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THE ZERO-LIFT FOREDRAG AND BODY BASE DRAG COEFFICIENTS OF A SERIES OF RING TAIL-STRUT-BODY CONFIGURATIONS AT MACH NUMBERS FROM 0.80 TO 4.50

By

Paul R. Connolly

May 1965

U S ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

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Paul R. Connolly

DA Project No. 1B222901A206

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Aerodynamics Branch
Advanced Systems Laboratory
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Abstract

An investigation of the aerodynamic characteristics of a family of ring tail-strut-body configurations was conducted at Mach numbers from 0.80 to 4.5. Rings varying from 1.25 to 2.50 calibers in diameter and from 0.60 to 1.50 calibers in length were tested. They were tested at various longitudinal positions and with internal expansion angles from 0° to 6°. The effect of changing from circular section support struts to streamlined struts was also investigated.

This report presents the zero-lift foredrag and base drag results and compares them, wherever possible, with theoretical estimates.

Foreword

The Aerodynamics Branch of the Advanced Systems Laboratory is currently engaged in a supporting research program directed toward a reduction in missile base drag. The program is being conducted as a part of Supporting Research Project Base Drag Reduction, AMC Management Structure Code No. 5221.11.148.

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List of Symbols

C_{A_B}	=	Base axial force coefficient, $\dfrac{\text{Base axial force}}{q_\infty S}$
C_{A_F}	=	Forebody axial force coefficient, $\dfrac{\text{Forebody axial force}}{q_\infty S}$
C_{D_B}	=	Zero lift base drag coefficient, C_{A_B} at zero incidence
C_{D_F}	=	Zero lift forebody drag coefficient, C_{A_F} at zero incidence
d	=	Model diameter
M_∞	=	Free stream Mach number
q_∞	=	Free stream dynamic pressure
S	=	Model reference area, $\dfrac{\pi d^2}{4}$

Section I. INTRODUCTION

The Army's assigned combat tasks are tactical in nature and are either ground based or ground directed. The tasks in general will be: (1) direct fire against personnel and vehicles, (2) local defense against air attacks, and (3) tactical bombardment. Weapons designed to accomplish these tasks will trend toward short-range, high-speed missiles operating within the earth's lower atmosphere. The performance and accuracy of missiles operating at high speeds within the earth's atmosphere are significantly degraded by drag forces.

Methods are currently available for satisfactorily optimizing all of the major missile drag components with the exception of the drag of the body base region. Since the base drag can be as high as 30 to 50 percent of the total drag of a missile during unpowered phases, and as high as 30 to 70 percent during sustained power phases, one of the most promising means of improving Army missile performance through aerodynamics is by optimization or reduction of base drag.

Three methods that appear promising for reducing base drag are: (1) favorable interference, (2) base bleed, and (3) optimizing afterbody/rocket nozzle geometry. Previous work performed on items (2) and (3) by the Aerodynamics Branch under the SR Project are reported in References 1 through 4. This report and References 5 and 6 present the results of an investigation concerned with reduction of base drag through favorable interference.

The design of a high speed missile is complicated by interaction between the various missile component flow fields. However, the flow field interactions do provide an opportunity to improve lift, stability, and drag characteristics through favorable interference. One of the earliest concepts for using favorable interference to reduce drag was the Busemann biplane which is discussed in Reference 7. Reference 7 shows that the wave drag of a two-dimensional, supersonic biplane, composed of two wings of finite thickness, can be reduced to that of a flat plate of zero thickness through proper geometrical considerations. A body-of-revolution concentric to a reflecting ring, analogous to the Buseman biplane, is discussed in References 8 and 9. Interference effects have been successfully used to reduce the wave drag of wing-body configurations at transonic speeds by the "area-rule" method. All of the above are concerned with reduction of wave drag through favorable interference. An indication that flow field interactions may be used to reduce base drag is presented in Reference 10, which shows that the bow wave from one body impinging on the wake of a second body has a large effect on the base pressure of the second body.

The need for a secondary flow field near the base of the body, which will induce the desired base pressure increment without an off-setting increase in wave drag, is met by the flow field from the missile stabilizing surfaces. Although conventional tail surfaces may be used to create a favorable base pressure increment, the interactions are local around the body circumference and the net results are small unless large tail surfaces or a large number of small tail surfaces are used. The flow field induced by a ring type stabilizing surface, concentric to the body, is more suitable for realizing favorable interference effects. However, to realize a net improvement using a ring tail, the ring tail must (a) produce the desired stability contribution, and (b) the net change in combined ring tail wave and friction drag and body base drag must be favorable.

Very little information is available on the static-longitudinal stability characteristics of ring tails. Therefore, a prerequisite to a study of ring tails as a device to reduce base drag is an investigation to determine the useful range of ring geometrical parameters from a stability viewpoint. That range of parameters can then be applied to the drag reduction problem. An experimental test program has been conducted by the Aerodynamics Branch on a body of revolution with a series of ring tails having diameters from 1.25 to 2.50 calibers. The tests were conducted at Mach numbers from 0.8 to 1.5 in the 1-foot transonic tunnel, Arnold Engineering Development Center, Tullahoma, Tennessee, and at Mach numbers from 1.75 to 4.50 in the Ballistic Research Laboratories Tunnel No. 1, Aberdeen Proving Grounds, Maryland. Ring tail geometric parameters which varied during the tests were diameter, chord, internal expansion angle, and longitudinal position on the fuselage.

While the primary purpose of the tests was to investigate the stability characteristics of ring tails, measurements were also made of the body base drag and configuration foredrag. This report presents the wind tunnel test measured values of the foredrag and base drag of the various configurations and compares them with theoretical estimates.

The basic wind tunnel data is tabulated in Reference 5.

Section II. APPARATUS AND PROCEDURE

The tests were conducted in the Aerodynamic Wind Tunnel, Transonic (1T) of the Propulsion Wind Tunnel Facility, Arnold Engineering Development Center, and in Supersonic Wind Tunnel No. 1, Ballistic Research Laboratories, Aberdeen Proving Grounds. A detailed description of these facilities is given in References 11 and 12.

The test bodies are 1.15 inches in diameter with a four caliber ogival nose and a total length of ten calibers as shown in Figure 1. The ring tails, which are described in Figure 2, are attached to the bodies with either four round support posts as shown in Figure 2, or with four faired support fins as shown in Figure 3. Each ring tail can be located in several longitudinal positions relative to the body. A photograph of the model installed in the transonic tunnel is presented in Figure 4, and in the supersonic tunnel in Figure 5. The model was sting mounted in the test section on a six-component, internal, strain-gage balance.

A 0.25-inch band of #80 transition grit was located 0.50 inch from the nose apex. In general the angle of attack range was from -4° to 6°. The Reynolds number during the test varied from 3×10^6 to 5×10^6, based on model length.

The accuracy of the base drag coefficient and axial foredrag coefficient varied from ±.008 and ±.012 respectively at M = 0.80 to ±.005 respectively at M = 4.50.

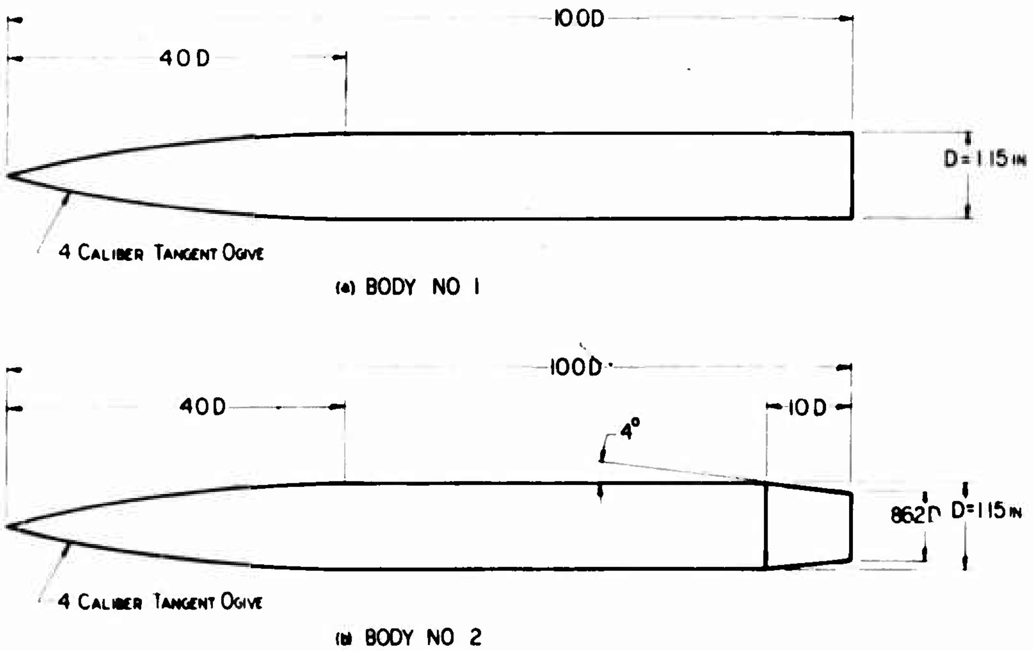
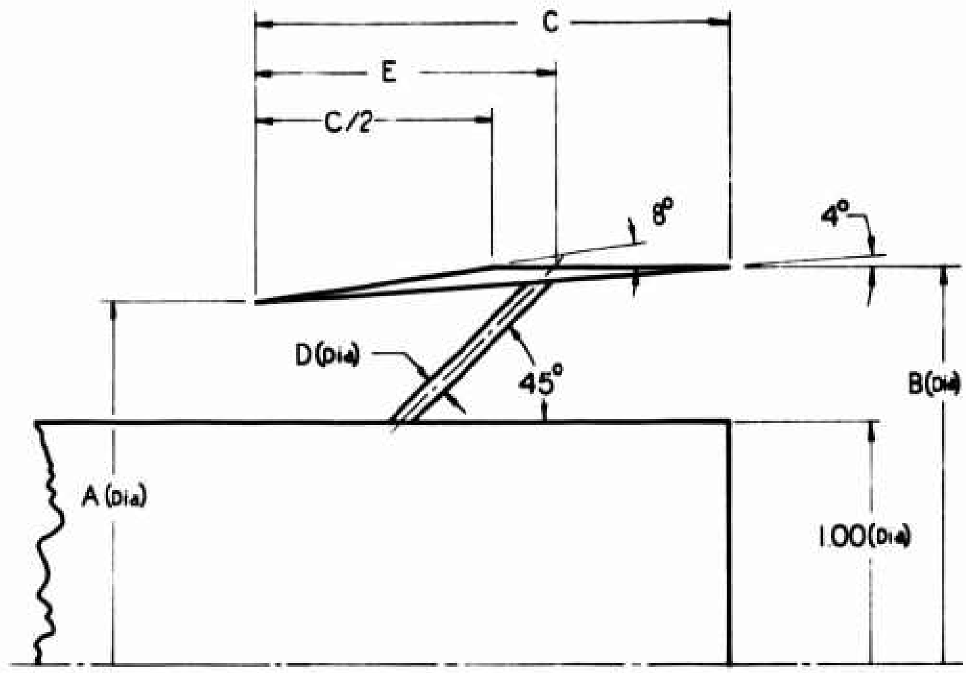


Figure 1. Body Configurations

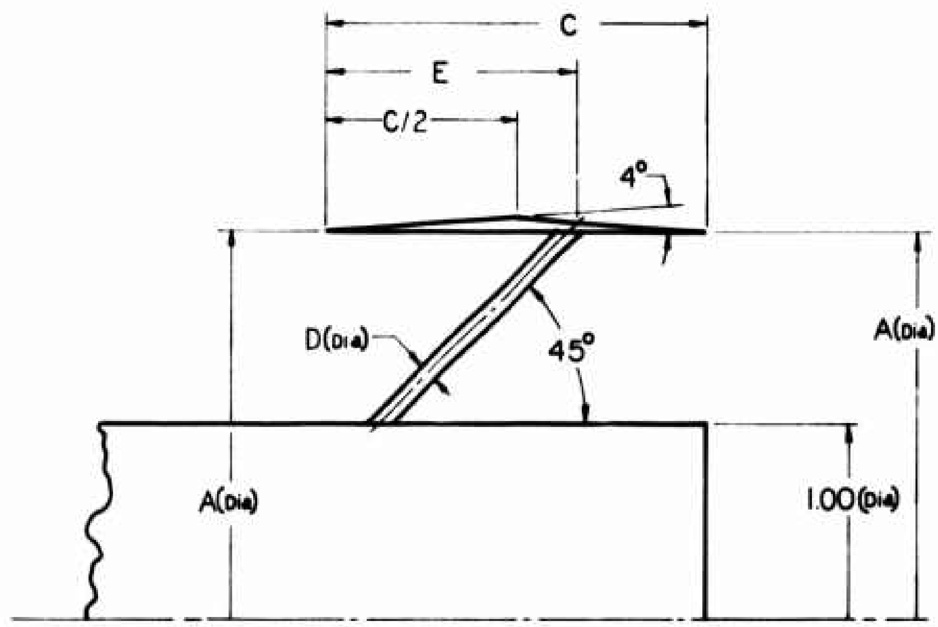


RING	A	B	C	D	E
T 1	1.500	1.605	.750	.046	.375
T 2	1.500	1.657	1.125	.052	.563
T 3	2.000	2.210	1.500	.080	.750
T 4	2.000	2.140	1.000	.070	.500
T 5	2.000	2.080	.600	.060	.300
T 10	2.500	2.675	1.250	.092	.625
T 11	2.500	2.605	.750	.080	.375
T 12	1.250	1.425	1.250	.048	.782
T 13	1.250	1.381	.937	.048	.623

(a) 4° INTERNAL EXPANSION

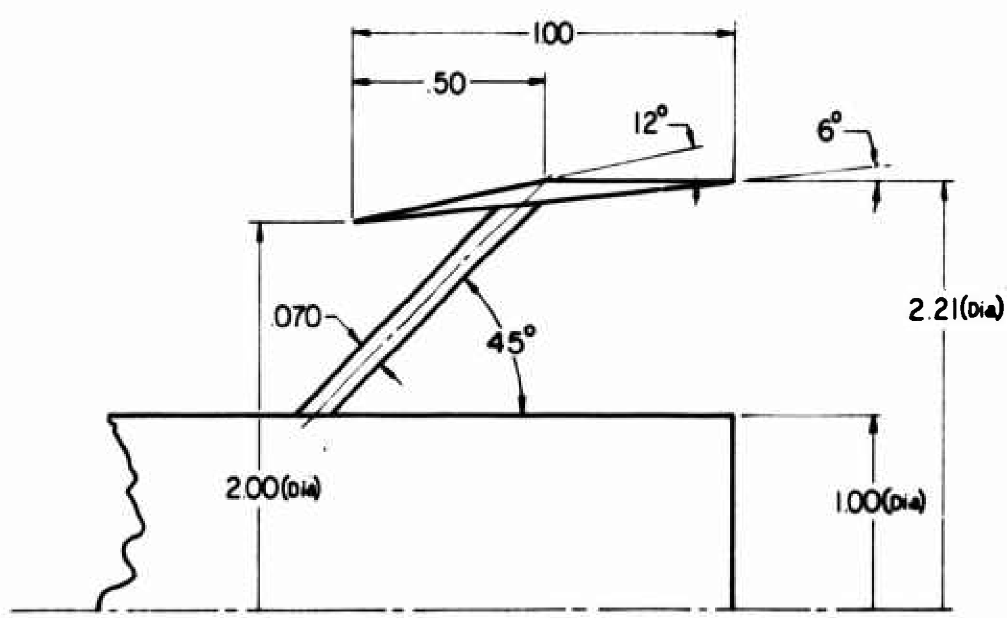
ALL DIMENSIONS IN CALIBERS

Figure 2. Ring Configurations



RING	A	C	D	E
T 7	2.000	1.000	.070	.500
T 14	1.316	.937	.048	.612

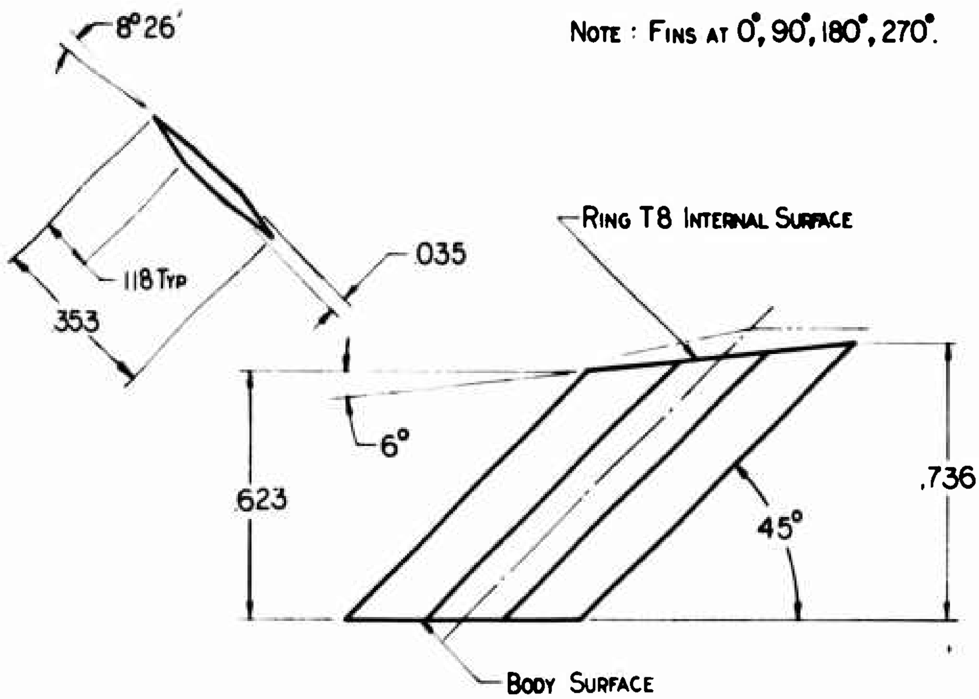
(b) 0° INTERNAL EXPANSION



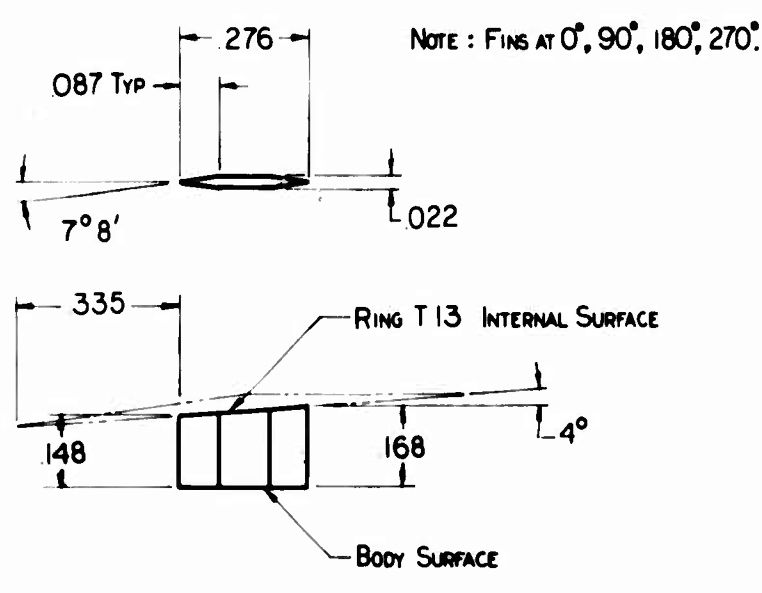
RING T8

(c) 6° INTERNAL EXPANSION

Figure 2 (Concluded)



(a) FIN NO. 8S



(b) FIN NO. 13S

ALL DIMENSIONS IN CALIBERS

Figure 3. Support Fin Configurations

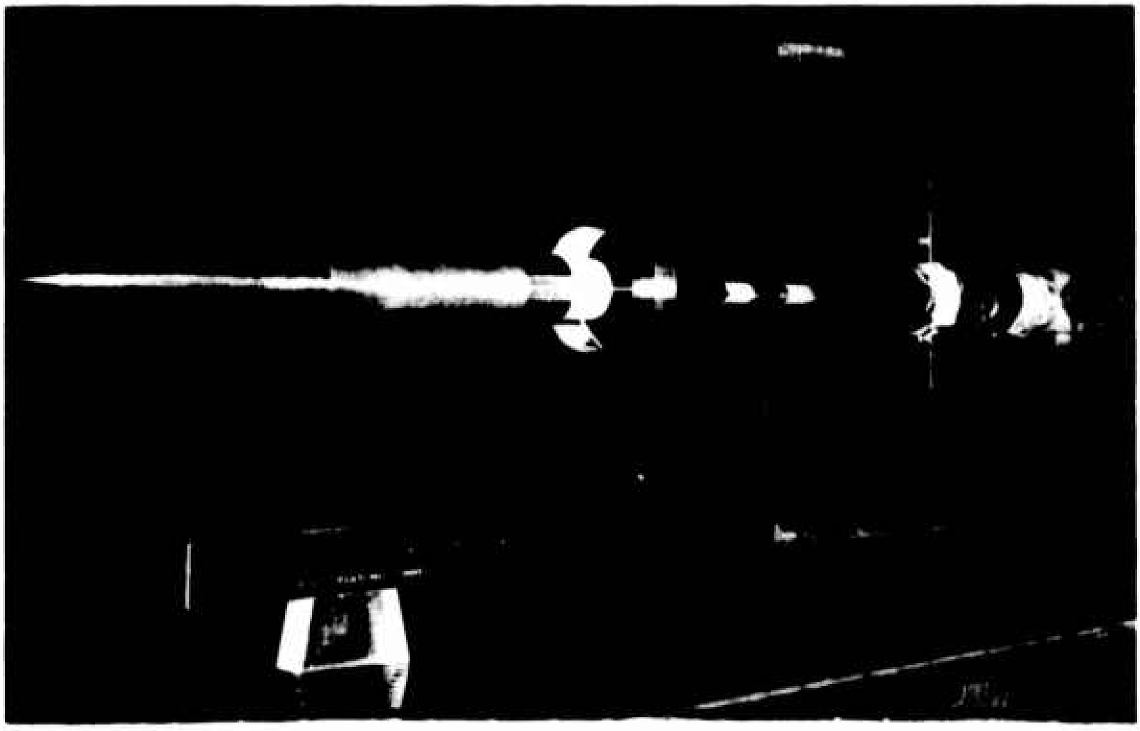


Figure 4. Model Installation - Transonic Tunnel

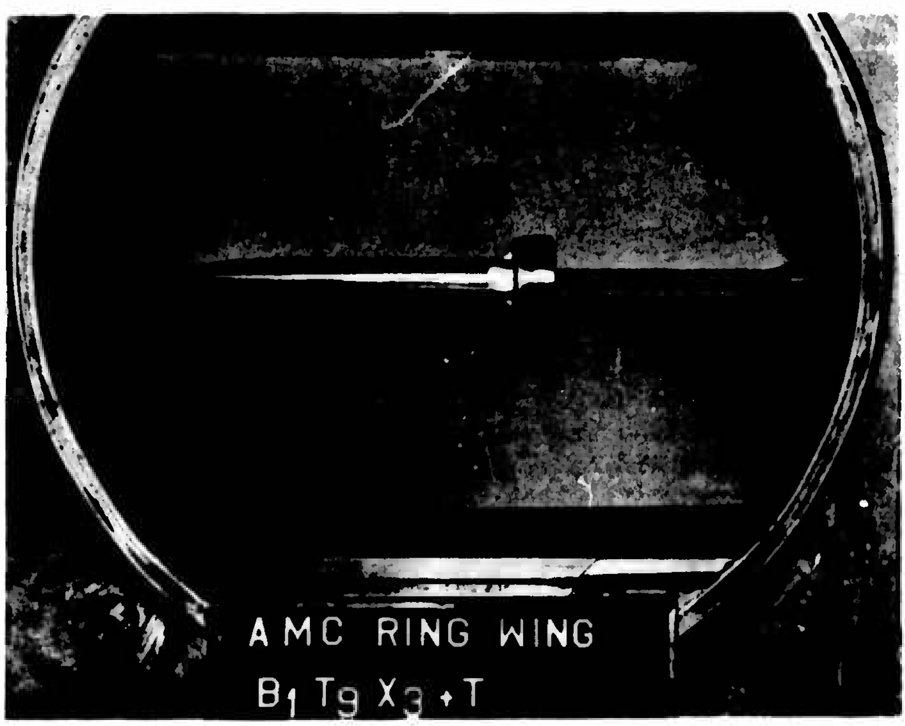


Figure 5. Model Installation - Supersonic Tunnel

Section III. RESULTS AND DISCUSSION

The purpose of this analysis is to investigate the ring tail drag and the effects of ring tails on body base drag. The variation of body alone base drag and body fore drag with Mach number is shown in Figure 6 and 7, respectively. This variation of body base drag with Mach number for various ring tail-strut-body configurations is shown in Figure 8. The increment in zero lift drag (excluding base drag) caused by the ring tail and support strut is presented in Figure 9.

1. Base Drag

To enable the effect of the ring tail on base drag to be seen easily, the body alone base drag estimate (from Reference 13) is shown in Figure 8. As the model sting support is approximately half a caliber in diameter, it will affect the measured base pressures, especially at the transonic Mach numbers. However, it is useful to present the results since they should show the base pressure trends correctly.

Both the ring and the support strut can have significant effects on the base drag. The diverging inside surface of the rings (except T_7 and T_{14}) causes an expansion fan from the ring leading edge. At low supersonic speeds this fan intersects the body, causing a reduction in the static pressure and an increase in the local Mach number near the body base region. This results in reduced base pressure, i.e., increased base drag. However, as the free stream Mach number is increased, the effect of the expansion fan is felt further downstream and eventually will have no adverse effect on the base drag. The maximum possible effect of the expansion fan caused by the diverging inside ring surface has been estimated by assuming that the local static pressure and Mach number just upstream of the base are the same as the conditions behind the expansion fan. The resulting base drag estimate is shown in Figure 8. Ring tails T_7 and T_{14}, which have zero inside surface slope, should not be affected by ring expansion fan.

Examination of the test results in Figure 8 shows that the "maximum expansion" estimate generally sets a maximum value of the base drag coefficient. Also at the higher test Mach numbers, the test results tend to be nearer the body alone estimate than the "maximum expansion" estimate showing the diminishing effect of the ring expansion fan with increasing Mach number. The large variations in base drag measured at transonic Mach numbers is probably due to multiple reflections of the expansion fan between the body and ring, and also tunnel and support sting interference effects.

The support struts induce a pressure field which affects the conditions just upstream of the base,and the base pressure is critically affected by these conditions. At the higher supersonic free stream Mach numbers, the circular support struts have a detached shock wave around them and there is a high pressure field behind this shock wave. This will cause increased base pressure and so reduced base drag. At low supersonic Mach numbers, the pressure rise across the detached shock wave is small and parts of the flow field behind this shock could be below the free stream static pressure (e.g., circular strut base flow area). This will cause increased base drag.

The base drag of ring tails T_7 and T_{14} should only be affected by the support struts. The test results for T_7 indicate considerable beneficial interference from $M = 1.5$ to 4.5; however, T_{14} only shows a small reduction in base drag at $M = 2.5$ and $M = 3.0$. This is probably because of the small ring diameter relative to the body diameter. The gap between ring and body is almost two-thirds filled with boundary layer and thus makes the results somewhat inconclusive.

Since these tests were primarily to check the stability characteristics of ring tails, further tests are planned to provide better understanding of the flow phenomenon and better evaluation of the effects of interference on base drag to be made.

2. Foredrag

Values of C_{D_F} have been estimated, by the methods in the appendix, over a Mach number range from 1.5 to 4.0. The broken line in Figure 9 is the C_{D_F} ignoring strut-ring beneficial interference, and the solid line is the C_{D_F} taking this interference into account. It is seen that the estimated values agree well with the test results and so the methods suggested in the appendix should be satisfactory at least for initial design drag estimates at supersonic speeds for ring tail-strut-body combinations.

The one configuration with poor agreement between test results and estimated values is B_2T_4 (Figure 9). This is probably because of interference between the ring tail and boattailed afterbody of B_2.

Section IV. CONCLUSIONS

An investigation of the aerodynamic characteristics has been made of a family of ring tail-strut-body configurations at Mach numbers of 0.80 to 4.5. Results of an analysis of the zero-lift fore drag and body base drag lead to the following conclusions:

1. Computation of ring strut wave drag at supersonic speeds using the method presented is adequate for engineering estimates.

2. Ring tails and their support struts have significant effects on base drag. Generally, the diverging ring strut configurations tend to increase body base drag while the nondiverging ring strut configurations decrease body base drag (except at transonic speeds).

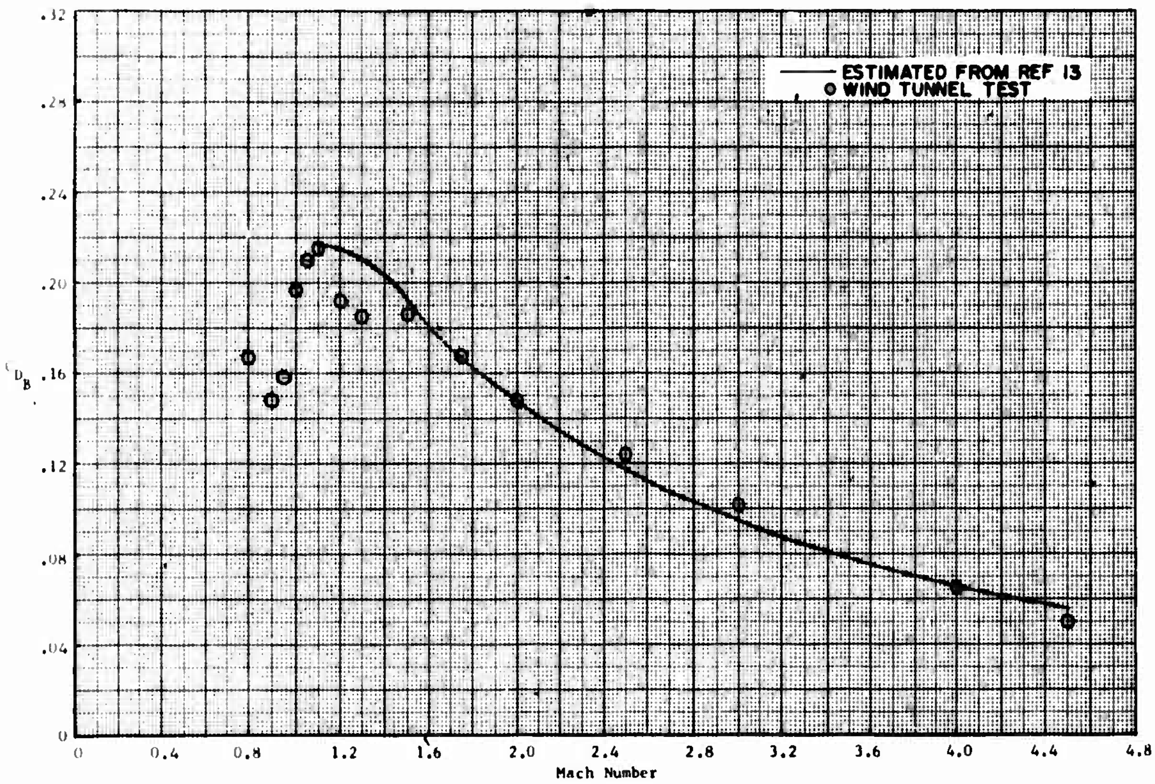


Figure 6. Body B1 Alone Base Drag versus Mach Number

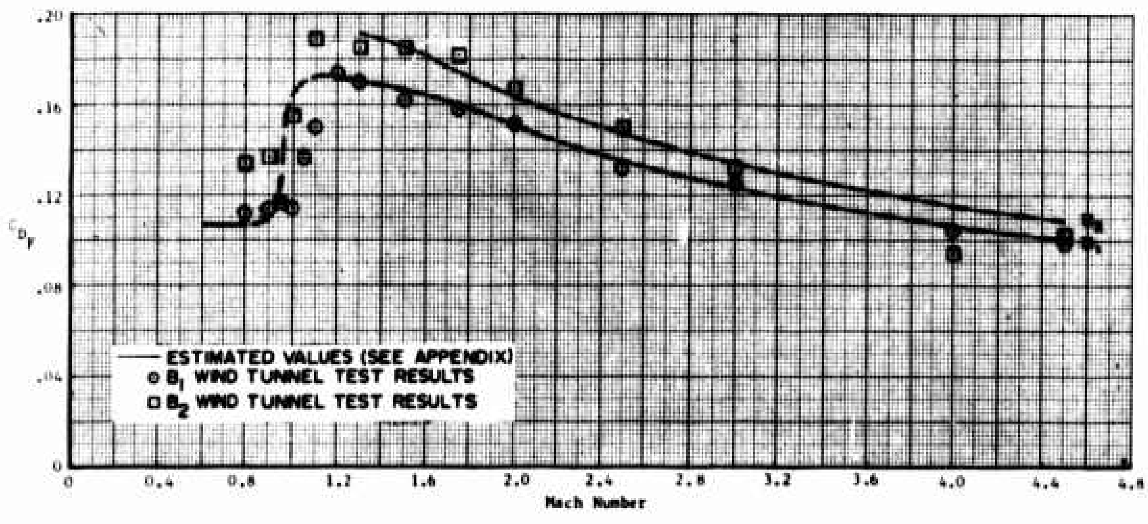


Figure 7. Zero Lift Foredrag Coefficient versus Mach Number for Bodies B1 and B2

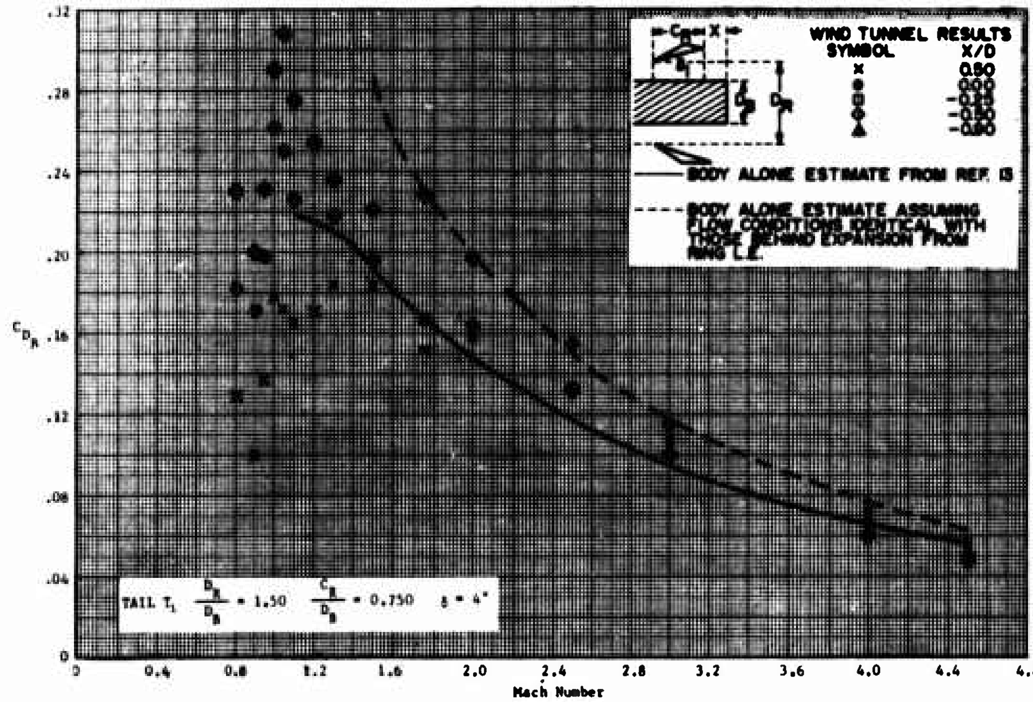


Figure 8a. Effect of Ring Tail and Support Strut on Body Base Drag Coefficient (Continued)

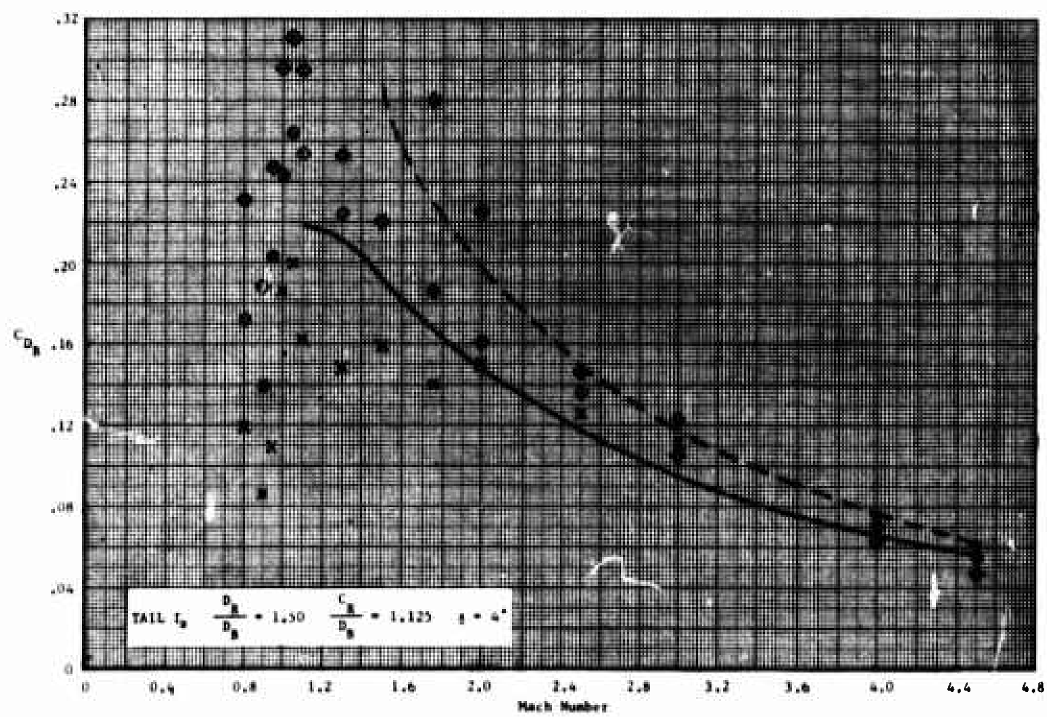


Figure 8b

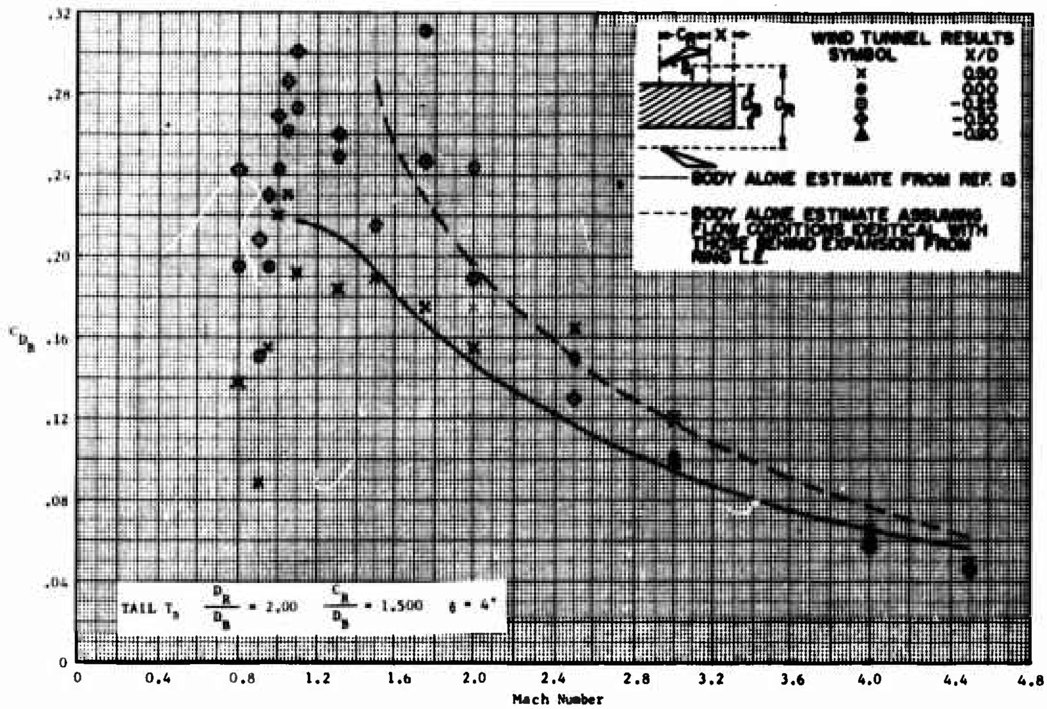


Figure 8c

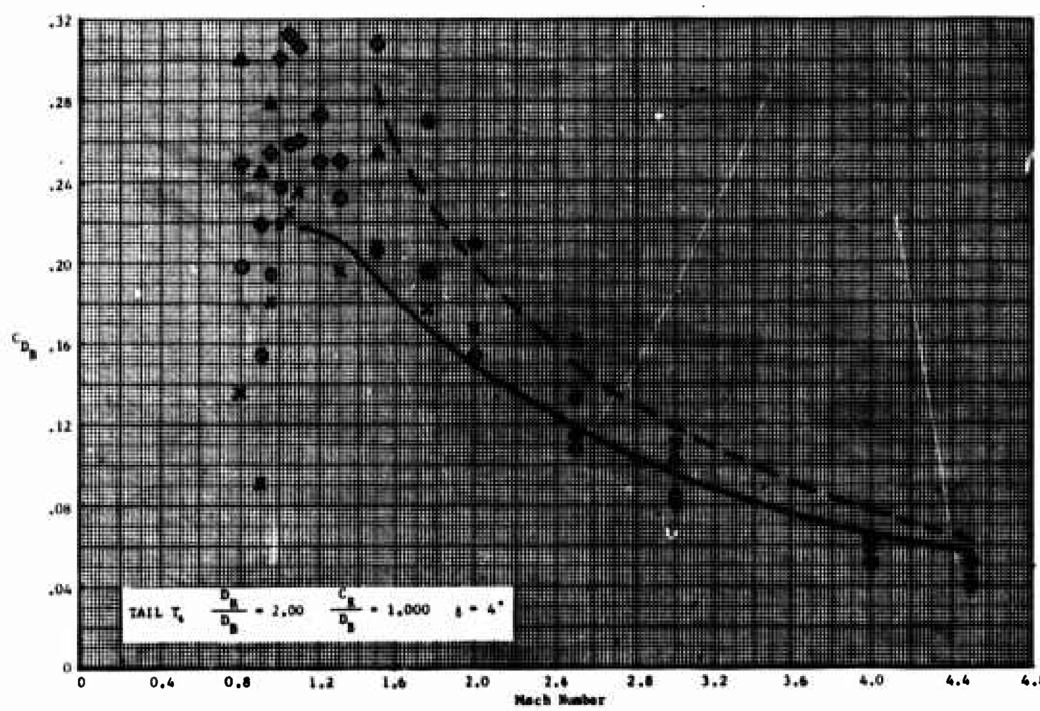
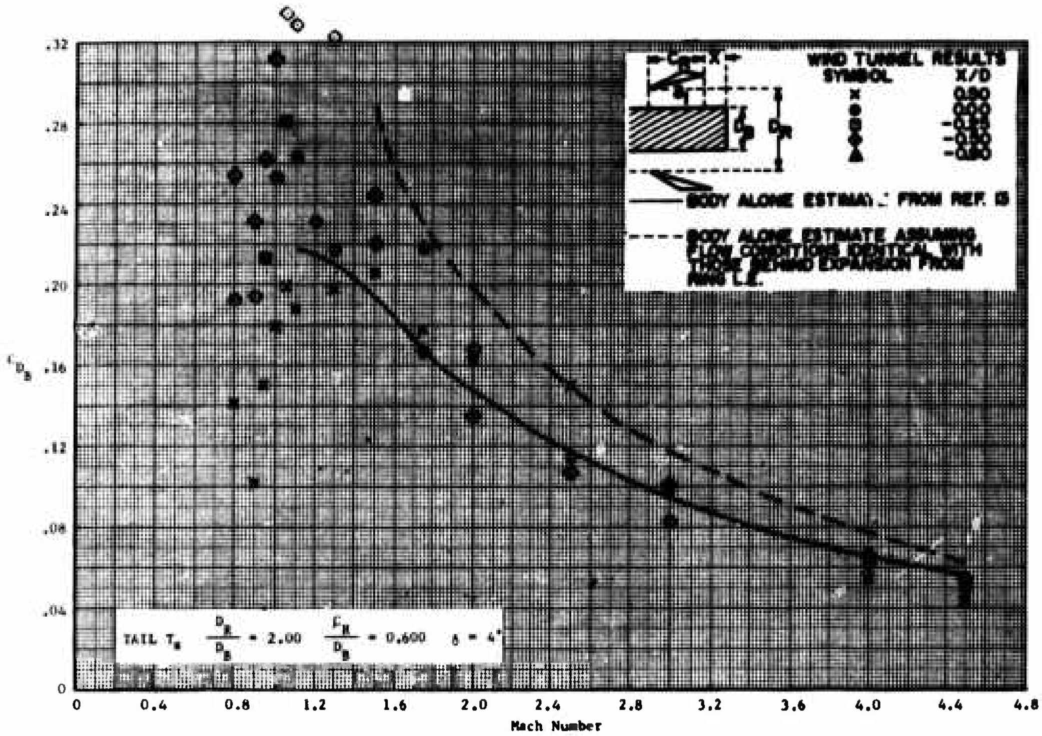


Figure 8d



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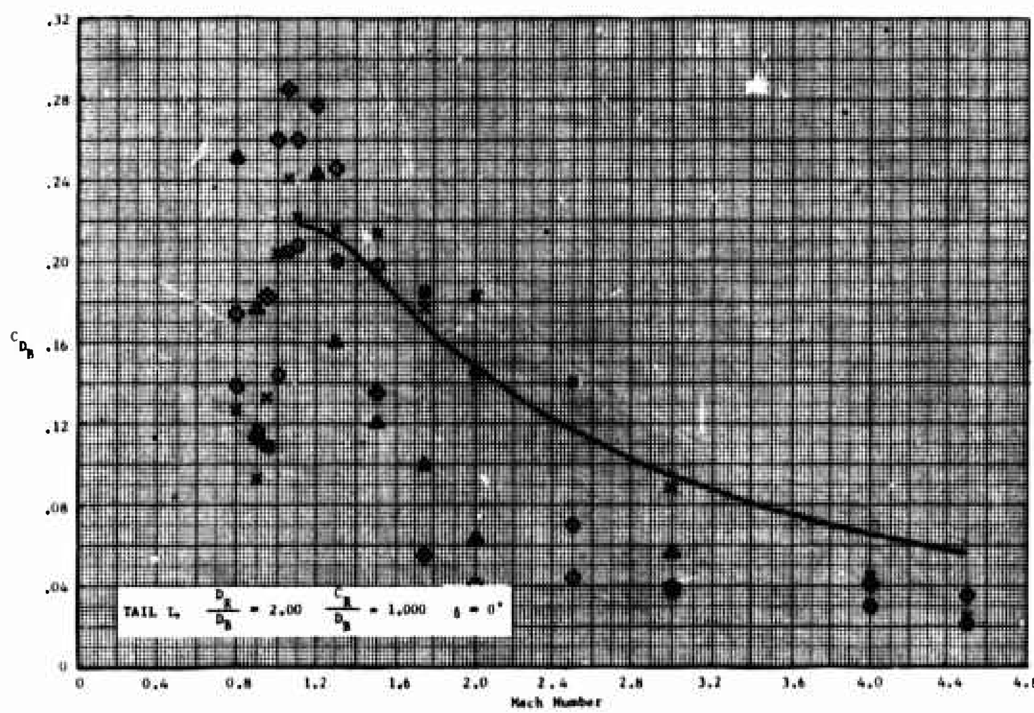

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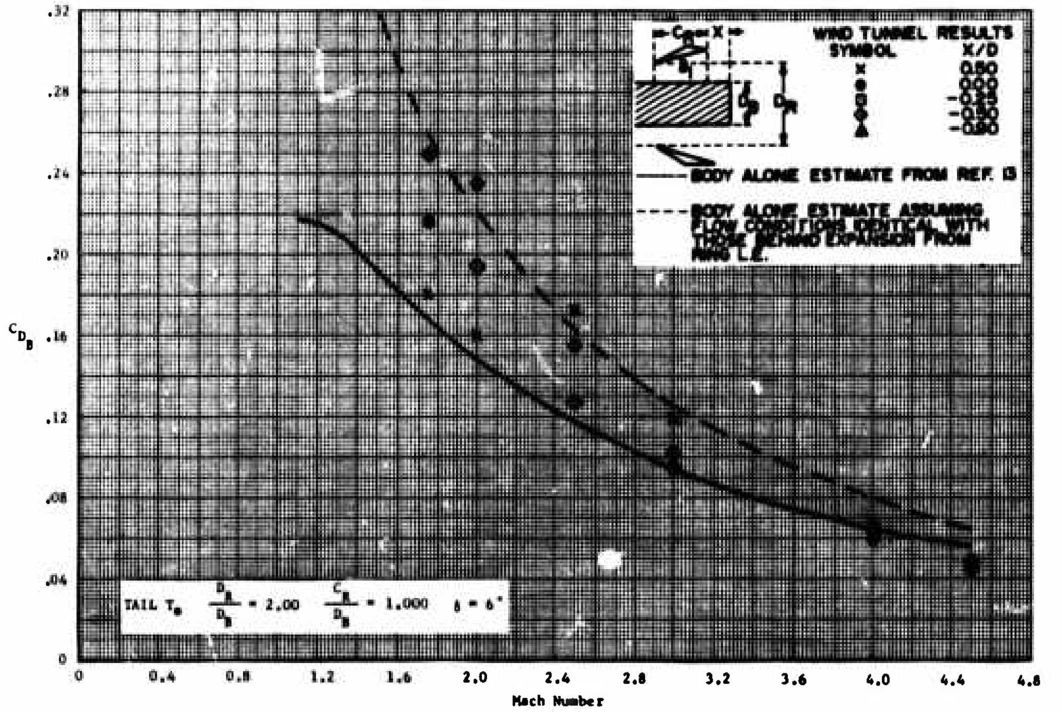


Figure 8g

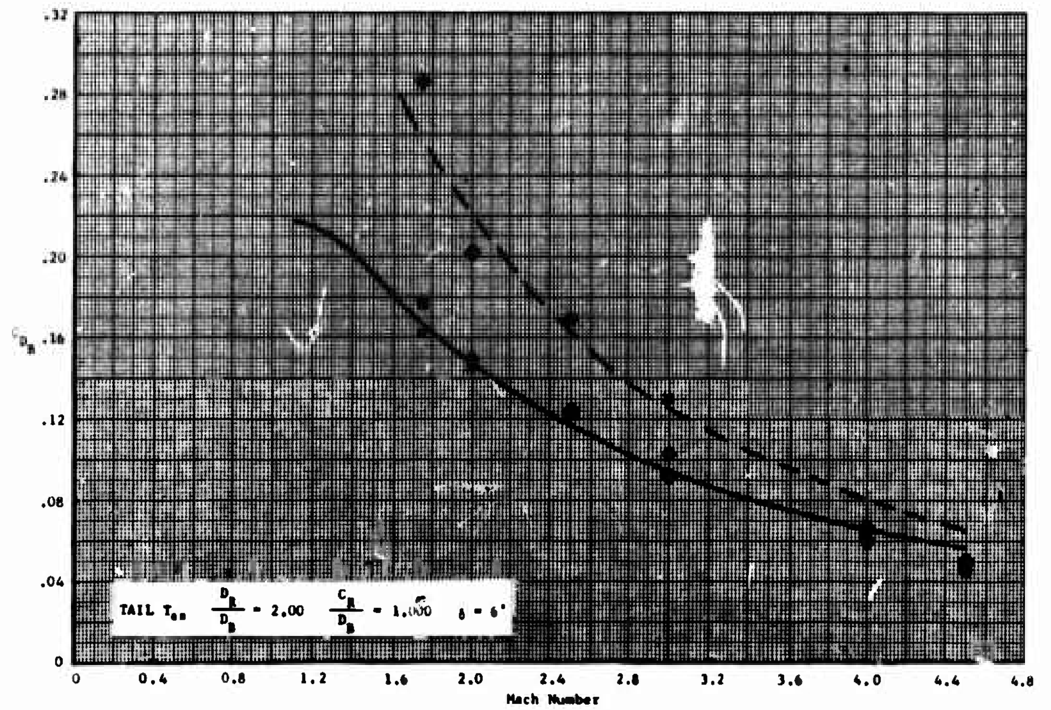


Figure 8h

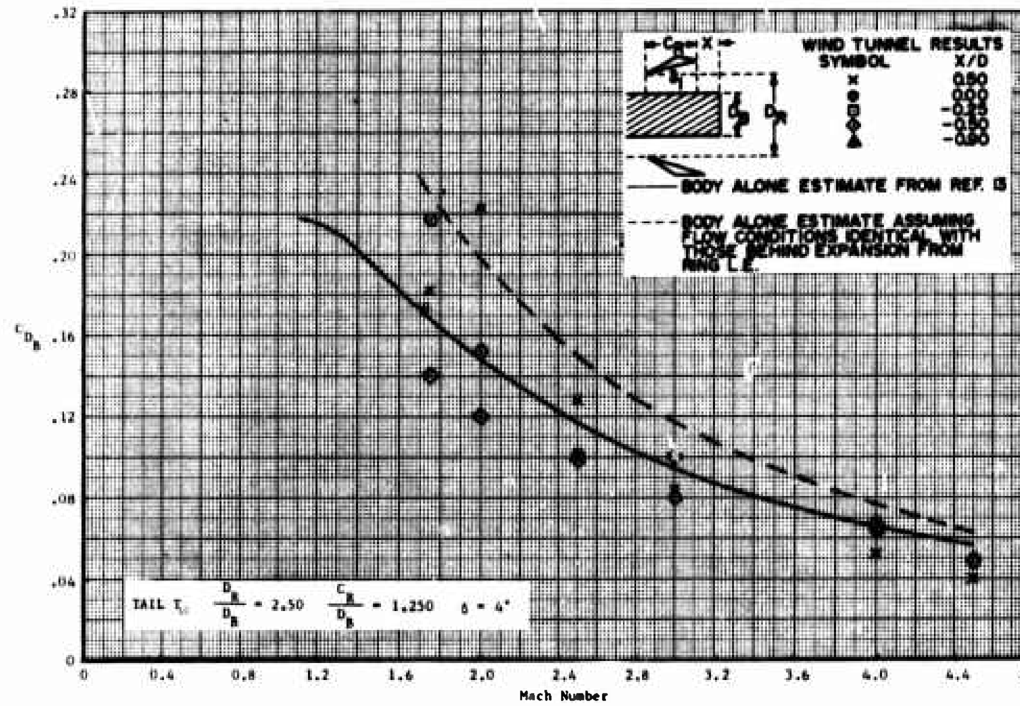


Figure 8i

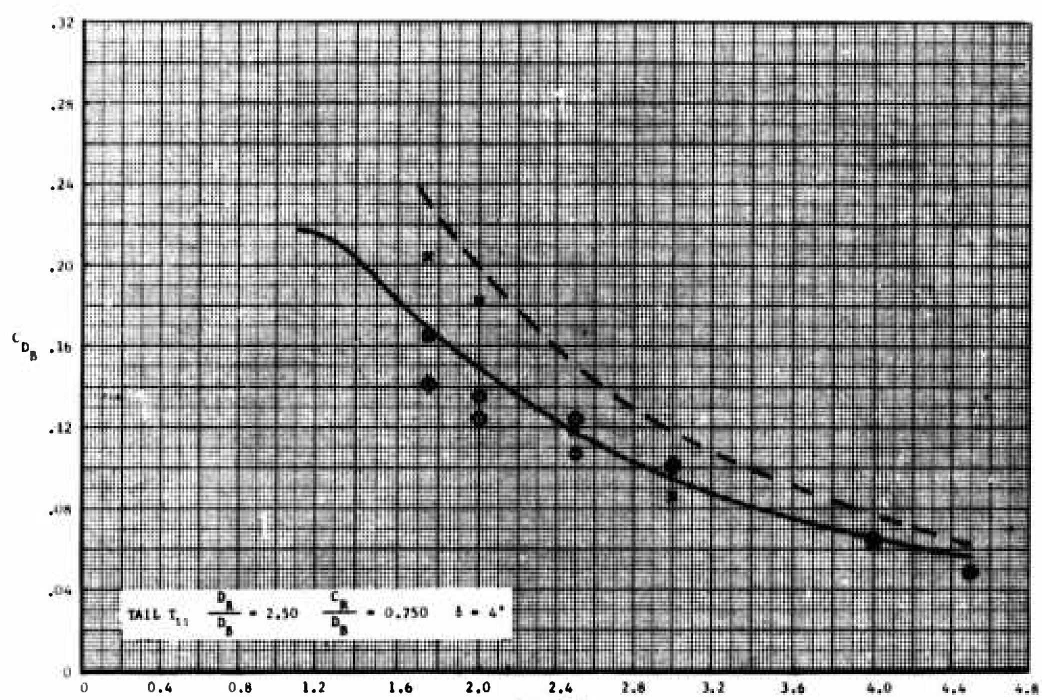
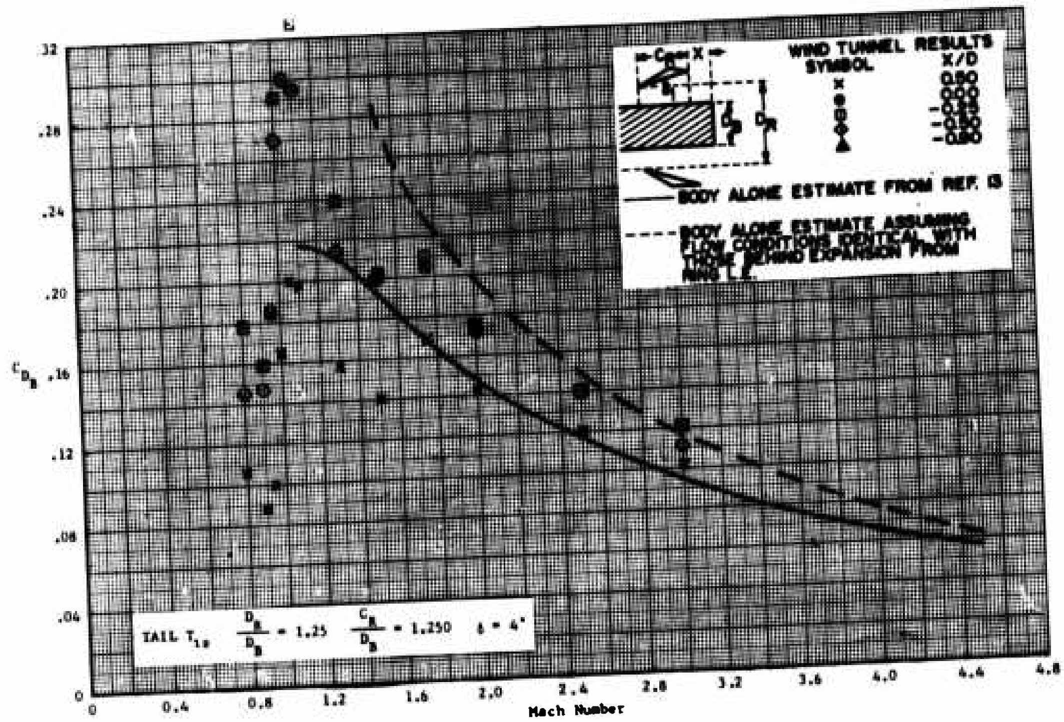


Figure 8j



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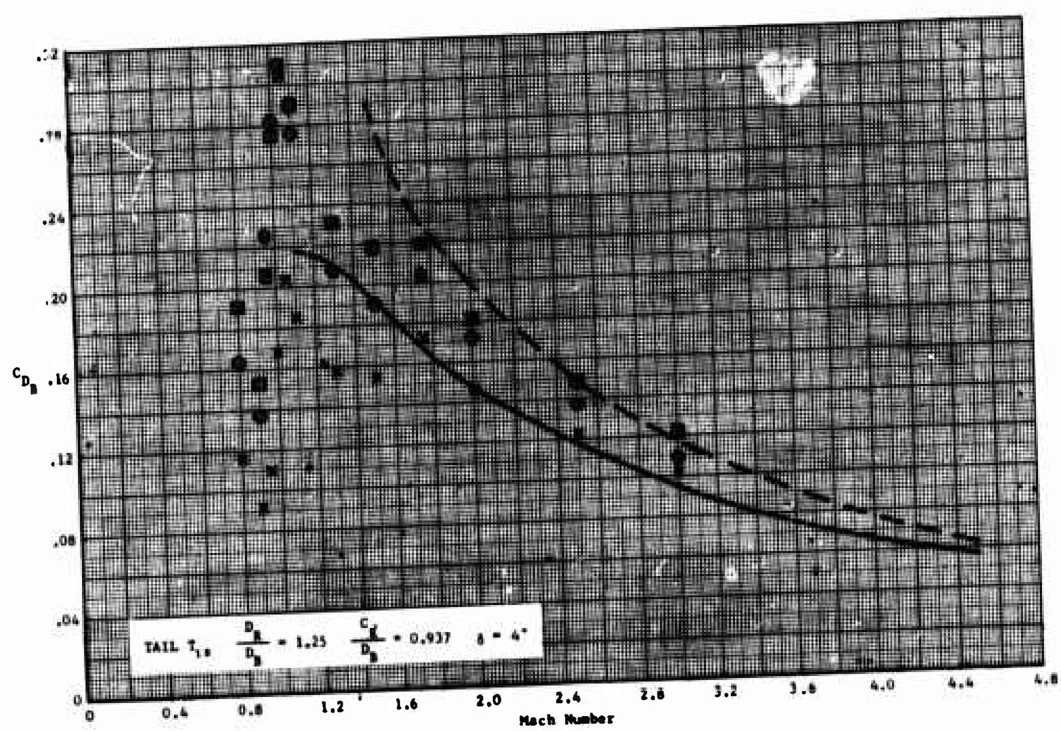

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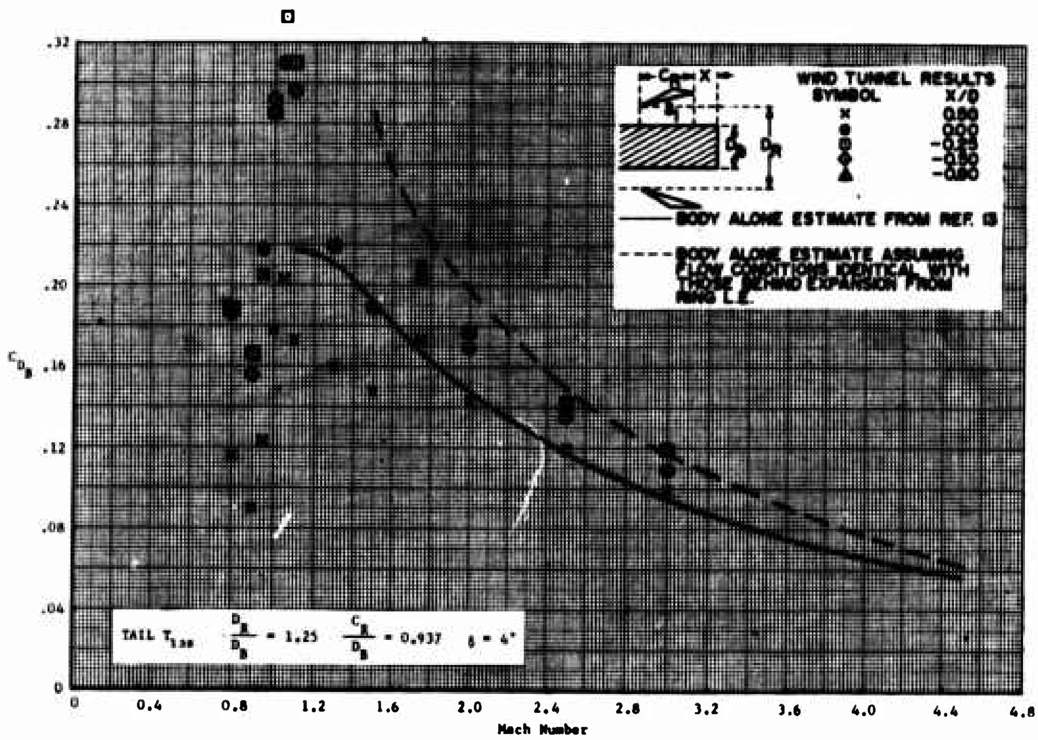

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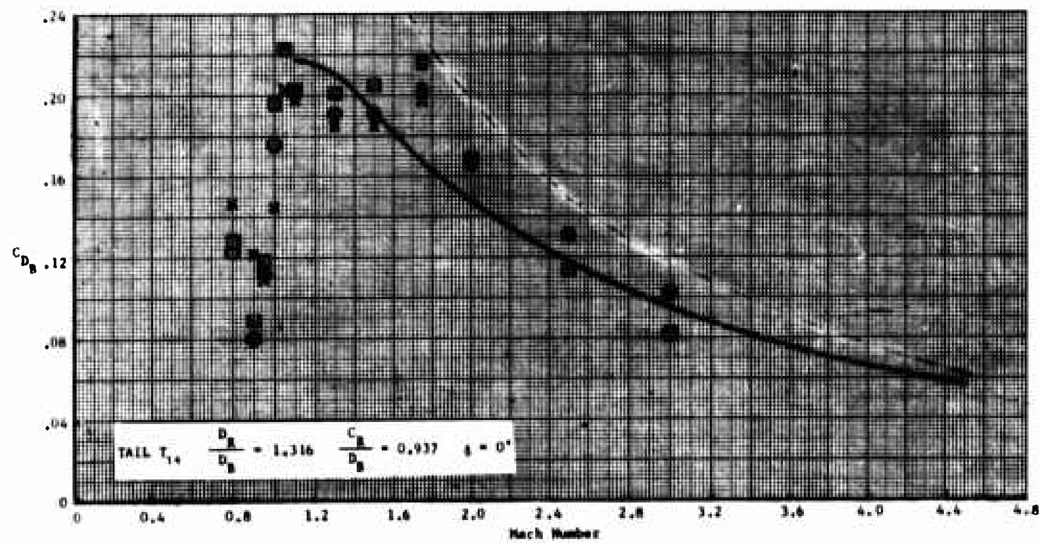

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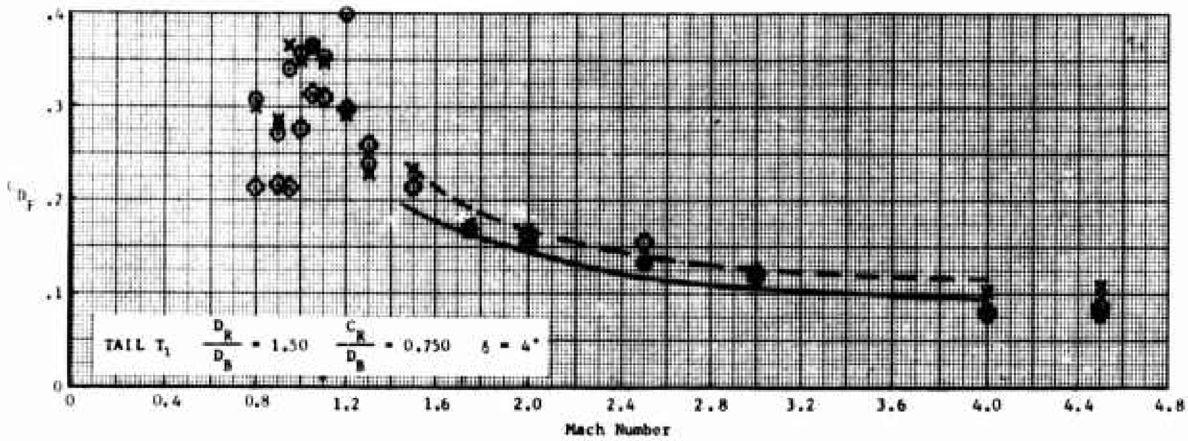
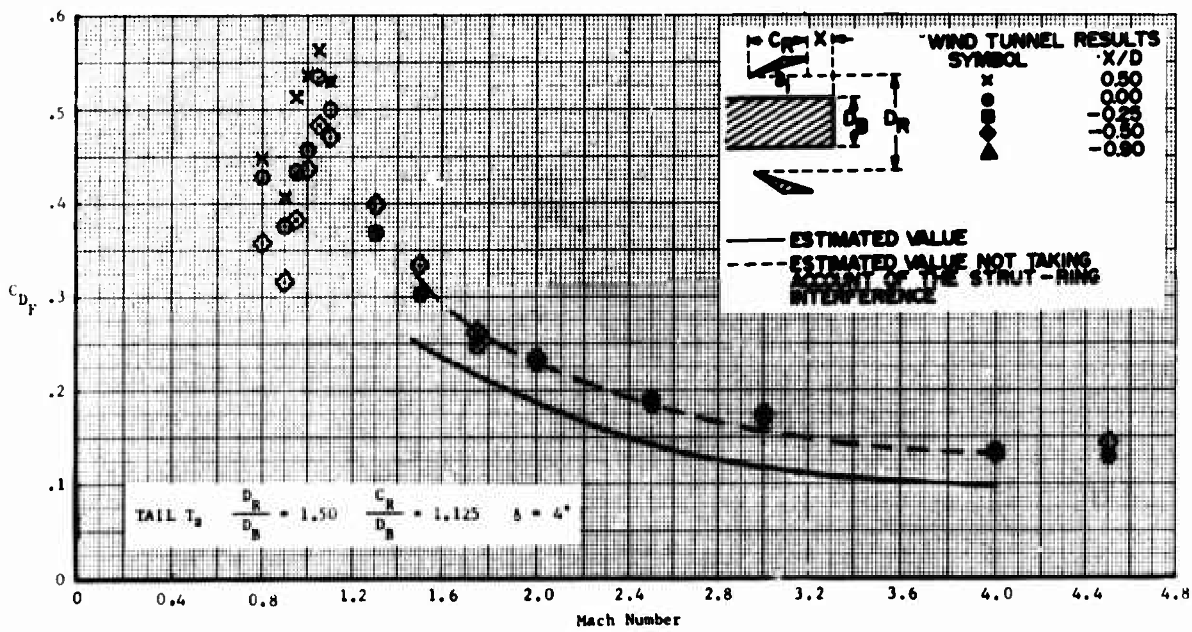


Figure 9a. Ring Tail and Support Strut Zero-Lift Foredrag versus Mach Number (Continued)



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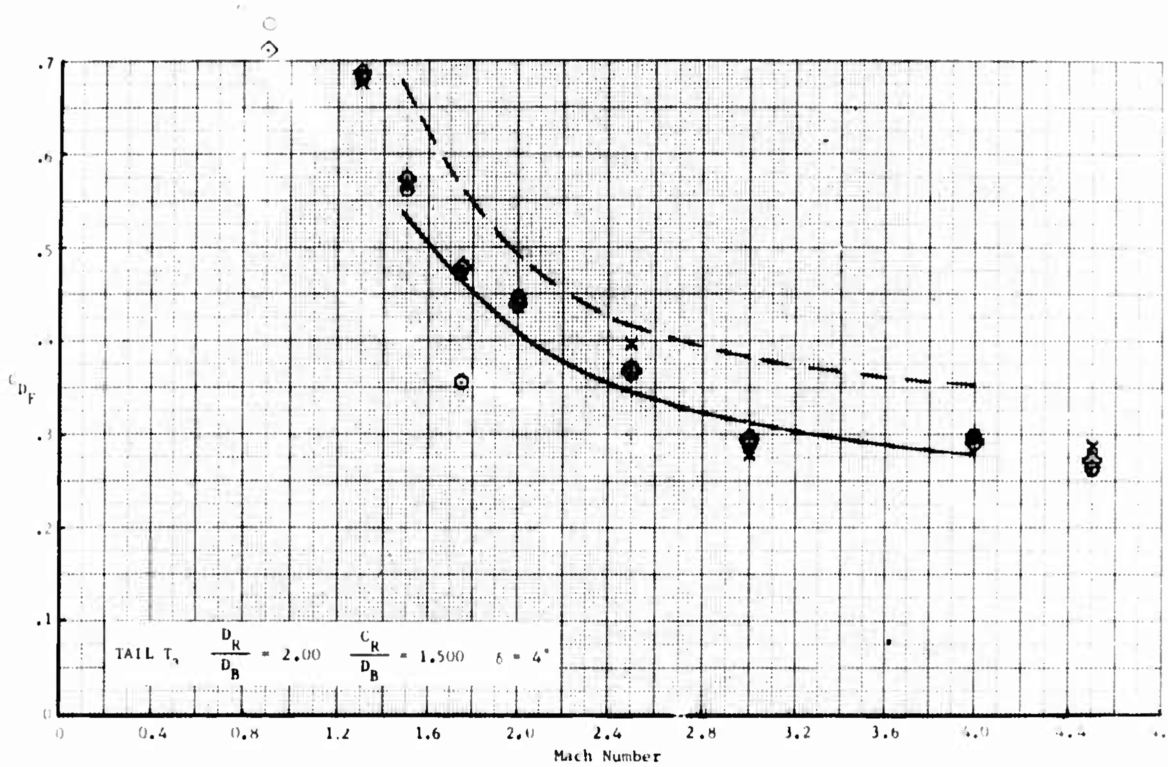

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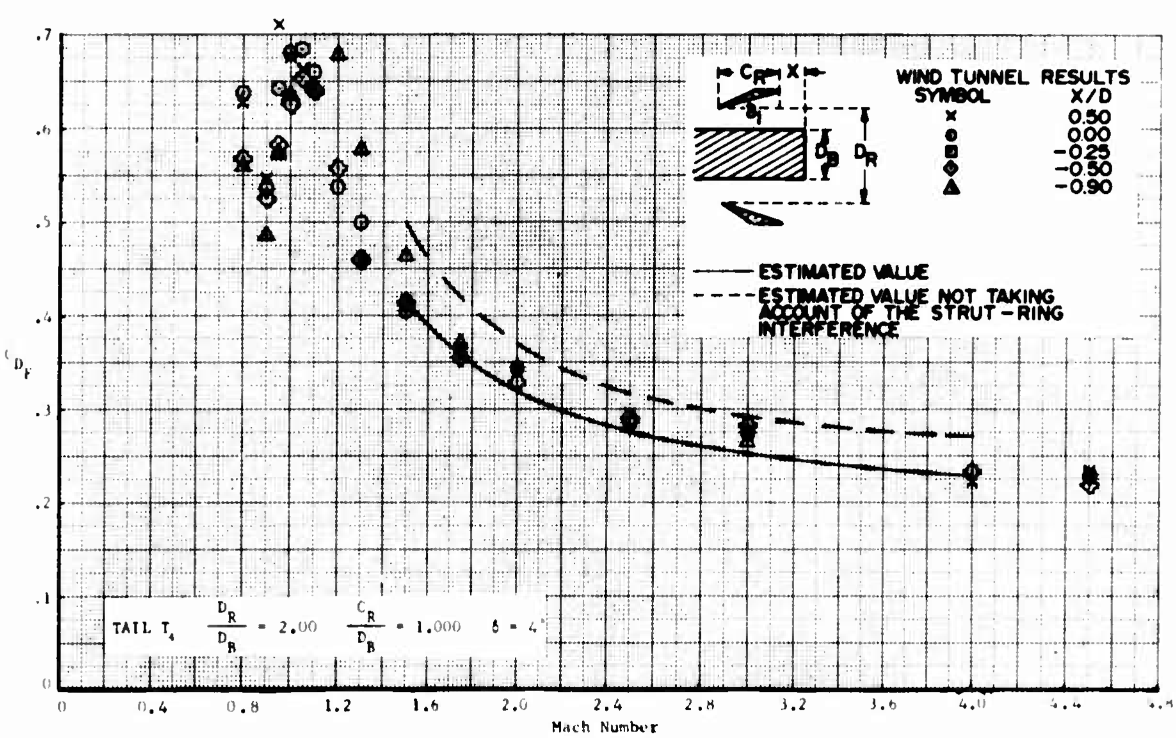

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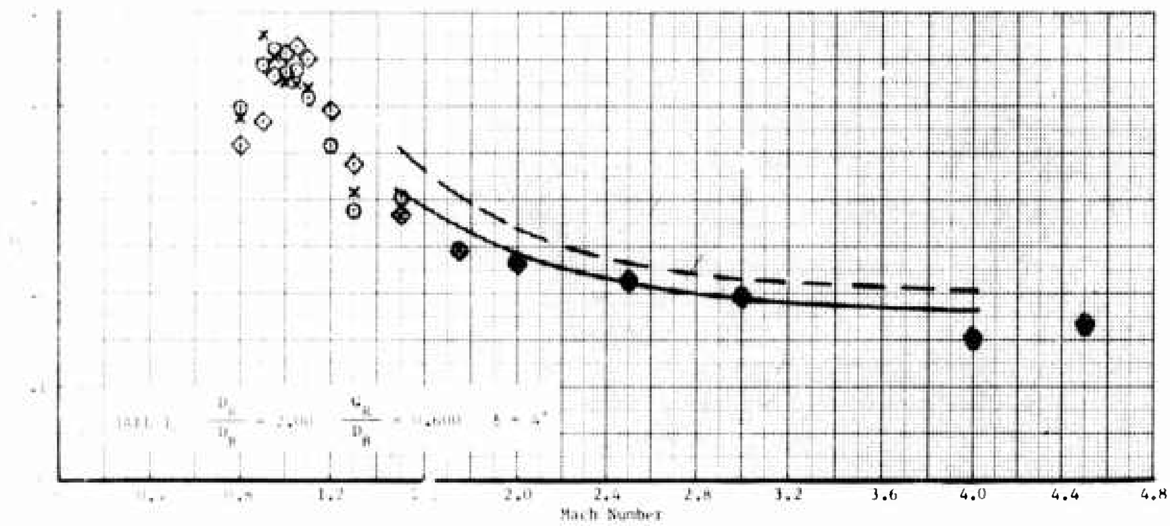

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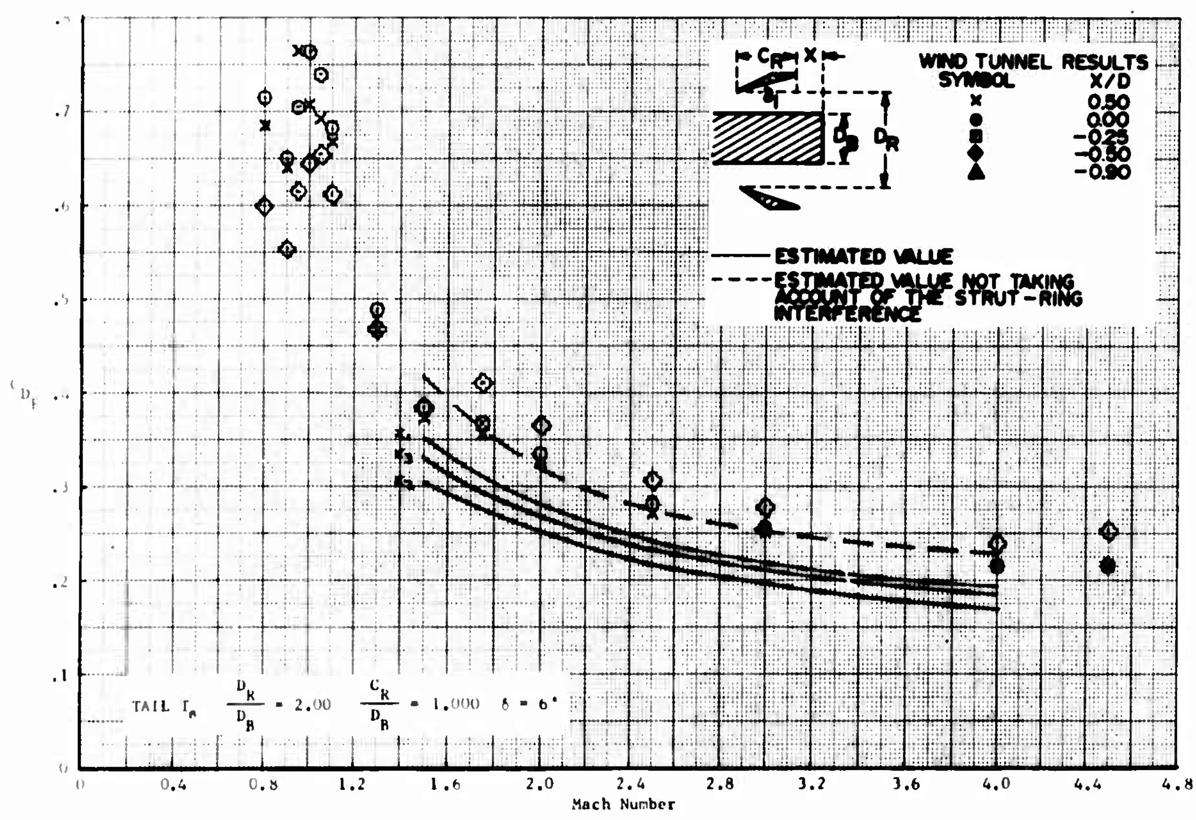

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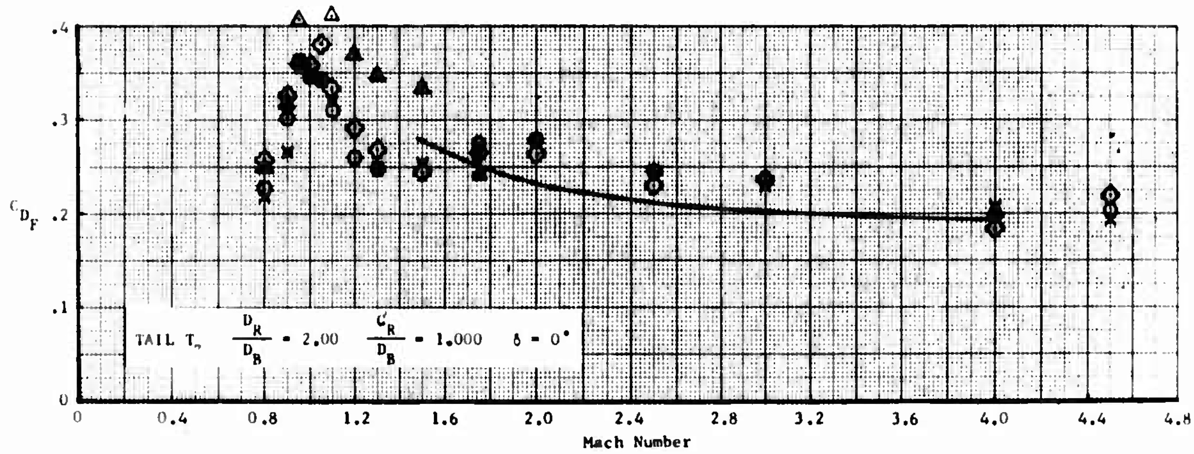

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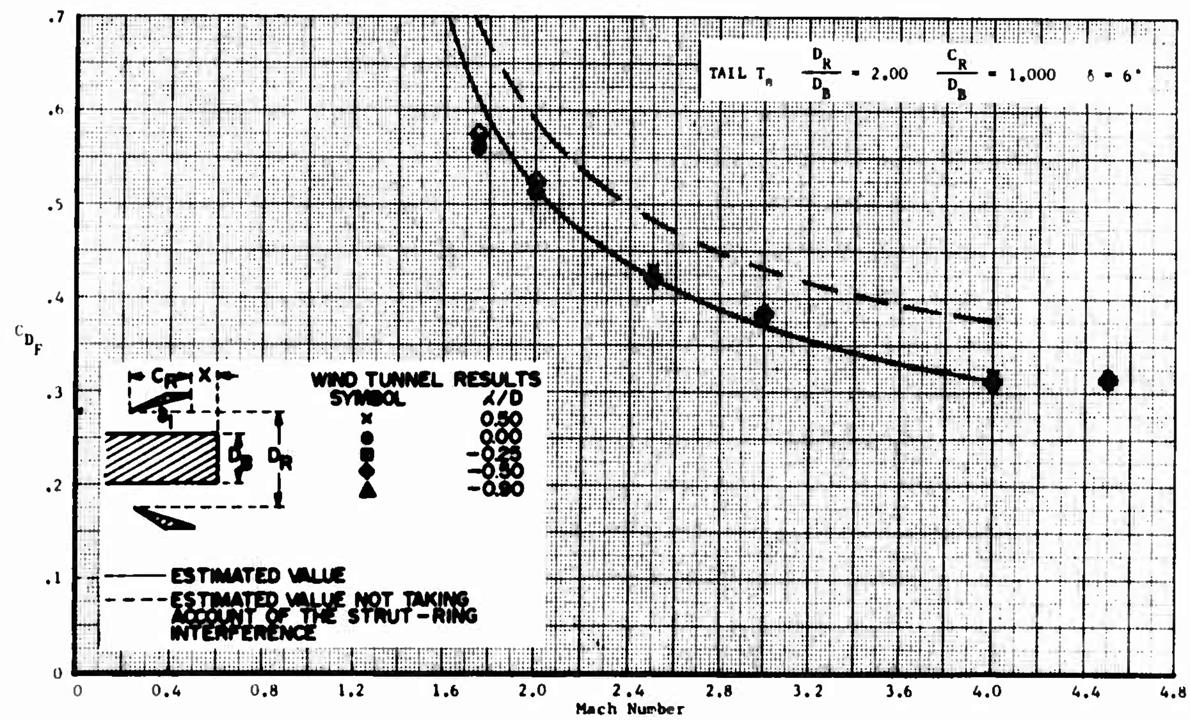

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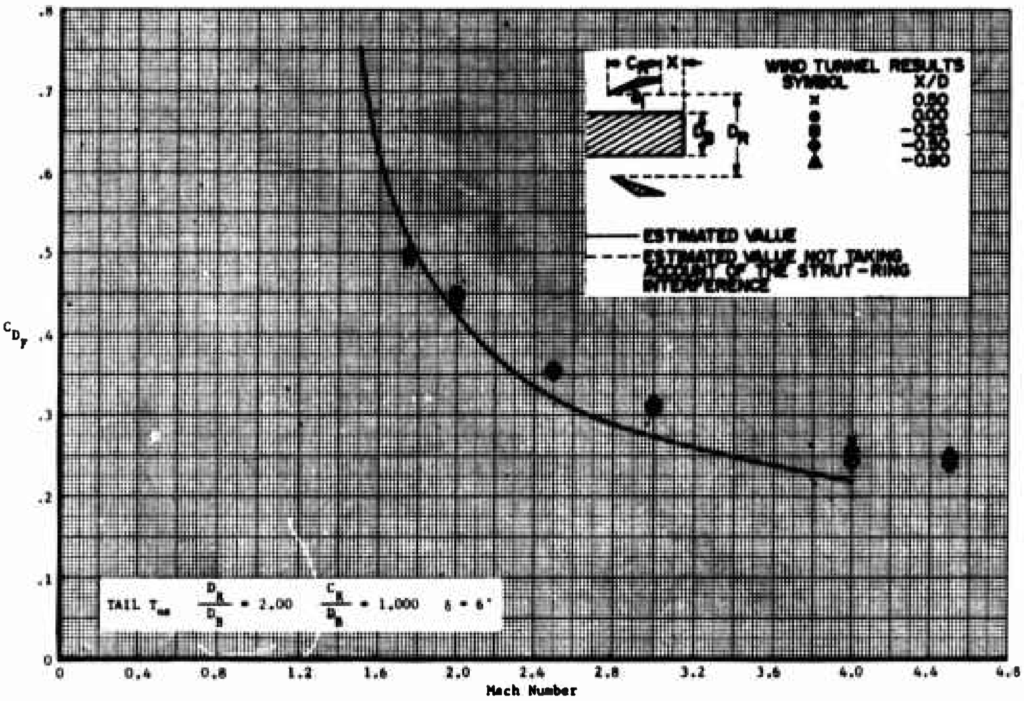

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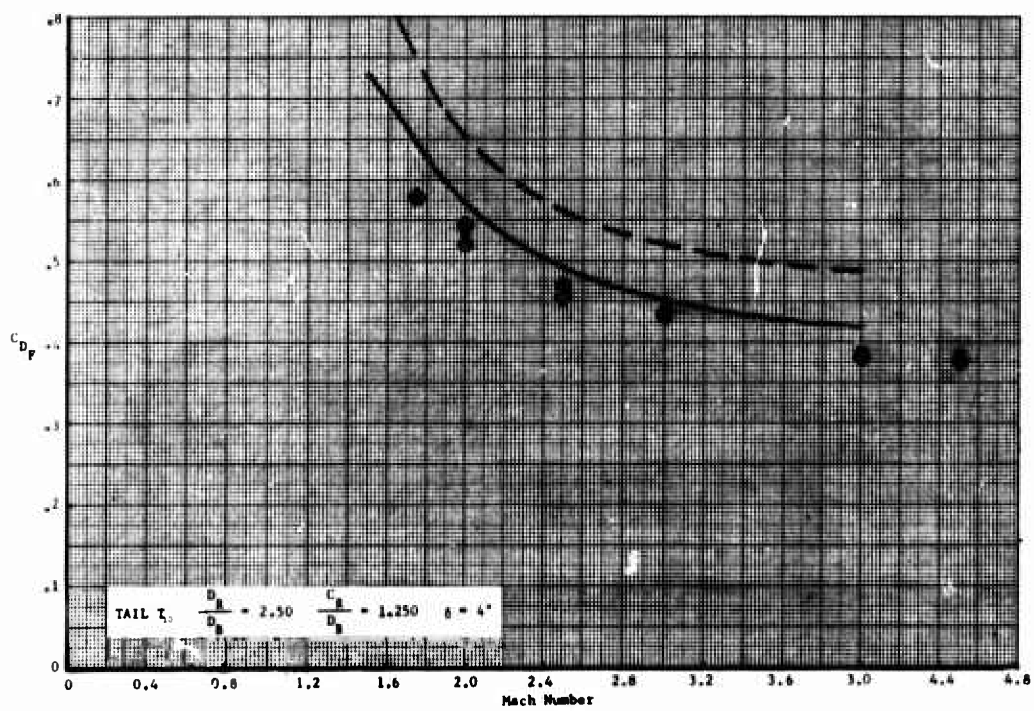

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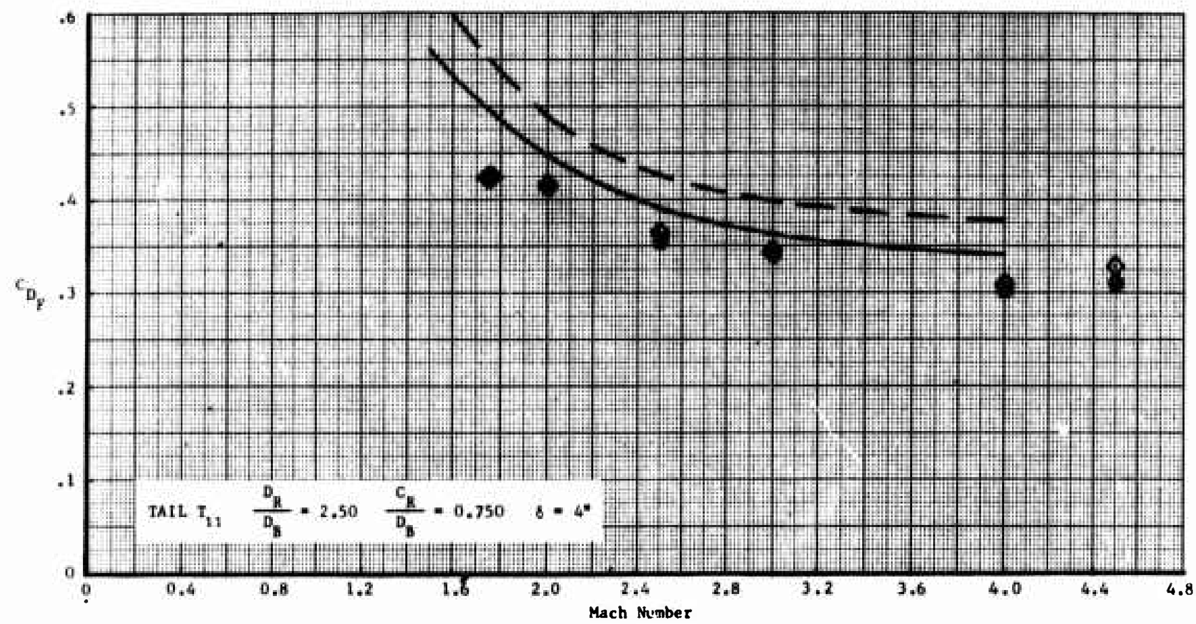

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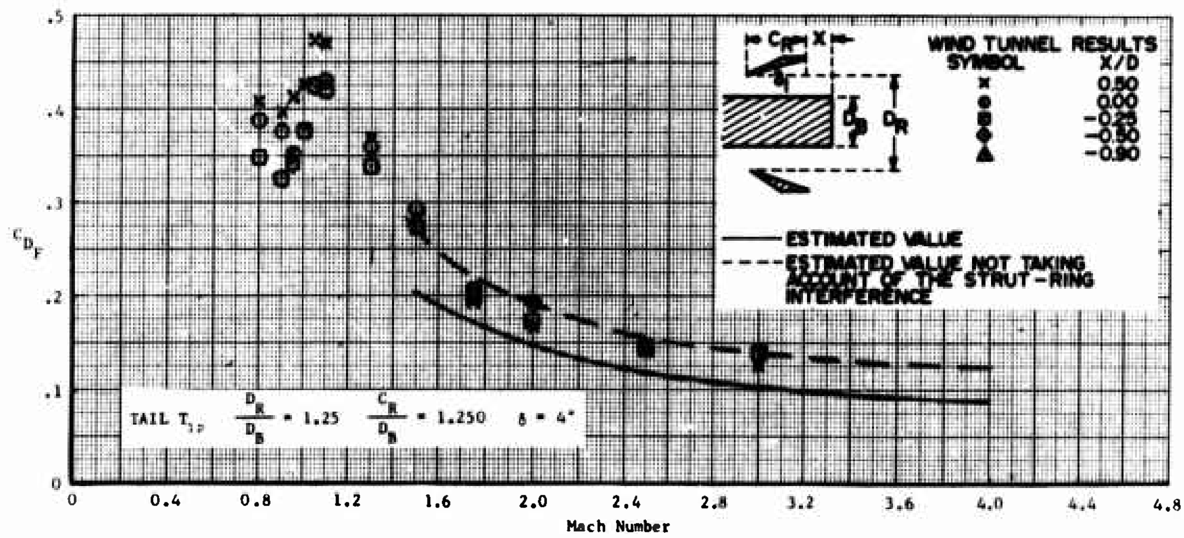

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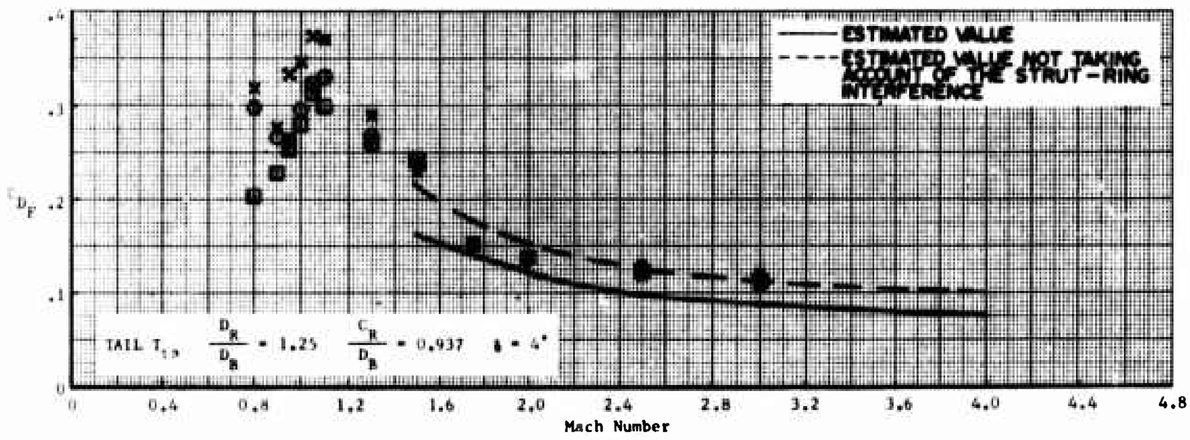

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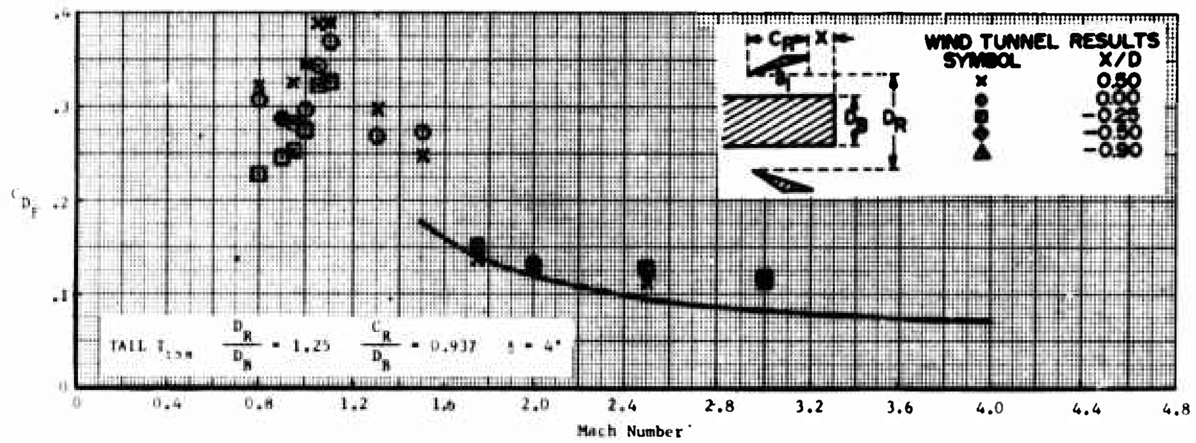

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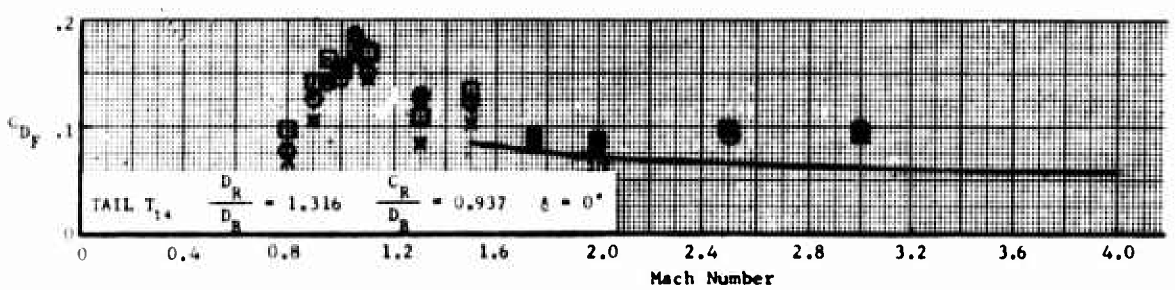

Figure 9o (Concluded)

Appendix

ESTIMATE OF ZERO-LIFT DRAG COEFFICIENT (EXCLUDING BASE DRAG) FOR RING TAIL-STRUT-BODY COMBINATIONS AT SUPERSONIC MACH NUMBERS

The various components of the drag are as follows:

(1) Body skin friction drag.
(2) Body wave drag.
(3) Ring tail skin friction drag.
(4) Ring tail wave drag.
(5) Support strut skin friction drag.
(6) Support strut wave drag.
(7) Strut-ring tail interference drag.
(8) Strut-body interference drag.

Of these eight components, items 1, 2, 3, 5 and 6 can be estimated by the usual routine methods. The estimate of the ring tail wave drag (item 4) was obtained by multiplying the two-dimensional section wave drag by the circumference. The section wave drag can be obtained by shock-expansion or other methods. This is probably accurate if the expansion wave from the ring leading edge does not impinge on the inner surface of the ring after reflection from the body. For a Mach number range of 1.5 to 4.0, only the smaller diameter rings at their forward positions and at the lower free stream Mach numbers violate this condition, but the estimates should still be acceptable for these conditions.

This leaves items 7 and 8, the interference drag, which will be negative due to the pressure field of the support strut acting over the forward facing inner ring surface and the boattail afterbody of body B_2. To estimate this interference drag accurately, one needs to know the pressure field around the strut. Since a.. exact calculation of the pressure field would involve very laborious and complicated computations, and as the interference drag is only a small percentage of the total drag, an approximate method would be used.

For the circular section struts, the shape of the detached shock wave for a two-dimensional circular cylinder was calculated using the methods suggested in Reference 14. From the inclination of the shock wave at any point, the ratio of the static pressure just behind the shock to the free stream static pressure can be calculated. Now downstream of the shock, the static pressure will decay exponentially to the free stream static pressure. The rate of decay is, very approximately, such that in a length of six strut diameters, the static pressure drops halfway to the free stream value. In the present case, the ring tail trailing edge is between 4.7 and 10.8 strut diameters downstream of the strut ring intersection. To ease the computation problems, the pressure was assumed constant downstream of the shock and the final resultant force on the ring was halved to allow for the pressure decay. The interference drag on the boattailed afterbody of body B_2 can be dealt with in a similar manner.

For the double wedge section strut, shock-expansion methods were used to calculate the pressure field. In this case, the forward force on the fin due to the high pressure caused by the front wedge is nearly cancelled out by the low pressure caused by the rear wedge. The resulting interference drag is negligible.

Figure 10 shows the force induced on a ring fin by a circular strut for various Mach numbers and for various lengths of the fin trailing edge behind the strut ring intersection.

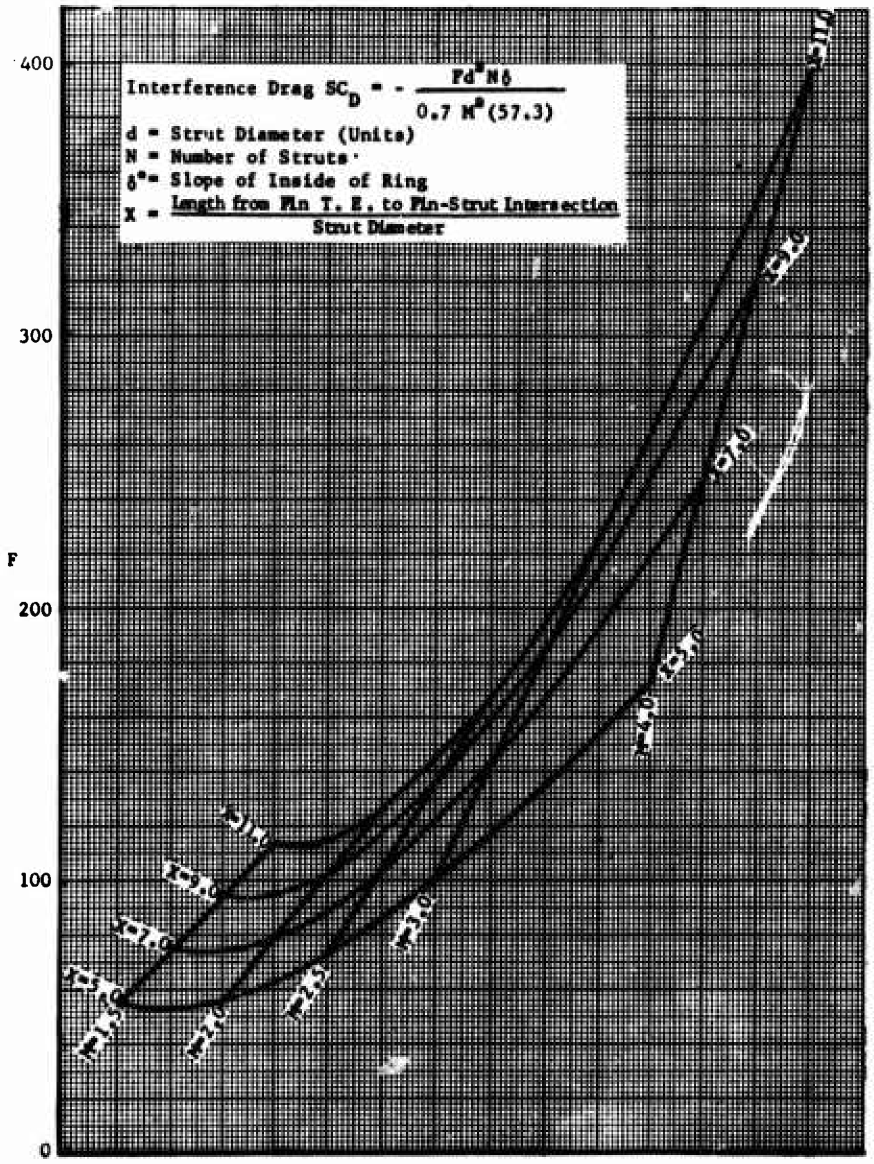

Figure 10. Fin-Strut Interference Drag Chart

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An investigation of the aerodynamic characteristics of a family of ring tail-strut-body configurations was conducted at Mach numbers from 0.80 to 4.5. Rings varying from 1.25 to 2.50 calibers in diameter and from 0.60 to 1.50 calibers in length were tested. They were tested at various longitudinal positions and with internal expansion angles from 0° to 6°. The effect of changing from circular section support struts to streamlined struts was also investigated.

This report presents the zero-lift foredrag and base drag results and compares them, wherever possible, with theoretical estimates.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Zero-lift foredrag Body base drag Ring tail-strut-body Mach numbers 0.80 to 4.50 Interference						

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