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# CALCULATIONS, AND COMPARISON WITH AN IDEAL MINIMUM, OF TRIMMED DRAG FOR CONVENTIONAL AND CANARD CONFIGURATIONS HAVING VARIOUS LEVELS OF STATIC STABILITY

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16. Abstract

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# CALCULATIONS, AND COMPARISON WITH AN IDEAL MINIMUM, OF TRIMMED DRAG FOR CONVENTIONAL AND CANARD CONFIGURATIONS HAVING VARIOUS LEVELS OF STATIC STABILITY

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## SUMMARY

Classical drag equations have been used to calculate total and induced drag and ratios of stabilizer lift to wing lift for a variety of conventional and canard configurations. The study was conducted to compare the flight efficiencies of such configurations that are trimmed in pitch and have various values of static margin. Another purpose was to make comparisons of the classical calculation methods with more modern lifting-surface theory.

Results from the calculations show that the conventional configurations generally had lower configuration drag coefficients, and hence higher flight efficiencies, than canard configurations with comparable values of gap, static margin, and ratio of stabilizer span to wing span. Also, in general, the canard configurations had larger variations of induced drag with static margin than the conventional configurations except for span ratios near zero, which are not usually employed. The minimum-induced-drag coefficient determined by the classical method was generally in agreement with that determined by lifting-surface theory for the canard configuration studied. This gives confidence in the accuracy of the classical calculation method.

## INTRODUCTION

Airplane designs may range from conventional designs, with stabilizer aft; to tandem designs, with wings of equal or nearly equal spans; to canard designs, with stabilizer forward. With aircraft operating costs increasing, it is desirable to compare the performance of these various configurations in order to determine more efficient configurations. The classical biplane theories of Munk and Prandtl (see refs. 1 to 4) provide formulas for calculating the induced drag and minimum induced drag of wing and stabilizer configurations. The total drag of these configurations may be determined by adding profile drag. These calculations are quite simple and permit the evaluation of the performance of many configurations with little effort. In reference 5 Munk's theory is used to show that the induced drag of inplane versions of canard and conventional configurations is the same if the canard and tail are carrying equal but opposite trim loads.

The purpose of this paper is to assess the performance of various wing and stabilizer configurations by use of the classical biplane theory with constraints added to specify static margin and trim for each configuration. Drag and lift ratios are determined for many vertical-gap and span ratios on conventional, tandem, and canard configurations. The drag performance is compared for the different configurations and related to an ideal minimum drag (Prandtl's method). Also, results from Prandtl's minimum-drag method are compared with some values of minimum induced drag calculated by the vortex-lattice method (ref. 6).

## SYMBOLS

| | |
|---|---|
| $A$ | aspect ratio, $b^2/S$ |
| $b$ | surface span |
| $C_D$ | drag coefficient, $D/qS_w$ |
| $C_{D,p}$ | total profile-drag coefficient, $\left(C_{D,p}\right)_w\left(1 + \frac{\mu^2}{\lambda}\right)$ |
| $C_L$ | lift coefficient, $L/qS_w$ |
| $C_{L_\alpha}$ | lift-curve slope |
| $C_{m_{C_L}}$ | static margin, fraction of $\bar{c}_w$ |
| $C_{m,o}$ | zero-lift pitching-moment coefficient, $\frac{M_{Y,o}}{qS_w\bar{c}_w}$ |
| $C_{m_\alpha}$ | pitching-moment-curve slope |
| $\bar{c}$ | mean aerodynamic chord |
| $D$ | drag |
| $G$ | vertical gap between stabilizer and wing |
| $K$ | ratio of wing lift to total lift, $L_w/L$ |

| | |
|---|---|
| $1 - K$ | ratio of stabilizer lift to total lift, $L_S/L$ |
| $L$ | total lift; individual surface lift when subscripted |
| $l$ | distance from center of gravity to $\frac{1}{4}\bar{c}_S$, positive to rear |
| $l_S$ | distance from $\frac{1}{4}\bar{c}_W$ to $\frac{1}{4}\bar{c}_S$ |
| $M_{Y,o}$ | pitching moment at zero lift |
| $q$ | dynamic pressure |
| $S$ | surface area |
| $V$ | free-stream velocity |
| $w$ | normal induced velocity about a surface |
| $x$ | distance from center of gravity to $\frac{1}{4}\bar{c}_W$, positive to rear |
| $\alpha$ | angle of attack |
| $\frac{\Delta x}{b_W/2}$ | distance from reference point to trim point in wing semispans |
| $\lambda$ | ratio of stabilizer aspect ratio to wing aspect ratio, $A_S/A_W$ |
| $\mu$ | ratio of stabilizer span to wing span, $b_S/b_W$ |
| $\sigma$ | interference factor |
| $\frac{\partial\epsilon}{\partial\alpha}$ | rate of change of downwash with angle of attack |

Subscripts:

| | |
|---|---|
| i | induced |
| min | minimum |
| p | profile |

s stabilizer

w wing

## THEORY

### Classical Theory

The classical equation developed by Munk and Prandtl for the total induced drag of a biplane is

$$D_i = \frac{1}{\pi q}\left(\frac{L_w^2}{b_w^2} + 2\sigma\frac{L_w L_s}{b_w b_s} + \frac{L_s^2}{b_s^2}\right) \tag{1}$$

This equation is given in references 3 and 4. An assumption in the development of this equation is that both lifting surfaces have elliptical span loadings. The terms $L_w^2/\pi q b_w^2$ and $L_s^2/\pi q b_s^2$ represent the induced drag of the wing and of the stabilizer, respectively. The term $2\sigma L_w L_s/\pi q b_w b_s$ represents the drag that results from mutual interference between the wing and stabilizer. Munk's equivalence theorem for stagger (ref. 3) allows the drag equation to be extended to conventional and canard configurations. The theorem states that the total induced drag of any multiplane system is unaltered if any of the lifting elements are moved in the direction of motion, provided that the element is moved along a streamline and is adjusted in attitude to maintain the same distribution of lift between the surfaces.

The term $\sigma$ in equation (1) is the factor for flow interference on one surface caused by the vortex system from the other surface. The vortices induce a flow field normal to the generating wing. This flow field extends upstream and downstream from the wing and affects other objects there. According to reference 3, the interference drag between two surfaces may be determined by integrating, across the span of one surface, the normal velocity induced by the other surface. Thus, from reference 3,

$$\int_{b_w} \frac{w_{w,s}}{V}\, dL_w = \frac{\sigma L_w L_s}{\pi b_w b_s q} \tag{2}$$

Values for the interference factor $\sigma$, shown in figure 1, were obtained from reference 4 and additional calculations. The factor was calculated by assuming an elliptic lift distribution on each surface and is given as a function of the ratios of gap to wing span $G/b_w$ and of stabilizer span to wing span $\mu$. The span ratio $\mu$ should never be larger than 1 for this theory to be applicable.

Prandtl obtained an equation for the minimum induced drag of a biplane by satisfying necessary conditions for a minimum without either a requirement for longitudinal trim or a specified level of static margin. The result from references 3 and 4 is

$$\left(D_i\right)_{min} = \frac{L^2}{\pi q b_w^2}\left(\frac{1 - \sigma^2}{1 - 2\sigma\mu + \mu^2}\right) \tag{3}$$

The ratio of stabilizer lift to wing lift for minimum induced drag is

$$\frac{L_s}{L_w} = \frac{\mu - \sigma}{\frac{1}{\mu} - \sigma} \tag{4}$$

## Extension of Theory

Drag equations.- The total drag of a configuration is the sum of profile drag and induced drag, or

$$D = D_p + D_i \tag{5}$$

The profile drag may be expressed as

$$D_p = qS_w\left(C_{D,p}\right)_w + qS_s\left(C_{D,p}\right)_s$$

If this equation is combined with equation (1), the total drag is

$$D = qS_w\left(C_{D,p}\right)_w + qS_s\left(C_{D,p}\right)_s + \frac{1}{\pi q}\left(\frac{L_w^{\ 2}}{b_w^{\ 2}} + 2\sigma\frac{L_w L_s}{b_w b_s} + \frac{L_s^{\ 2}}{b_s^{\ 2}}\right) \tag{6}$$

By using the ratios

$$K = \frac{L_w}{L} = \frac{1}{1 + \frac{L_s}{L_w}} \qquad \mu = \frac{b_s}{b_w} \qquad \lambda = \frac{A_s}{A_w}$$

and assuming that

$$\left(C_{D,p}\right)_s = \left(C_{D,p}\right)_w$$

equation (6) may be rewritten as

$$D = q\left(C_{D,p}\right)_w S_w\left(1 + \frac{\mu^2}{\lambda}\right) + \frac{L^2}{\pi q b_w^{\,2}}\left[K^2 + 2\sigma K\,\frac{1 - K}{\mu} + \frac{(1 - K)^2}{\mu^2}\right] \tag{7}$$

or, in normalized coefficient form,

$$\frac{C_D}{C_L^{\,2}/\pi A_w} = \frac{\left(C_{D,p}\right)_w}{C_L^{\,2}/\pi A_w}\left(1 + \frac{\mu^2}{\lambda}\right) + K^2 + 2\sigma K\,\frac{1 - K}{\mu} + \frac{(1 - K)^2}{\mu^2} \tag{8}$$

where

$$\frac{C_{D,p}}{C_L^{\,2}/\pi A_w} = \frac{\left(C_{D,p}\right)_w}{C_L^{\,2}/\pi A_w}\left(1 + \frac{\mu^2}{\lambda}\right)$$

and

$$\frac{C_{D,i}}{C_L^{\,2}/\pi A_w} = K^2 + 2\sigma K\,\frac{1 - K}{\mu} + \frac{(1 - K)^2}{\mu^2}$$

The value K for the lift ratio in equation (8) may be chosen arbitrarily for use in this expression or chosen to reflect selected values of static margin at trim conditions. The development of K for these practical constraints is given in the following section.

Similarly, the equation for minimum induced drag (eq. (3)) may be written

$$\left(\frac{C_D}{C_L^{\,2}/\pi A_w}\right)_{min} = \frac{\left(C_{D,p}\right)_w}{C_L^{\,2}/\pi A_w}\left(1 + \frac{\mu^2}{\lambda}\right) + \frac{1 - \sigma^2}{1 - 2\sigma\mu + \mu^2} \tag{9}$$

The term $C_L^{\,2}/\pi A_w$ is the induced-drag coefficient of an isolated elliptically loaded wing.

Lift equations.- The value of the lift for each of the surfaces must be known in order to calculate the drag coefficient. Specifically, an expression is needed for relating surface lift to a static margin and to a trimmed lift condition. The conditions required for trim are that the sum of the vertical forces and the sum of the pitching moments be zero. That is,

$$\left.\begin{aligned} L_w + L_s - L &= 0 \\ -L_w x - L_s l - M_{Y,o} &= 0 \end{aligned}\right\} \tag{10}$$

The lift ratio is calculated by applying Cramer's rule and using the definitions of lift and pitching-moment coefficients:

$$\frac{L_s}{L_w} = -\frac{\dfrac{x}{\bar{c}_w} + \dfrac{C_{m,o}}{C_L}}{\dfrac{l}{\bar{c}_w} + \dfrac{C_{m,o}}{C_L}} \tag{11}$$

The locations of the wing and stabilizer with respect to a center of gravity (c.g.) are given by $x/\bar{c}_w$ and $l/\bar{c}_w$. If the center of gravity is properly located, a particular configuration will have a desired static margin $C_{m_{C_L}}$. The static margin for a conventional configuration may be expressed by the following equation:

$$C_{m_{C_L}} = -\frac{\dfrac{x}{\bar{c}_w} + \dfrac{l S_s \left(C_{L_\alpha}\right)_s}{\bar{c}_w S_w \left(C_{L_\alpha}\right)_w}\left(1 - \dfrac{\partial\epsilon}{\partial\alpha}\right)}{1 + \dfrac{S_s \left(C_{L_\alpha}\right)_s}{S_w \left(C_{L_\alpha}\right)_w}\left(1 - \dfrac{\partial\epsilon}{\partial\alpha}\right)} \tag{12}$$

This equation was obtained by combining

$$C_{m_\alpha} = \left[-\frac{x}{\bar{c}_w} - \frac{l S_s \left(C_{L_\alpha}\right)_s}{\bar{c}_w S_w \left(C_{L_\alpha}\right)_w}\left(1 - \frac{\partial\epsilon}{\partial\alpha}\right)\right]\left(C_{L_\alpha}\right)_w$$

$$C_{L_\alpha} = \left[1 + \frac{S_s \left(C_{L_\alpha}\right)_s}{S_w \left(C_{L_\alpha}\right)_w}\left(1 - \frac{\partial\epsilon}{\partial\alpha}\right)\right]\left(C_{L_\alpha}\right)_w$$

$$C_{m_{C_L}} = \frac{C_{m_\alpha}}{C_{L_\alpha}}$$

Similarly, the static margin for a canard configuration may be expressed by

$$C_{m_{C_L}} = -\frac{\frac{x}{\bar{c}_w}\left(1 - \frac{\partial \epsilon}{\partial \alpha}\right) + \frac{l S_s \left(C_{L_\alpha}\right)_s}{\bar{c}_w S_w \left(C_{L_\alpha}\right)_w}}{\left(1 - \frac{\partial \epsilon}{\partial \alpha}\right) + \frac{S_s \left(C_{L_\alpha}\right)_s}{S_w \left(C_{L_\alpha}\right)_w}} \tag{13}$$

This equation was obtained by combining

$$C_{m_\alpha} = \left[-\frac{x}{\bar{c}_w}\left(1 - \frac{\partial \epsilon}{\partial \alpha}\right) - \frac{l S_s \left(C_{L_\alpha}\right)_s}{\bar{c}_w S_w \left(C_{L_\alpha}\right)_w}\right]\left(C_{L_\alpha}\right)_w$$

$$C_{L_\alpha} = \left[\left(1 - \frac{\partial \epsilon}{\partial \alpha}\right) + \frac{S_s \left(C_{L_\alpha}\right)_s}{S_w \left(C_{L_\alpha}\right)_w}\right]\left(C_{L_\alpha}\right)_w$$

$$C_{m_{C_L}} = \frac{C_{m_\alpha}}{C_{L_\alpha}}$$

Now $\frac{l}{\bar{c}_w} = \frac{l_s}{\bar{c}_w} + \frac{x}{\bar{c}_w}$, where $l_s/\bar{c}_w$ is the distance in wing chords between $\bar{c}_w/4$ and $\bar{c}_s/4$, and

$$\left(C_{L_\alpha}\right)_w = \frac{2\pi A_w}{A_w + 2}$$

$$\left(C_{L_\alpha}\right)_s = \frac{2\pi A_s}{A_s + 2}$$

$$\frac{S_s}{S_w} = \mu^2 \frac{A_w}{A_s}$$

Thus equations (12) and (13) can be solved to obtain $x/\bar{c}_w$ and $l/\bar{c}_w$ in terms of static margin $C_{m_{C_L}}$ and stabilizer length $l_s/\bar{c}_w$. For a conventional configuration,

$$\frac{l}{\bar{c}_w} = -C_{m_{C_L}} + \frac{l_s/\bar{c}_w}{1 + \mu^2 \frac{A_w + 2}{A_s + 2}\left(1 - \frac{\partial\epsilon}{\partial\alpha}\right)} \tag{14}$$

$$\frac{x}{\bar{c}_w} = -C_{m_{C_L}} - \frac{\mu^2 \frac{A_w + 2}{A_s + 2}\left(1 - \frac{\partial\epsilon}{\partial\alpha}\right)}{1 + \mu^2 \frac{A_w + 2}{A_s + 2}\left(1 - \frac{\partial\epsilon}{\partial\alpha}\right)} \frac{l_s}{\bar{c}_w} \tag{15}$$

and for a canard configuration,

$$\frac{l}{\bar{c}_w} = -C_{m_{C_L}} + \frac{1 - \frac{\partial\epsilon}{\partial\alpha}}{\left(1 - \frac{\partial\epsilon}{\partial\alpha}\right) + \mu^2 \frac{A_w + 2}{A_s + 2}} \frac{l_s}{\bar{c}_w} \tag{16}$$

$$\frac{x}{\bar{c}_w} = -C_{m_{C_L}} - \frac{\mu^2 \frac{A_w + 2}{A_s + 2}}{\left(1 - \frac{\partial\epsilon}{\partial\alpha}\right) + \mu^2 \frac{A_w + 2}{A_s + 2}} \frac{l_s}{\bar{c}_w} \tag{17}$$

Equations (14) and (15) are substituted into equation (11) to obtain the lift ratio for a conventional configuration, and equations (16) and (17) are substituted into equation (11) to obtain the lift ratio for a canard configuration. These lift ratios are used in equation (8) to calculate the drag coefficients of various configurations.

The downwash used in the determination of static margin was calculated according to the method presented in reference 7. This method includes the effects, at a distance behind the wing, of the bound vortex and the effects, at the wing-body center line an infinite distance behind the wing, of the rolled trailing vortices. The calculations have been modified to account for a spanwise variation of downwash from the trailing vortex system and for the effect of stabilizer or wing height.

## RESULTS AND DISCUSSION

### Scope of Calculations

Calculations of total-drag coefficient, induced-drag coefficient, profile-drag coefficient, and ratio of stabilizer lift to wing lift were made for both conventional and canard configurations over a range of pertinent parameters. The drag coefficients were generally normalized by $C_L^2/\pi A_w$. The parameters consisted of span ratio $b_s/b_w = \mu$, gap ratio $G/b_w$, static margin $C_{m_{C_L}}$, and zero-lift pitching-moment coefficient $C_{m,o}$. The following parameters were fixed for most calculations: wing and stabilizer aspect ratios, trim lift coefficient, profile-drag coefficient, and distance from wing to stabilizer. Some calculations for minimum induced drag were made according to classical theory, in which no constraint is placed on static margin.

Figure 2 is provided to aid in defining configuration geometry. The ratio of stabilizer span to wing span $b_s/b_w$, or $\mu$, was varied from 0.1 to 1.0, and gap to wing span ratios $G/b_w$ of 0, 0.2, and 0.4 were employed. Static margin $C_{m_{C_L}}$ was varied from -0.6 to 0.2 in various calculations. Zero-lift pitching-moment coefficients $C_{m,o}$ of 0 and 0.12 were used along with a wing profile-drag coefficient of 0.01. Except where otherwise indicated, wing and stabilizer aspect ratios were 6, the trim lift coefficient was 0.6, and the distance between wing and stabilizer was $3\bar{c}_w$.

### Comparison With Classical Minimum-Drag Theory

The first results of this investigation (see fig. 3) are presented to compare the drag coefficients of conventional and canard configurations at various span ratios and to relate these values of drag to an ideal minimum drag. The plots of induced drag show that the conventional configurations have nearly minimum induced drag and that static margin has very little effect. The canard configurations have greater induced drag, and hence lower flight efficiencies, than the conventional configurations at the same span ratio and show an increase in induced-drag coefficient with an increase in static margin. The induced-drag coefficients for both conventional and canard configurations decrease as gap and span ratios increase, with the tandem configurations having the lowest induced drag. This decrease in induced drag for both configurations as span ratio is increased is caused by the transfer of some of the wing loading to the canard or tail. (See the lift ratios in fig. 3.) The induced drag for the tandem configuration decreases as gap ratio is increased because of a decrease in the interference factor. (See fig. 1.) The profile-drag coefficient shown in figure 3 is the same for each of the configurations and increases with increase in span ratio because of the corresponding increase in surface area.

The plots of total-drag coefficients show that the differences between conventional and canard configurations and the effects of static margin are similar to those for the induced-drag coefficient. However, as span ratio is increased, the total-drag coefficient increases because of the addition of profile drag. As a result, the tandem configuration has a higher total-drag coefficient than either a conventional or a canard configuration. One should note that the total-drag coefficient (see eq. (8)) is the sum of the profile-drag and induced-drag coefficients; hence, any variation with span ratio is dependent on the relative magnitudes of the profile-drag coefficient $C_{D,p}$ and the induced-drag parameter $C_L^2/\pi A_w$. Thus at a higher lift coefficient or a lower profile-drag coefficient, the variation of total drag with $\mu$ may show different trends from those of figure 3.

The ratios of stabilizer lift to wing lift for canard configurations are higher than those for the conventional configurations of a given span ratio. (See fig. 3.) The higher lift ratios of the canard configuration result from the static-margin constraint. This "loading up" of the canard results in a higher drag for the canard configuration than for the conventional configuration. At some points the lift ratio for the conventional configuration is lower than the lift ratio for the minimum-drag configuration. In these instances the induced drag is essentially the same. (See figs. 3(b) and 3(c).)

## Effects of Static Margin

The effects of variations in static margin on the induced-drag coefficients and lift ratios of conventional and canard configurations with zero gap ratio are shown in figure 4. For a static margin of about zero and a span ratio of 0.6, the induced drag is about 15 percent less for the conventional configuration than for the canard configuration. The canard configuration shows larger variations of induced drag with static margin than the conventional configuration except for span ratios near zero, which are not usually employed. The lift-ratio plots show that for large span ratios, the canard is loaded to a greater extent than is the tail on the conventional configuration.

In reference 5, Munk's theory is used to calculate the trim drag of a conventional and a canard configuration with respectively down and up stabilizer loads of 10 percent of the total lift for trim purposes. The calculations showed that the induced drag was the same for both configurations. These points are plotted in figure 4 so that the static margin can be seen. The static margin in these two instances is considerably different. The canard monoplane from reference 5 has a static margin of about 0.1, which is unstable; the conventional monoplane from reference 5 has a static margin of about -0.5, which is usually considered excessively stable.

## Effect of Zero-Lift Pitching-Moment Coefficient

The zero-lift pitching-moment coefficient $C_{m,o}$ can have a large effect on configuration drag by changing the magnitude of the trim loads. To illustrate the effects of $C_{m,o}$, a study was made of the lift ratios and drag coefficients for conventional and canard configurations having various static margins, two gap ratios, and two values of $C_{m,o}$. The configurations had a span ratio of 0.3 and $C_{m,o}$ values of 0 and 0.12. The results of this study are presented in figure 5 as a function of static margin.

The conventional configurations have lower drag values than the canard configurations at the larger static margins. The effect of adding a positive $C_{m,o}$ is to reduce the drag of the conventional configuration at the higher static margins and to reduce the drag of the canard configuration through nearly all of the static margin range. For $C_{m,o} = 0.12$, the canard configurations in the region of interest, near zero static margin, have lower drag values than conventional configurations.

The effect on the lift ratio of adding a positive $C_{m,o}$ is to reduce stabilizer trim loads for both the conventional and canard configurations. This effect can be seen in figure 5 as an upward shift of the lift ratios for the conventional configurations and the downward shift for the canard configurations.

## Comparison With Lifting-Surface Theory

The results presented so far have been based on the assumption of elliptically loaded surfaces. In practice, the interference effects between the wing and the stabilizer will result in distortion of the lift distribution on the aft surface. This effect is likely to be most severe for a canard configuration. A comparison of the results of the present method with those obtained by a more accurate analysis is therefore of interest. Some calculations of induced drag by a vortex-lattice method given in reference 6 are used for this purpose.

Induced-drag coefficients for the canard configuration of reference 6 are given as a function of moment trim point in figure 6 for five values of gap to wing-span ratio $G/b_w$. The configuration planform shown in figure 6 has a ratio of canard span to wing span $\mu$ of 0.67. The value of the total lift coefficient is 0.2. As indicated in reference 6, the spanwise lift distribution for each surface is almost elliptical. The different values of moment trim points (center-of-gravity locations) were obtained by varying the ratio of canard lift to wing lift. The induced-drag portion of equation (9) was used together with interference factors from figure 1 to calculate a minimum-induced-drag coefficient for each gap ratio of figure 6. These values are plotted at the proper value of $\frac{\Delta x}{b_w/2}$ in figure 6. The minimum induced drag obtained by this method gives good results. The difference between the induced-drag coefficients calculated by the two methods is less than 2 counts (0.0002). The close fore-and-aft positions of the canard and wing may contribute to the good agreement shown in figure 6. If the two surfaces were farther apart in the fore-and-aft direction, greater uncertainty would exist in the relative positions of the wing and the vortex systems.

## CONCLUDING REMARKS

Classical drag equations have been used to calculate total and induced drag and ratios of stabilizer lift to wing lift for a variety of conventional and canard configurations. The study was conducted to compare the flight efficiencies of such configurations that are trimmed in pitch and have various values of static margin. Another purpose was to make comparisons of the classical calculation methods with more modern lifting-surface theory. The following observations are made on an analysis of this work:

The conventional configurations generally had lower configuration drag coefficients, and hence higher flight efficiencies, than canard configurations with comparable values of gap, static margin, and ratio of stabilizer span to wing span.

In general the canard configurations showed larger variations of induced drag with static margin than the conventional configurations except for span ratios near zero, which are not usually employed.

For a zero-lift pitching-moment coefficient of 0.12 in the vicinity of zero to small-negative static margins (stable), the canard configurations have lower drag characteristics than conventional configurations with similar values of gap and ratio of stabilizer span to wing span.

The minimum induced-drag coefficient determined by the classical calculation method was generally in agreement with that determined by the lifting-surface theory for the canard configuration studied. This gives confidence in the accuracy of the classical calculation method.

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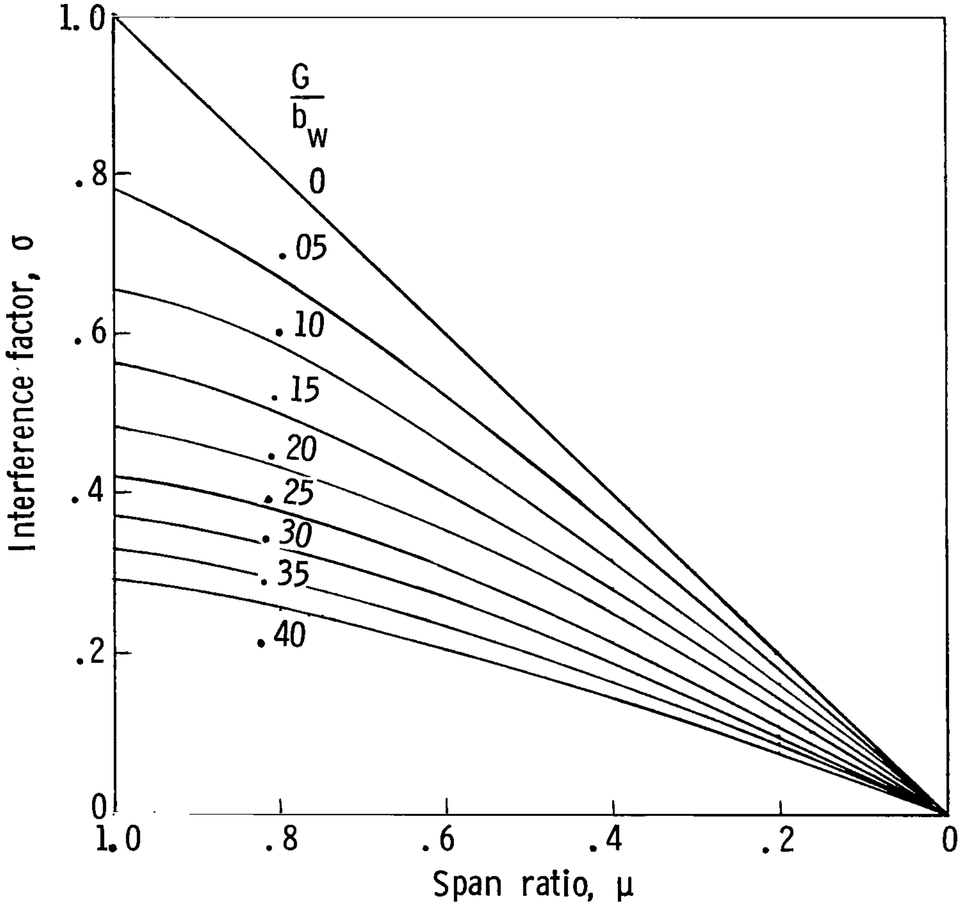



Figure 1.- Prandtl's drag interference factor for multiplane configurations with elliptical span loadings.

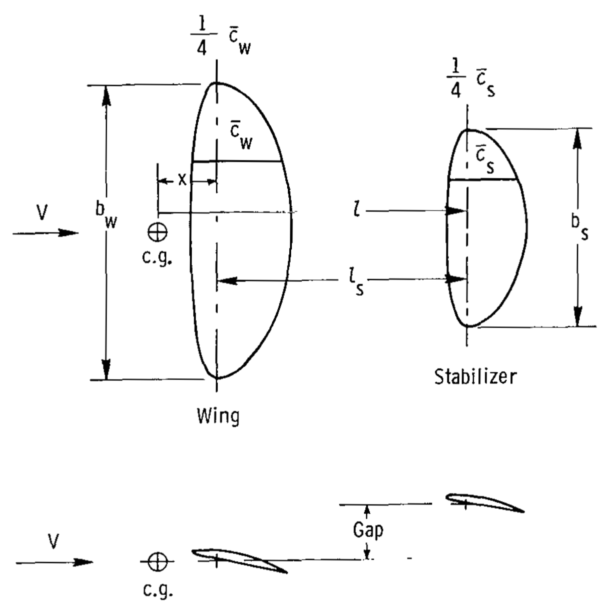
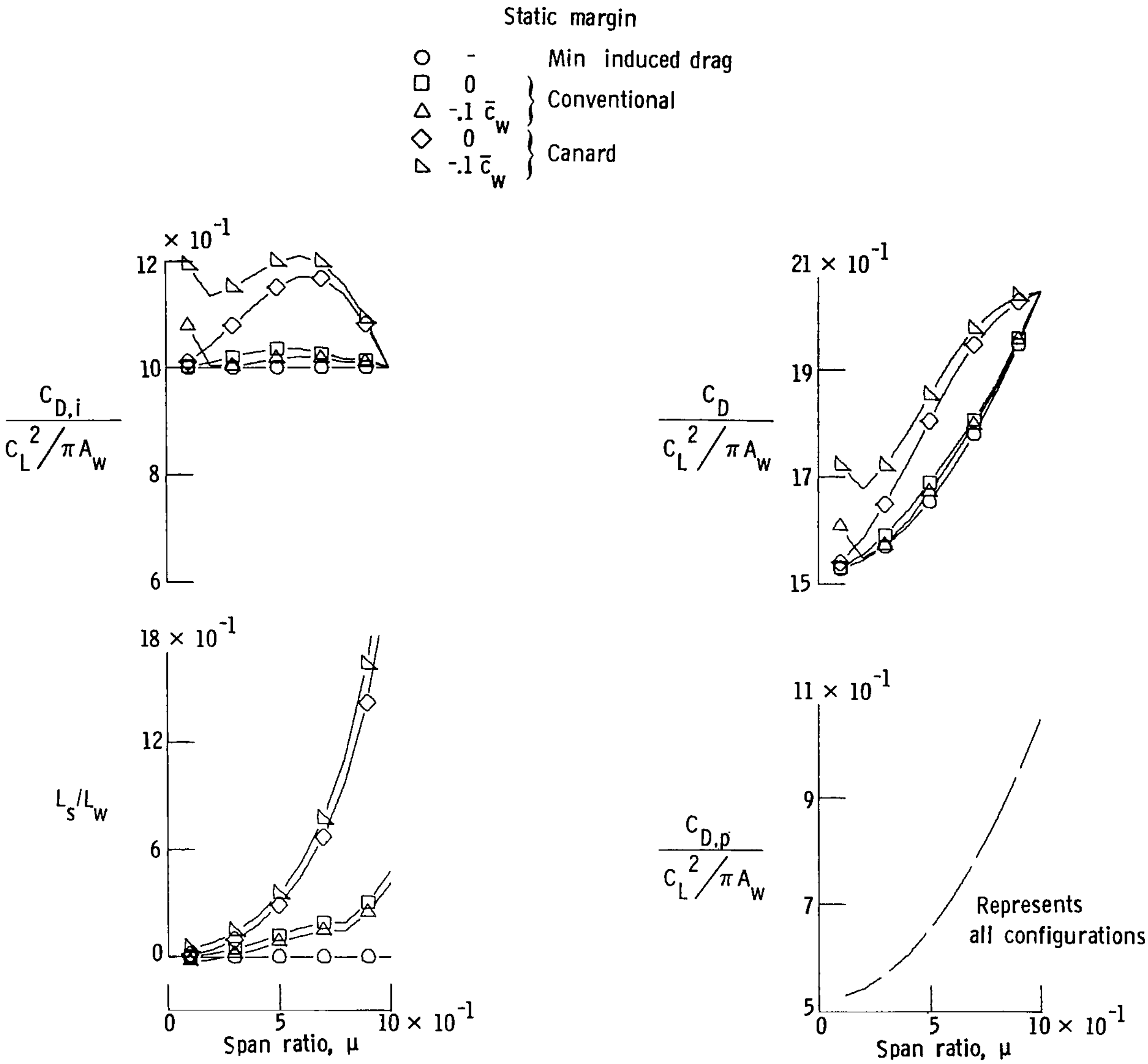
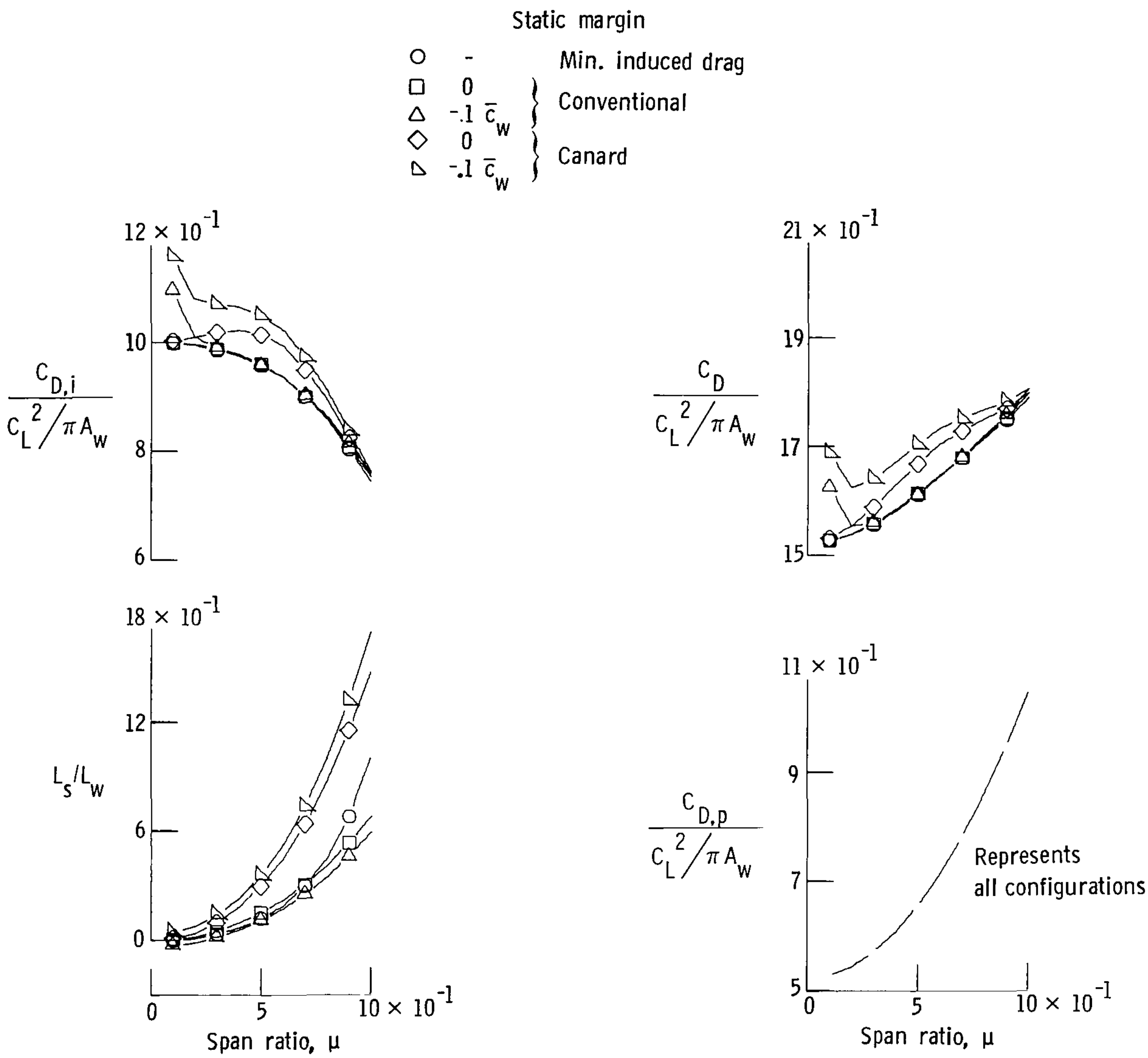



Figure 2.- General configuration geometry.



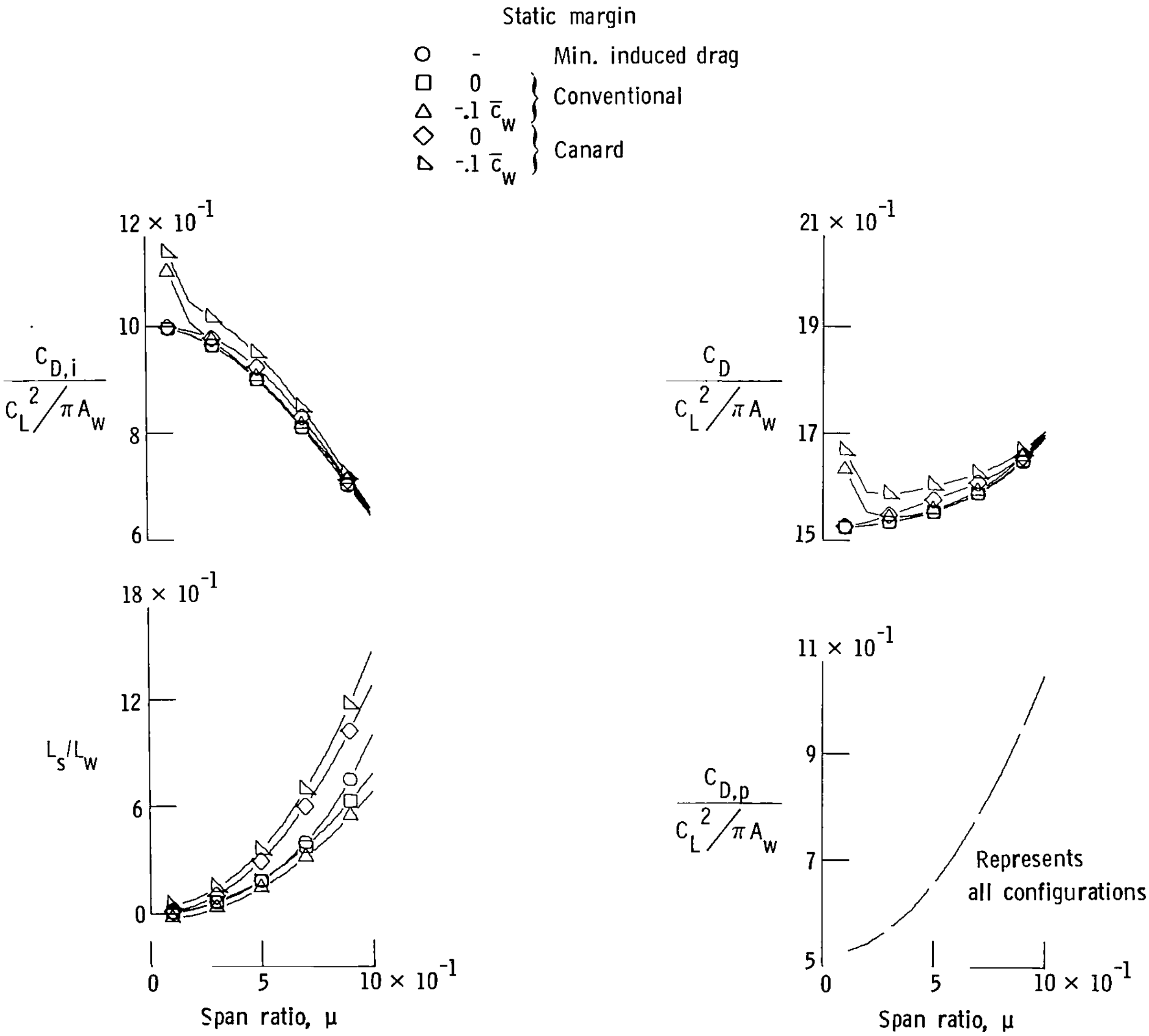

(a) $G/b_w = 0$.

Figure 3.- Drag coefficients and lift ratios for two conventional, two canard, and one minimum-induced-drag configuration as a function of span ratio. $A_w = 6$; $A_s = 6$; $l_s/\bar{c}_w = 3$; $C_{m,o} = 0$; $(C_{D,p})_w = 0.01$; and $C_L = 0.6$.



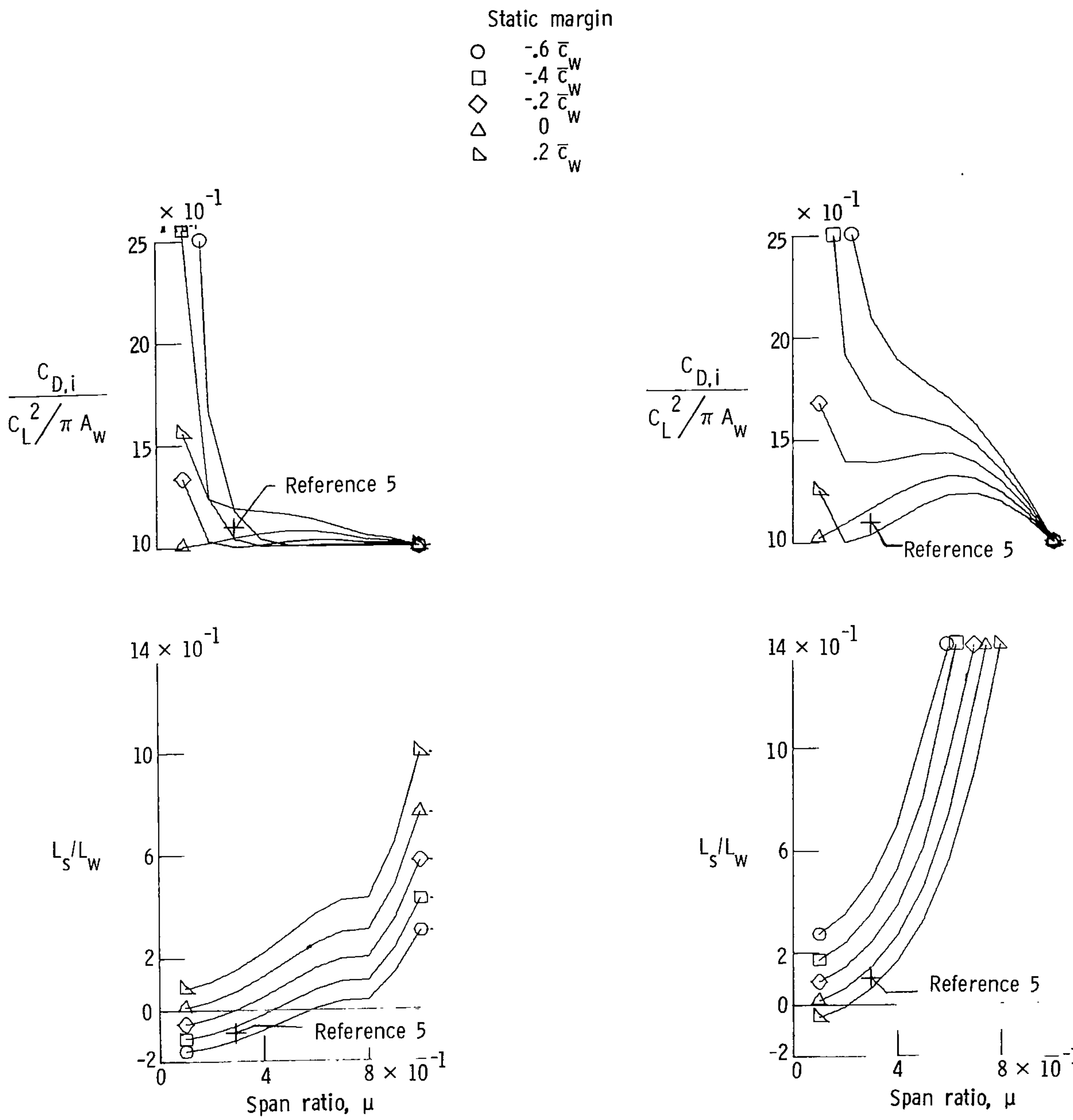

(b) $G/b_w = 0.2$.

Figure 3.- Continued.




(c) $G/b_w = 0.4$.

Figure 3.- Concluded.




(a) Conventional configuration. (b) Canard configuration.

Figure 4.- Induced-drag coefficients and lift ratios for conventional and canard configurations as a function of span ratio for various static margins. $A_w = 6$; $A_s = 3$; $l_s = 3\bar{c}_w$; $C_{m,o} = 0$.

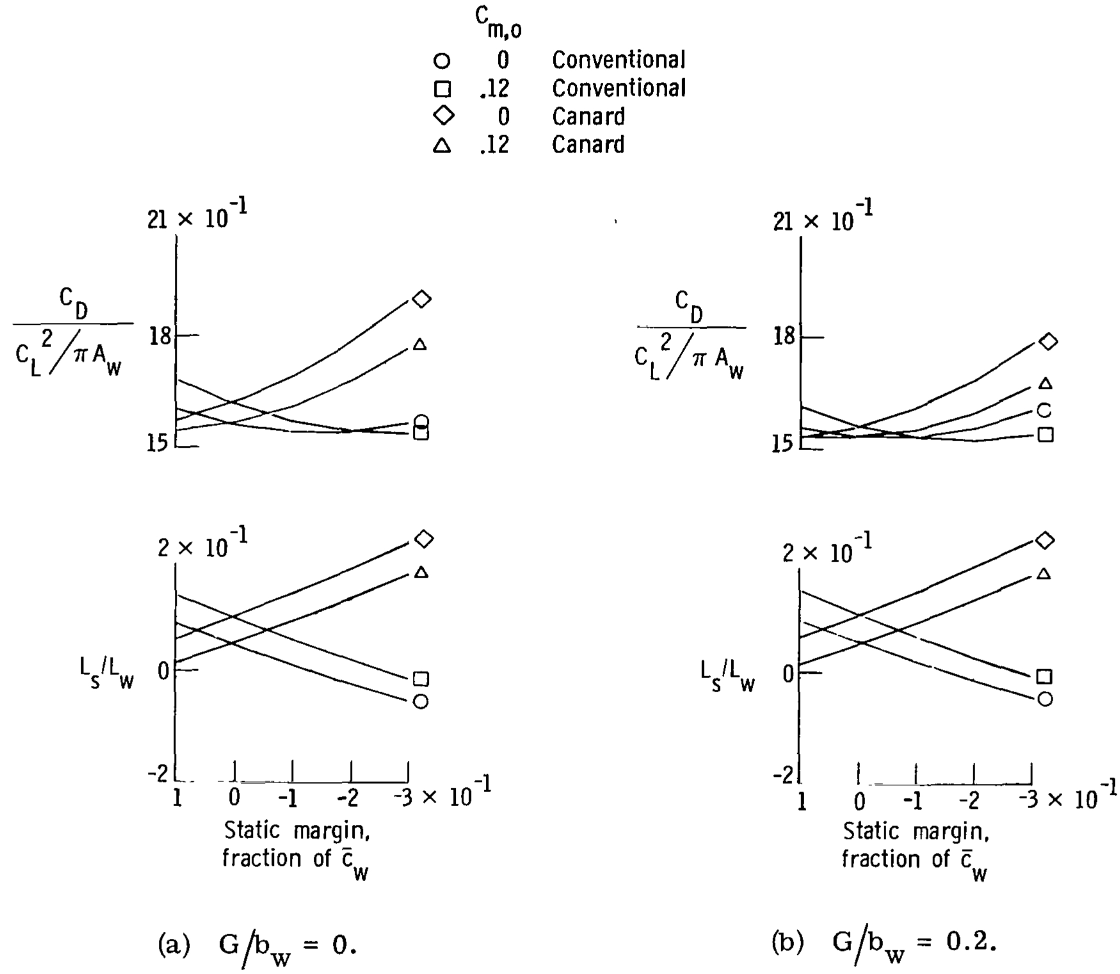



Figure 5.- Drag coefficients and lift ratios for conventional and canard configurations as a function of static margin. $A_w = 6$; $A_s = 6$; $\mu = 0.3$; $C_{D,p} = 0.01$; $l_s = 3\bar{c}_w$; $C_L = 0.6$.

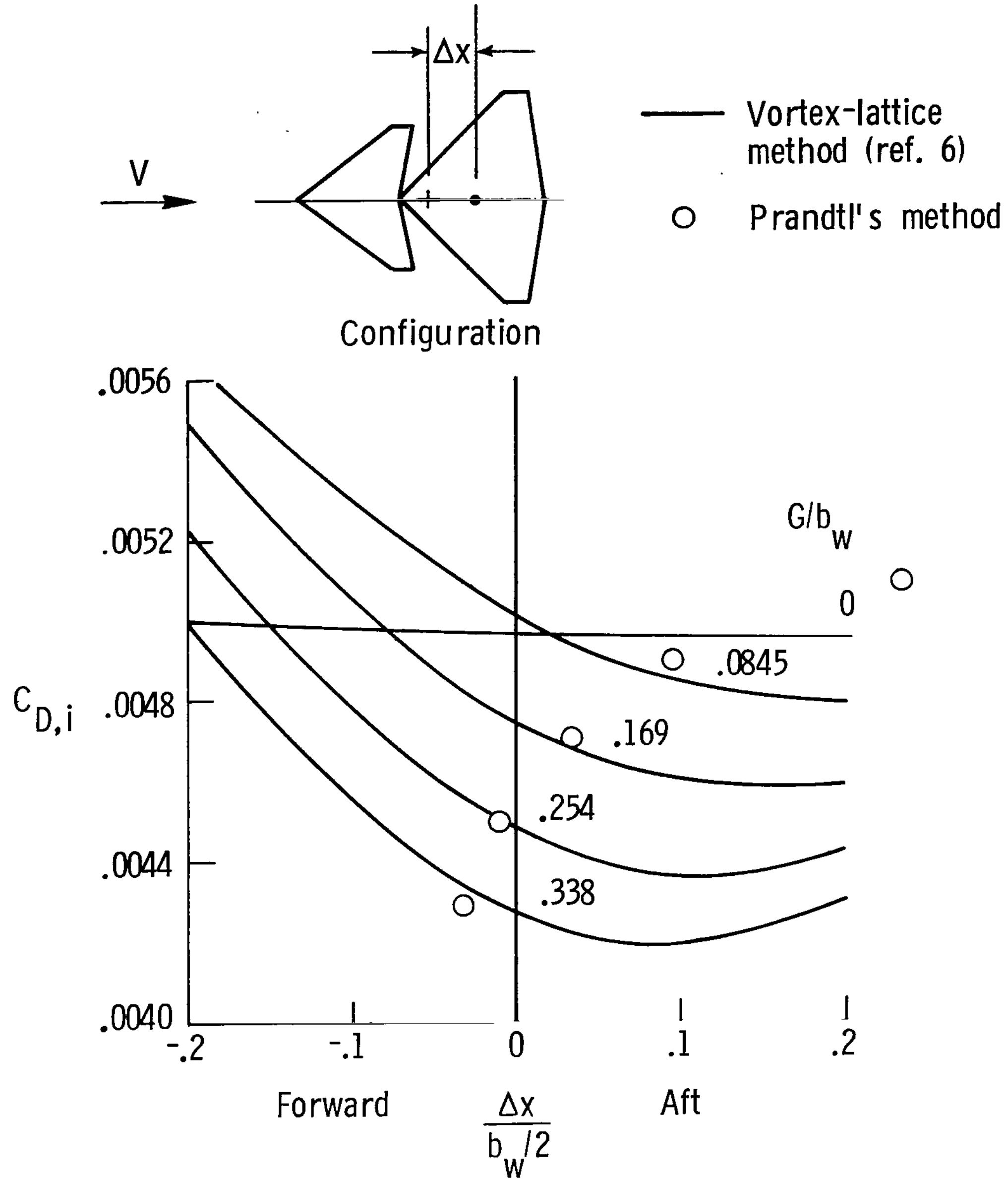



Figure 6.- Induced-drag coefficients calculated by the vortex-lattice method and minimum-induced-drag coefficients calculated by Prandtl's method, both as a function of moment trim point for a canard configuration at five values of gap ratio. $\mu = 0.67$; $A_w = 2.5$; $A_s = 1.03$; $l_s/\bar{c}_w = 1.13$; $C_L = 0.2$; $C_{m,o} = 0$; $C_{D,p} = 0$.



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