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AD NUMBER
AD150694

CLASSIFICATION CHANGES

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AUTHORITY

WL/DOA ltr, 9 Mar 1993; WL/DOA ltr, 9 Mar 1993

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AD 150694

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U. S. AIR FORCE

PROJECT RAND

RESEARCH MEMORANDUM

POSSIBLE CIRCUMNAVIGATION OF THE EARTH
WITH UNREFUELED STRATEGIC BOMBARDMENT
AIRCRAFT, AND OTHER APPLICATIONS:
ABRIDGED EDITION (U)
Achievement of Very High Lift-Drag Ratios
at Supersonic Speeds Through Drag
Transformation and Reduction (U)

Roger P. Johnson

RM-2154

ASTIA Document Number AD 150694

April 10, 1958   Copy No. ___53___

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FOREWORD

This report raises the possibility of truly significant improvements in the supersonic combat range of chemically fueled, aerodynamically supported aircraft or missiles. These potential improvements would ensue from the very high supersonic lift-drag ratios of ring-body configurations. Such lift-drag ratios would be achieved through what is termed 'drag transformation and reduction,' an effective marriage of the techniques of thickness-drag cancellation, laminarized supersonic boundary layer, and reduction of drag-due-to-lift.

Experimental research at an early date is strongly urged in order to establish the degree of physical realization of the theoretical gains described in this report. In this way (1) effective design applications can be formulated and (2) the experience gained can be brought to bear on extensions of the concept.

SUMMARY

Three potential aerodynamics advances — thickness-drag cancellation, laminarized supersonic boundary layer, and reduction of drag-due-to-lift — are brought to bear on a family of ring-body configurations representing, by virtue of their very high lift-drag ratios, a possible breakthrough in strategic weapon systems. Each of the three major features of this novel aerodynamics concept has been treated in the literature previously with varying degrees of completeness. All three are brought together here to achieve this potential breakthrough in strategic weapon systems. The following is a summary of the capabilities which could be realized from specific applications of this concept:

o Circumnavigation of the earth with all-supersonic, unrefueled, chemical-energy strategic bombers is indicated to be a possibility for the striking force of the mid-sixties. This is predicated on the 1958 state-of-the-art in propulsion and structures and on successful verification of the aerodynamics concept described herein.

o A Mach-2, sea-level, long-range strategic missile of the weight and general size of the SM-62A Snark could be developed to operate over a 5000 n mi range. For the more reasonable flight profile of high-altitude supersonic cruise and sea-level supersonic dash to the target, the range could be extended or the size of the missile could be reduced. The state-of-the-art requirements for such a missile are essentially those of the circumnavigational manned bomber and are therefore dependent upon realization of this new concept in supersonic aerodynamics.

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o Mach-3 air-to-surface missiles having the approximate warhead and guidance weights of current ASM's and a range (from airborne launch) of 500 to 1800 n mi could be developed for launching weights (including boosters) of 4600 to 6800 lb. With a warhead of twice the weight of that in the ASM and for the same distances to target, the launching weights for a similar group of missiles would be about 8200 to 11,700 lb. The preliminary estimates for these ASM's employ only two (thickness-drag cancellation and reduction of drag-due-to-lift by body camber) of the major features of this aerodynamics concept.

o A Mach-2 supersonic transport of the general size and weight of the intercontinental DC-8 could be designed with almost 2-1/2 times the 5800 n mi maximum range of this airplane, if all three major factors were used. Using only two of the major factors, laminarized supersonic boundary layer and thickness-drag cancellation, a 10 per cent increase over the DC-8 range is indicated. These ranges are based on a fuel-to-gross-weight ratio of about 1/2, which is typical of personnel transports of current design.

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CONTENTS

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I. INTRODUCTION

The as-yet unsatisfied distance requirement of manned offensive weapon systems and the need for smaller, faster, cheaper, and more effective systems, once the distance requirement is met, invite the attention of specialists in many fields, including structures, propulsion, aerodynamics, and preliminary design. Of these specialists the aerodynamicist is in an especially good position to influence the range capability of a given weapon system in a direct fashion, through improvement of the ratio of lift to drag (L/D).

With reservations about the over-simplification and the less than universal applicability of the Breguet range equation,

$$R = \frac{V}{c} \frac{L}{D} \ln \left[\frac{W_{init}}{W_{final}} \right]$$

$$= \frac{a}{c} \left(M \frac{L}{D} \right) \ln \left[\frac{W_{init}}{W_{final}} \right]$$

let us note the direct proportionality of range to lift-drag ratio and to Mach number, M. Improvements in either or both terms that do not increase specific fuel consumption, c, or increase the empty- to gross-weight ratio, $\frac{W_{final}}{W_{init}}$, will directly increase range.

The maximum lift-drag ratio is a simple and convenient figure-of-merit that may be used to characterize the aerodynamics state-of-the-art of a lift-supported vehicle. For a conventional wing-body-type configuration it is determined from the relation

$$\frac{L}{D}\bigg]_{max} = \sqrt{\frac{1}{4KC_{D_o}}}$$

$$= \sqrt{\frac{1}{4K\,(C_{D_f} + C_{D_t})}}$$

where

K = drag-due-to-lift factor

$$C_{D_f} = \frac{\sum\limits_{i=1}^{n} A_{w_{comp}} C_{f_{comp}}}{A_{ref}} \quad , \text{ total-viscous-drag coefficient, the}$$
summation of the component drags

and

$$C_{D_t} = \frac{\sum\limits_{i=1}^{n} C_{D_{t_{comp}}} \cdot A_{comp}}{A_{ref}} \quad , \text{ total-thickness-drag coefficient, the}$$
summation of the component drags

In their order of introduction the areas used above are component wetted area $A_{w_{comp}}$, selected over-all reference area A_{ref}, and component reference area, A_{comp}. These expressions succinctly present the general problem areas for the aerodynamicist and the designer, both of whom strive to improve the attainable maximum lift-drag ratio for successive vehicle designs. The three coefficients that the aerodynamicist seeks to reduce are drag-due-to-lift factor, K, skin-friction coefficient, C_f, and the component thickness-drag coefficients, $C_{D_{t_{comp}}}$.

The particular class of configurations, ring-bodies, for which this analysis is performed (Fig. 1) does not necessarily represent the optimum
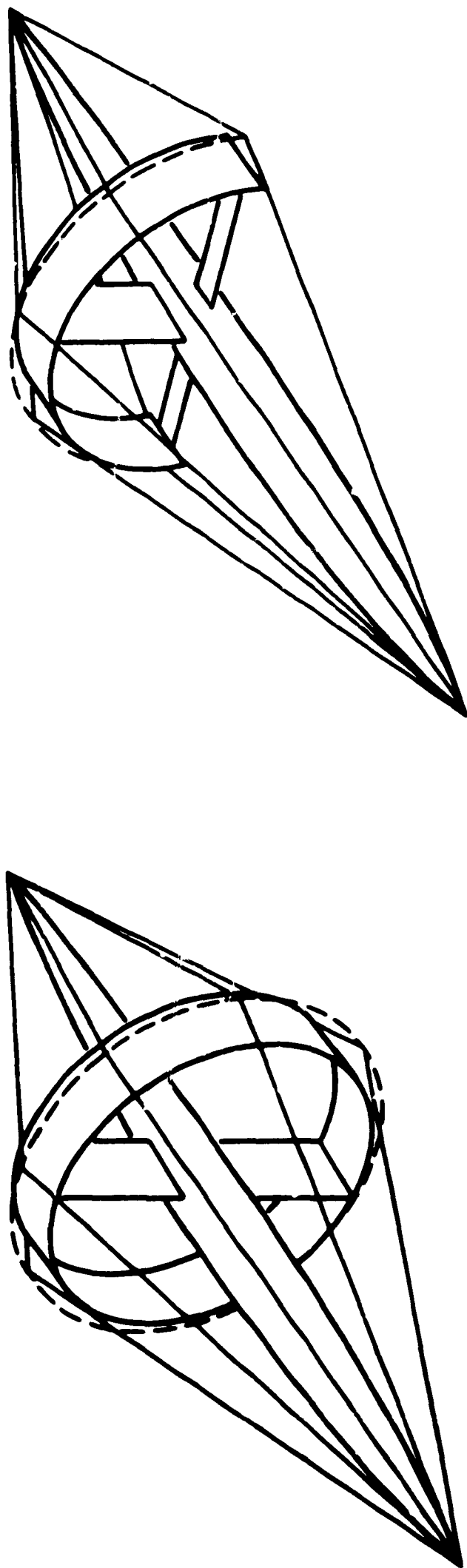
Half-ring-body

Complete-ring-body

Fig. 1—Schematic drawing of typical supersonic ring-body configurations

of all possible classes. It was used because it offered an opportunity to reduce, in principle, all three of these coefficients simultaneously and because the development of the aerodynamic theories involved was available in the literature.[1,2] The present investigation is a logical outgrowth of the analytical development by the author[3] of the non-lifting ring-body, which was first suggested by Ferri.[4]

The improvement in lift-drag-ratio values relative to those of conventional wing-body configurations is effected principally through a concept termed 'drag transformation and reduction.' This concept involves the elimination of body and 'wing' thickness drag (at the cost of increased 'wing' wetted area) and the reduction of average skin-friction coefficient, as a result of boundary-layer control, to maintain a laminar boundary layer over various portions of the wetted surfaces. The rest of the improvement is due to the use of drag-due-to-lift factors which are generally less than the level of the values which are typical for operational supersonic aircraft. This is a consequence of minimizing the wave-drag part of drag-due-to-lift.

II. AERODYNAMIC METHOD AND RESULTS

The general class of configurations considered in the present analysis is termed 'ring-body.' These configurations lie within the circumscribed double Mach cone defined by the length of the body and the Mach angle associated with the flight Mach number. Both complete-circular ring-wings and half-circular ring-wings, as shown in Fig. 1, were considered. Calculations were made for both the complete- and the half-ring subclasses, using both axially symmetric and cambered central bodies.

The detailed derivation of the mathematical relations and the general substantiation of the calculations will be reported in subsequent research memoranda. For present purposes it is sufficient to observe that the choices between alternative schemes at each step were made to approximate the optimal design and to maintain the tractability of these relations to mathematical analysis.

As was suggested in the introduction, the parasitic or non-lifting drag is effectively reduced to a minimum by eliminating the thickness drag (sometimes referred to as aero-lift wave drag or pressure drag) and reducing the friction (viscous) drag contribution by laminarizing the boundary layer over the wetted surfaces. These are two of the features in this aerodynamics concept. The third feature, which will be introduced below, affects the lifting drag, which comprises a vortex drag (similar to subsonic flow) and a wave drag. The vortex-drag contribution is approximately minimized by the assumed spanwise loading on the ring-wing. This loading varies circumferentially as the sine of the angle ϕ measured from the horizontal, as shown in Fig. 2. This vortex-drag contribution is
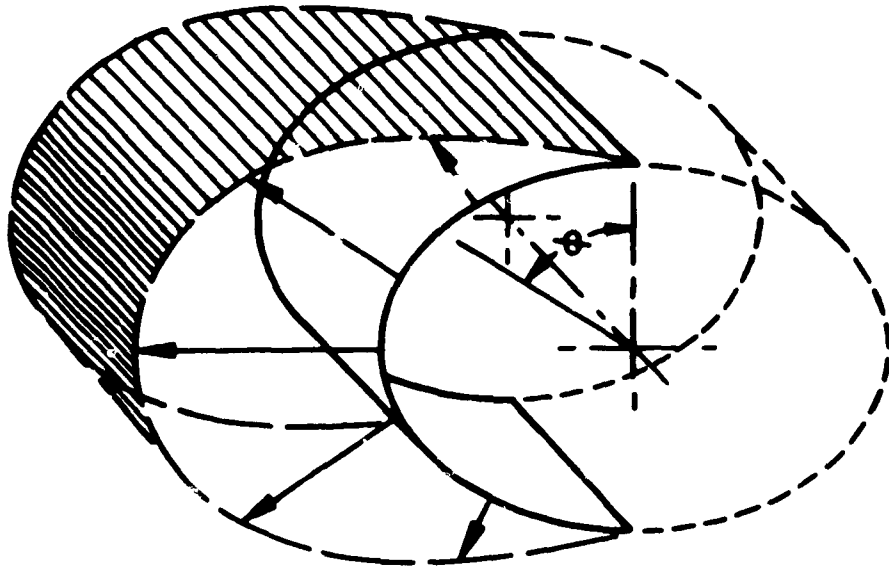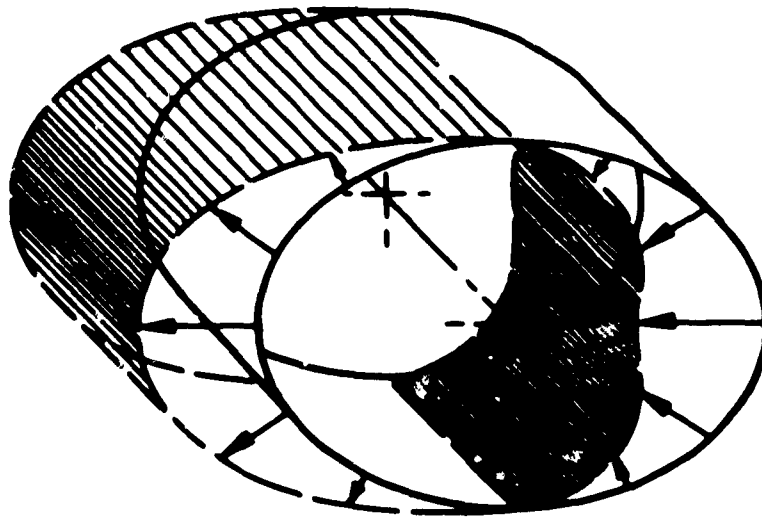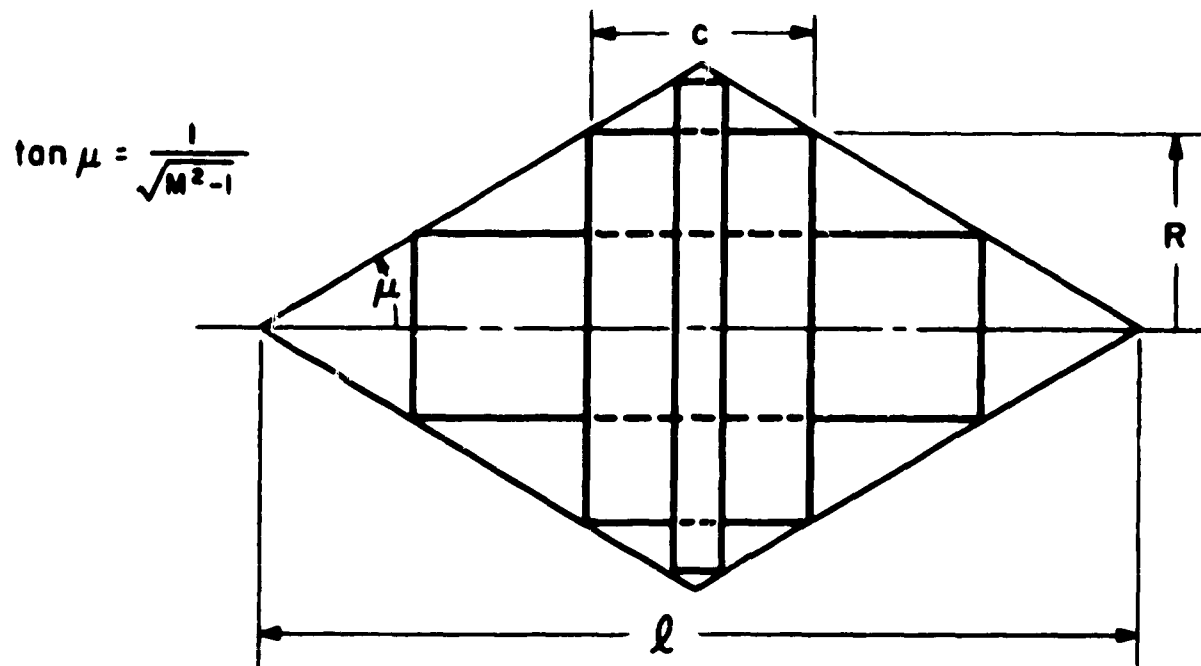
Complete--ring wing   Half--ring wing

Fig.2——Assumed radial air-load distributions on complete- and half-ring wings

reduced, for a family of cylindrical shells inscribed in a right circular double Mach cone, as the cylinder radius is increased.

$$\tan \mu = \frac{1}{\sqrt{M^2-1}}$$

These sin ϕ type loadings are constant along the chord of the ring, as illustrated by the sketches of Fig. 2. The wave-drag contribution to drag-due-to-lift is related to how well the ideal elliptic loading along the axis is approximated by projections of the above-described loadings along Mach planes. This process of projection is illustrated in Fig. 3. In general the approximation of the projection of the real loading to the ideal elliptic loading along the axis worsens as the ring is moved outward. The combined effect of the two contributions to drag-due-to-lift declines to an asymptotic value associated with two-dimensional flow. This general combination of vortex and wave drag is referred to as 'basic' ring-body drag-due-to-lift.

However, the wave-drag contribution can be made to decline as the ring is moved out, if the local loading due to body camber adds to (and subtracts from) the projected loading from the wing to form an elliptic loading along the axis. This is the minimum contribution of wave drag.

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Projection onto axis of air loads
on body cambered for zero net lift

Projection onto axis of air loads on ring

Loadings projected onto axis

Body loading

Wing and body loading

Wing loading
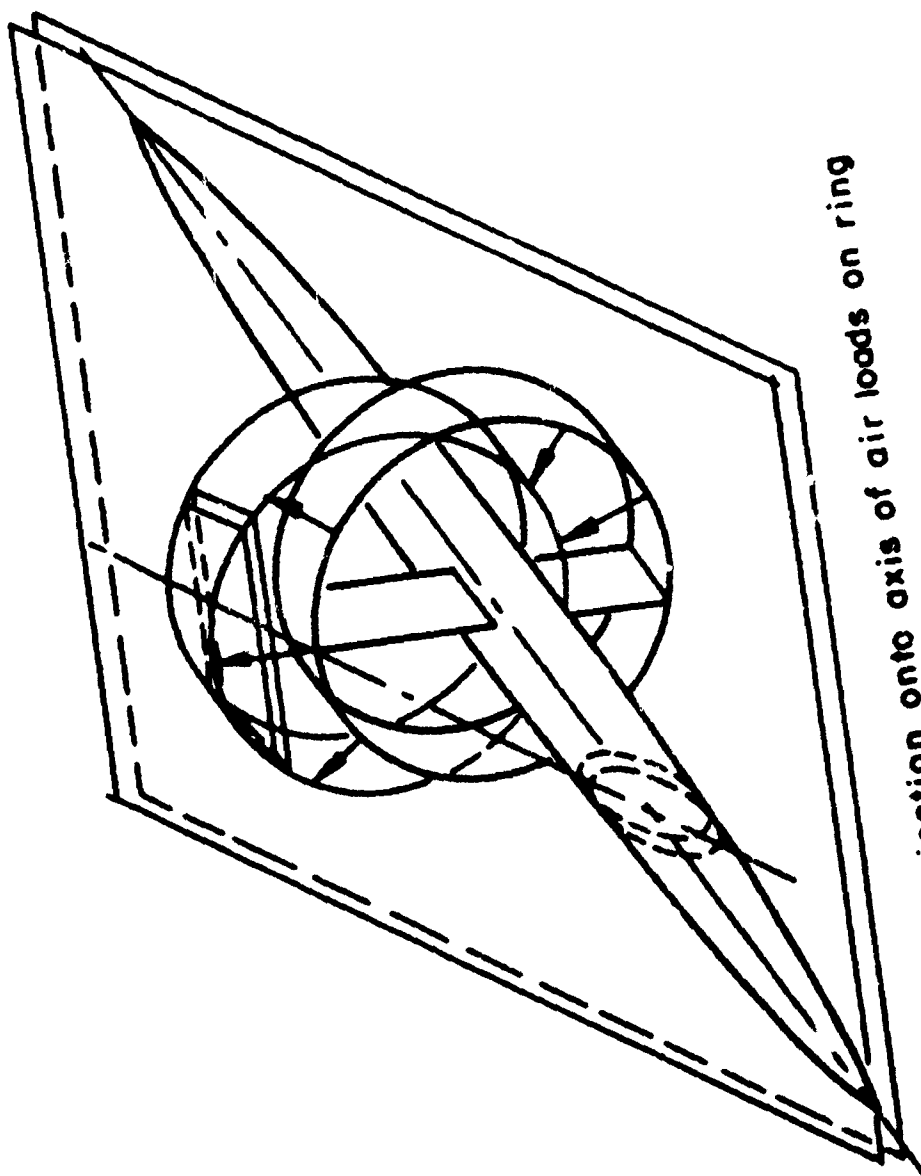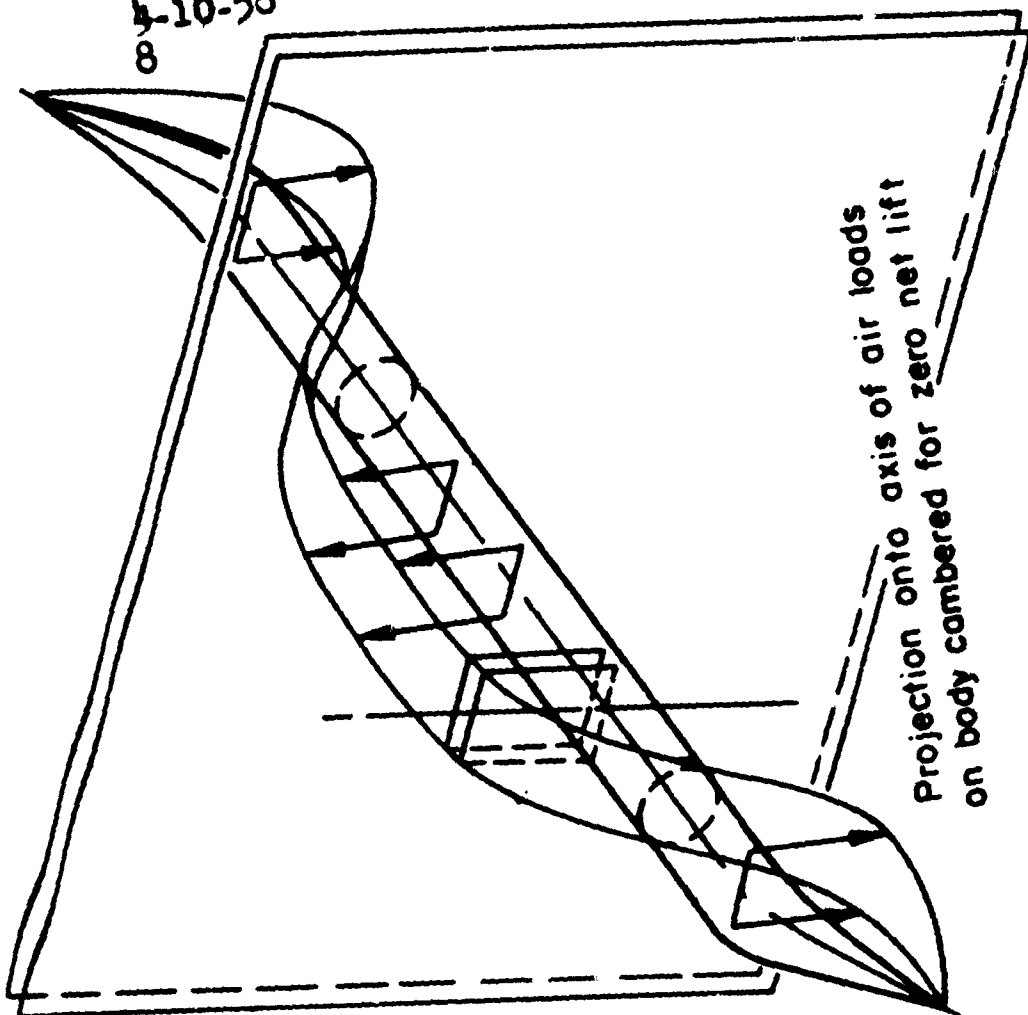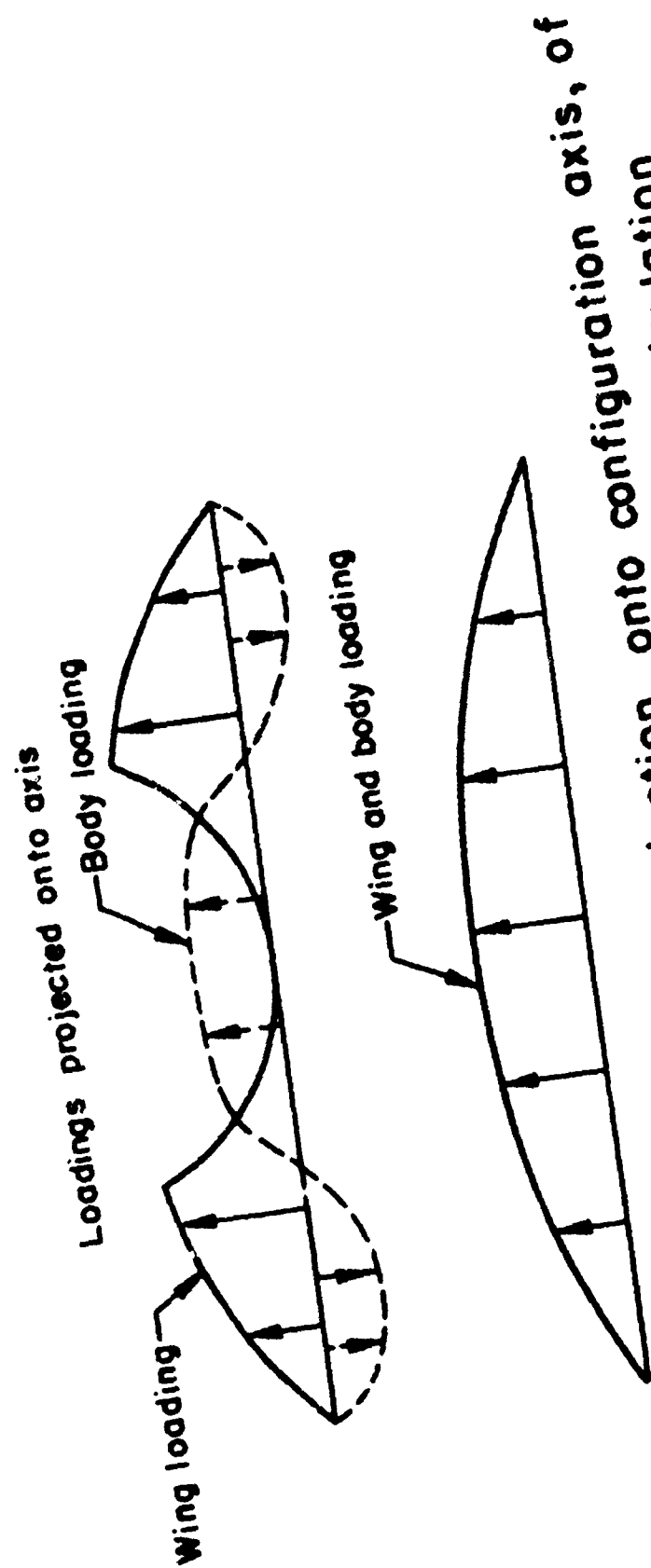
Fig. 3—Pictorial representation of projection, onto configuration axis, of
components' air loads for wave—drag-due-to-lift calculation

This minimal contribution for wave drag combines with the near-minimal contribution for vortex drag to approximate lower-bound[5] values for drag-due-to-lift. This combination of vortex and wave drag is referred to as 'cambered' ring-body drag-due-to-lift and represents the third feature of the aerodynamics concept.

There is, of course, an infinite number of extents of camber between the zero and the ideal cases described above.

The preceding descriptions of drag can be summarized mathematically by the relation

$$D = D_{f_{wing}} + D_{f_{body}} + D_{lift}$$

$$D = \left[(2 + \delta) \pi Rc\right] C_f \, q + \left[c^{3/2} \, a \, (\frac{\beta L}{qc})^{1/2}\right] C_f \, q + (d + e)(\frac{\beta L}{qc})^2 \, q$$

where

δ = ratio of wetted area of two full-chord struts to one-half the wing wetted area

R = wing radius

c = (ring) wing chord

C_f = average skin-friction coefficient

q = dynamic pressure

a = body wetted area factor

$\beta = \sqrt{M^2 - 1}$

L = lift

d = wave-drag coefficient

e = vortex-drag coefficient

For the half-ring-body configurations the central-body cross-sectional area distribution along the axis and the total body volume are determined through an involved mathematical process which proceeds from the assumed loading on the ring. This point is mentioned here because it introduces a well-defined, formal constraint on the body volume and wing lift, hence on the average bulk density of the configuration and the operational altitude. This constraint applies less formally to the complete-ring-body configurations. (This is similar to experience with conventional aircraft.) Thus the equation above, which relates body wetted area and drag-due-to-lift and which was derived for the half-ring configuration, is used for the complete-ring configuration and gives an accurate basis for comparison. Specifically the volume-lift relation for these ring-bodies is

$$\text{Volume} = 0.320 \ \frac{\beta^2 L R}{q}$$

This volume of the central body is expected to be the only useful volume of the configuration. The lift-drag relation given above can be used to optimize the lift-drag ratio. Typical results of these rather involved lift-drag ratio optimizations are given by Fig. 4, where $\frac{L}{D}$ is plotted versus the ratio of ring chord to central-body length, $\frac{c}{l}$. In part (a) of Fig. 4 the pair of dashed-line curves bracket the results for basic half-ring body configurations, with the indicated range of interest of skin-friction coefficient, $0.0003 \leq C_f \leq 0.0021$, at $M \cong 1.5$. The lower limiting value is about half the value achieved in the first, limited supersonic experiments at laminarization, and the upper limiting value is typical of turbulent boundary layers at $M \cong 1.5$. The pair of solid-line curves in part (a) give the same type of information for the cambered
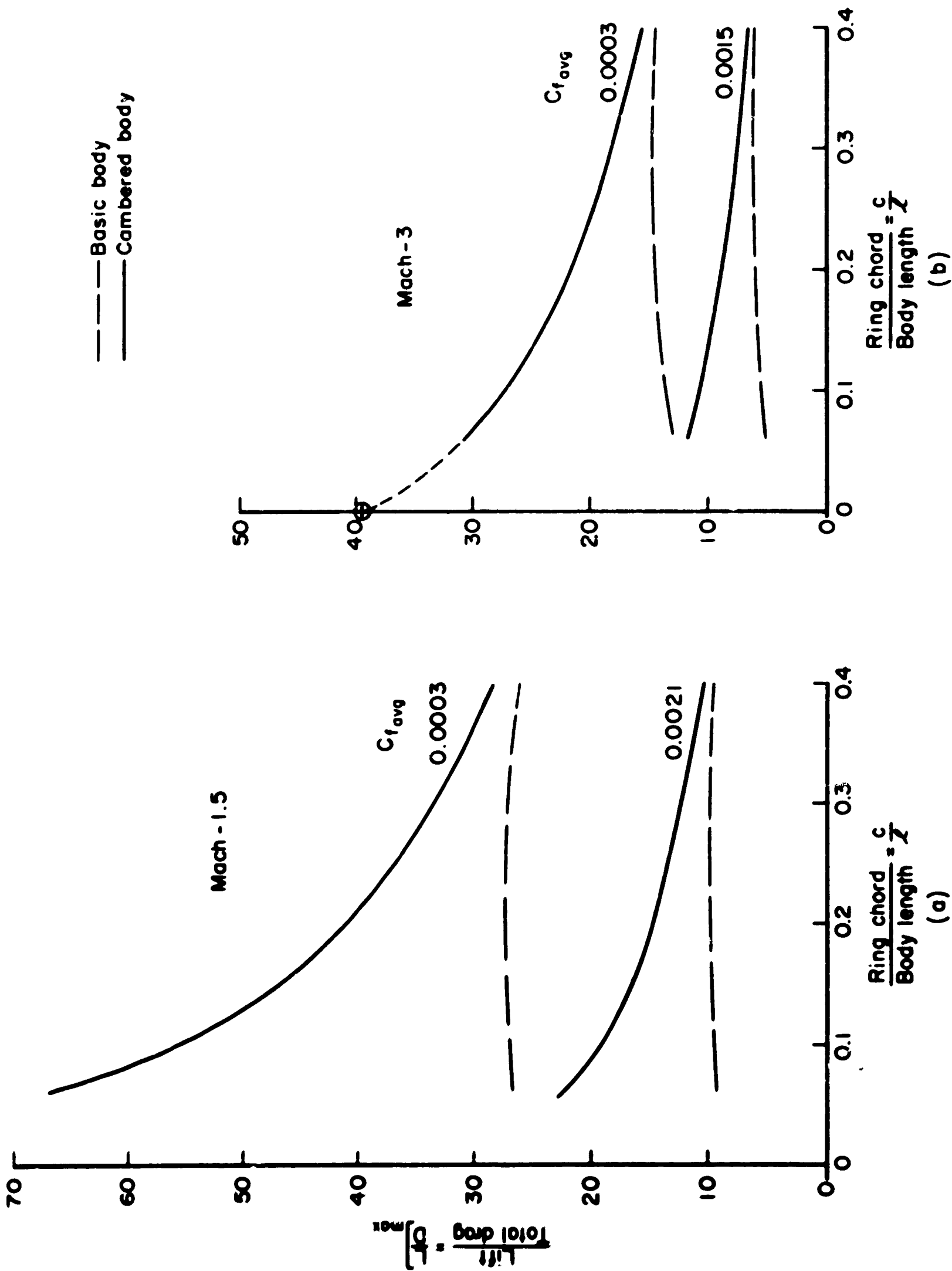
Fig. 4 — Half-ring-body maximum lift-drag ratios versus ring-chord—body-length ratio

half-ring-body configurations. Similar remarks apply to part (b) of Fig. 4 except that the design Mach number here is approximately 3, and $0.0003 \leq C_f \leq 0.0015$. These curves also pertain to half-ring-body configurations. The upper limiting value for $M \cong 3$ is lowered because of the Mach-number effect on turbulent skin-friction coefficient. An example of the maximum lift-drag ratio for the limiting value $\frac{c}{\ell} = 0$ is indicated on Fig. 4(b) to show that $\frac{L}{D}$ is finite at the limit.[*] For simplicity, the corresponding curves for complete-ring-body configurations are omitted, since they are similar to those of Fig. 4 and their values are quite uniformly about 10 per cent lower.

A very interesting and striking feature of these configurations may be noted by comparing the $\frac{L}{D}$ values of part (a) of Fig. 4 to those of part (b) for the same value of $\frac{c}{\ell}$ and C_f. The fact that the product of Mach number and lift-drag ratio, $M \frac{L}{D}$, is essentially a constant means that higher Mach numbers offer no inherent advantage or disadvantage to vehicle range.

Concurrently with the calculations of lift-drag ratio, the physical characteristics of these configurations were determined in a general fashion. These included such properties as body-to-ring diameter ratio, body fineness ratio ($\frac{\text{length}}{\text{diameter}}$), body-frontal-area-to-wing-reference-area ratio, surface wetted areas, and body volume. This information permitted the preliminary configuration designs presented in the next section.

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[*] It should be noted that the L/D value for the basic half-ring configuration declines as the limiting value $c/\ell = 0$ is approached. This is a consequence of the sum of the decreasing vortex- and increasing wave-drag-due-to-lift approaching the asymptotic value, while the zero-lift drag increases slowly. The net effect is a decline in L/D. In the case of the complete-ring configuration, both the vortex- and wave-drag-due-to-lift decrease at a moderate to rapid rate, while the zero-lift drag increases slowly. The net effect here is a rapid rise in L/D.

III. APPLICATIONS

In this section realistic hardware applications of the performance figures previously cited are described. The designs are of the 'back-of-the-envelope' type, and the sizing has in most cases been set by the vehicle selected for comparison.

It should be pointed out at this juncture that while the details of the theoretical external aerodynamics of the ring-body configurations can be stated precisely and the associated geometries calculated exactly, the practical engineering data for final comparison await the experimental substantiation of the concept introduced in this report.
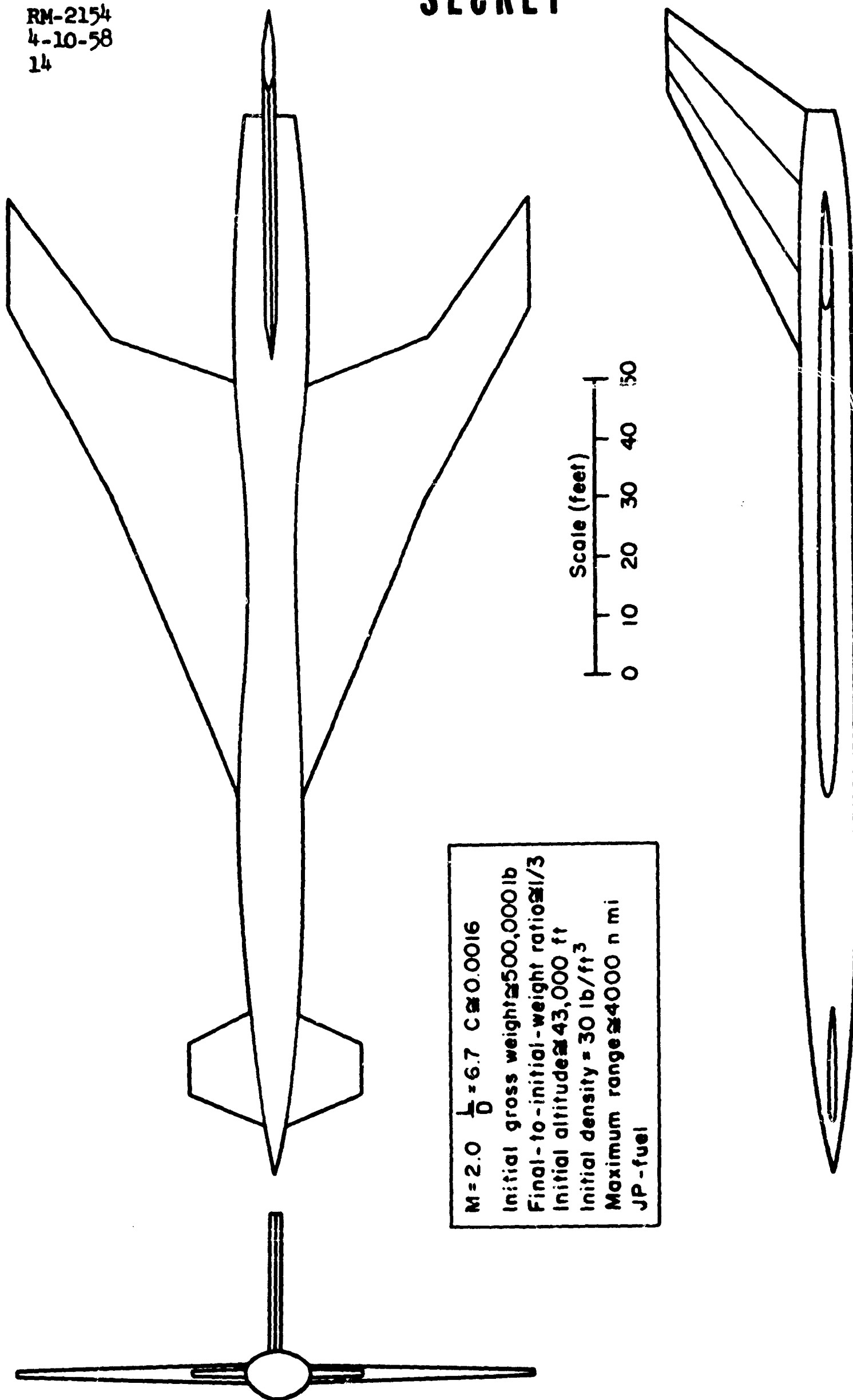
A. STRATEGIC LONG-RANGE BOMBER

An important possible application of this aerodynamics concept is a cambered half-ring body with a design Mach number of about 3.0 and having as a comparison vehicle an advanced design[6] scaled for a gross weight of about 500,000 lb (Figs. 5 and 6). The configuration sketched in Fig. 6 has a body volume equal to the total displacement volume of the configuration shown in Fig. 5. The average density (initial gross weight divided by total volume) assumed for both configurations is 30 lb/ft^3. Figures 5 and 6 are drawn to the same scale, so that general impressions as to size can be readily obtained. The ring chord is about 6 per cent of the body length. As is usually the case with conventional airplanes, definite altitudes are associated with the vehicles' maximum lift-drag ratio, gross weight (lift), and volume (density). For the vehicle in Fig. 6 the product of Mach number and lift-drag ratio, $M \frac{L}{D}$, is 97.5. By comparison, the canard configuration of Fig. 5 has an $M \frac{L}{D}$ of about 15, based on uncorrected wind-tunnel data. The latter value could be raised

$M = 2.0 \quad \frac{L}{D} = 6.7 \quad C_D \cong 0.0016$

Initial gross weight $\cong$ 500,000 lb
Final-to-initial-weight ratio $\cong$ 1/3
Initial altitude $\cong$ 43,000 ft
Initial density = 30 lb/ft^3
Maximum range $\cong$ 4000 n mi
JP-fuel

Scale (feet)

0　10　20　30　40　50

Fig.5—Canard airplane configuration of Mach-2 design with no lift-interference

M=3.15, $\frac{L}{D}$=31.0, C_f=0.0003, $\frac{t}{c}$≅0.06
Initial gross weight≅500,000 lb
Final-to-initial-weight ratio≅1/3
Initial altitude=30,000 ft
Initial density=30 lb/ft³
Maximum range≅25,000 n mi
JP-fuel; thickness-drag cancellation
laminarized boundary layer and body camber
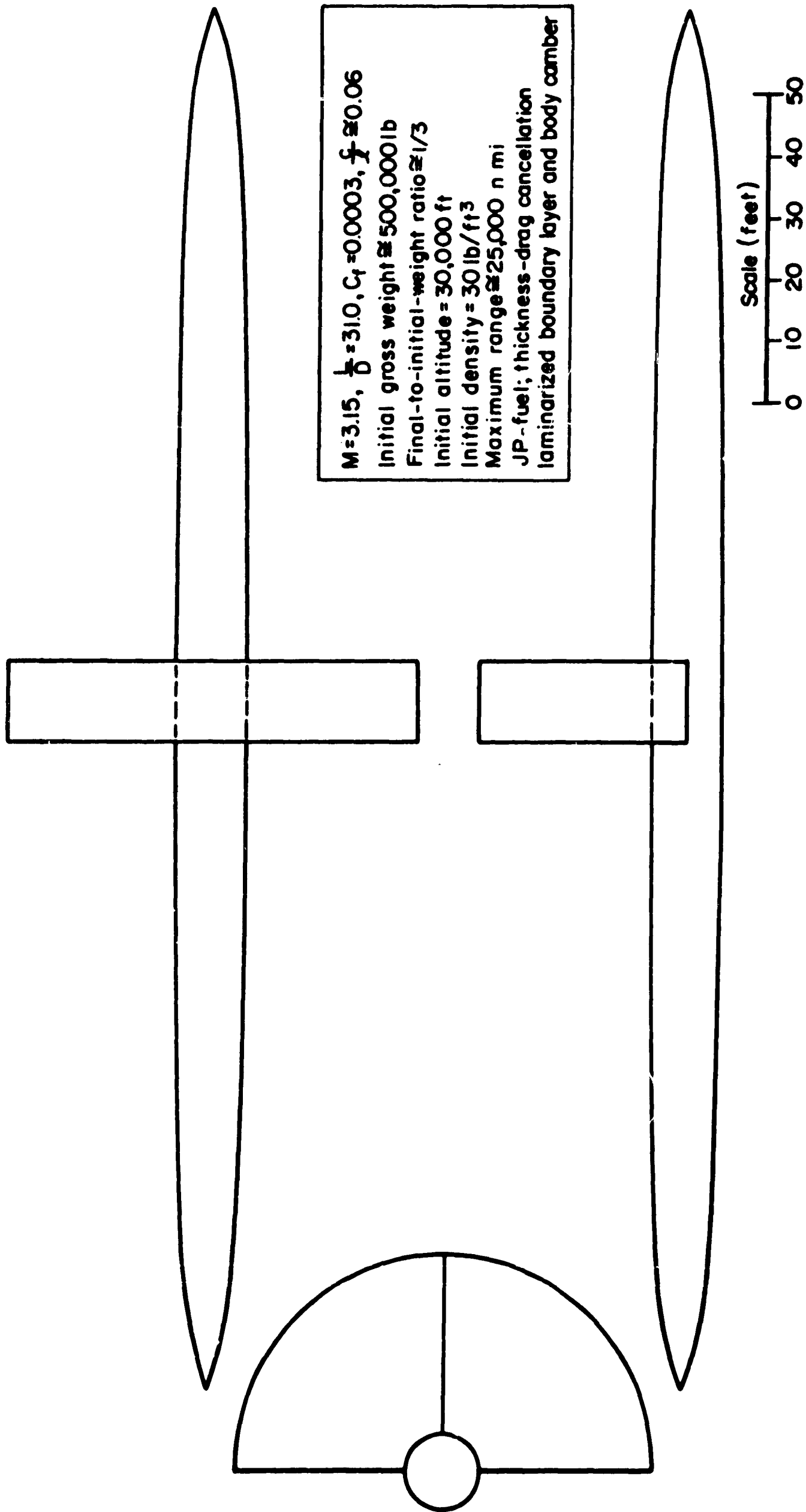
Scale (feet)
0 10 20 30 40 50

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Fig.6—Cambered half-ring-body, supersonic, intermediate-altitude, manned strategic bomber

to about 20 by reducing the average skin-friction coefficient by a factor of about five, thus reducing C_f to the value of the ring-body configuration, 0.0003.

Figure 7 affords a brief pictorial comparison of the all-out range capabilities of the Mach-2 canard-type aircraft with laminarized boundary layer and a 25 per cent range increase and the circumnavigational strategic bomber at M ≈ 3. This range increase could be attributed to successful application of an elementary lift-interference system. JP-fuels are assumed to be used in both vehicles. The range of the ring-body configuration is predicated upon 1958 state of the art in propulsion and structures and the use of all three features of the aerodynamics concept. Also shown as a matter of general interest is the order of magnitude of the M = 2 range of the B-58A. The B-58A is shown to be able to fly from Wheelus Air Force Base, Tripoli,to Moscow. The 'Super Canard' could fly from Turner Air Force Base, Georgia,to Peking, China, and the 500,000 lb cambered ring-body could circumnavigate the earth. The immensity of the strategic advantage made possible by such potential performance is clear.

B. STRATEGIC LONG-RANGE MISSILE

The second application given here concerns a ring-body of the same weight (post-launch) and immersed volume as the SM-62A SNARK, which is shown in Fig. 8. A complete-ring-body configuration (Fig. 9) was selected for convenience of calculation. To demonstrate the unprecedented capability of an all-supersonic, all-sea-level, intercontinental mission it is necessary to assume the use of borane fuels (ramjet operation). The design sketched in Fig. 9 is not necessarily the optimum of the many possible configurations for the all-supersonic sea-level mission at M = 2.2 However, it provides an indication of the vehicle configuration and a basis

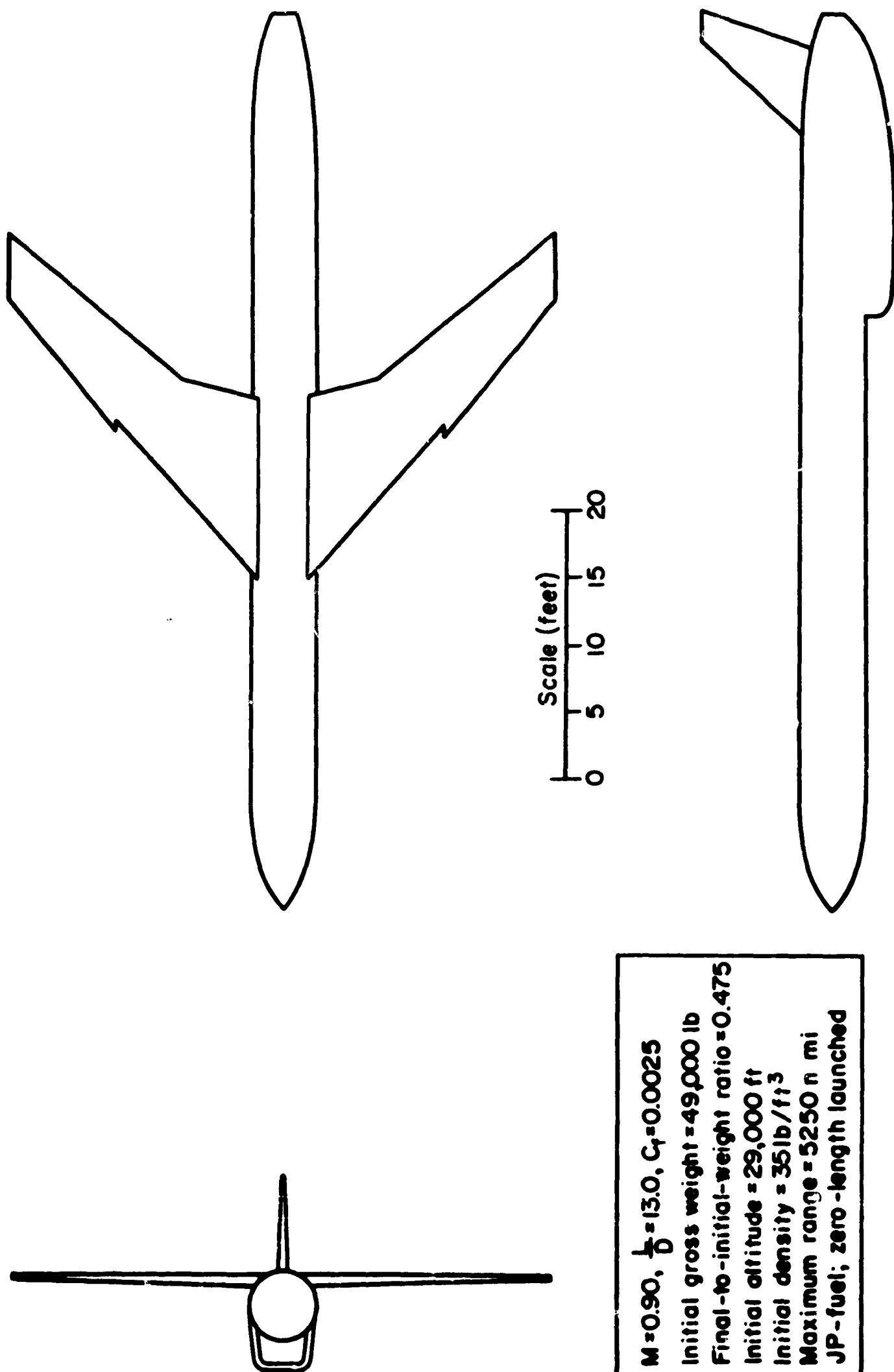Fig. 7—Maximum-supersonic-range capabilities: Super Canard
configuration at Mach 2.0; cambered half-ring-body strategic
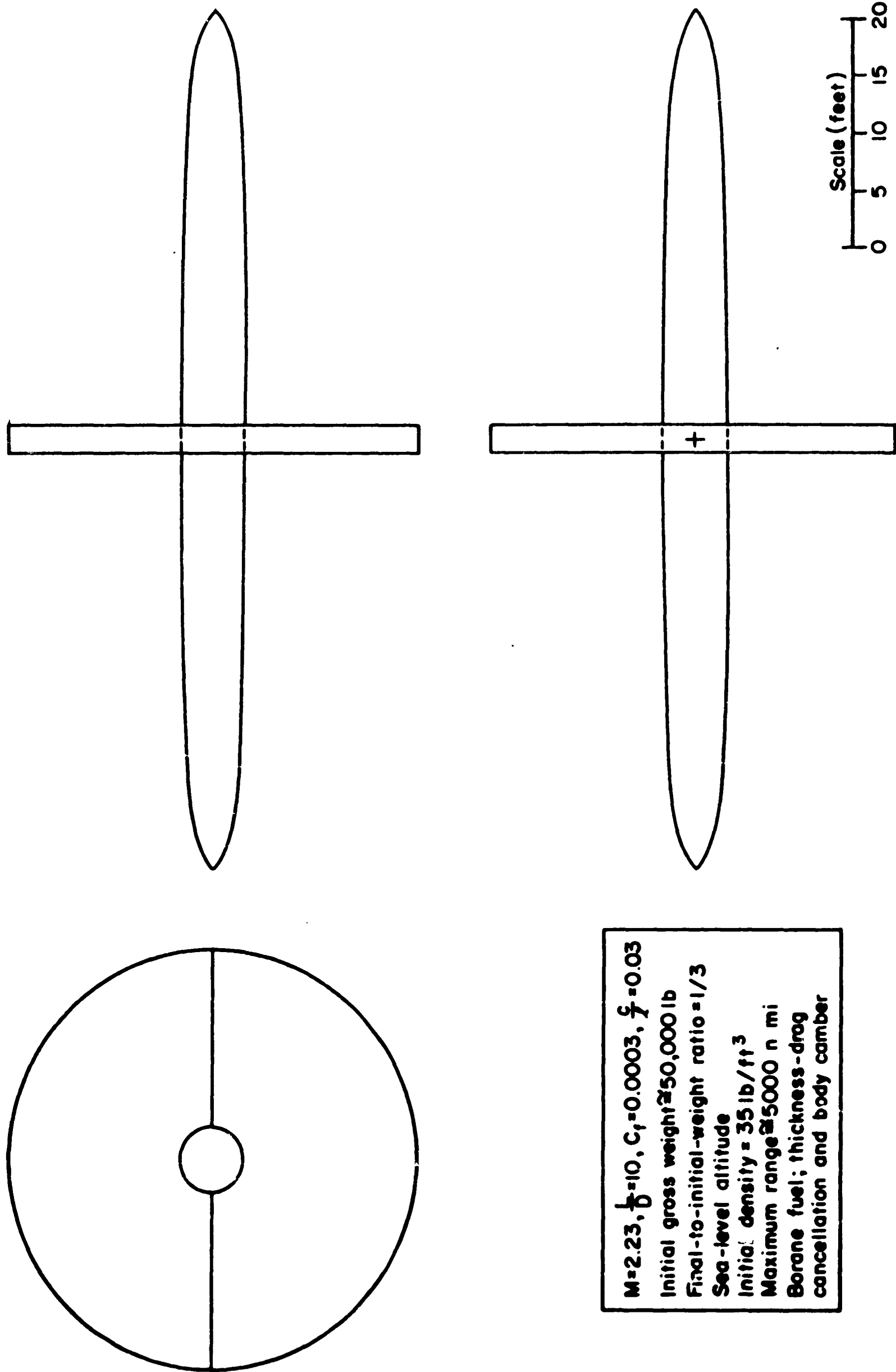bomber at Mach 3.2; and Convair B-58A at Mach 2.0

Scale (feet)

0 5 10 15 20

M=0.90, $\frac{L}{D}$=13.0, C_f=0.0025
Initial gross weight=49,000 lb
Final-to-initial-weight ratio=0.475
Initial altitude=29,000 ft
Initial density=35 lb/ft^3
Maximum range=5250 n mi
JP-fuel; zero-length launched

Fig.8—Northrop SM-62A SNARK—subsonic, intermediate-altitude strategic missile

Scale (feet)

0   5   10   15   20

M=2.23, $\frac{b}{D}$=10, C_f=0.0003, $\frac{t}{c}$=0.03
Initial gross weight≅50,000 lb
Final-to-initial-weight ratio =1/3
Sea-level altitude
Initial density = 35 lb/ft³
Maximum range≅5000 n mi
Borane fuel; thickness-drag
cancellation and body camber

Fig. 9——Cambered, complete-ring-body, supersonic, sea-level strategic missile

for a performance estimate. Ranges of about 5000 n mi would be possible for this vehicle with an $M \frac{L}{D}$ of 22, a basic specific fuel consumption of 1.9 with borane fuels, and a fuel weight which is two-thirds the gross weight. Assuming for the moment that this configuration could fly a constant lift-drag ratio profile rather than a constant altitude, the Breguet range equation would apply and the range would be approximately 8000 n mi. These 5000 n mi range capabilities of the SNARK (using JP-fuel and flying at high altitudes) and the complete-ring-body are illustrated in Fig. 10, which shows the significant intercontinental capability of this supersonic sea-level missile in a flight from Castle Air Force Base, California, to Moscow. For practical applications a mixed-altitude mission would probably be employed, but the order of magnitude of the range would be the same. The equations for all-out range of these two different missions are:

$$R = \frac{a}{c} \left(M \frac{L}{D} \right)_{init.} \left[1 - \frac{W_{final}}{W_{init.}} \right] \quad ; \quad \text{constant altitude}$$

$$R = \frac{a}{c} \left(M \frac{L}{D} \right)_{constant} \ln \frac{W_{init.}}{W_{final}} \quad ; \quad \text{constant } \frac{L}{D}, \text{Breguet}$$

The state-of-the-art requirements for this configuration and its stated performance are a '1958-type' weight ratio, a fuel-consumption value bracketed by sea-level afterburning turbojet and ramjet values with borane fuels, and, in aerodynamics, thickness-drag cancellation and boundary-layer laminarization to an average effective skin-friction coefficient of 0.0003.

C. AIR-TO-SURFACE MISSILE

The third offense weapon application suggested to illustrate this aerodynamics concept is the air-to-surface missile. An efficient, truly

Fig. 10——Maximum-range capabilities: SM-62A SNARK at Mach 0.9
and intermediate altitude; complete-ring-body missile at Mach 2.2
and sea level; the same missile at Mach 2.2 and intermediate altitude
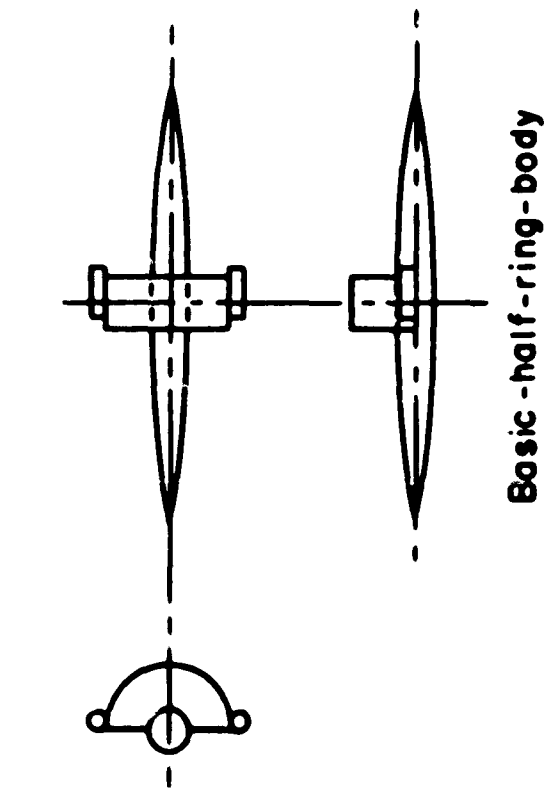
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effective weapon of this type would significantly extend the useful life of the present subsonic manned strategic bomber force. Shown in Fig. 11 are two half-ring-body configurations which bracket a family of missiles designed for M = 3 ranges of 500 to 1800 n mi at altitude (using JP-fuels). The respective gross weights of the missiles are approximately 4600 to 6800 lb (3200 to 4600 lb without boosters). The total of the payload and guidance system allowances is essentially that of current ASM designs.

Some indication of the usefulness of the 1800 n mi weapon is given by the pictorial representation of Fig. 12, which indicates that it would be possible to reach all SU targets from outside the 'geographic + 200 n mi' perimeter with ASM's launched from B-52's based in the ZI. Subject to the date of availability of the ASM, this could be an important strategic advantage. The indicated external stowage is consistent with the relative dimensions of the B-52 and the ASM's.
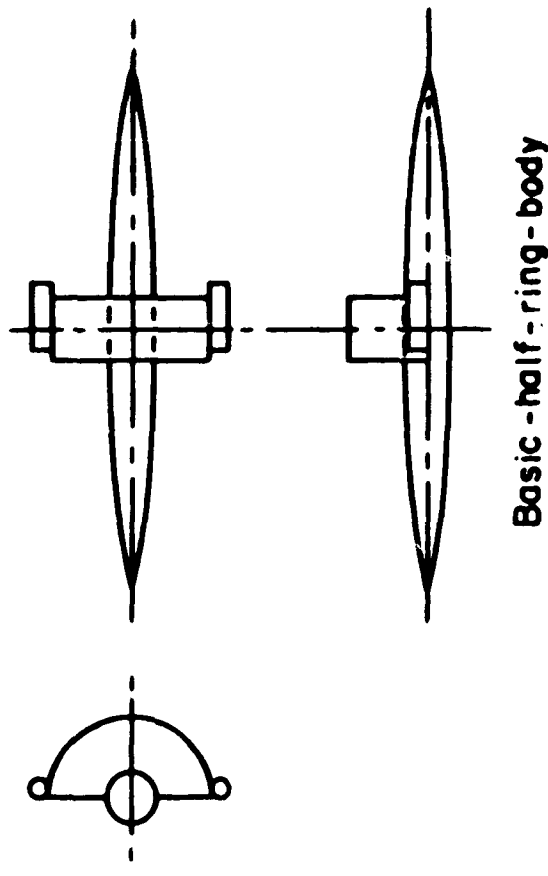
The state-of-the-art requirements for this ASM application are arbitrarily quite conservative in weight ratio and ramjet fuel consumption (3.0); and no skin-friction coefficient reduction is required below the nominal 0.0015 of turbulent boundary layers at M = 3. However, thickness-drag cancellation and body camber are essential features.

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Basic-half-ring-body

M ≅ 3   Range ≅ 1800 n mi
Gross weight ≅ 6750 lb (4650 lb without booster)

Basic-half-ring-body

M ≅ 3.0   Range ≅ 500 n mi
Gross weight ≅ 4650 lb (3200 lb without booster)

Scale (feet)

0   5   10   15   20
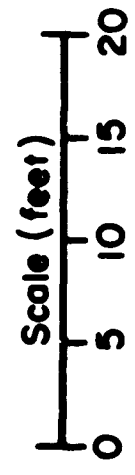
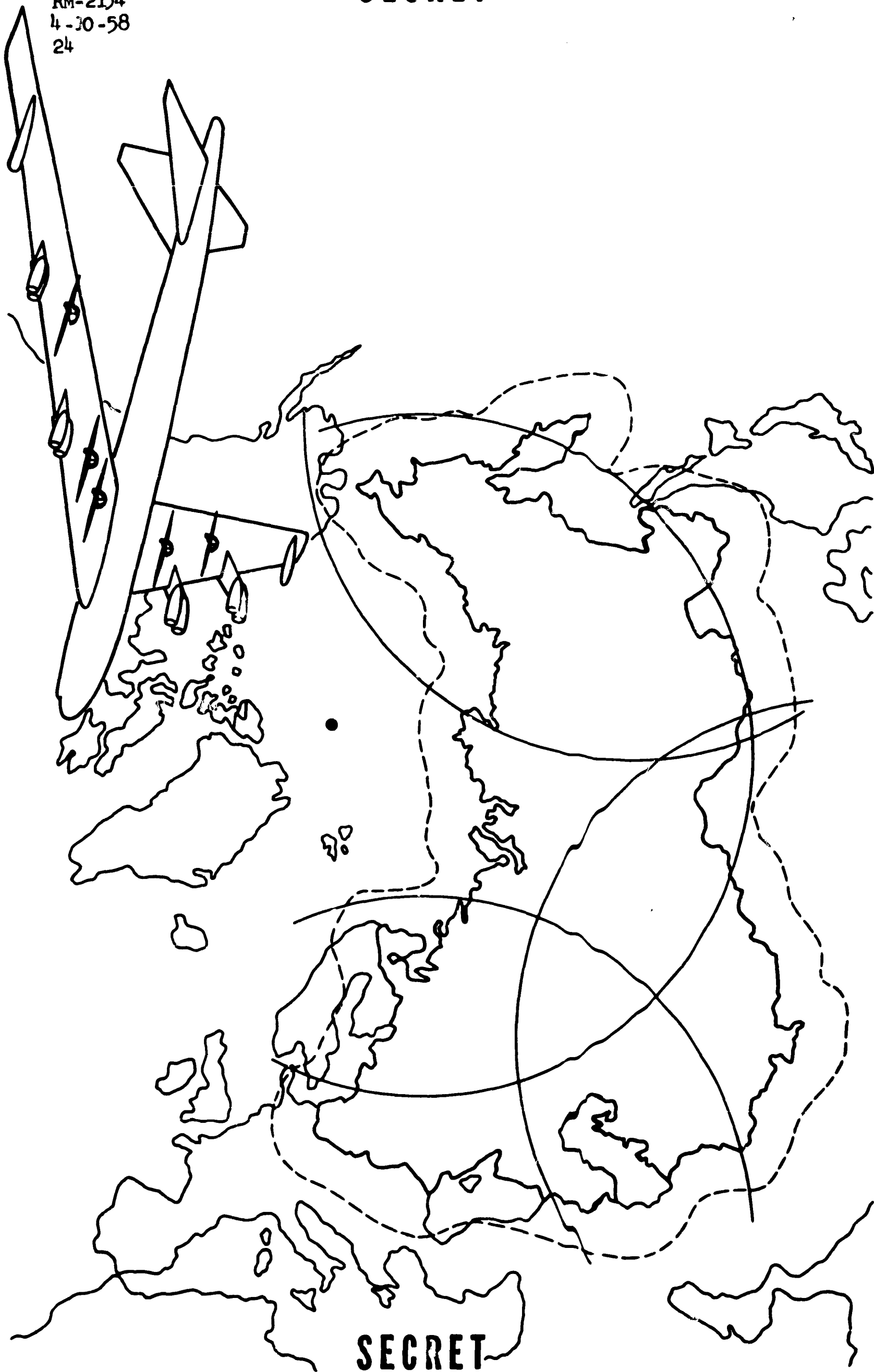Fig. II —— Three-view drawings of B-52 launched air-to-surface missiles

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Fig.12—Pictorial representation of complete coverage of Soviet Union with 1800 n mi range
half-ring-body ASM's launched from B-52's 200 n mi outside geographic perimeter

D. SUPERSONIC TRANSPORT

The final application illustrated here is that of a supersonic transport of the general size of the Douglas DC-3, Boeing 707, or KC-135. Figure 13 shows a three-view sketch of the DC-8. The nominal reference weight used is 300,000 lb, and the average density is about 15 lb/ft^3, which is typical of personnel transports. A Mach-2.2 cambered-half-ring-body transport of this density is found to have an $M \frac{L}{D}$ factor of about 93; hence, its range would be 246 per cent of the 5800 n mi maximum range of the 'intercontinental,' Mach-0.81 DC-8, or about 14,300 n mi. This range is achieved through the use of all three features of the aerodynamics concept, the DC-8 weight ratio, and the rather high specific fuel consumption value of 2.5 for afterburning turbojets. The general appearance of the airplane would be similar to that of the strategic bomber in Fig. 6. The relatively small ring-wing of this transport airplane, with chord-length ratio $\frac{c}{l}$ = 6 per cent, has a projected wing-planform area, S_w = 2 Rc, that results in the relatively high wing loading (ratio of take-off gross weight to wing-planform area) of 225 lb/ft^2.

To indicate the flexibility of the aerodynamics concept to particular problems of the designer, a related transport airplane (Fig. 14) was designed to have a low wing loading. Omitting the body-camber feature of the concept leads to appreciably different optimum configurations and lessened aerodynamic performance as well as reduced wing loading. The Mach-2.2 basic half-ring-body transport shown in Fig. 14 has a wing loading of only 55 lb/ft^2 (versus 104 lb/ft^2 for the DC-8) based on projected wing planform area. The chord-length ratio of the wing is 27 per cent. The $M \cdot \frac{L}{D}$ factor of about 42 for this configuration corresponds to a maximum range of about 6500 n mi, which is 12 per cent greater than that of the DC-8.

$M = 0.81, \frac{L}{D} = 16.5, C_f = 0.0030$
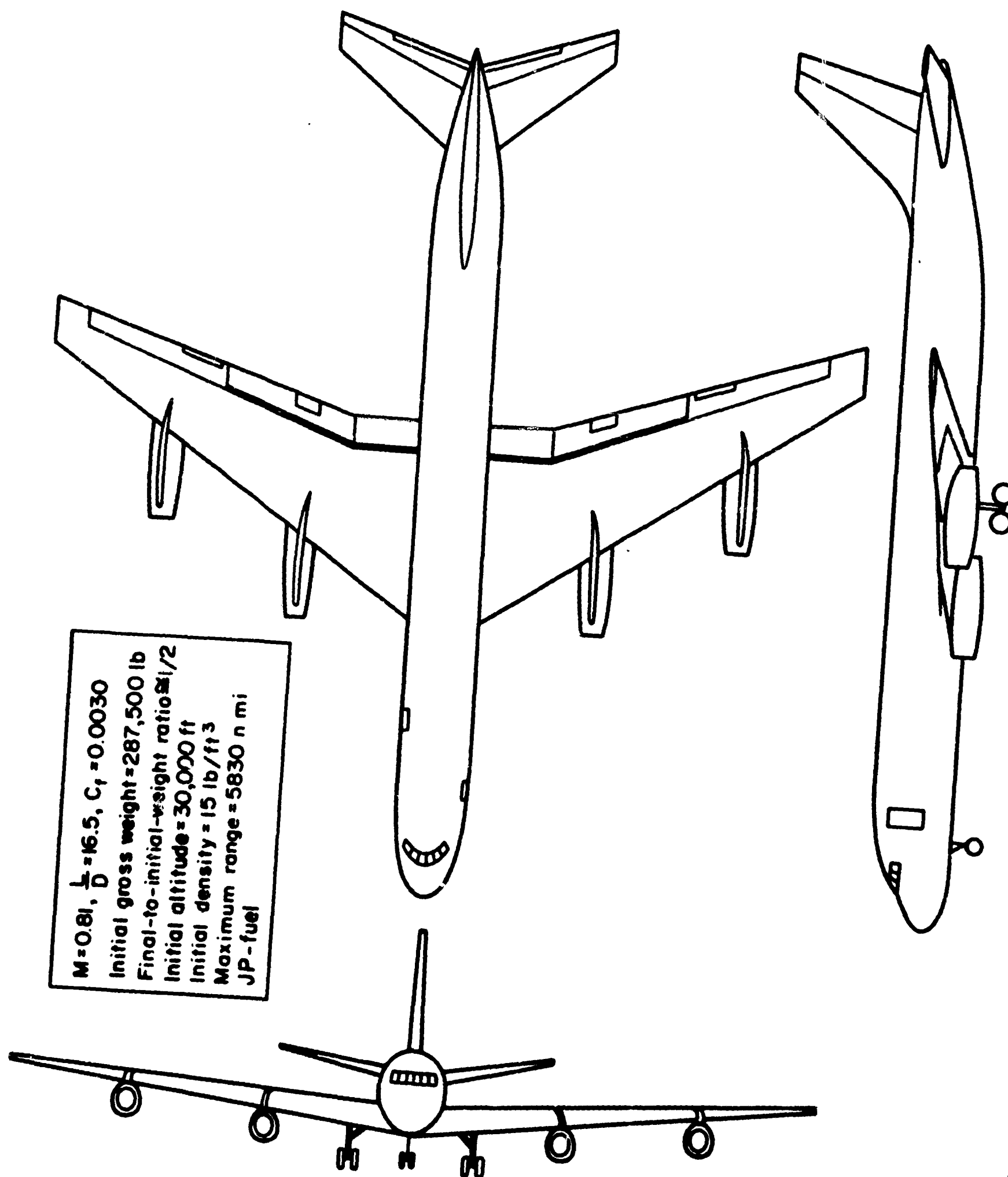Initial gross weight = 287,500 lb
Final-to-initial-weight ratio = 1/2
Initial altitude = 30,000 ft
Initial density = 15 lb/ft^3
Maximum range = 5830 n mi
JP-fuel

Fig.13—Douglas DC-8 subsonic intermediate-altitude transport airplane

$M=2.23$, $\frac{l}{b}=19.0$, $C_f=0.0003$, $\frac{t}{c}\cong 0.27$
Initial gross weight $\cong 300,000$ lb
Final-to-initial-weight ratio $\cong 1/2$
Initial altitude $=50,000$ ft
Initial density $=15$ lb/ft^3
Maximum range $\cong 6500$ n mi
JP-fuel; thickness-drag cancellation
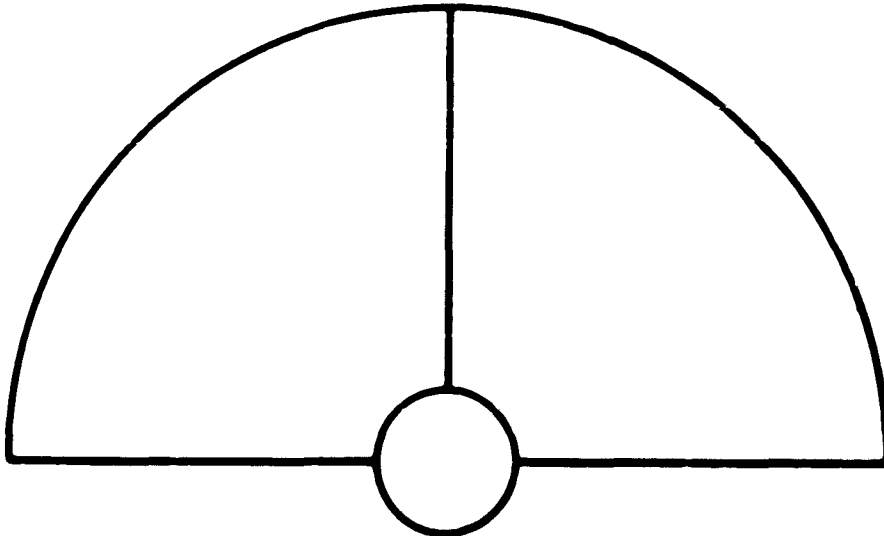 and laminarized boundary layer
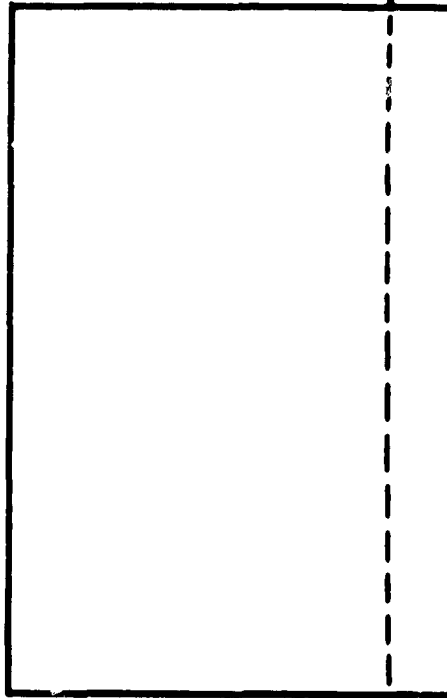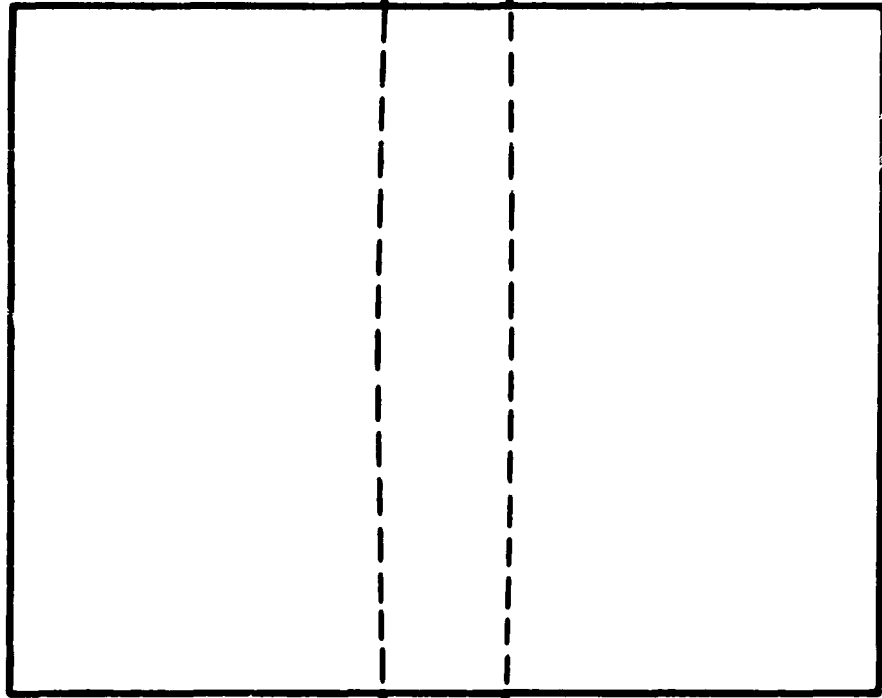
Fig. 14——Basic half-ring-body, supersonic, high-altitude transport airplane

Figure 15 summarizes the range capabilities of the DC-8, the basic half-ring-transport and the cambered half-ring transport. From a common take-off point at Westover Air Force Base, Massachusetts, the DC-8 with a Mach-0.81 range of 5800 n mi could reach Dahran, the basic half-ring transport with a Mach-2.2. range of 6500 n mi could reach Karachi, and the Mach-2.2 cambered half-ring transport could almost reach Madagascar and return to Westover.

Fig. 15——Maximum-range capabilities: Douglas DC-8 at Mach 0.81
and 30,000 ft, and basic- and cambered-half-ring-body
transport airplanes at Mach 2.2 and intermediate altitudes

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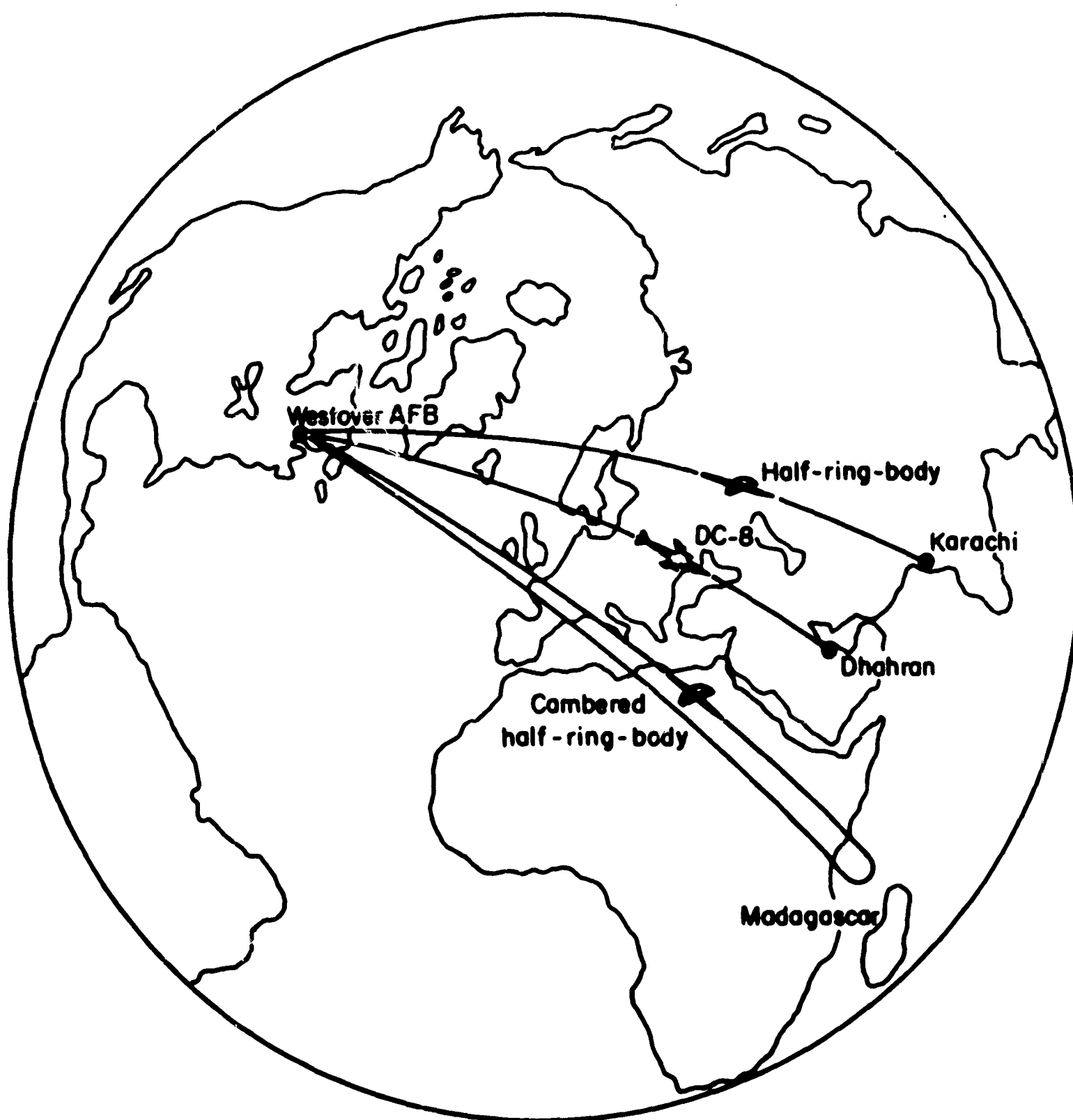## IV. DRAG TRANSFORMATION AND REDUCTION:
CURRENT STATUS AND SUGGESTED RESEARCH

The three major features of the concept of drag transformation and reduction--thickness-drag cancellation, laminarized supersonic boundary layer, and reduction of drag-due-to-lift--are discussed below with respect to current theoretical or experimental status and required experimental research. Such research is needed at an early date to permit an over-all evaluation and design application of this aerodynamics concept. The potential performance gains in vehicle applications are so great (assuming full verification of the concept) that early and intensive research is vital.

A. THICKNESS-DRAG CANCELLATION

The thickness-drag cancellation part of the concept is supported indirectly by experiment. The successful experimental verifications of the 'Transonic Area Rule'[7,8] and of the 'Supersonic Area Rule'[9,10] in the low supersonic Mach number range indicate that the Hayes[11] drag method (evaluation of drag at a distant control surface where + and - pressure perturbations can cancel each other), which was used in this concept, is substantiated in the experimental realm. The internal compression inlets[12] as considered recently for the design of engine nacelles have been shown experimentally to have high total pressure ratios (therefore low energy losses) in deceleration of the flow from Mach 3 to Mach 0.5 in the free stream at the engine compressor face. The losses associated with much more limited decelerations of, say, Mach 3 in the free stream down to Mach 2 within the ring would be very small, since the inlet's normal-shock and boundary-layer-separation losses are not relevant to this concept.

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It is suggested that initially a basic complete-ring-body model with low chord-length ratio and with provision for elementary boundary-layer suction* be fabricated and wind-tunnel-tested at Mach 3 to establish specifically, for the general class of configurations of interest here, the principle of thickness-drag cancellation.

B. SUPERSONIC LAMINARIZED BOUNDARY LAYER

There is only one relevant existing experimental effort in the field of supersonic boundary-layer control. Pfenninger[13,14] has had good success in his first attempts at maintaining a laminar boundary layer on a wing model at supersonic speeds in the Daingerfield wind tunnel at M = 2.2 and 2.8. Effective skin-friction coefficients (allowing for the equivalent drag of pumping power as well as the momentum defect in the boundary-layer wake) of 0.00056 and 0.00059 were obtained at these respective Mach numbers and at a wing-chord Reynolds number of 12.7×10^6. These results strikingly parallel, even to the approximate numerical values, the initial success of the subsonic tests[15] with the special glove fitted to the wing of an F-94B airplane. At the upper limit of wing-chord Reynolds numbers (about 36×10^6) attainable with that airplane, values less than $C_f = 0.0003$ have been reached at subsonic Mach numbers. The performance results stated in the body of this report were based upon this $C_f = 0.0003$ level at supersonic Mach number. The initial supersonic tests reveal an improvement by a factor of about three from the turbulent boundary

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*The provision for boundary layer suction in this model is to insure that the virtual surfaces of the model in a viscous flow (air) can be made substantially those which were assumed for the potential flow. This is essential to this experiment, which is designed to check a potential flow concept.

layer skin-friction coefficient of roughly 0.0018. A further halving, as was accomplished by subsonic research, is needed to attain the ranges quoted in the text.

It is concluded that the supersonic-laminar-boundary-layer research program should be pursued with all practical speed and effort. In effect this means immediate and substantial renewed funding of experimental supersonic-boundary-layer research. The experimental part of this program should proceed to complete-configuration ring-body model tests.

It is further concluded that application studies, based upon these experimental boundary-layer data, with their numerous implications for the configurations, should be conducted concurrently with the research program. There is a substantial need for coming to grips with the applications of this second major feature of the aerodynamics concept.

C. REDUCTION OF DRAG-DUE-TO-LIFT

Theoretical investigations of reduction in drag-due-to-lift through interference-generated over-pressure fields have been reported by Rossow[16] and quite extensively by Ferri.[17] However, the work which is more directly applicable to the present thesis involves approximating the desired elliptic load projection on the body axis to minimize wave-drag-due-to-lift. A combination of this minimum drag with minimum vortex drag permits an approach to Jones'[5] lower bound of drag-due-to-lift. The particular device suggested here for improving the over-all, projected, longitudinal loading of the ring + body has been investigated directly, but in a limited way, for the purpose of minimizing airplane trim drag in the pitch direction. Body camber was used in a conventional wing-body model[18]

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which was tested as a part of a basic wind-tunnel research program, and it was also used in the design and testing of the Northrop T-38 supersonic trainer. However, the most impressive example of the efficiency of improving the longitudinal load projection is a delta-wing-body wind-tunnel model[19] designed to minimize supersonic pitching moment at M = 1.2. Fortuitously, the loading is such that the projection along the Mach plane for M = 1.2 is a reasonable approximation to an elliptic loading along the axis. In consonance with the previous discussion of wave drag-due-to-lift, these tests did show a substantial improvement at M = 1.2 in the curve of lift-drag ratio versus Mach number for this configuration. It appears to be an anomaly of the sort which sometimes occurred in research before the Transonic Area Rule was formulated. (An example would be the occurrence of an 'unreasonably' low transonic thickness drag from a free-flight drop model.[20] In the design field one could cite the larger T-33 with a maximum speed greater than that of the parent F-80, and the higher-than-generally-anticipated drag-divergence Mach numbers of the XB-51 and B-52.)

It is suggested that theoretical research on the means of effectively utilizing body camber for the ring-body configurations be instated, and that the results be checked with a 'sophisticated' ring-body model which also incorporates the other two major features.

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V. CONCLUSIONS

The magnitude of the range extension made possible by application of the concept of drag transformation and reduction to strategic weapon systems of a ring-body configuration indicates strongly that the following measures be implemented:

o That a basic complete-ring-body model with low chord-length ratio and with provision for elementary boundary-layer control be fabricated and wind-tunnel-tested at Mach 3 to establish the principle of thickness-drag cancellation.

o That supersonic-laminar-boundary-layer research, including application studies, be pursued with all practical speed and effort.

o That theoretical research on means of effectively utilizing body camber for ring-body configurations be begun, and that these results be checked with a ring-body model which incorporates thickness-drag cancellation and means of producing a supersonic laminarized boundary layer.

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