Some Effects of Interference Flowfields on Supersonic Configurations

M. Leroy Spearman*
NASA Langley Research Center, Hampton, Virginia

A summary of selected results for various basic research models is presented in order to illustrate some effects of interference flowfields at supersonic speeds. Some general effects of wings and tails on typical cruciform missile configurations are shown. Several arrangements of cruise-type missile concepts are presented to show the effects of added body volume on the lift-drag ratio. In addition, the effects of several tail arrangements and some effects of body cross section on the directional stability characteristics are included.

Nomenclature

a_n = instantaneous normal acceleration
C_D = drag coefficient
C_L = lift coefficient
$\Delta C_L(T)$ = lift increment due to tail
C_m = pitching moment coefficient
C_{m_δ} = tail pitching moment effectiveness
C_{n_β} = directional stability parameter
C_{Y_β} = side force parameter
h = body height
L/D = lift-drag ratio
$(L/D)_{max}$ = maximum lift-drag ratio
M = Mach number
W/A = weight loading based on body cross-sectional area
α = angle of attack, deg
δ = body wedge angle, deg

Model Components

B = body
W = wing
T = tail assembly
V = vertical tail

Coefficients for the configurations presented herein are nondimensional in various ways. Detailed information for the basic data may be found in the referenced papers. The numerical value of the coefficients, however, does not affect the interpretation of the results.

Introduction

WING/BODY/TAIL configurations, when moving through air, induce flowfield changes that can have a significant effect on the aerodynamic characteristics at supersonic speeds. These flowfield changes may be manifested as variations in the local dynamic pressure and airflow direction. The interaction of induced flowfields with the components of a configuration can produce aerodynamic effects that may be either detrimental or beneficial. This paper will draw from a large data bank of some generic wind tunnel studies of various configurations. Among the geometric variables that have been studied are wing and tail location, wing and tail planform, body shape and size, and so on. The studies indicate some synergistic effects wherein the generation of an induced flowfield results in improved aerodynamics. Likewise, some antienergetic effects may occur that result in adverse aerodynamics.

The purpose of the paper is to lead to an awareness of some of the many factors, as well as the interaction of such factors, that must be considered when combining wing/body/tail configurations. Such awareness provides useful insight into the geometric trades that should be considered in determining a suitable concept consistent with desired requirements.

Maneuverable Cruciform Missiles

The effects of wings and tails on typical aft-tail controlled maneuverable cruciform missiles are illustrated in Figs. 1 and 2. The trapezoidal planform configuration of Fig. 1 shows the effects of the wing and tail components on the variation of lift with angle of attack (unpublished results). The addition of either the tail or the wing results in an increase in lift with increasing angle of attack. The increment in lift due to the tail is shown on the right, both with and without the wing. It will be noticed that the tail-lift increment is reduced by the addition of the wing. At low angles of attack, where the tail is directly in the wake of the wing, this reduction in tail-lift increment is as much as 50%. At higher angles of attack, where the tail is primarily affected by the downwash from the wing, the tail contribution is reduced by about 25%.

In Fig 2, it can be seen that the increment in pitching moment due to the tail deflection at zero angle of attack is reduced across the Mach number range by the presence of a wing. However, the normal acceleration available, for the example shown, is still considerably better for the wing-on case. This simply illustrates that, even though the tail effectiveness is reduced by the wing flowfield, the tail control is still sufficient to rotate the configuration so that wing lift is generated to provide high maneuvering capability.[1-3]

Cruise Missile Efficiency

Of interest to cruise-type missiles is the trade between volumetric efficiency and aerodynamic efficiency. The results for such a trade study are reported[4] for a delta wing model with various body arrangements at a Mach number of 2. The basic model (Fig. 3) consisted of a 54.5 deg delta wing to which various bodies could be added for the purpose of increasing the volume. Body A was used on all models to house the force balance and alternate bodies were attached to the wing on the side opposite body A. The alternate bodies had variations in wedge angle, height, length, and longitudinal

Presented as Paper 86-2078 at the AIAA/AAS Aerodynamics Astrodynamics Conference, Williamsburg, VA, Aug. 18-20,1986, received Jan. 11, 1987, revision received Feb. 6, 1987.

*Senior Technical Specialist, Systems Analysis Branch, Advanced Vehicles Division.

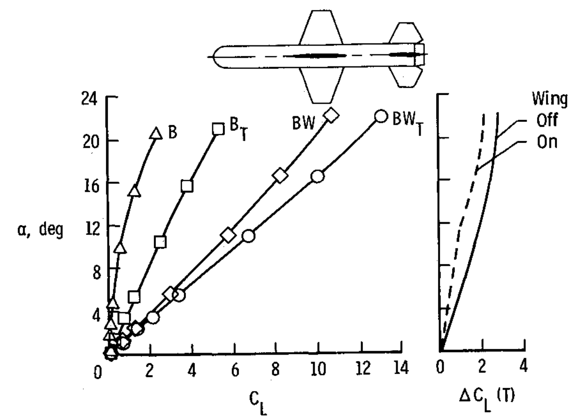

Fig. 1 Effects of wing and tail on lift, $M=19$.

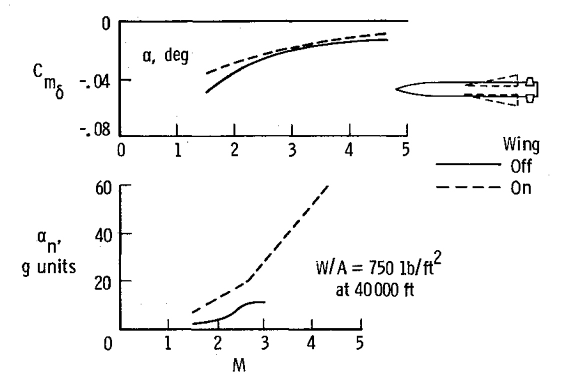

Fig. 2 Effect of wing on longitudinal maneuvering characteristics.

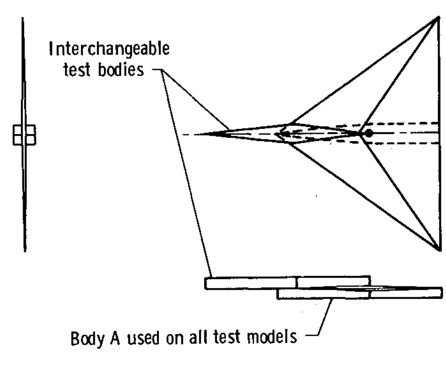

Fig. 3 Wing-body interference study model, 54.5 deg delta wing.

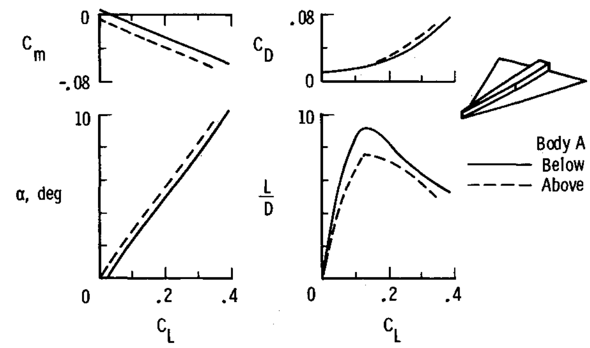

Fig. 4 Longitudinal characteristics for basic 54.5 deg delta wing/body, $M=2$.

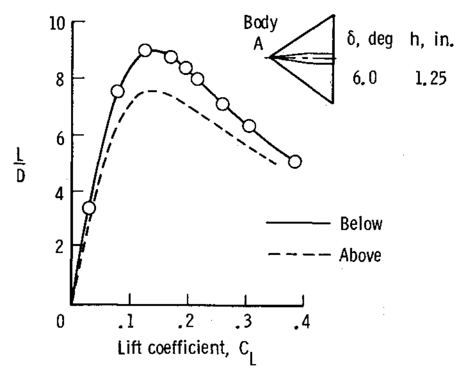

Fig. 5 Lift-drag characteristics for basic wing/body, $M=2$.

Table 1 Body geometry

Body	δ, deg	h, in.	Body volume, in.^{3}	Total volume (including body A), in.^{3}
A	6	1.25	35.52	35.52
1	3.5	1.25	25.65	61.17
2	3.5	2.15	44.11	79.63
3	6	.88	31.03	66.55
4	6	1.25	44.08	79.6
5	6	1.65	58.19	93.97
6	8.5	.88	44.17	79.69
7	8.5	1.25	62.75	98.27
8	6	1.25	24.61	60.13
9	6	1.25	35.49	71.01
10	6	1.25	46.41	81.93

Note: Bodies 8, 9, and 10 project 8.11 in. ahead of the wing apex and have overall lengths of 18.32 and 26.43 in., respectively.

location. Bodies were added to either the top or the bottom of the basic model in order to determine the difference in interference flowfield effects. Details of geometry for the bodies are presented in Table 1.

Longitudinal characteristics for the basic model (wing with body A) are shown in Fig. 4. The forebody wedge of body A creates a compression field with a positive pressure increase over the forward portion of the wing. Thus, when the body is mounted below the wing, the induced flowfield causes a positive increment in lift and pitching moment. Conversely, when the body is mounted above the wing, the induced flowfield results in a negative increment in lift and pitching moment. In addition, the flowfield induced by the body wedge on the bottom side of the wing results in a lower drag due to lift and a substantially higher maximum lift-to-drag ratio.

Basic Wing/Body Configuration

The effects of body A on the lift-drag ratio are shown in Fig. 5. Primarily because of the induced lift, the body mounted below the wing results in a maximum lift-drag ratio of about 9 and of about 7.6 when mounted above the wing.

Effect of Wedge Angle

In Fig. 6, the lift-drag ratios are shown for bodies with varying wedge angle and a constant height added either above or below the basic wing/body configuration. Increasing the volume by increasing the wedge angle results in a progressive

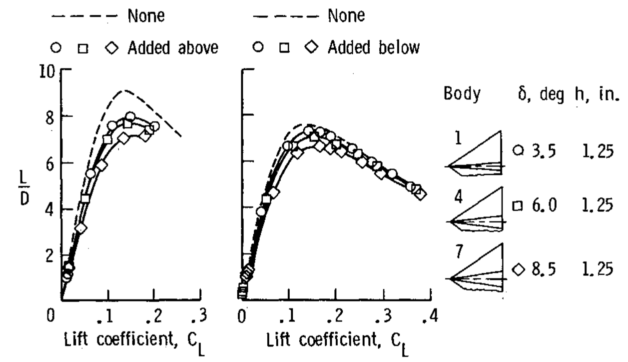

Fig. 6 Lift-drag characteristics for basic wing/body, with added bodies having varying wedge angles with constant height, $M=2$.

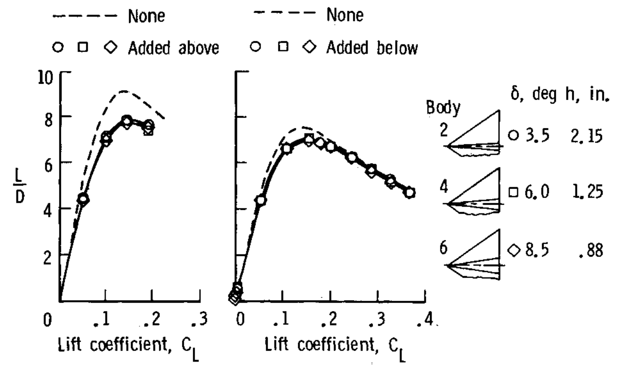

Fig. 8 Lift-drag characteristics for basic wing/body with added bodies having constant volumes, $M=2$.

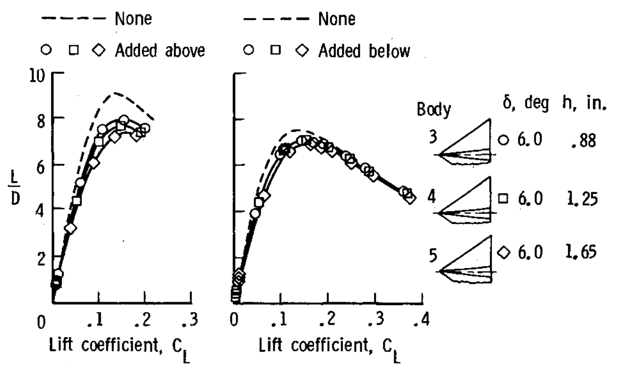

Fig. 7 Lift-drag characteristics for basic wing/body with added bodies having varying heights with constant wedge angle, $M=2$.

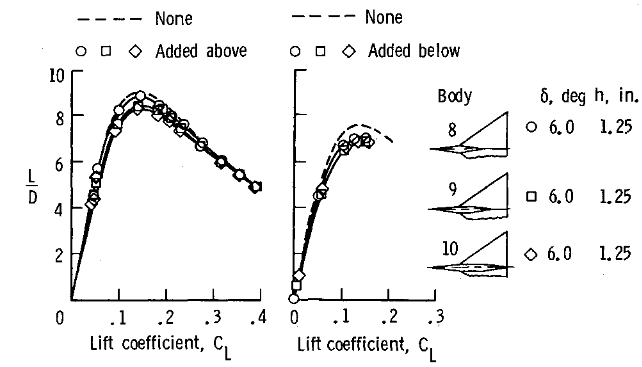

Fig. 9 Lift-drag characteristics for basic wing/body with added bodies having varying lengths with constant wedge angle and height, $M=2$.

decrease in maximum lift-drag ratio. The effect on the maximum lift-drag ratio is more noticeable when the bodies are added above the wing than when added below, but lift-drag ratios are consistently higher for the top additions.

Effect of Wedge Height

The effect of increasing the wedge height for a constant wedge angle (Fig. 7) is to substantially reduce the maximum lift-drag ratio when added above the wing, but to cause only minor reductions when added below the wing. Again the lift-drag ratios are consistently higher with the top additions.

Effect for Constant Volume Body

When both the wedge angle and height are varied in such a manner as to maintain a constant body volume, the effect of the added bodies is essentially constant (Fig. 8). Again, the effect is more noticeable and the values of maximum lift-drag ratios are higher for the bodies added above the wing.

Effect of Body Length

Some tests were made using bodies of varying length, but having a constant wedge angle and body height (Fig. 9). These bodies differed from the ones previously discussed in that the apex of the bodies was located forward of the apex of the wing. The effects of the addition of these bodies was, in general, somewhat less than those bodies previously discussed, all of which had the body apex coincident with the wing apex. The maximum values of lift-drag ratio are again consistently higher with the top-side additions. The addition of body 8 above the wing, for example, reduced the maximum lift-drag ratio from about 9 to only about 8.8 even though the body volume was about doubled.

Summary of Added Body Effects

A summary of the effects of added bodies to cruise missile efficiency is shown in Fig. 10 in the form of maximum lift-drag ratio as a function of total body volume (added bodies plus basic body A). This figure clearly illustrates that some discretion in the body/wing geometric arrangement can result in maximizing the efficiency. It is obvious that a range of maximum lift-drag ratios can be obtained at a constant body volume and that a range of body volumes can produce a constant maximum lift-drag ratio. In the extreme, it can be seen where a body volume increase of about 150% can be made while increasing the maximum lift-drag ratio.

Plainly, the shape, size, and location of bodies added to a wing can result in significant differences in the aerodynamics efficiency. Such body additions cause several effects to occur simultaneously, among which are changes in the induced flowfield strength, changes in the induced flowfield region, and changes in body drag.

Generally, the effects of added bodies above the wing cause greater reductions in the maximum lift-drag ratio, although the absolute values of lift-drag ratio are higher because of the higher value for the basic wing/body configuration.

Cruise Missile Directional Stability

A basic research cruise missile wing/body/tail model (Fig. 11) has been used to study the effects of various vertical tail arrangements. The model had a 68 deg delta wing and was tested with various vertical tail planforms and locations. Details of the study will be found in Ref. 5. Characteristics of the vertical tails are presented in Table 2.

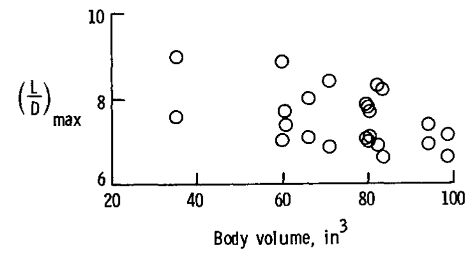

Fig. 10 Maximum values of lift-drag ratio as a function of total body volume, $M = 2$.

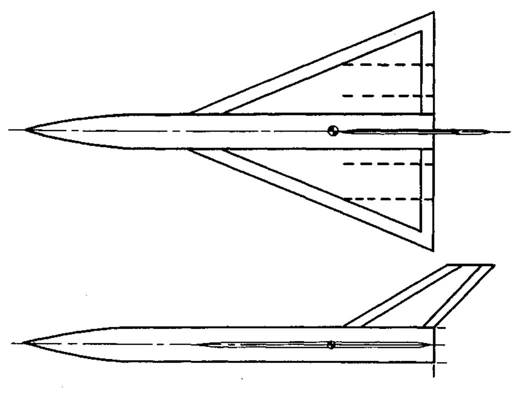

Fig. 11 Cruise missile tail study model.

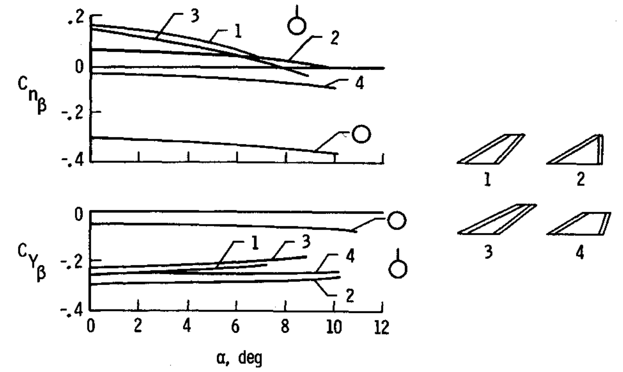

Fig. 12 Directional stability characteristics for body/tail with various tail planforms of constant area, $M = 1.6$.

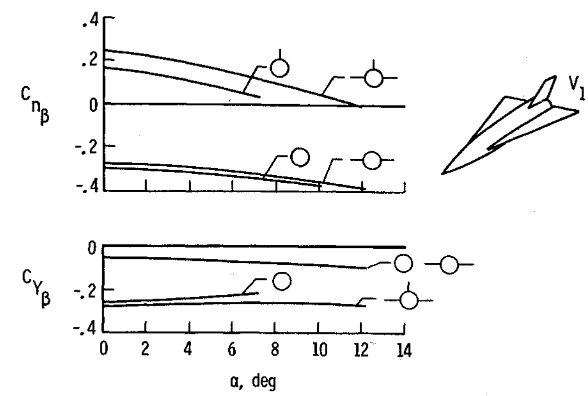

Fig. 13 Directional stability characteristics for 68 deg delta wing/body/tail, $M = 1.6$.

Table 2 Vertical tail geometry

V	Λ, deg	Area, in.^{2}	Taper	Aspect ratio	Height, in.
1	60	31.5	0.5	0.88	5.25
2	60	31.5	0.5	0.88	5.25
3	65	31.5	0.5	0.88	5.25
4	60	31.5	0.5	0.49	3.94
5	60	15.75	0.5	0.88	3.71
6	60	31.5	0.5	0.88	5.25
Twin tail location % semispan					
Inboard		30			
Outboard		60			

Effects of Tail Planform

The directional stability characteristics for several planforms on a body are shown in Fig. 12 for $M = 1.6$. The planforms have equal areas, but differ in leading-edge sweep angle, taper ratio, and aspect ratio. Generally speaking, the conventionally swept planforms 1 and 3 provide the highest directional stability for the lowest values of sideforce. However, the directional stability contribution for these two tails decreases fairly rapidly with increasing angle of attack, probably due to a loss in effectiveness near the tip caused by an interference flow from the forebody. Tail 2, while effective in producing side force, results at a lower level in directional stability since the center of pressure in the tail is probably further forward. The decrease in directional stability with increasing angle of attack is less since there is less tail area outboard to be affected for the forebody flow. Tail 4 also produces a fairly high side force; however, since the tail center of pressure moves even further forward, there is a further decrease in directional stability and, in fact, direction instability occurs across the angle-of-attack range. The effectiveness of tail 4 is essentially invariable with the angle of attack, however, because of the reduced height, apparently none of the tail surface area is affected by the forebody flow.

Among the interrelated effects illustrated with these data are: carry-over effects from the tail to the body, cross-flow effects on the tail, body boundary-layer effects on tail, forebody flowfield effects, and spanwise and chordwise loading on the tail.

Effects of Wing

The effects of adding a 68 deg delta wing to the body and body/tail (V_1) are shown in Fig. 13 for $M = 1.6$. The addition of the wing to the body had no measureable effect on the side force, although a small stabilizing increment in directional stability did occur, apparently due to a rearward shift in the center of pressure of the body. Adding the wing to the bodytail results in an increase in side force as well as a subtantial increase in directional stability. The indication of an increase in tail effectiveness probably results from a shielding of the tail from some of the adverse cross-flow effects from the body as well as from some of the forebody flow effects.

Effects of Twin Tails

A study of some twin-tail arrangements was made for the 68 deg delta wing/body/tail cruise missile model. Twin tails were located at either 30 or 60% of the wing semispan and had panel areas either equal to V_1 or one-half V_1. Some directional stability characteristics for these twin-tail arrangements are presented in Fig. 14 for $M = 1.6$. The results for V_5, with a total area (both tails) equal to that for V_1, indicates a

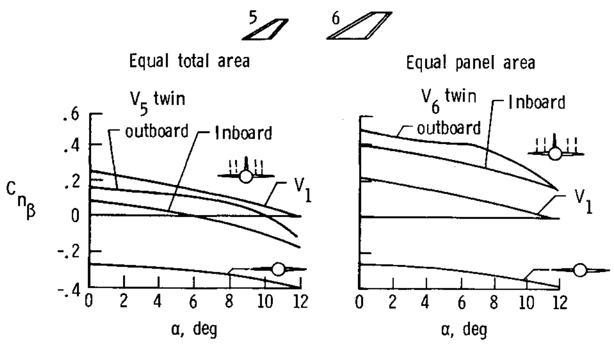

Fig. 14 Directional stability characteristics for 68 deg delta wing/body/tail with various tail sizes and locations, $M=1.6$.

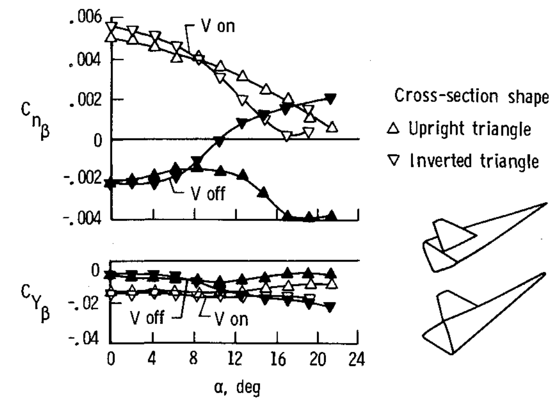

Fig. 15 Directional stability characteristics for body/tail with triangular body cross sections, $M=2.2$.

somewhat lower level of directional stability than that for the single centerline tail V_1. This is not surprising, since losses in tail lift due to such things as tip effects and boundary layer are not reduced by one-half when the tail panel size is reduced by one-half. There is a significant effect of tail spanwise location, however. The inboard location shows the lowest level of directional stability, probably as a result of an adverse sidewash induced by the forebody vortex flowfield. The directional stability for the outboard location is substantially better, indicating that the tails are probably located outboard of the forebody vortex flow and may be in a favorable sidewash field. Similar results are shown for tail V_6, which has a panel area twice that for V_1. In this case, the directional stability is considerably higher for the twin tails (either inboard or outboard) than that for the single tail, althought not by a factor of 2.

Body Cross-Sectional Effects

Inasmuch as the body cross flow is an important factor in the tail contribution to directional stability, some results taken from Ref. 6 are presented to illustrate this effect. The illustration, shown in Fig. 15, is for a triangular body, upright and inverted, with a single centerline vertical tail at $M=2.2$. At low angles of attack (up to about 8 deg), the directional stability and the tail contribution to the directional stability are greater for the flat-top inverted triangle than for the flat-bottom upright triangle. In this region, the flat-top body apparently acts as an end plate for the vertical tail, thereby increasing its effectiveness. Above 8 deg angle of attack, however, the characteristics for the triangular cross-section concepts are considerably altered. The inverted triangular body shows a large increase in side force with increasing angle of attack that is translated into a stabilizing trend in directional stability and, in fact, the body alone becomes directionally stable above about 11 deg. At the same time, the tail contribution decreases rapidly until, at angles of attack above 14 deg, the addition of the tail results in a decrease in side force and directional stability. The increase in side force and stability for the body with increasing angle of attack is probably a result of an increase in the lifting effectiveness of the v-shaped underside of the body. This body lift apparently produces a vortex flow around the upper surface of the body and creates a sidewash angle that reduces and eventually reverses the tail contribution.

A different phenomena occurs for the upright triangular body where, at low angles of attack, the tail contribution is slightly less than for the inverted triangle, probably because the tail is subjected to some adverse flowfield effects from the sloping body sides. Above about 8 deg angle of attack, the side force of the body alone tends to decrease and the body becomes increasingly unstable directionally. These changes probably occur as a result of an adverse sidewash over the afterbody from a vortex flow induced by the lifting flat bottom of the body. The tail contribution for the upright triangle remains relatively high since, for one thing, the tail is able to transmit some carry-over forces to the side of the body—an effect that is not possible with the inverted triangle.

This illustration serves to point out several factors relative to body cross-sectional effects on directional stability. Among these effects are: direct forces and moments of the body, cross-flow effects around body, induced effects of the tail on the body, and effects of forebody vortex flow.

The interaction of these effects is well demonstrated by the inverted triangle concept wherein the body alone becomes inherently stable at high angles of attack as a result of direct force changes that, at the same time, produce a sidewash angle that nullified and reversed the tail contribution.

Conclusions

It has been the purpose of this paper to outline some interference flowfields on the aerodynamic characteristics of wing/body/tail combinations at supersonic speeds. Recognition of some of the factors involved in induced flowfields can lead to configuration arrangements that utilize beneficial interference effects rather than detrimental effects. Some of the effects illustrated are:

1) Aft-tail control effectiveness may be adversely affected by the presence of a wing, but the overall maneuvering capability may still be better when utilizing wing lift.

2) The addition of bodies to increase the volume of a wing/body combination can result in significant differences in aerodynamic efficiency that are highly dependent on the shape, size, and location of the additions.

3) Directional stability for configurations with equal area vertical tails is highly dependent on the tail planform and location.

4) Directional stability characteristics for wing/body/tail configurations reflect the interrelated effects of body cross flow, carry-over lift, forebody vortex flow, boundary-layer effects, etc.

5) Directional stability characteristics for a body/tail configuration was highly dependent on body cross section and indicated that favorable effects on one component may be accompanied by adverse effects on another.

It is clear that the aerodynamic behavior of bodies, wings, and tails at supersonic speeds can be drastically altered by interference flowfields. Hence, it is important that particular attention be given to interference effects when combining wing/body/tail configurations rather than considering only the characteristics of the isolated components.

References

[1]Spearman, M. L. and Fournier, R. H., "Aerodynamic Characteristics of a Maneuverable Missile with Cruciform Delta Wings and Aft Tail Controls at Mach Numbers From 1.50 to 4.63," NASA TM X-1863, 1969.

[2]Spearman, M. L. and Fournier, R. H., "Aerodynamic Characteristics of a Wingless Maneuverable Missile with Cruciform Aft Tail Controls at Mach Numbers from 1.50 to 4.663," NASA TM X-2365, 1971.

[3]Spearman, M. L., "Supersonic Aerodynamic Characteristics of a Tail-Control Cruciform Maneuverable Missile with and without Wings," NASA TM 84600, 1983.

[4]Morris, O. A., "Aerodynamic Characteristics in Pitch at a Mach Number of 2.01 of Several Wing-Body Combinations with Wedge-Shaped Bodies Located Above and Below a 54.5° Swept Delta Wing," NASA TN D-1823, 1963.

[5]Lamb, M., Sawyer, W. C., and Thomas, J. L., "Experimental and Theoretical Supersonic Lateral-Directional Stability Characteristics of a Simplified Wing-Body Configuration with a Series of Vertical-Tail Arrangements," NASA TP 1878, 1981.

[6]Fuller, D. E. and Campbell, J. F., "Supersonic Lateral-Directional Stability Characteristics of a 45° Swept Wing-Body–Tail Model with Various Body Cross-Sectional Shapes," NASA TN D-2376, 1964.

U.S. Postal Service

STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION

Required by 39 U.S.C. 3685)

1A. TITLE OF PUBLICATION	1B. PUBLICATION NO.	2. DATE OF FILING
Journal of Aircraft	2 7 8 0 8 0	9-28-87

3. FREQUENCY OF ISSUE	3A. NO. OF ISSUES PUBLISHED ANNUALLY	3B. ANNUAL SUBSCRIPTION PRICE
Monthly	12	$23.00

4. COMPLETE MAILING ADDRESS OF KNOWN OFFICE OF PUBLICATION *(Street, City, County, State and ZIP+4 Code) (Not printers)*

370 L'Enfant Promenade S.W., Washington, D.C. 20024

5. COMPLETE MAILING ADDRESS OF THE HEADQUARTERS OF GENERAL BUSINESS OFFICES OF THE PUBLISHER *(Not printer)*

Same as above.

6. FULL NAMES AND COMPLETE MAILING ADDRESS OF PUBLISHER, EDITOR, AND MANAGING EDITOR *(This item MUST NOT be blank)*

PUBLISHER *(Name and Complete Mailing Address)*

American Institute of Aeronautics and Astronautics, Inc. (Same as above.)

EDITOR *(Name and Complete Mailing Address)*

Thomas M. Weeks -- Same as above.

MANAGING EDITOR *(Name and Complete Mailing Address)*

William O'Conner -- Same as above.

7. OWNER *(If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding 1 percent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a partnership or other unincorporated firm, its name and address, as well as that of each individual must be given. If the publication is published by a nonprofit organization, its name and address must be stated.) (Item must be completed.)*

FULL NAME	COMPLETE MAILING ADDRESS
American Institute of Aeronautics and Astronautics, Inc.	Same as above.

8. KNOWN BONDHOLDERS, MORTGAGEES, AND OTHER SECURITY HOLDERS OWNING OR HOLDING 1 PERCENT OR MORE OF TOTAL AMOUNT OF BONDS, MORTGAGES OR OTHER SECURITIES *(If there are none, so state)*

FULL NAME	COMPLETE MAILING ADDRESS
None	

9. FOR COMPLETION BY NONPROFIT ORGANIZATIONS AUTHORIZED TO MAIL AT SPECIAL RATES *(Section 423.12 DMM only)*
The purpose, function, and nonprofit status of this organization and the exempt status for Federal income tax purposes *(Check one)*

(1) [X] HAS NOT CHANGED DURING PRECEDING 12 MONTHS
(2) [ ] HAS CHANGED DURING PRECEDING 12 MONTHS
(If changed, publisher must submit explanation of change with this statement.)

10. EXTENT AND NATURE OF CIRCULATION *(See instructions on reverse side)*	AVERAGE NO. COPIES EACH ISSUE DURING PRECEDING 12 MONTHS	ACTUAL NO. COPIES OF SINGLE ISSUE PUBLISHED NEAREST TO FILING DATE
A. TOTAL NO. COPIES *(Net Press Run)*	4,017	3,300
B. PAID AND/OR REQUESTED CIRCULATION 1. Sales through dealers and carriers, street vendors and counter sales	-----	------
2. Mail Subscription *(Paid and/or requested)*	3,568	2,876
C. TOTAL PAID AND/OR REQUESTED CIRCULATION *(Sum of 10B1 and 10B2)*	3,568	2,876
D. FREE DISTRIBUTION BY MAIL, CARRIER OR OTHER MEANS SAMPLES, COMPLIMENTARY, AND OTHER FREE COPIES	73	73
E. TOTAL DISTRIBUTION *(Sum of C and D)*	3,641	2,949
F. COPIES NOT DISTRIBUTED 1. Office use, left over, unaccounted, spoiled after printing	376	351
2. Return from News Agents	----	-----
G. TOTAL *(Sum of E, F1 and 2—should equal net press run shown in A)*	4,017	3,300

11. I certify that the statements made by me above are correct and complete

SIGNATURE AND TITLE OF EDITOR, PUBLISHER, BUSINESS MANAGER, OR OWNER
Chris Troll, Controller

PS Form 3526 ... 1984 *(See instruction on reverse)*

Notice to Subscribers

We apologize that this issue was mailed to you late. As you may know, AIAA recently relocated its headquarters staff from New York, N.Y. to Washington, D.C., and this has caused some unavoidable disruption of staff operations. We will be able to make up some of the lost time each month and should be back to our normal schedule, with larger issues, in just a few months. In the meanwhile, we appreciate your patience.