TECHNICAL REPORT R-72

A SUPERSONIC AREA RULE AND AN APPLICATION TO THE DESIGN OF A WING-BODY COMBINATION WITH HIGH LIFT-DRAG RATIOS

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SUMMARY

As an extension of the transonic area rule, a concept for interrelating the wave drags of wing-body combinations at moderate supersonic speeds with axial developments of cross-sectional area has been derived. The wave drag of a combination at a given supersonic speed is related to a number of developments of cross-sectional areas as intersected by Mach planes. On the basis of this concept and other design procedures, a structurally feasible, swept-wing—indented-body combination has been designed to have relatively high maximum lift-drag ratios over a range of transonic and moderate supersonic Mach numbers. The wing of the combination has been designed to have reduced drag associated with lift and, when used with an indented body, to have low zero-lift wave drag. Experimental results have been obtained for this configuration at Mach numbers from 0.80 to 2.01. Maximum lift-drag ratios of approximately 14 and 9 were measured at Mach numbers of 1.15 and 1.41, respectively.

INTRODUCTION

Reference 1 showed that near the speed of sound, the zero-lift drag rise for a wing-body combination having a thin, low-aspect-ratio wing is primarily dependent on the axial development of cross-section area normal to the airstream. Also, it was found that contouring the bodies of wing-body combinations to obtain improved axial developments of cross-sectional area for the combinations results in substantial reductions in the drag-rise increments at transonic speeds.

More recently, by considering the physical nature of the flow at moderate supersonic speeds, a concept has been developed which should interrelate qualitatively the zero-lift wave drag of wing-body combinations at these speeds with axial developments of cross-sectional areas. This relationship is basically the same as that arrived at independently in reference 2 on the basis of the considerations of reference 3. On the basis of this concept and other design procedures, a structurally feasible, swept-wing—indented-body combination has been designed to have relatively high lift-drag ratios over a range of transonic and moderate supersonic Mach numbers.

The present paper describes the supersonic area rule, the considerations involved in the design of the special configuration, and some experimental results for the configuration obtained at Mach numbers from 0.80 to 2.01. The results presented for Mach numbers of 1.41, 1.61, and 2.01 were obtained from reference 4.

SYMBOLS

b	wing span, in.
C_D	drag coefficient
C_L	lift coefficient
c	wing chord, in.
$\bar{c}$	mean aerodynamic chord, in.
L/D	lift-drag ratio
M	Mach number
y	spanwise distance from center line, in.
α	angle of attack, deg
ΔC_D	increment of drag coefficient for an increment in lift coefficient

[1] Supersedes recently declassified NACA Research Memorandum L53H31a by Richard T. Whitcomb and Thomas L. Fischetti, 1953.

ΔC_L incremental drag coefficient
μ Mach angle, deg
ϕ roll angle, deg

Subscripts:

max maximum
min minimum

CONCEPT FOR INTERRELATING WAVE DRAG WITH AREA DEVELOPMENTS AT SUPERSONIC SPEEDS

BASIS OF CONCEPT

The major part of the supersonic wave drag for a wing-body combination results from losses associated with shocks at considerable distances from the configuration. Thus, the wave drag may be estimated by considering the stream disturbances produced by a configuration at these distances. At moderate supersonic speeds, these disturbances may be considered in individual stream tubes, such as A in figure 1. If small

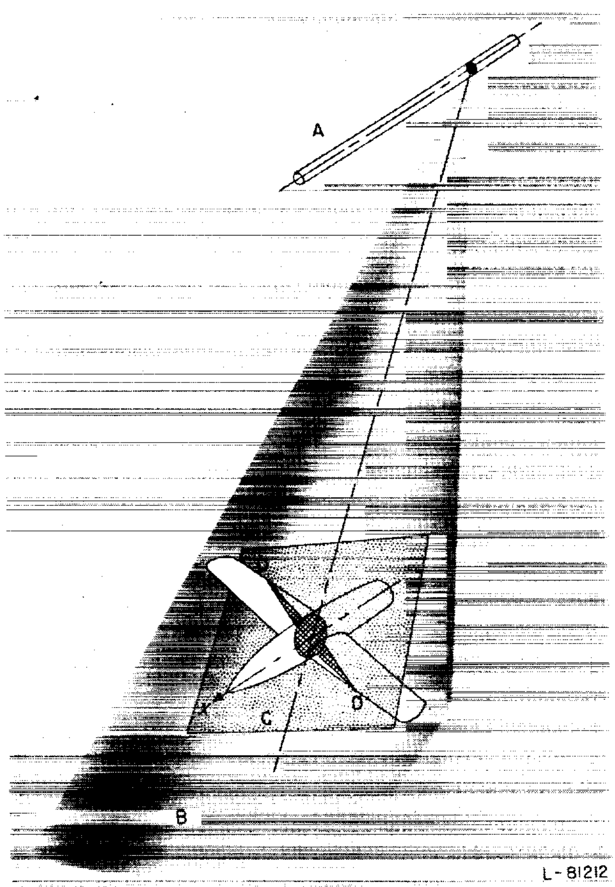


FIGURE 1.—Geometric relations considered in developing area rule for supersonic speeds.

induced velocities are assumed, the effects of changes in the configuration arrive at points on this tube along Mach lines which lie on cone segments, such as B. For reasonable distances from the configuration (roughly 2 spans or greater) and for conventional, relatively low-aspect-ratio wings, the surface of these cone segments in the region of the configuration may be assumed to be the Mach planes, such as C, tangent to the cone segments between the tube A and the axis of symmetry.

Consideration of the propagation of the local effects of the configuration indicates that the variations in the disturbances at the stream tube A generally may be assumed to be approximately proportional to streamwise changes in the normal components of the total areas of the cross sections, such as DD, intersected by these Mach planes. Therefore, the wave losses in the stream tube are functions of the axial development of these cross-sectional areas. Obviously, the losses in the set of stream tubes along a given radial sector are functions of one axial development of cross-sectional area, whereas those in tubes in circumferentially displaced sectors are functions of various developments determined by sets of Mach planes with axes of tilt rotated about the axis of symmetry. Except for the substitution of streamwise changes of cross-sectional area for singularities, these considerations are essentially the same as those presented on page 93 of reference 3.

PROCEDURE FOR DETERMINING AREA DEVELOPMENTS

From the foregoing considerations, the zero-lift wave drag for a wing-body combination at a given moderate supersonic Mach number can be seen to be related to a number of developments of the normal components of cross-sectional areas as intersected by Mach planes which are inclined to the stream at the Mach angle μ (fig. 2). The various developments are obtained with the axis of tilt of these Mach planes rolled to various positions around the center line of the configuration. This procedure is illustrated in figure 2. For clarity, the position of the axis of tilt of the Mach plane is maintained and the configuration is rolled. For configurations symmetrical about horizontal and vertical planes, the area developments are determined for various roll angles ϕ from 0° to 90°. The approximate wave drag for the combination is an average of functions of a number of area developments so determined.

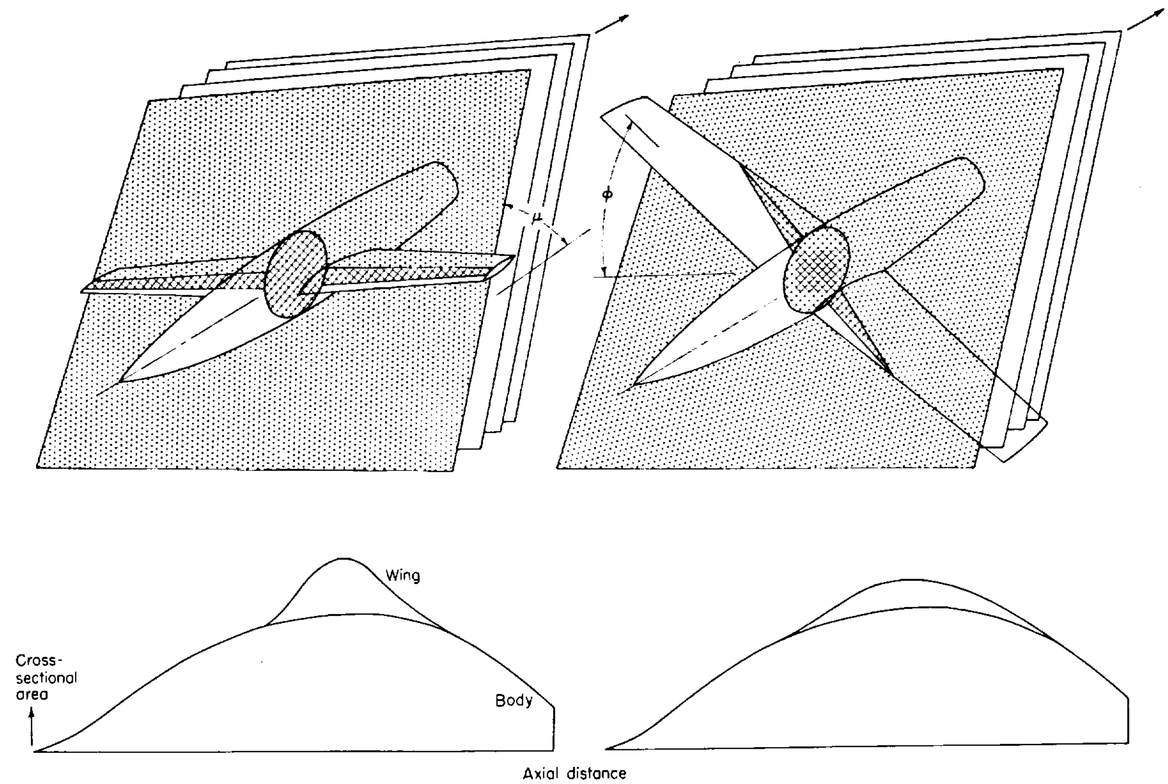


FIGURE 2.—Procedure for determining area developments related to wave drag at moderate supersonic Mach numbers.

The area developments obtained for the configuration shown in figure 2 with the two representative roll angles are presented at the bottom of the figure. As indicated by these curves, the various developments for a given Mach number may differ considerably. The partial end-plate effect of the body on the field of the wing affects the applicability of this simplified concept. For most practical combinations, this effect should be of secondary importance. Obviously this relationship reduces to the transonic area rule at a Mach number of 1.0.

APPLICATION TO THE REDUCTION OF WAVE DRAG

On the basis of this concept, the approximately minimum wave drag for a wing-body combination at a given supersonic speed would be obtained by shaping the body so that the various area developments for this speed are the same as those for bodies of revolution with low wave drag. Experimental results, such as those presented in reference 5, have indicated that body shapings so designed usually provide substantially greater reductions in drag at moderate supersonic speeds than do those shapes designed to improve the development for a Mach number of 1.0.

For most configurations, somewhat more satisfactory developments can be obtained by shaping the body noncircularly rather than axially symmetrically. Obviously, the body contours used should not cause severe local velocity gradients or boundary-layer separation. In general, for combinations of practical wings with bodies with sufficiently conservative contours, the area developments for the various values of ϕ will deviate from the most desirable shapes. The possibilities of improving the various area developments at and off the design conditions through the use of body indentation are strongly dependent on the geometry of the wing.

DESIGN OF WING-BODY COMBINATION

The wing of the combination has been designed to have reduced drag associated with lift and, when used with an indented body, to have low zero-lift wave drag on the basis of the concept described in the preceding section for a range of transonic and moderate supersonic Mach numbers. In particular, the parameters of the wing generally have been selected so that it is possible to obtain with a given body indentation relatively smooth area developments for the various values of ϕ (fig. 2) at the Mach numbers under consideration. Therefore, the area developments for the wing must be similar for the various Mach numbers and values of ϕ.

DESCRIPTION OF CONFIGURATION

The configuration is shown in figure 3. The wing, which is cambered and twisted, has 60° of sweep, an aspect ratio of 4, and a taper ratio of 0.333. It has NACA 64-series airfoil sections which vary in thickness from 12 percent chord at the root to 6 percent chord at the 50-percent-semispan station and then remains constant at 6 percent chord to the tip as shown in figure 4. The coordinates of the wing sections are listed in table I.

The body shape used as a basis for the design of the indented configuration discussed herein is that for the body described in reference 6. For the primary configuration, the body has been indented axially symmetrically to obtain relatively smooth area developments at a Mach number of 1.4 (fig. 5). The coordinates for the body are listed in table II. The ratio of the body volume to the two-thirds power to the wing area for this combination is the same as that for the configuration of reference 6. The body incidence is 5° with respect to the reference plane of the wing (fig. 4).

CONSIDERATIONS INVOLVED IN DESIGN

Wing sweep.—A comparison of the area developments for moderate supersonic speeds for various wing plan forms in combination with indented bodies has indicated that the area developments for the various values of ϕ over a range of Mach numbers are most similar when the wing leading and trailing edges are swept behind the Mach lines. Also, the experimental results obtained thus far have indicated that the actual effects of indentation on drag approach the estimated effects most closely for such conditions (ref. 1, for example). With the higher wing aspect ratios which become structurally feasible because of the thicker wing sections allowed through the use of body indentation, swept wings with the leading and trailing edges swept behind the Mach lines have the lowest drags associated with lift (ref. 7). With the 60° of sweep chosen for the configuration described herein, these advantages should be realized over a wide range of moderate supersonic speeds.

Wing section-thickness-to-chord ratios.—Analysis of area developments and experimental results

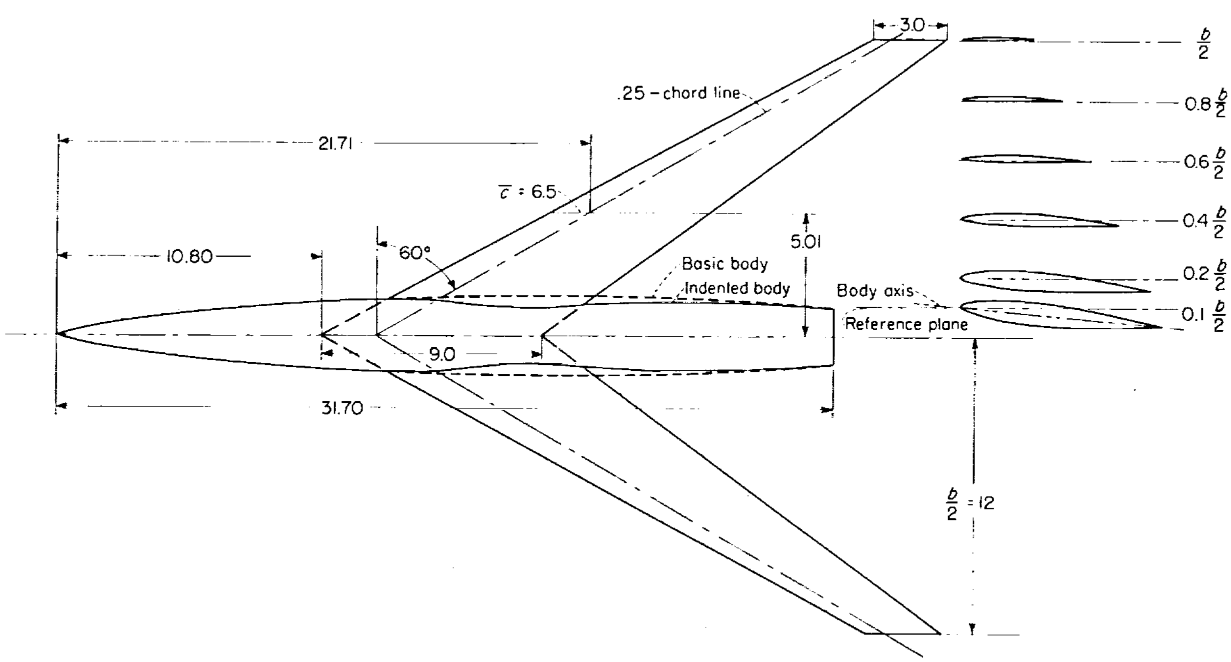


FIGURE 3.—Dimensions of model of wing-body configuration. All dimensions are in inches.

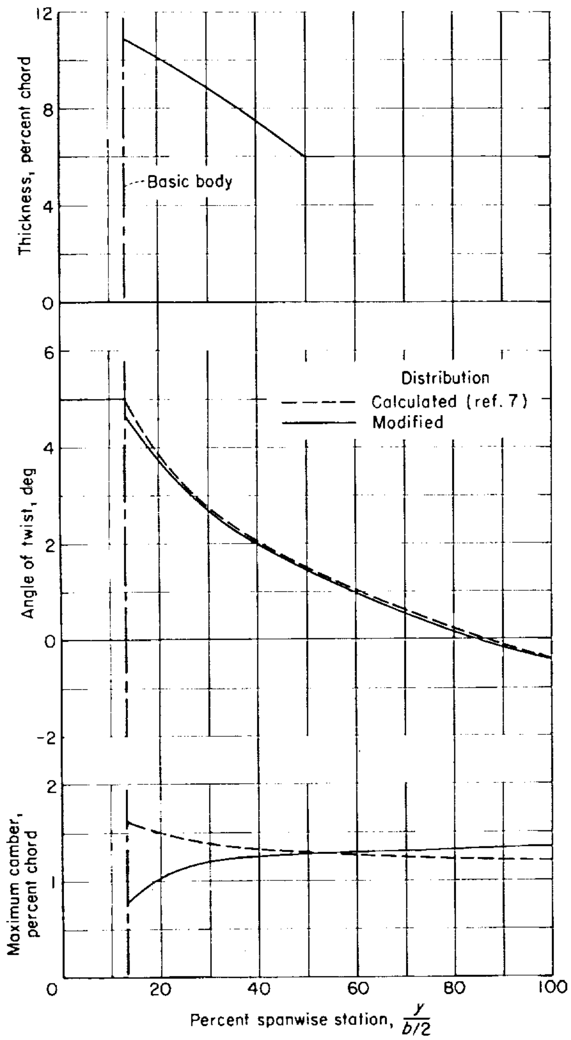
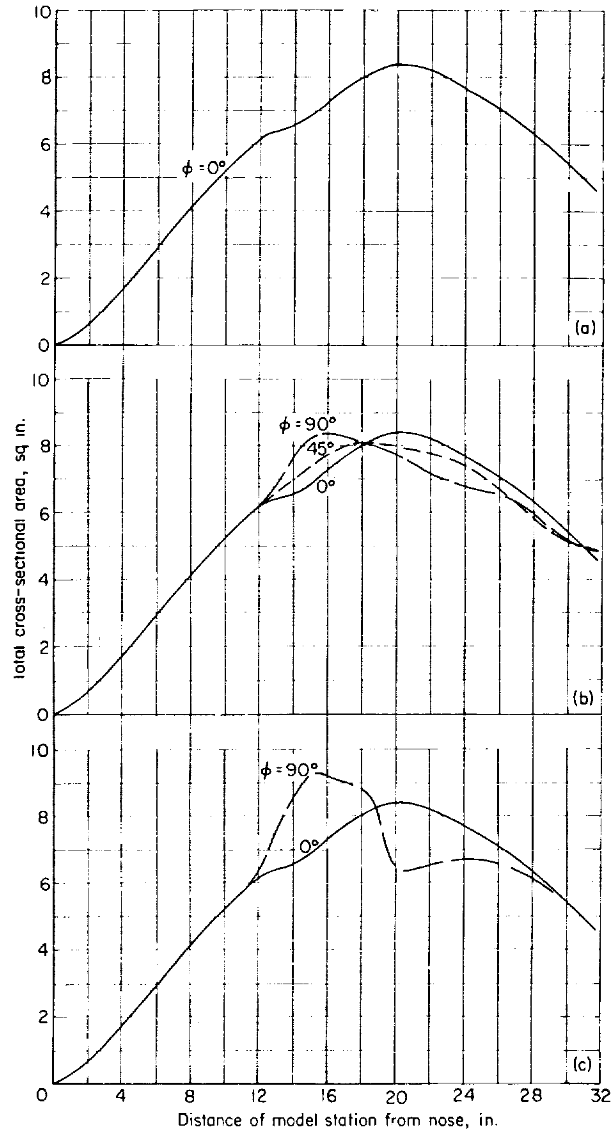


FIGURE 4.—Spanwise distributions of section thickness, angle of twist, and maximum camber of wing.



(a) $M=1.0$.
(b) $M=1.4$.
(c) $M=1.6$.

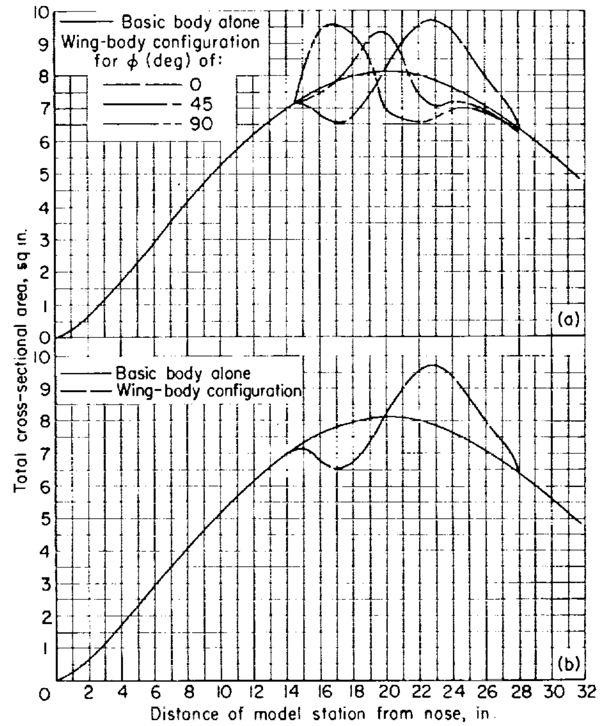
FIGURE 5.—Representative axial developments of cross-sectional area for the 60° swept wing in combination with the body indented for $M=1.4$ at $M=1.0$, 1.4, and 1.6.

(ref. 8) have indicated that, generally, the effectiveness of a body indentation in reducing wave drag at and off design Mach numbers and at lifting conditions is considerably greater for a wing having the section-thickness-to-chord ratio decrease from root to tip than for one with a uniform thickness-to-chord ratio equal to the mean value for the tapered-thickness wing. The estimated variation of supersonic wave drag with change in wing thickness-to-chord ratio at a given Mach number for wings with bodies indented to obtain the smoothest area developments for each combination is generally less pronounced than that for the same wings in combination with an unindented body. It follows that the most satisfactory inboard section-thickness-to-chord ratios should be considerably higher for indented configurations than for normal combinations. However, because of the limitations to the magnitude of feasible indentations, as discussed previously, body indentation obviously cannot be used to reduce the drag increments of indefinite increases in wing thickness-to-chord ratios.

Wing aspect ratio and structural characteristics.—With the wing swept behind the Mach line, the drag due to lift is reduced by increasing the aspect ratio (refs. 7 and 8). Because of the relatively thick wing sections allowed with body indentation, aspect ratios significantly higher than those previously used for practical configurations can now be considered. An actual wing of the relatively high-aspect-ratio configuration proposed herein appears to be structurally feasible. The deflection of the wing of this configuration under a given load at the 70-percent-semispan station would be approximately half of that for the highly swept wing discussed in reference 6.

Body contours and area developments.—With the primary body indentation used, the axial development of cross-sectional area for the combination for the median value of ϕ (45°) at the design Mach number of 1.4 (fig. 5) is approximately the same as that for the body used as a basis for the design. At the extreme values of ϕ (0° and 90°) the developments differ somewhat from those for the basic unindented body alone; however, the estimated drag increment for the combination associated with such variations in the area developments is negligible. The area developments for Mach numbers between 1.0 and 1.4 are all relatively smooth as indicated by the developments for the extremes of this range presented in figure 5. At Mach numbers greater than 1.4, the developments become relatively irregular as indicated by the developments for a Mach number of 1.6 (fig. 5). The fuselage indentation designed for a Mach number of 1.4 is very similar to that for a Mach number of 1.0 (table II). This similarity results from designing the wing of this particular configuration to have similar area developments at all Mach numbers.

The area developments obtained for this combination at Mach numbers up to 1.6 are considerably smoother than those obtained for the same conditions for unswept, moderately swept, and delta wings with approximately the same aspect ratio and mean section-thickness-to-chord ratios in combination with indented bodies. As examples of such developments, those obtained for a 45° swept wing with an aspect ratio of 4, a taper ratio of 0.3, and NACA 65A006 airfoil sections in combination with a body indented axially symmetrically to improve the area developments for a Mach number of 1.4 are presented in figure 6.



(a) $M=1.4$.
(b) $M=1.0$.

FIGURE 6.—Representative axial developments of cross-sectional area for a 45° swept wing in combination with a body indented for $M=1.4$ at $M=1.4$ and 1.0.

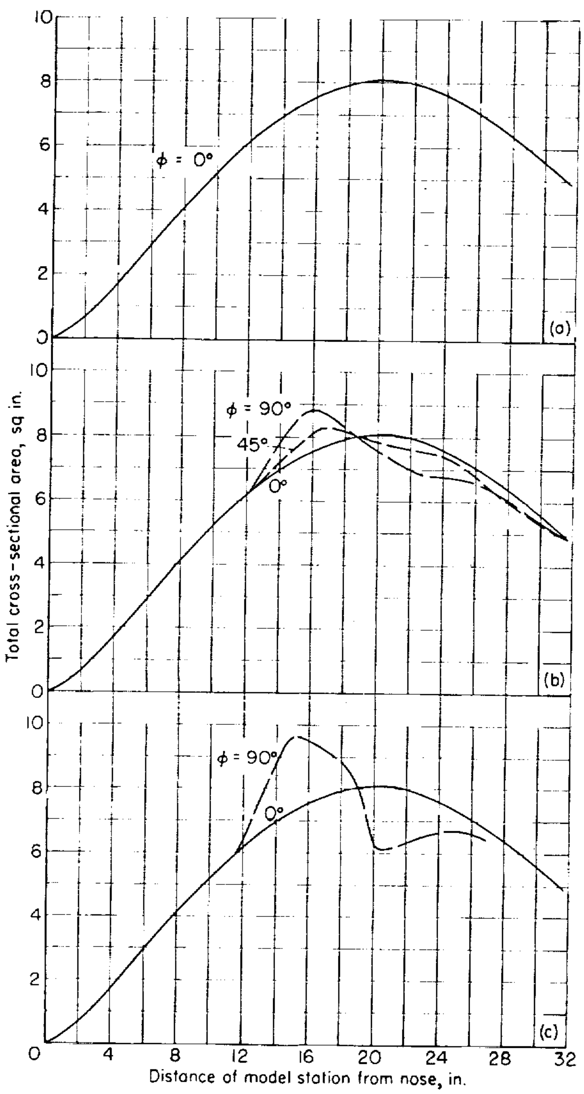
Wing twist and camber.—Results obtained at low supersonic speeds (ref. 9) indicate that the favorable effects of twist and camber on the lift-drag ratios can be added to those of body indentation. The basis for the twist and camber used is the mean surface form theoretically required for a uniform load at a lift coefficient of 0.25 at a Mach number of 1.4 (ref. 7). This theoretical form has been modified by reducing the camber near the wing-body juncture. (See fig. 4.) An analysis of the effects of the body on the induced field due to lift at supersonic speeds has indicated that such a modification should improve the drag associated with the lift.

EXPERIMENTS

APPARATUS AND METHODS

Experimental results for Mach numbers from 0.80 to 1.15 were obtained in the Langley 8-foot transonic tunnel. Those for Mach numbers from 1.41, 1.61, and 2.01 were obtained in the Langley 4- by 4-foot supersonic pressure tunnel (ref. 4).

The 60° swept wing was tested not only in combination with the body designed to obtain smooth area developments at a Mach number of 1.4 but also with a basic unindented body and a body indented so that the axial development of cross-sectional area for the combination for a Mach number of 1.0 is the same as that for the basic body alone. Axial developments of cross-sectional area for the configuration indented for a Mach number of 1.0 are presented in figure 7.



(a) $M=1.0$.
(b) $M=1.4$.
(c) $M=1.6$.

FIGURE 7.—Representative axial developments of cross-sectional area for the 60° swept wing in combination with the body indented for $M=1.0$ at $M=1.0$, 1.4, and 1.6.

These developments are presented for various values of ϕ at Mach numbers of 1.0, 1.4, and 1.6. The model dimensions are shown in figure 3.

Lift and drag data were measured by means of a sting-supported internal strain-gage balance. All data presented are essentially free of the effects of wall-reflected disturbances. The maximum errors of the drag coefficients at transonic speeds are of the order of ± 0.0005; those of the lift coefficients, ± 0.002. These limits include the effect of possible errors in the measurements of angle of attack. The results have been adjusted to the condition of stream static pressure on the base of the body.

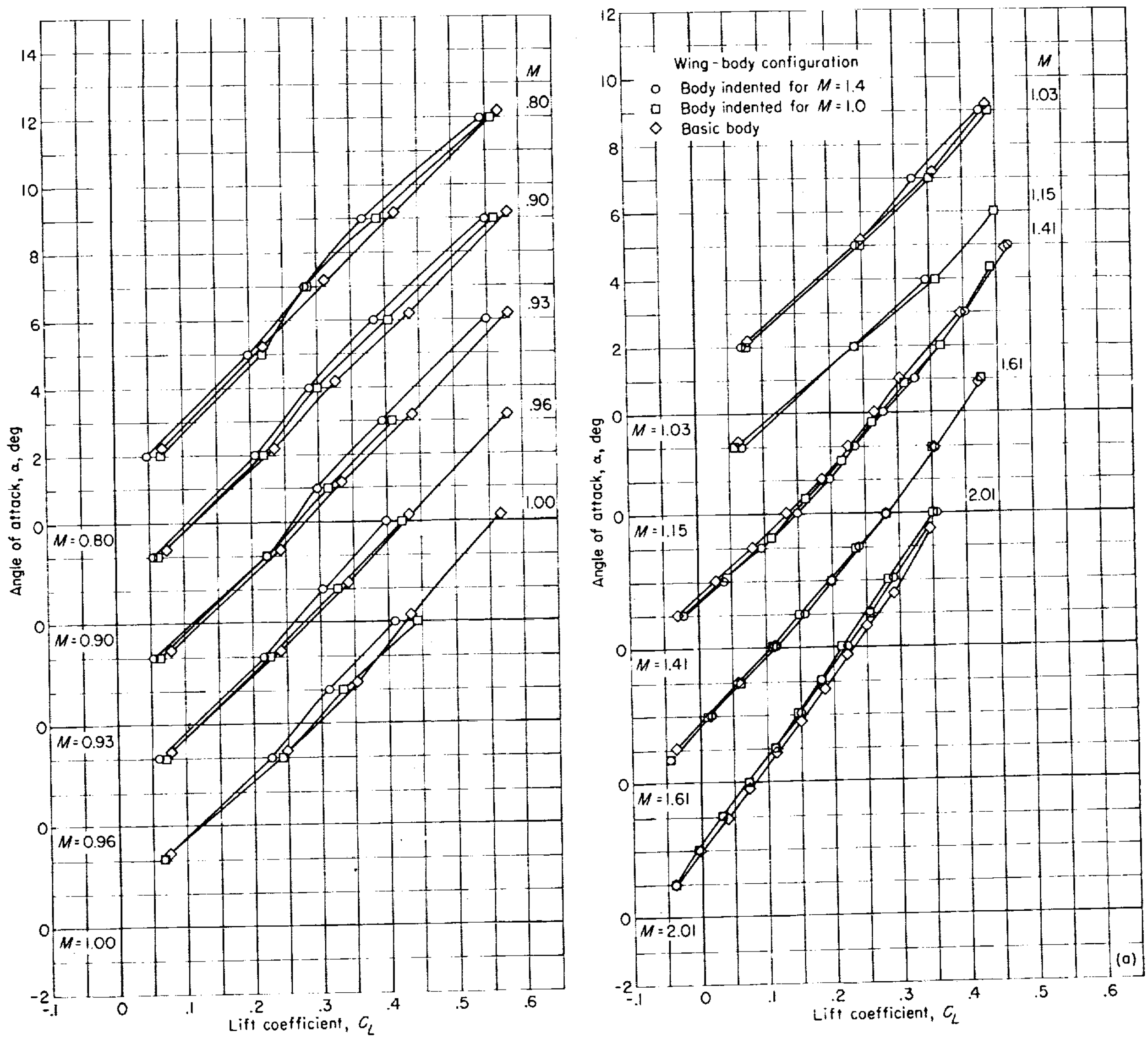
The Reynolds number per foot was approximately 4.0×10^6 for the tests in the 8-foot transonic tunnel and 3.7×10^6 for those in the 4- by 4-foot supersonic pressure tunnel.

RESULTS AND DISCUSSION

Lift and drag coefficients.—The variations of the angle of attack and drag coefficient with lift coefficient for the various test Mach numbers are presented in figure 8. The coefficients are based on a wing area of 1 square foot.

Minimum drag coefficient.—The variations of minimum drag coefficient with Mach number are presented in figure 9. The increment between the coefficients at Mach numbers of 0.80 and 1.41 for the configuration indented for a Mach number of 1.4 is approximately 0.0035. This value is approximately 0.0007 greater than the increment measured for the basic body alone. The difference is associated with the small variations of the area developments for the configuration at this Mach number from the development for the basic body, as indicated in figure 5. At lower supersonic Mach numbers, the drag coefficients for this configuration are approximately the same as that for a Mach number of 1.41. At the higher test Mach numbers, the drag coefficients are considerably greater. These variations are consistent with the changes of the area developments with Mach number, as shown in figure 5.

Because of the similarity of the fuselage indentations designed for Mach numbers of 1.0 and 1.4, the minimum drag coefficients measured for the two configurations at the various test Mach numbers are roughly the same. The small variations in drag are consistent with the differences of the area developments for the two configurations



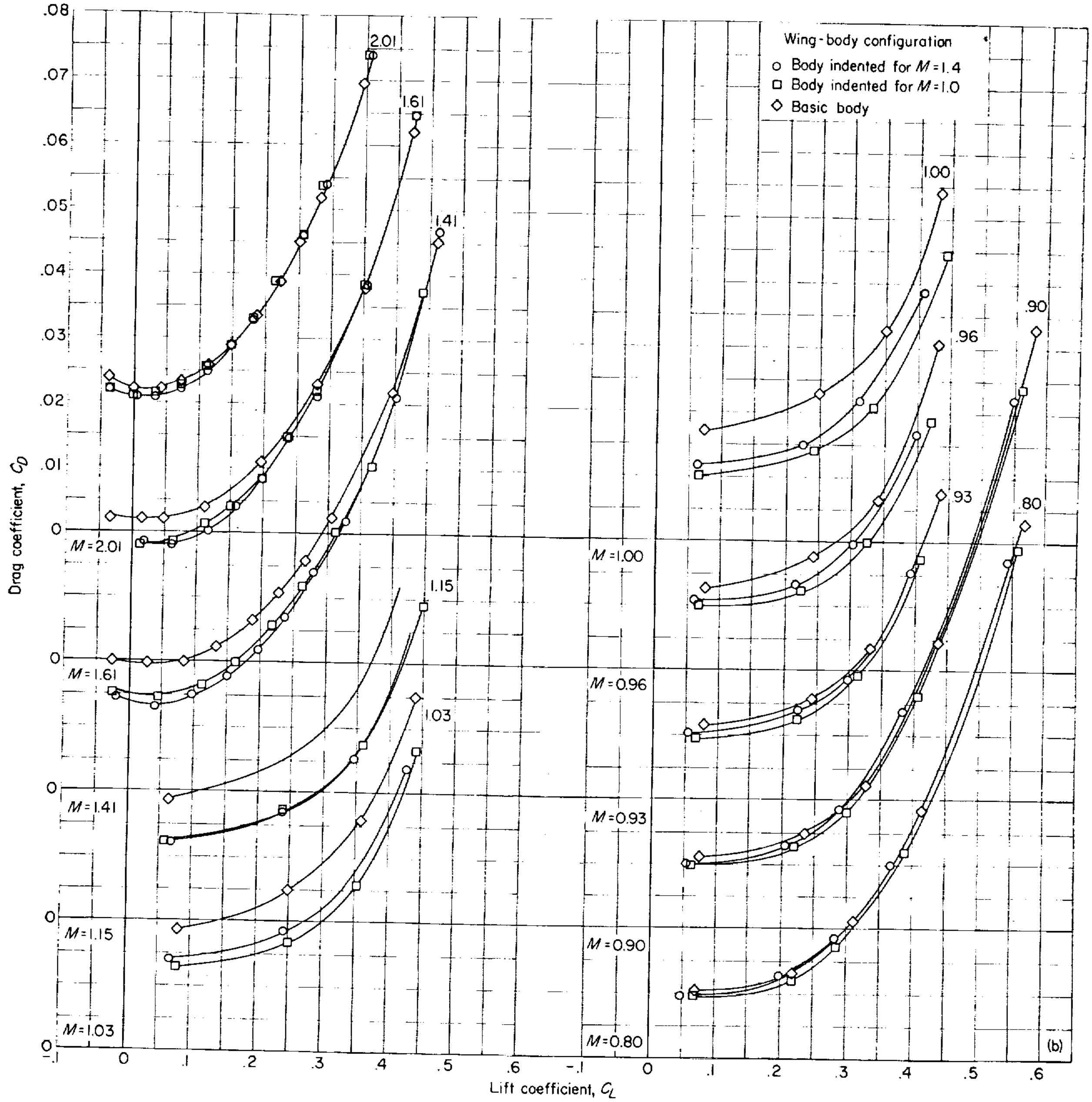
(a) Angle of attack.

FIGURE 8.—Variations of angle of attack and drag coefficient with lift coefficient for configurations tested.

At a Mach number of 1.0, the drag coefficient for the configuration designed to have smooth area development at this condition is 0.002 less than that designed for a Mach number of 1.4, whereas at a Mach number of 1.41 the drag coefficient of the configuration designed for this condition is 0.001 less than for the configuration designed for a Mach number of 1.0.

The indented configurations provide approximately a one-third reduction in drag coefficient in comparison with the configuration with the basic body at supersonic Mach numbers up to 1.41. (The relative improvement would have been slightly less if the size of the basic body had been decreased to have the same volume as that of the indented bodies.) At the higher test Mach numbers, the improvements progressively decrease until at a Mach number of 2.01 the reductions are only roughly 5 percent.

Maximum lift-drag ratios.—Variations of the maximum lift-drag ratios with Mach number are shown in figure 10. At a Mach number of 1.15, the ratio for the configuration with the body indented for a Mach number of 1.4 is approximately 14. This very high value results not only from the small minimum drag coefficient shown in



(b) Drag coefficient.
FIGURE 8.—Concluded.

figure 9 but also from the relatively low drag-due-to-lift factor, as shown in figure 11. (The drag-due-to-lift values presented in fig. 11 are for the lift coefficient range between 0.15 and 0.25.)

The maximum lift-drag ratio for the configuration indented for a Mach number of 1.4 decreases to a value of approximately 9 at a Mach number of 1.41 (ref. 4). The relatively low ratio for this condition is associated with the large drag-due-to-lift factor shown in figure 11. The measured factor is approximately 90 percent greater than the value predicted on the basis of linear theory (ref. 7) for this Mach number. In reference 6, similar excessive drag-due-to-lift factors are shown for a body combined with a highly swept wing.

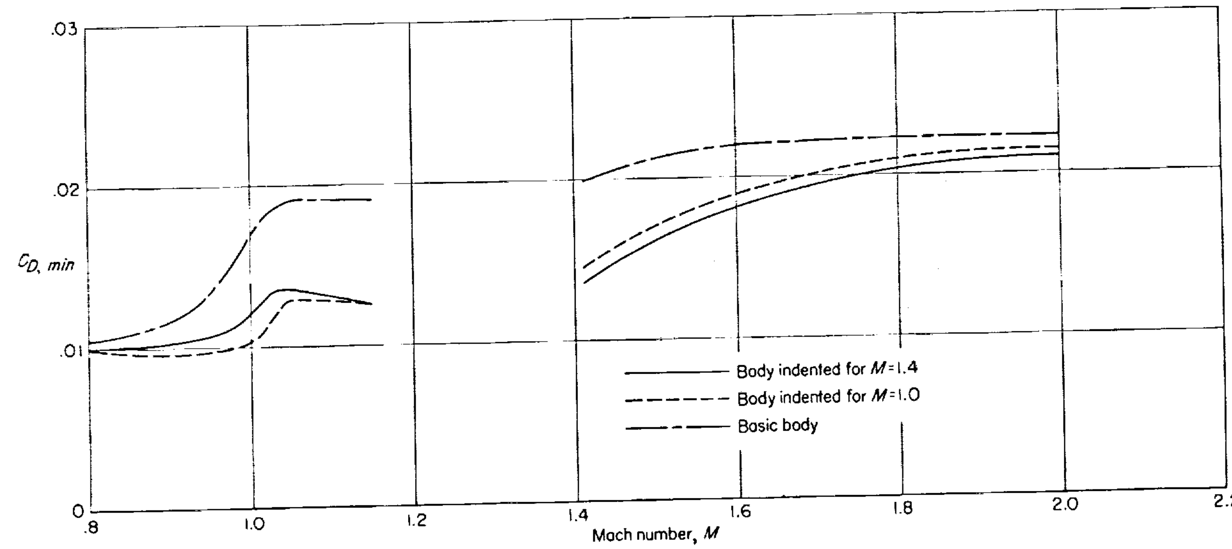


FIGURE 9.—Variation of minimum drag coefficient with Mach number.

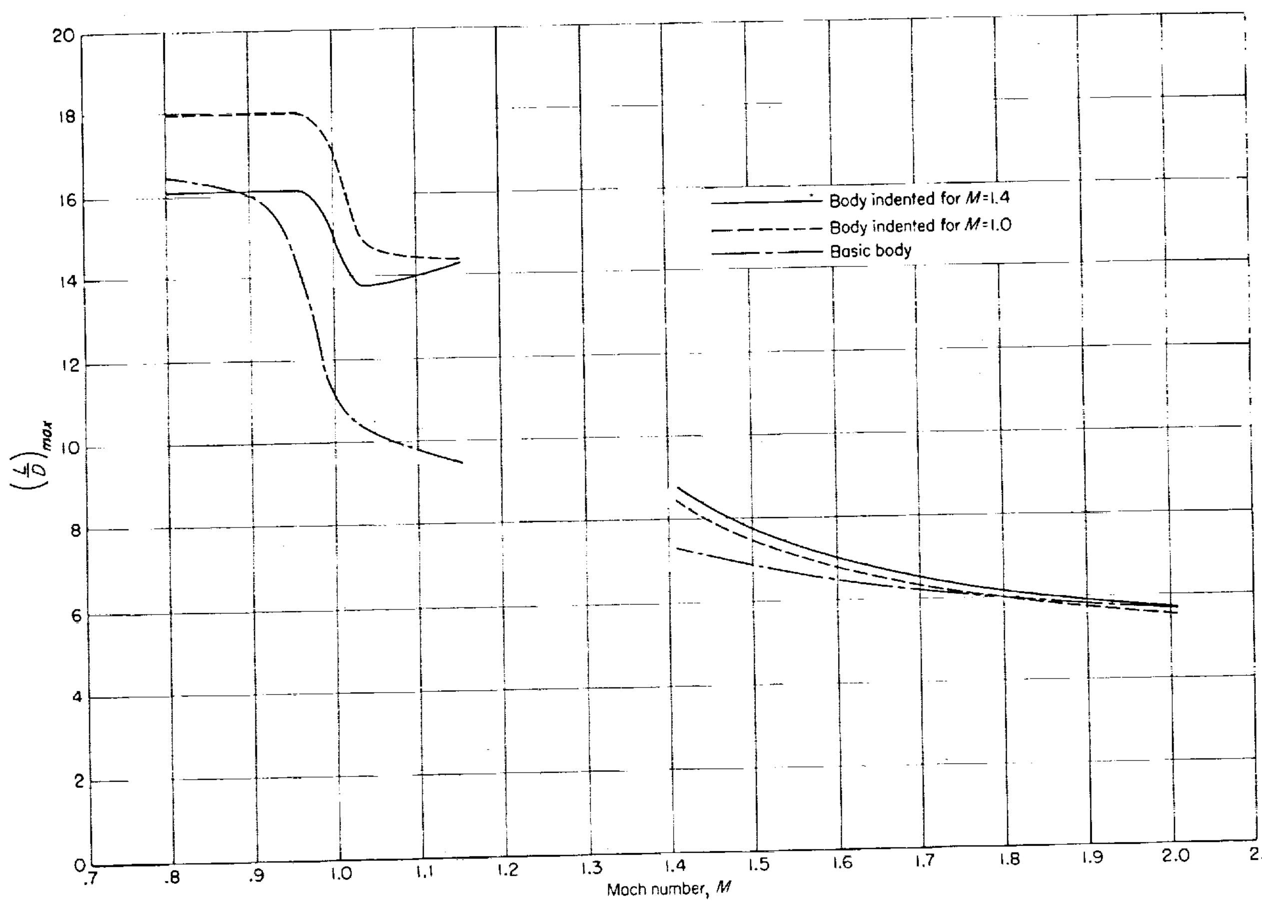


FIGURE 10.—Variations of maximum lift-drag ratios with Mach number.

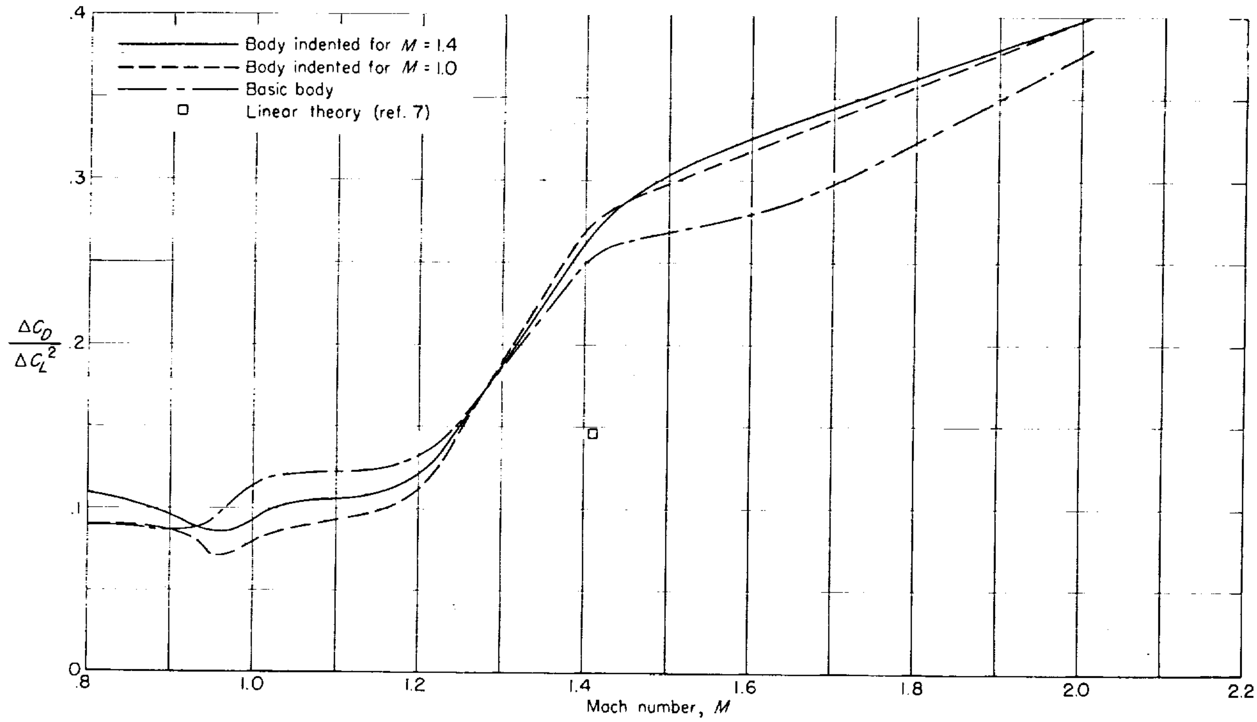


FIGURE 11.—Variations of the drag-due-to-lift factors with Mach number.

These large drags probably result primarily from boundary-layer separation and nonlinearities of the field above the upper surface of the wing. Boundary-layer-flow observations made for the wing of reference 6 indicated such separation. This boundary-layer breakdown probably results from a shock wave above the wing in an action similar to that for configurations with less sweep at subsonic Mach numbers.

At the test Mach numbers greater than 1.41, the maximum lift-drag ratios progressively decrease. These reductions are caused primarily by the increases of the minimum drag shown in figure 9.

The maximum lift-drag ratios measured for the configuration with the body indented for a Mach number of 1.4 (fig. 10) are slightly greater than those with the body indented for a Mach number of 1.0 at Mach numbers higher than 1.15, but are somewhat less at lower supersonic speeds, as would be expected. The lift-drag ratios for the configuration designed for a Mach number of 1.4 at subsonic speeds are substantially less than for the configuration designed for a Mach number of 1.0. This difference is caused by a higher drag-due-to-lift factor for the configuration designed for a Mach number of 1.4 (fig. 11).

At a Mach number of 1.14 the maximum lift-drag ratios for the configurations with indented bodies are approximately 50 percent greater than for the configuration with the basic body. This improvement results not only from the reduced minimum drag (fig. 9) but also, in part, from some lessening of the drag-due-to-lift factor (fig. 11). At a Mach number of 1.41 the body indentation designed for this condition improves the maximum lift-drag ratio by 20 percent, whereas the body indentation designed for a Mach number of 1.0 increases the ratio by 15 percent. These relatively small improvements of the lift-drag ratios, in spite of the pronounced reductions of the minimum drag coefficient (fig. 9), result primarily from the fact that at this condition the indentations substantially increase the drag-due-to-lift factors (fig. 11). The exact reason for this effect is unknown. However, it may be conjectured that the adverse pressure gradients produced by the indentation in the region of the wing aggravate the boundary-layer separation which is probably present above the wing for this condition.

With an increase in Mach number beyond 1.41, the favorable effects of the indentations on the maximum lift-drag ratios continue to decrease until at a Mach number of 2.01 they provide no favorable effects. At these higher speeds, the decrease of effectiveness is due primarily to the reductions of the improvements in the minimum drag.

CONCLUDING REMARKS

A supersonic-area-rule concept has been presented whereby the wave drag of a wing-body combination is related to a number of developments of cross-sectional areas as intersected by Mach planes. This concept has been applied to a special wing-body configuration, which has been tested at Mach numbers from 0.80 to 2.01. The relatively high lift-drag ratios for the supersonic speeds of the investigation suggest that judicious application of the proposed supersonic area rule should result in considerable improvements of the possible performance of airplanes designed for these speeds.

LANGLEY RESEARCH CENTER,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
LANGLEY FIELD, VA., *August 18, 1953.*

REFERENCES

1. Whitcomb, Richard T.: A Study of the Zero-Lift Drag-Rise Characteristics of Wing-Body Combinations Near the Speed of Sound. NACA Rep. 1273, 1956. (Supersedes NACA RM L52H08.)
2. Jones, Robert T.: Theory of Wing-Body Drag at Supersonic Speeds. NACA Rep. 1284, 1956. (Supersedes NACA RM A53H18a.)
3. Hayes, Wallace D.: Linearized Supersonic Flow. Rep. No. AL-222, North American Aviation, Inc., June 18, 1947.
4. Sevier, John R., Jr.: Investigation of the Effects of Body Indentation and of Wing-Plan-Form Modification on the Longitudinal Characteristics of a 60° Swept-Wing—Body Combination at Mach Numbers of 1.41, 1.61, and 2.01. NACA RM L55E17, 1955.
5. Loving, Donald L.: A Transonic Investigation of Changing Indentation Design Mach Number on the Aerodynamic Characteristics of a 45° Sweptback-Wing—Body Combination Designed for High Performance. NACA RM L55J07, 1956.
6. Hall, Charles F., and Heitmeyer, John C.: Aerodynamic Study of a Wing-Fuselage Combination Employing a Wing Swept Back 63°.-Characteristics at Supersonic Speeds of a Model With the Wing Twisted and Cambered for Uniform Load. NACA RM A9J24, 1950.
7. Jones, Robert T.: Estimated Lift-Drag Ratios at Supersonic Speed. NACA TN 1350, 1947.
8. Carmel, Melvin M.: Transonic Wind-Tunnel Investigation of the Effects of Aspect Ratio, Spanwise Variations in Section Thickness Ratio, and a Body Indentation on the Aerodynamic Characteristics of a 45° Sweptback Wing-Body Combination. NACA RM L52L26b, 1953.
9. Harrison, Daniel E.: The Influence of a Change in Body Shape on the Effects of Twist and Camber As Determined by a Transonic Wind-Tunnel Investigation of a 45° Sweptback Wing-Fuselage Configuration. NACA RM L53B03, 1953.

TABLE I

AIRFOIL COORDINATES

Chord station	Ordinate, percent chord					
	10-percent-semispan station (c=8.40 in.)		20-percent-semispan station (c=7.80 in.)		40-percent-semispan station (c=6.60 in.)	
	Upper surface	Lower surface	Upper surface	Lower surface	Upper surface	Lower surface
0	0. 06	0. 06	0. 12	0. 12	0. 29	0. 29
. 5	1. 09	−. 70	1. 00	−. 67	. 92	−. 30
. 75	1. 29	−. 84	1. 18	−. 82	1. 05	−. 36
1. 25	1. 66	−1. 09	1. 44	−1. 05	1. 26	−. 58
2. 5	2. 07	−1. 74	1. 93	−1. 50	1. 67	−. 91
5	2. 52	−2. 56	2. 59	−2. 12	2. 23	−1. 33
10	3. 09	−3. 93	3. 36	−3. 16	2. 96	−1. 91
15	3. 35	−5. 22	3. 77	−3. 98	3. 46	−2. 32
20	3. 45	−6. 20	4. 67	−4. 00	3. 79	−1. 70
30	3. 14	−7. 71	4. 04	−5. 80	3. 97	−3. 35
40	2. 41	−8. 82	3. 53	−6. 64	3. 82	−1. 79
50	1. 05	−9. 42	2. 49	−7. 04	3. 27	−3. 89
60	−. 74	−9. 64	1. 05	−7. 16	2. 38	−3. 85
70	−2. 68	−9. 61	−. 64	−7. 00	1. 11	−3. 70
80	−4. 77	−9. 40	−2. 53	−6. 82	−. 30	−3. 58
90	−6. 88	−9. 18	−4. 50	−6. 68	−1. 80	−3. 44
100	−8. 82	−8. 94	−6. 48	−6. 50	−3. 26	−3. 28

Chord station	Ordinate, percent chord					
	60-percent-semispan station (c=5.40 in.)		80-percent-semispan station (c=4.20 in.)		100-percent-semispan station (c=3.00 in.)	
	Upper surface	Lower surface	Upper surface	Lower surface	Upper surface	Lower surface
0	0. 65	0. 65	0. 95	0. 95	1. 97	1. 97
. 5	1. 11	. 24	1. 55	. 59	2. 50	1. 50
. 75	1. 28	. 17	1. 67	. 50	2. 57	1. 43
1. 25	1. 45	0	1. 86	. 36	2. 83	1. 33
2. 5	1. 78	−. 26	2. 21	. 14	3. 20	1. 17
5	2. 20	−. 61	2. 76	−. 07	3. 77	. 93
10	2. 85	−1. 04	3. 52	−. 31	4. 56	. 63
15	3. 33	−1. 28	4. 19	−. 43	5. 10	. 53
20	3. 72	−1. 46	4. 62	−. 48	5. 60	. 50
30	4. 07	−1. 72	5. 22	−. 57	6. 34	. 47
40	4. 02	−1. 91	5. 36	−. 62	6. 53	. 53
50	3. 78	−1. 87	5. 12	−. 55	6. 40	. 77
60	3. 24	−1. 74	4. 62	−. 19	6. 00	1. 13
70	2. 39	−1. 43	3. 88	. 09	5. 36	1. 50
80	1. 35	−1. 15	2. 91	. 36	4. 53	2. 00
90	. 21	−1. 11	1. 93	. 59	3. 70	2. 40
100	−. 09	−1. 00	. 88	. 83	2. 83	2. 83

TABLE II

BODY COORDINATES

(a) Forebody

Fuselage station	Radius, in.
0	0
.5	.165
1.0	.282
1.5	.378
2.0	.460
2.5	.540
3.0	.612
3.5	.680
4.0	.743
4.5	.806
5.0	.862
5.5	.917
6.0	.969
6.5	1.015
7.0	1.062
7.5	1.106
8.0	1.150
8.5	1.187
9.0	1.222
9.5	1.257
10.0	1.290
10.5	1.320
11.0	1.350
11.5	1.380
12.0	1.405
12.5	1.430
13.0	1.452
13.5	1.475

(b) Afterbody

Fuselage station	Radius, in.		
	Basic body	Body indented for $M=1.4$	Body indented for $M=1.0$
14.0	1.493	1.461	1.470
14.5	1.512	1.440	1.460
15.0	1.526	1.410	1.440
15.5	1.540	1.365	1.400
16.0	1.552	1.318	1.360
16.5	1.565	1.270	1.320
17.0	1.575	1.226	1.260
17.5	1.585	1.195	1.220
18.0	1.590	1.110	1.190
18.5	1.598	1.150	1.170
19.0	1.602	1.140	1.150
19.5	1.606	1.140	1.140
20.0	1.606	1.160	1.140
20.5	1.604	1.200	1.160
21.0	1.602	1.250	1.200
21.5	1.600	1.280	1.250
22.5	1.587	1.310	1.299
23.5	1.570	1.335	1.328
24.0	1.560	1.345	1.340
25.0	1.532	1.350	1.350
26.0	1.501	1.350	1.350
27.0	1.460	1.330	1.330
28.0	1.414	1.310	1.310
29.0	1.364	1.271	1.280
30.0	1.305	1.230	1.230
31.0	1.231	1.180	1.180
31.7	1.185	1.150	1.150

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