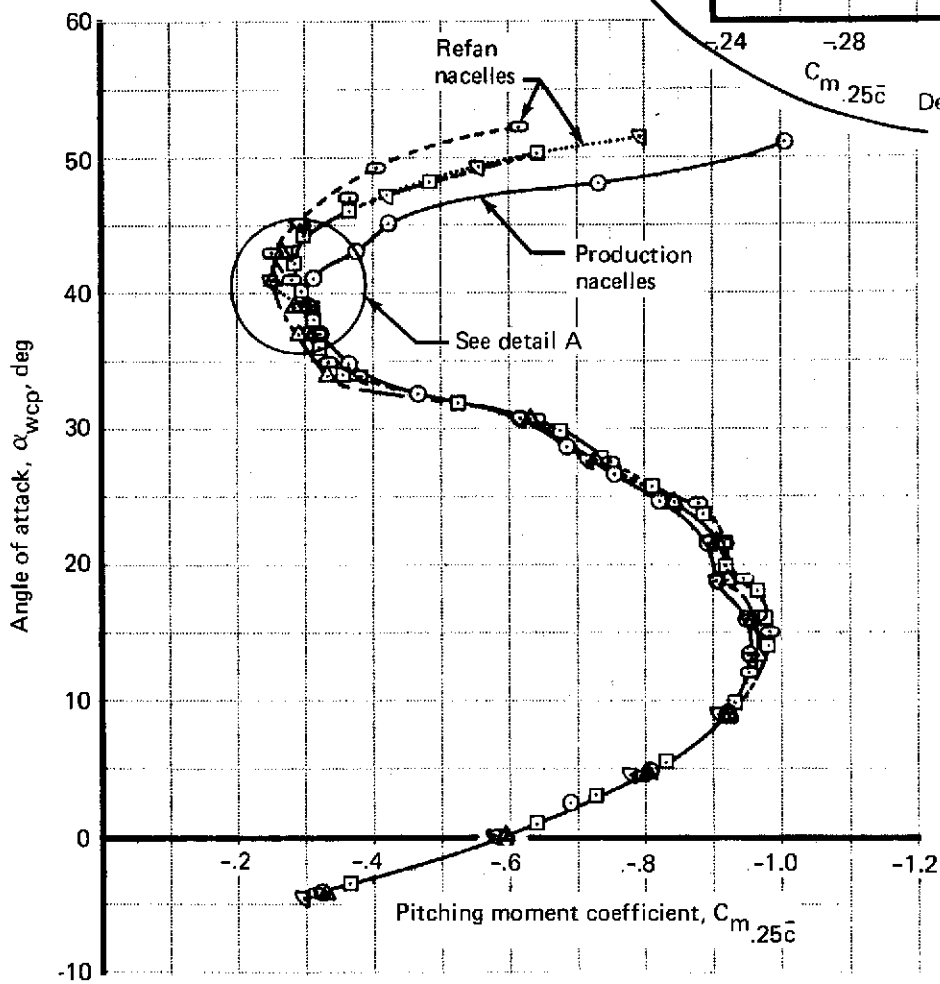
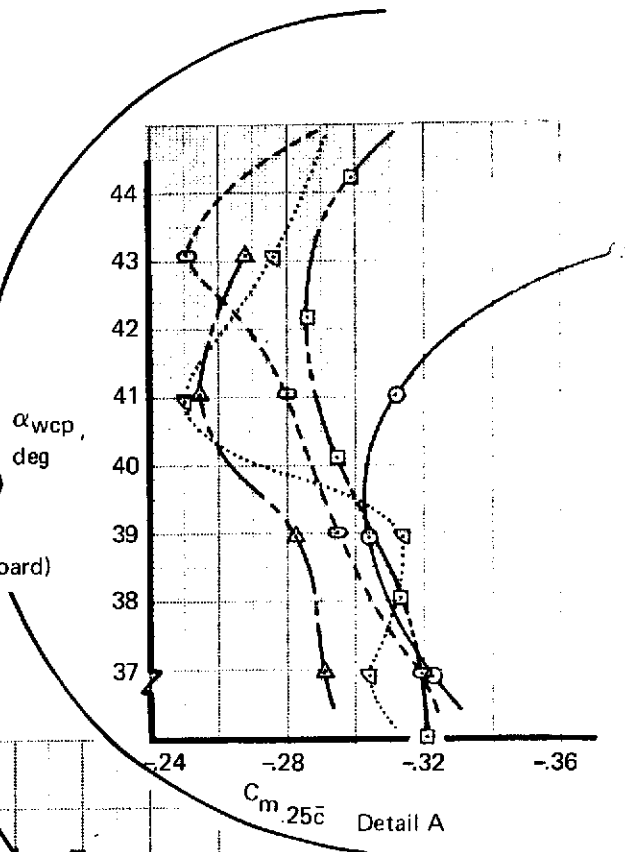


FIGURE 6.—EFFECT OF NASA REFAN NACELLE LOCATION ON PITCHING MOMENT—
FLAPS 40°, GEAR DOWN

727-200

Flaps up

$\Delta_{wcp} = -1^\circ$

$\delta_e = +17^\circ$

Symbol	Nacelle/location
—○—	Basic / production
- - □ - -	Refan / (A)(production)

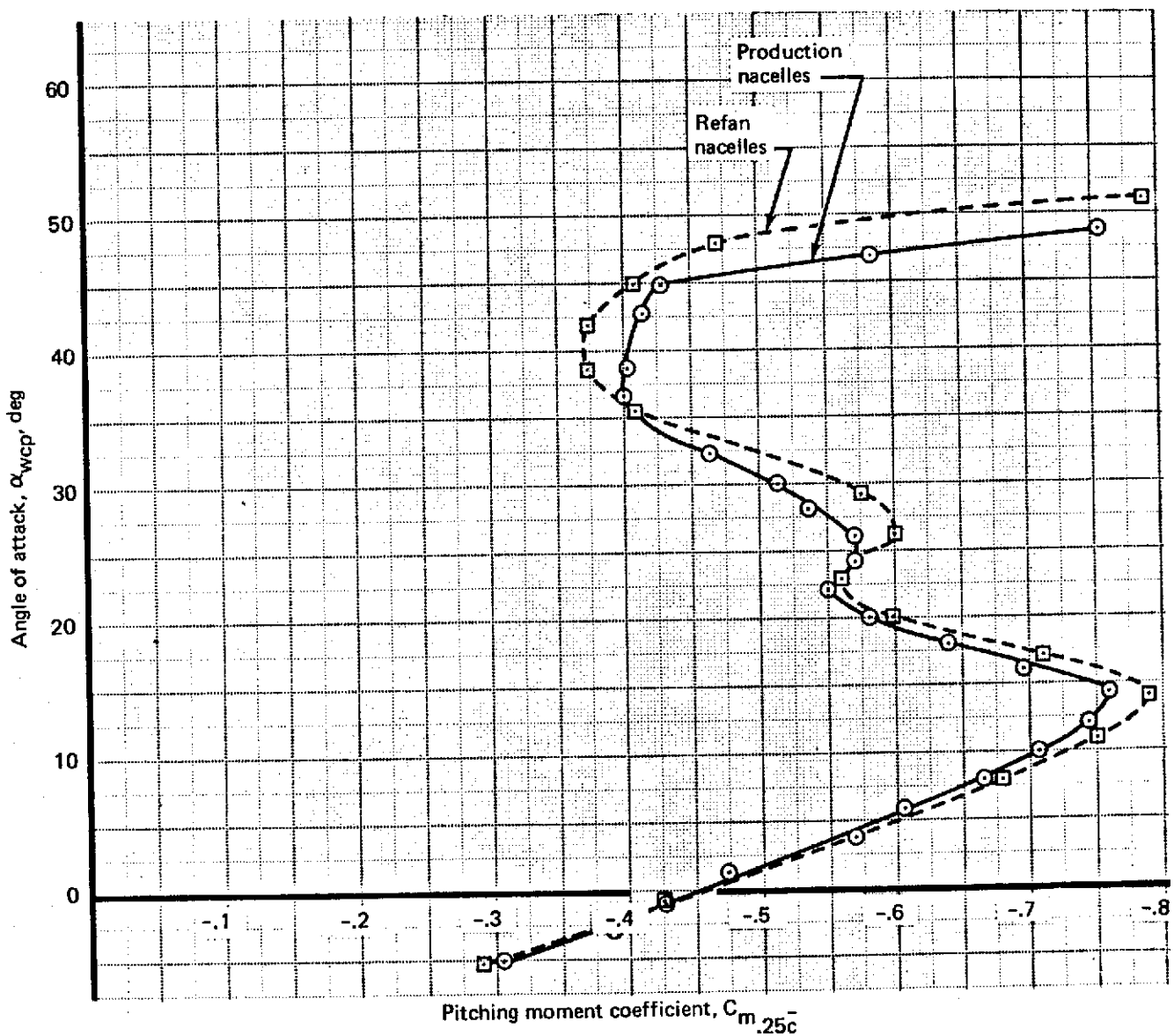


FIGURE 7.—EFFECT OF THE NASA REFAN NACELLES ON PITCHING MOMENT—
FLAPS UP, GEAR UP

727-200
 Flaps 40°
 Gear down
 $\Delta_{wcp} = -0.4^\circ$
 $\delta_e = +17^\circ$

Symbol	Nacelle/location
—○—	Basic/production
- - -□- - -	Refan/(A) (production)

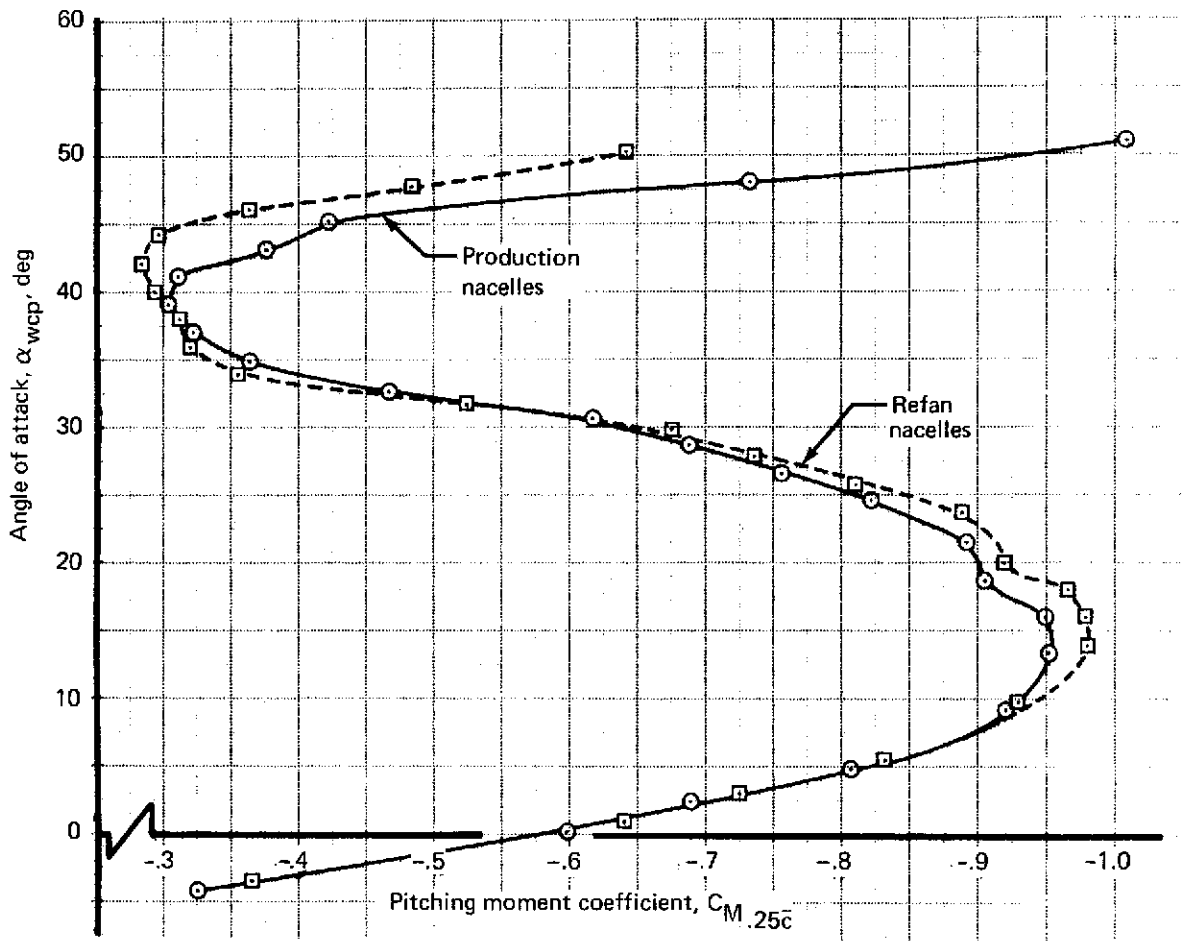


FIGURE 8.—EFFECT OF THE NASA REFAN NACELLES ON PITCHING MOMENT—FLAPS 40°, GEAR DOWN

727-200

Flaps up
Vertical and horizontal Tails on

$$\alpha_{wcp} = 5.3^\circ$$

Symbol	Nacelle/location
—○—	Basic/production
- - □ - -	Refan/Ⓐ (production)

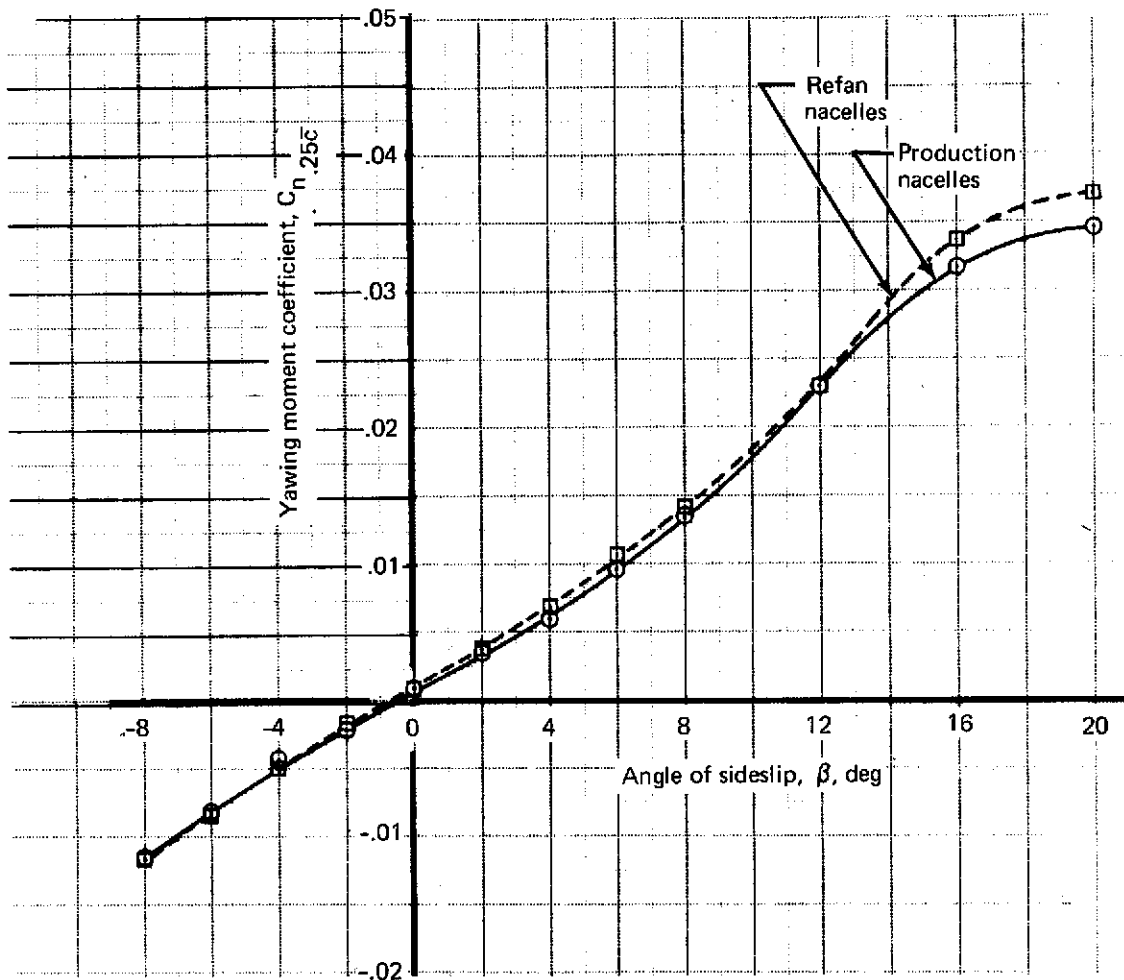


FIGURE 9.—EFFECT OF THE NASA REFAN NACELLES ON YAWING MOMENT—FLAPS UP, GEAR UP

727-200

Flaps up
Vertical and horizontal tails on
 $\alpha_{wcp} = 5.3^\circ$

Symbol	Nacelle/location
—○—	Basic/production
- - □ - -	Refan/Ⓐ (production)

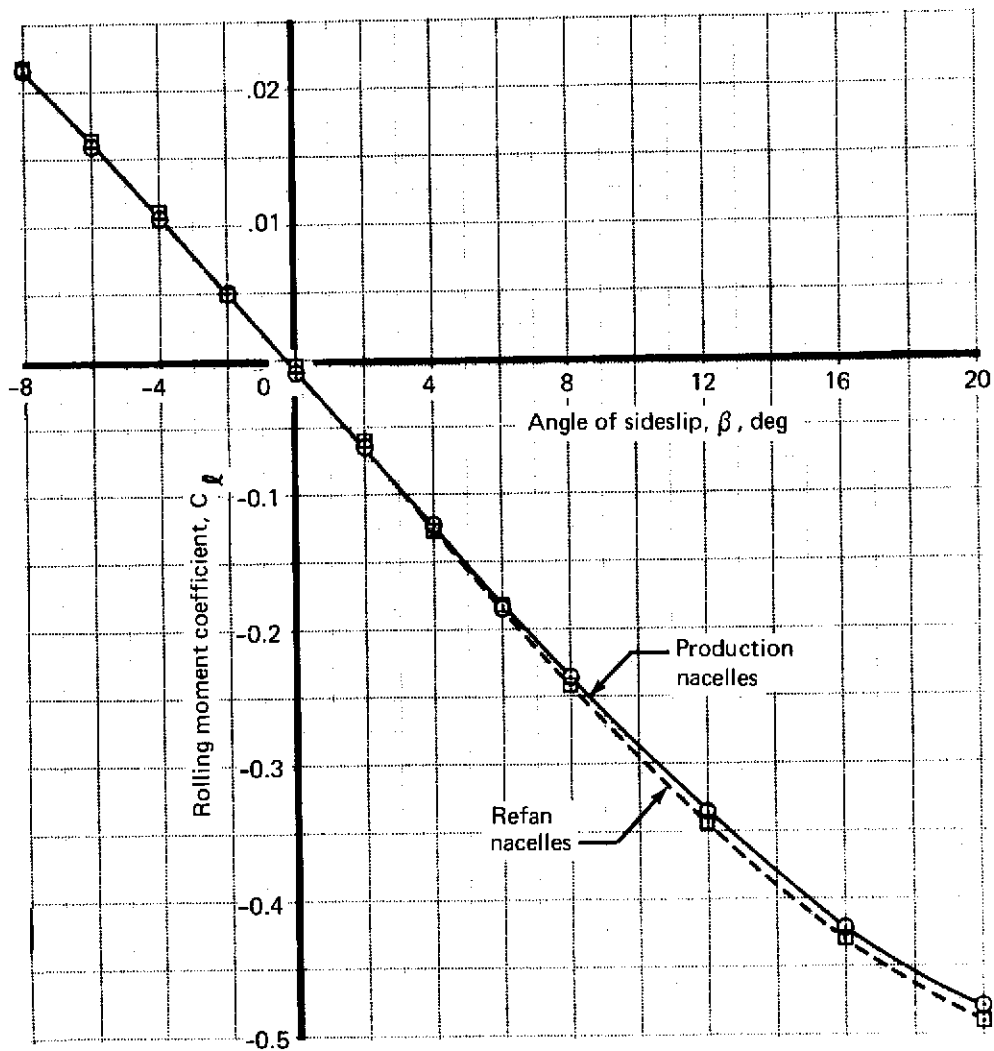


FIGURE 10.—EFFECT OF THE NASA REFAN NACELLES ON ROLLING MOMENT—FLAPS UP, GEAR UP

727-200

Flaps up
Vertical and horizontal tails on
 $\alpha_{wcp} = 5.3^\circ$

Symbol	Nacelle/location
—○—	Basic/production
—□—	Refan/Ⓐ (production)

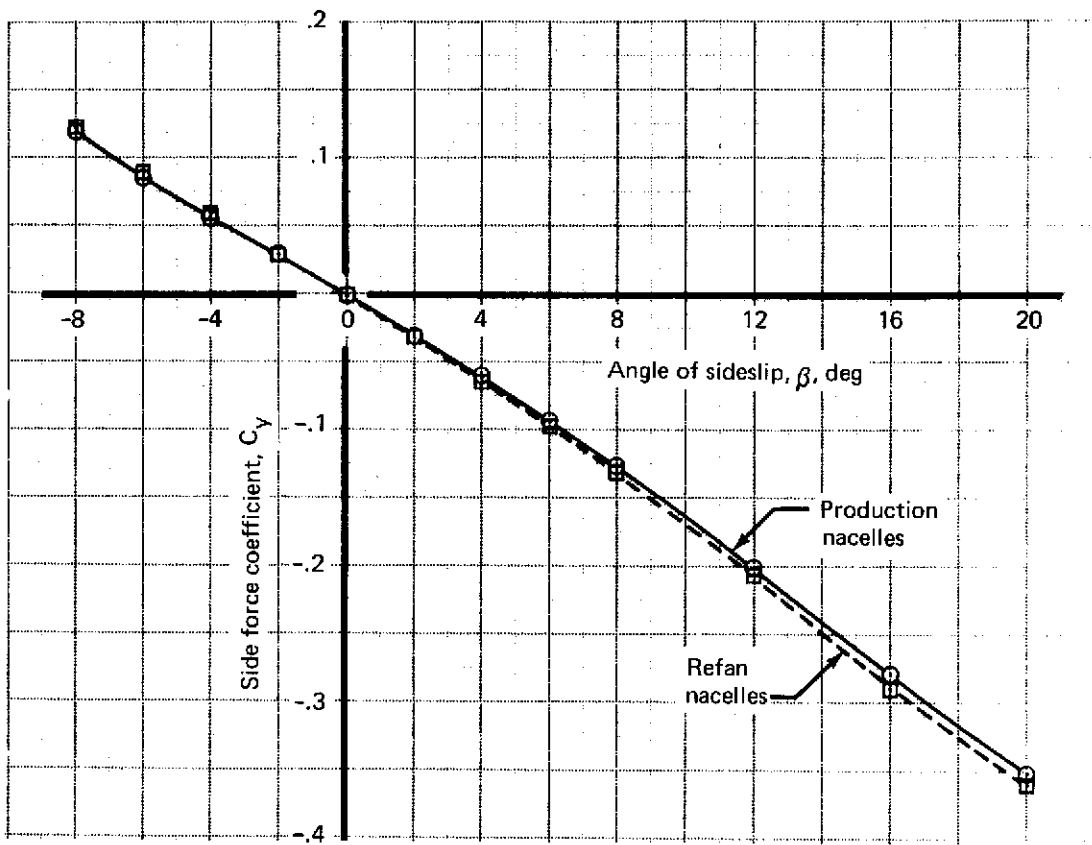


FIGURE 11.—EFFECT OF THE NASA REFAN NACELLES ON SIDE FORCE—FLAPS UP, GEAR-UP

727-200

Flaps 40°
Gear down
Vertical and horizontal tails on
 $\alpha_{wcp} = 6.2^\circ$

Symbol	Nacelle/location
○	Basic/production
□	Refan/Ⓐ (production)

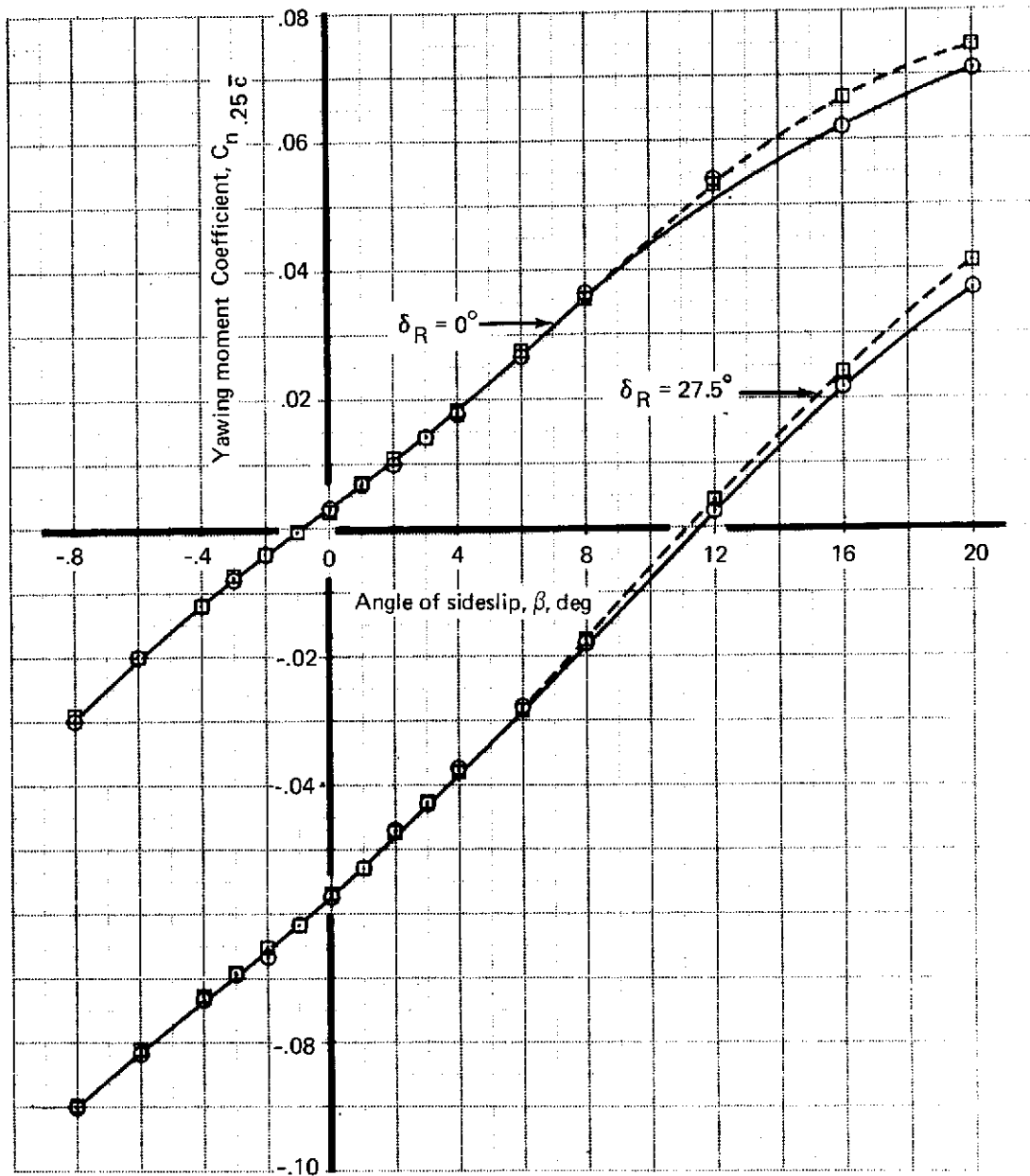


FIGURE 12.—EFFECT OF THE NASA REFAN NACELLES ON YAWING MOMENT CHARACTERISTICS AT $\delta_R = 0$ AND $\delta_R = 27.5$ DEGREES FLAPS 40°, GEAR DOWN

Flaps 40°
 Gear down
 Vertical and horizontal tails on
 $\alpha_{wcp} = 6.2^\circ$

Symbol	Nacelle/location
—○—	Basic/production
---□---	Refan(A) (production)

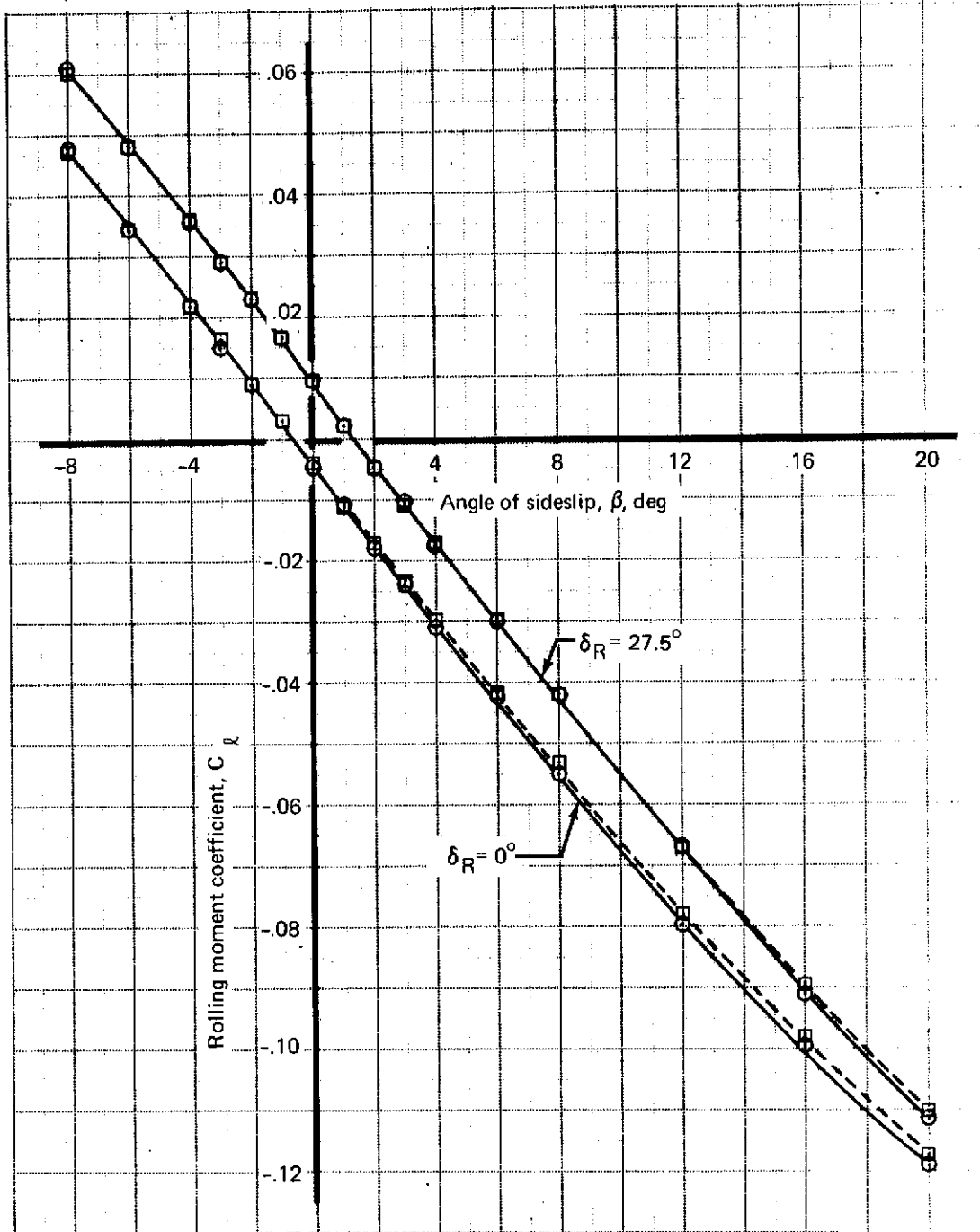


FIGURE 13.—EFFECT OF THE NASA REFAN NACELLES ON ROLLING MOMENT CHARACTERISTICS AT $\delta_R = 0$ AND $\delta_R = 27.5$ DEGREES FLAPS 40°, GEAR DOWN

Flaps 40°
 Gear down
 Vertical and horizontal tails on
 $\alpha_{wcp} = 6.2^\circ$

Symbol	Nacelle/location
—○—	Basic/production
- - □ - -	Refan/Ⓐ (production)

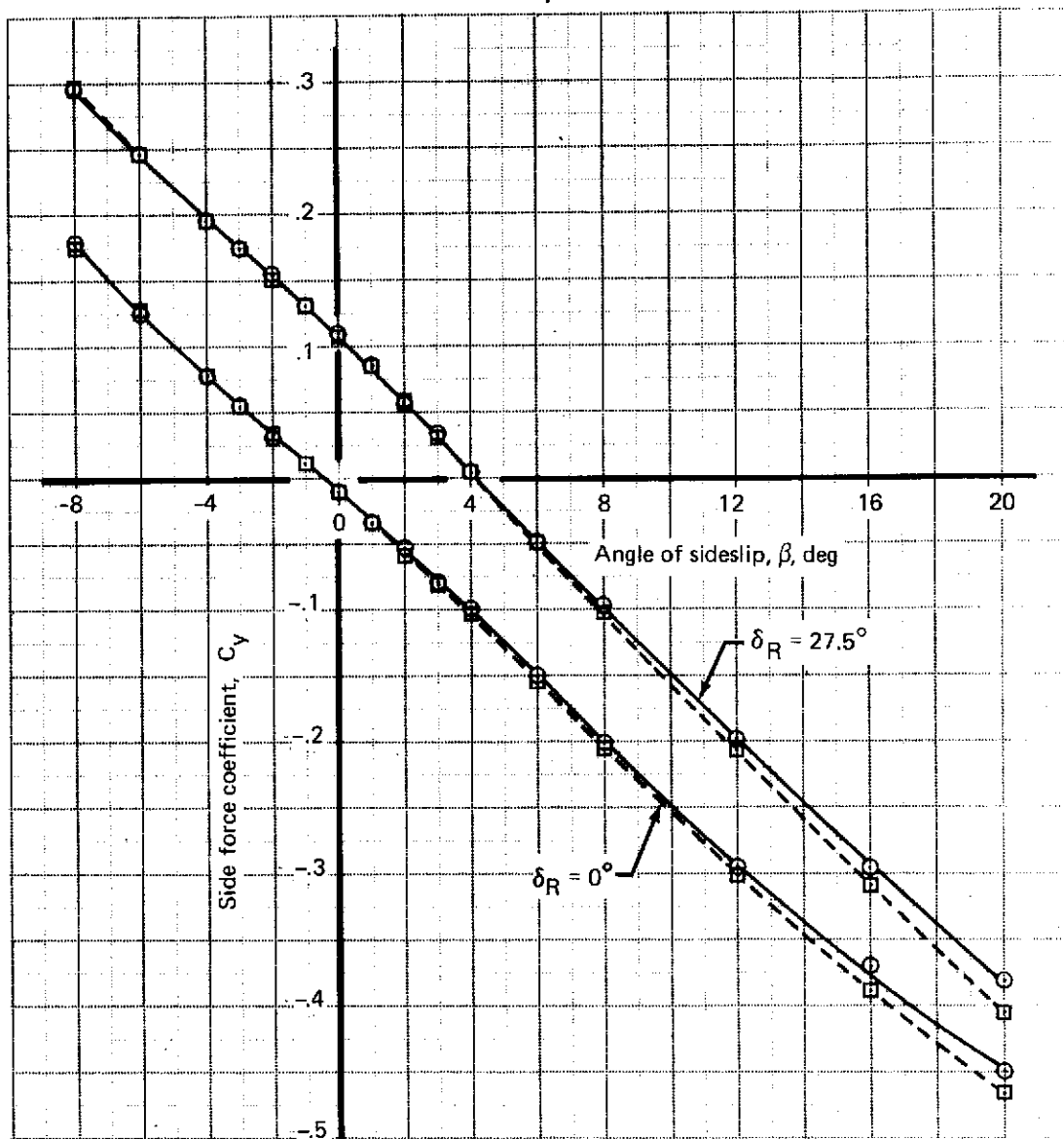


FIGURE 14.—EFFECT OF THE NASA REFAN NACELLES ON SIDE FORCE CHARACTERISTICS AT $\delta_R = 0$ AND $\delta_R = 27.5$ DEGREES FLAPS 40° , GEAR DOWN