NASA Technical Memorandum 84309

The Effect of Asymmetric Ablation on Trim Angle of Attack

Robert L. Kruse

MAY 1983

25th Anniversary
1958-1983

NASA

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The Effect of Asymmetric Ablation on Trim Angle of Attack

Robert L. Kruse
Ames Research Center
Moffett Field, California

NASA
National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

1983

NOMENCLATURE

A — reference area, maximum body cross-sectional area of modified configuration

C_D — drag coefficient

C_{L_α} — lift-curve slope

C_{m_α} — pitching-moment-curve slope

$C_{m_q} + C_{m_{\dot\alpha}}$ — damping-in-pitch derivative, $\dfrac{\partial C_m}{\partial(ql/v)} + \dfrac{\partial C_m}{\partial(\dot\alpha l/v)}$

d — diameter of maximum cross-sectional area of unmodified configuration

I_x — moment of inertia about roll axis

I_y — moment of inertia about transverse axis through center of gravity

l — reference length, minor axis of maximum cross-sectional area

M — Mach number

m — model mass

p — static pressure

q — free-stream dynamic pressure

Re_l — Reynolds number based on free-stream properties and model reference length, l

r_n — radius of spherical nose

r — radius of unmodified configuration

v — model velocity

x — distance along flightpath

X_{cg} — axial distance from model nose to center-of-gravity position

α — angle of attack, projected onto the vertical plane, between the model longitudinal axis and stream direction

α_r — resultant angle of attack, $\tan^{-1}\sqrt{\tan^2\alpha + \tan^2\beta}$

α_t — resultant trim angle of attack

α_{rms} — root mean square resultant angle of attack, $\left(\dfrac{\int_o^x \alpha_r^2\, dx}{x}\right)^{1/2}$

β — angle of sideslip, angle projected onto the horizontal plane between model longitudinal axis and stream direction

SUMMARY

Ballistic range tests were conducted to determine the effect of an asymmetrically ablated heat shield on the trim angle of attack of an entry vehicle. The tests, which were in support of Project Galileo, were conducted in atmospheric air at Mach numbers from 0.7 to 2.0. For the results for the configuration that was tested, the deduced trim angle varied between 13° and 21°.

INTRODUCTION

A spinning, axially symmetric vehicle entering a planetary atmosphere at an angle of attack will assume a coning motion with the axis of symmetry turning around the velocity vector. Normally, with a positive static margin, the angle of attack will diminish as the dynamic pressure builds up, so that the coning motion will vanish. However, if the coning rate and the vehicle's spin rate are equal, one side of the vehicle will be constantly subjected to the oncoming relative flow. Under ablation conditions more material would be eroded from that side of the heat shield than from other sides of the shield, causing the original axisymmetric configuration to become asymmetric. As a result, a moment component could develop to oppose the original stabilizing-restoring moment so that the vehicle could orient itself at a trim angle of attack during entry. If this moment component is large and unanticipated, the trim angle of attack could seriously jeopardize the vehicle's performance, and, in extreme cases, its survival. An investigation was made in the Ames Pressurized Ballistic Range using models of an assumed asymmetrically ablated configuration to determine how large a trim angle might become.

TESTS

Tests were conducted in the Ames Pressurized Ballistic Range, which can be evacuated or pressurized to 10 atmospheres to suit test requirements. The range is 62 m long with 24 spark-shadowgraph stations spaced irregularly along it. The tests ranged from Mach 0.7 to 2.0, and a range pressure of 375 mmHg was used. During the first test the model experienced considerable swerve and flew out of the field of view. The remaining tests were therefore conducted at a pressure of 250 mmHg so that the model would remain within the confines of the optical system.

The models were launched from a 57-mm, smooth-bore, powder-gas gun. They were adapted to the gun by a four-piece plastic (nylon) sabot and launched at 0° angle of attack.

The trim angle of attack from the free-flight motions was determined using the data reduction program described in reference 2. It should be noted that the nature of the test violated some of the simplifying assumptions of the tricyclic motion equation. For example, the model was not axisymmetric (inertial), and it had a large trim angle and nonlinear aerodynamics. In the tests reported in reference 3, inertially asymmetric models were used in ballistic range tests to obtain trim angle of attack, and the results using the tricyclic equation were compared with those using graphic procedures. The results compared favorably, and the use of the method of reference 2 appears to be justified.

Because the model was inertially asymmetric, the resulting X and Z axes were angularly displaced from those of the unmodified axisymmetric configuration (the Y axis was not affected). Calculations indicated that the inertial values about the X and Z axes between the two configurations differed by approximately 2%. This difference was considered small when compared with other errors, approximations, and simplifications, and the trim angle of attack was determined using the original axes as principal axes.

MODELS

The basic configuration used in the tests (prior to the modifications simulating an asymmetrically ablated heat shield) was a 50°, half-angle, blunted cone with a nose to base radius ratio of 0.5. Information in reference 1 was used to determine the modification necessary to simulate the heat-shield recession representative of entry into Jupiter's atmosphere. The geometry selected was chosen as a representation of a "worst case" (fig. 1). The conical flare was modified by turning it around an axis 0.254 cm from the axis of symmetry, and machining a new surface parallel to the previously existing one (fig. 1), thus removing material from about one-half the flare surface and from a part of the spherical nose. The nose recession measured along the centerline was one and one-half times the flare recession, which resulted in a new nose to base radius ratio of 0.816. The model was then internally ballasted to put the center of gravity on the centerline of the basic configuration so that the trim angle of attack would be due solely to shape change rather than partly to shape change and partly to the offset of the center of gravity.

RESULTS AND DISCUSSION

The physical properties of the models, aerodynamic data obtained from the tests, and test conditions are given in table 1. Model motions are presented in figure 2 where angle of attack, α, is plotted versus the angle of sideslip, β. These motions are typical of a statically stable, asymmetric, rolling body because the precessing ellipses are not symmetric about the origin, a result of the model flying at a trim angle of attack. The circles are the measured data points, and the curves are the best least-squares fit of the equations of motion. The quality of the fits to the data points is somewhat less than desired, probably due to the unsymmetrical aerodynamic characteristics resulting from the model asymmetry. The circular, dashed arc on each plot represents the path of the trim-vector head as determined by the data-reduction procedure of reference 2. The trim vector's distance from the origin is the magnitude of the trim angle of attack, while the arc length represents the angle through which the model rolls during its oscillatory, rolling flight. It is seen that the models experience a significant trim angle of attack in all flights.

The drag coefficient, C_D, determined from the model's deceleration, is shown in figure 3, where it is presented as a function of both Mach number and α_{rms} and appears to increase with increasing Mach number. This increase is believed to be due to Mach number and not increasing α_{rms} since the drag coefficient of these shapes has been found to decrease with increasing α_{rms} (ref. 4).

CONCLUSIONS

Ballistic range tests using models with a simulated, asymmetrically ablated heat shield have shown that a significant trim angle of attack could result from the asymmetry. Linear analysis indicates that the trim angle lies between 13° and 21° for Mach numbers between 0.7 and 2.0. Test results indicate that the configuration is stable for the geometry chosen to be representative of the "worst case," and for the test conditions considered.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California 94035, December 21, 1982

REFERENCES

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2. Malcolm, Gerald N.; and Chapman, G. T.: A Computer Program for Systematically Analyzing Free-Flight Data to Determine the Aerodynamics of Axisymmetric Bodies. NASA TN D-4766, Sept. 1968.
3. DeRose, Charles E.: Trim Attitude, Lift and Drag of the Apollo Command Module with Offset Center-of-Gravity Positions at Mach Numbers to 29. NASA TN D-5276, June 1969.
4. Sammonds, Robert I.: Dynamics of High-Drag Probe Shapes at Transonic Speeds. NASA TN D-6489, Sept. 1971.

TABLE 1.– DATA SUMMARY

Model properties: $A \cong 0.001898\ \text{m}^2$; mass $\cong$ 119.6 gm; $l \cong 4.826$ cm; $X_{cg} \cong 1.651$ cm; $I_y \cong 0.0137$ gm-cm^2; $I_x \cong 0.0199$ gm-cm^2						
Test	M	Re_l, $\times 10^{-6}$	α_t, deg	α_{rms}, deg	C_D	p, mmHg
1799	0.94	0.50	16.2	18.3	1.026	373.7
1800	.95	.35	16.2	19.6	.980	251.4
1801	.71	.26	13.1	19.0	.837	250.3
1802	.70	.26	13.0	18.6	.837	251.8
1814	1.95	.73	19.5	22.0	1.217	252.1
1815	1.46	.55	21.1	24.4	1.193	252.9

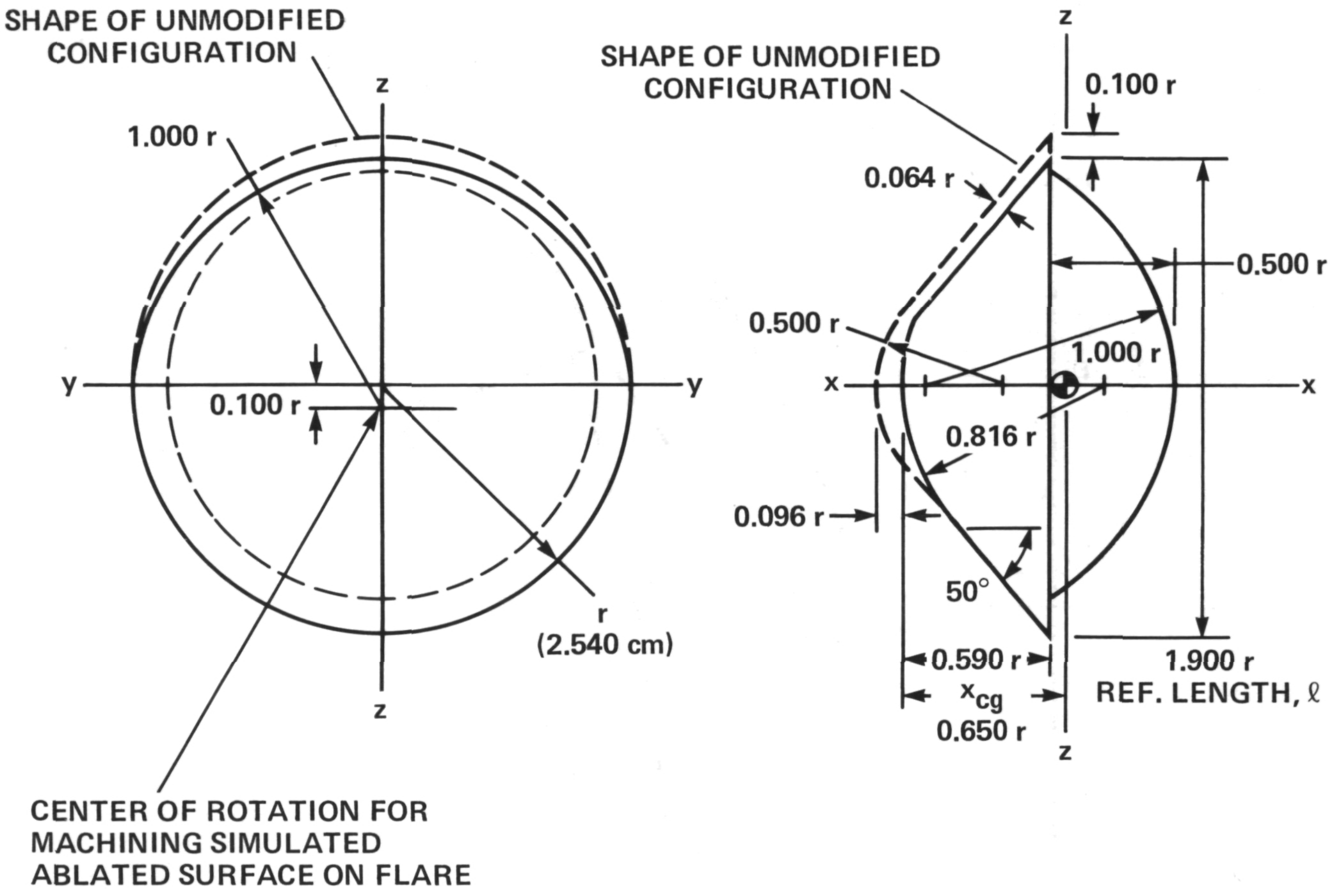
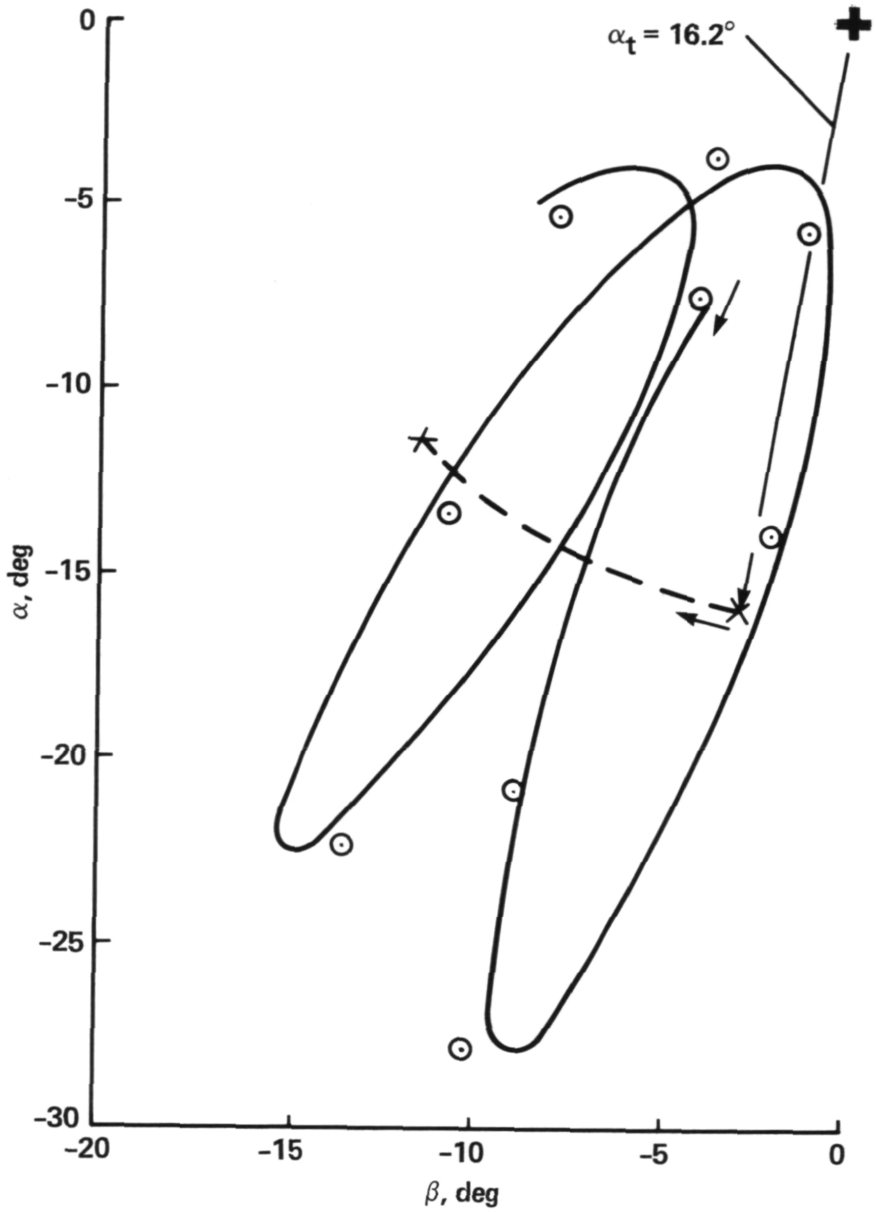
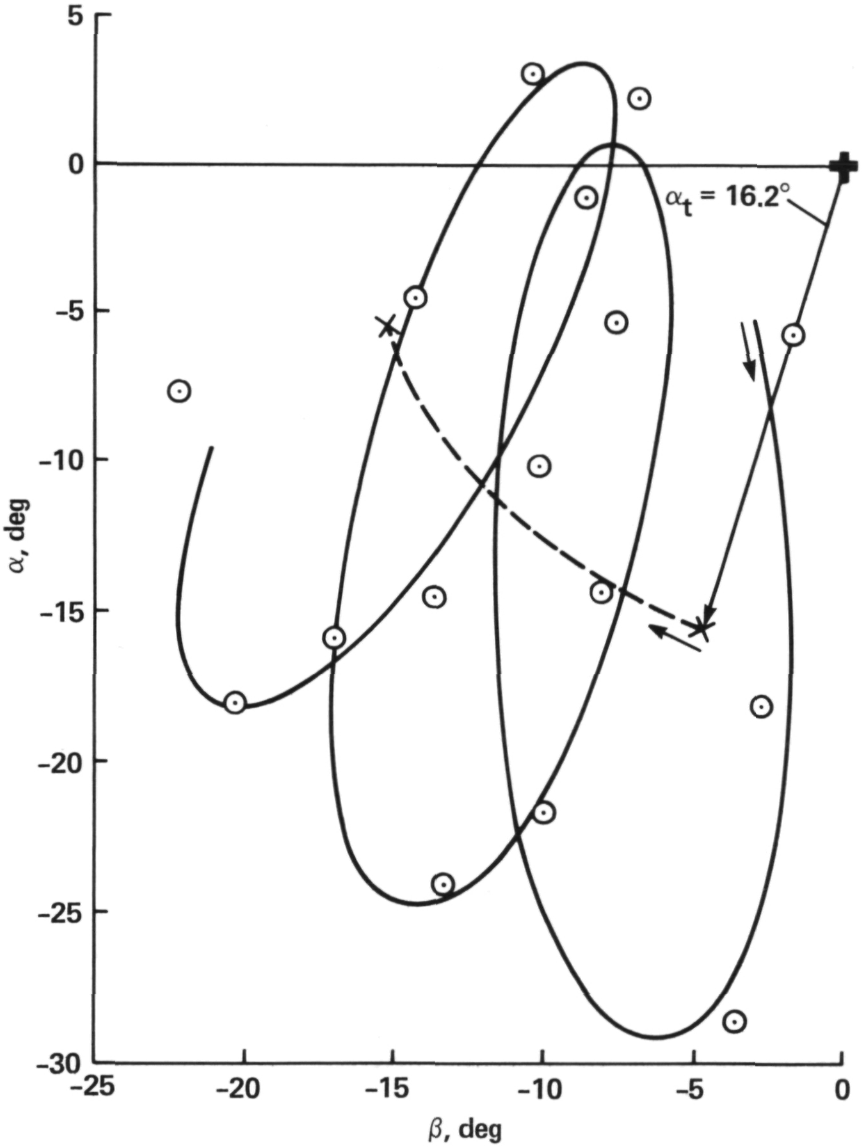


Figure 1.– Model configuration.



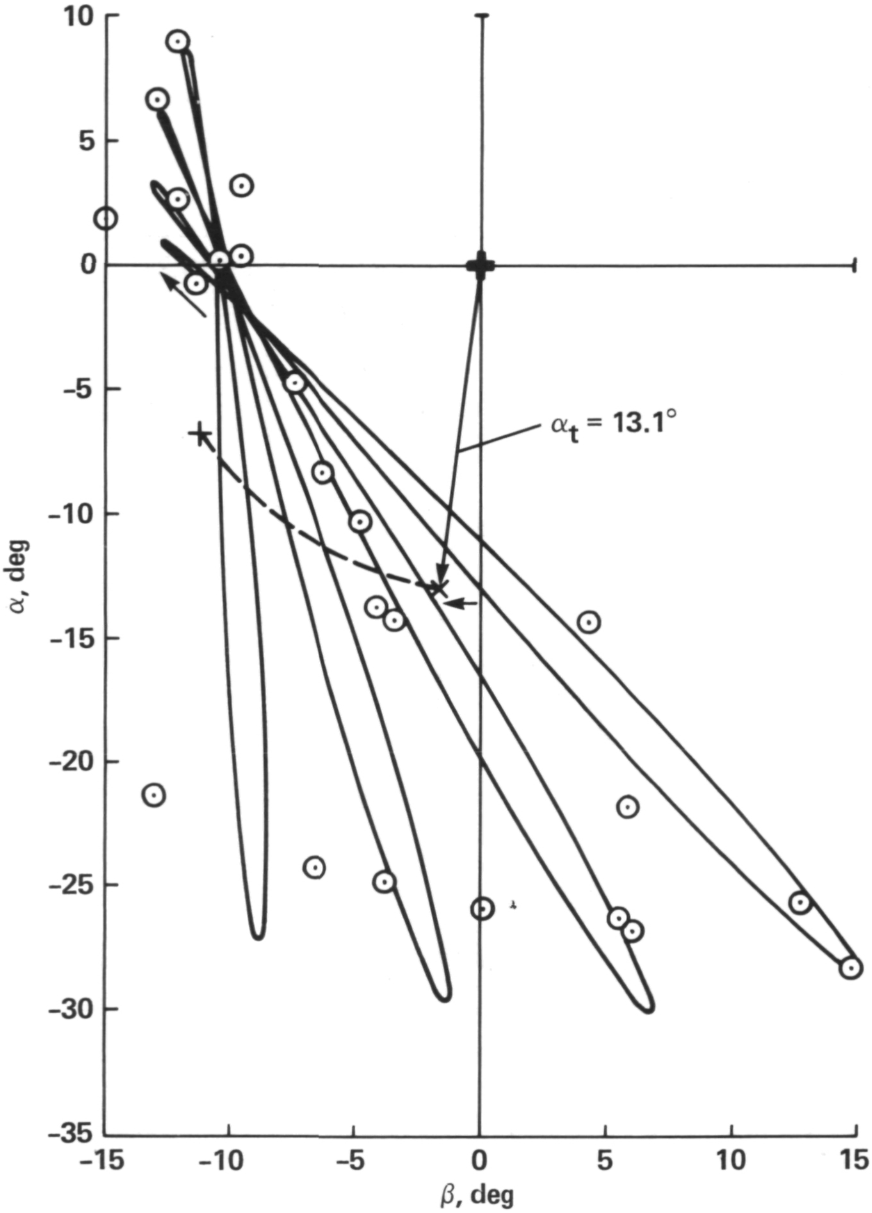
(a) Test 1799

Figure 2.– Angular motions.



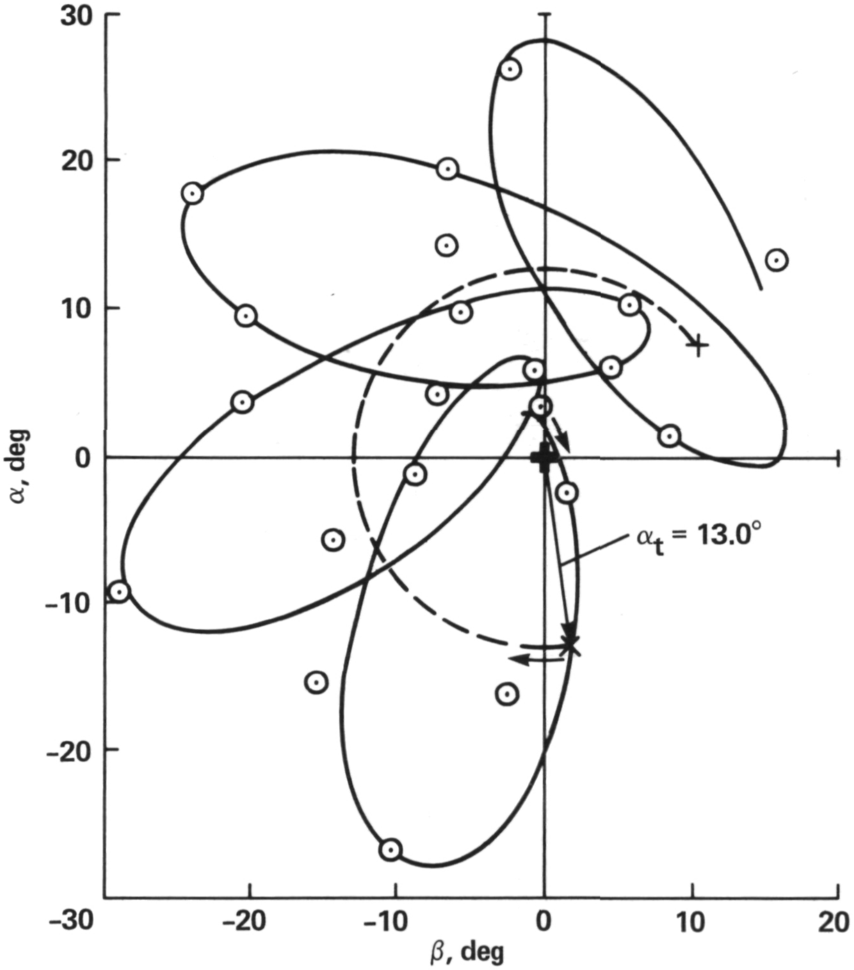
(b) Test 1800

Figure 2.– Continued.



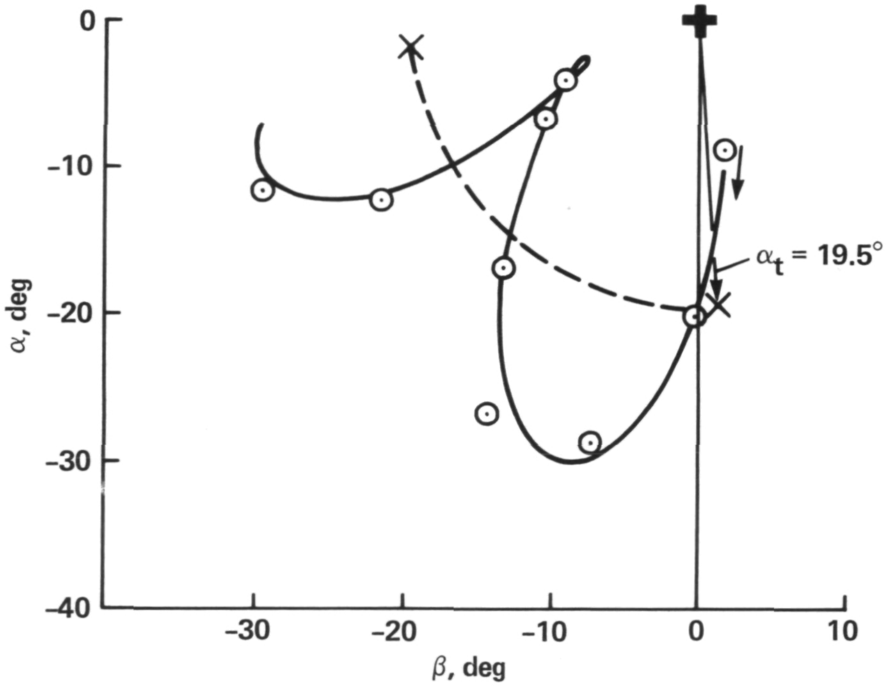
(c) Test 1801

Figure 2.– Continued.



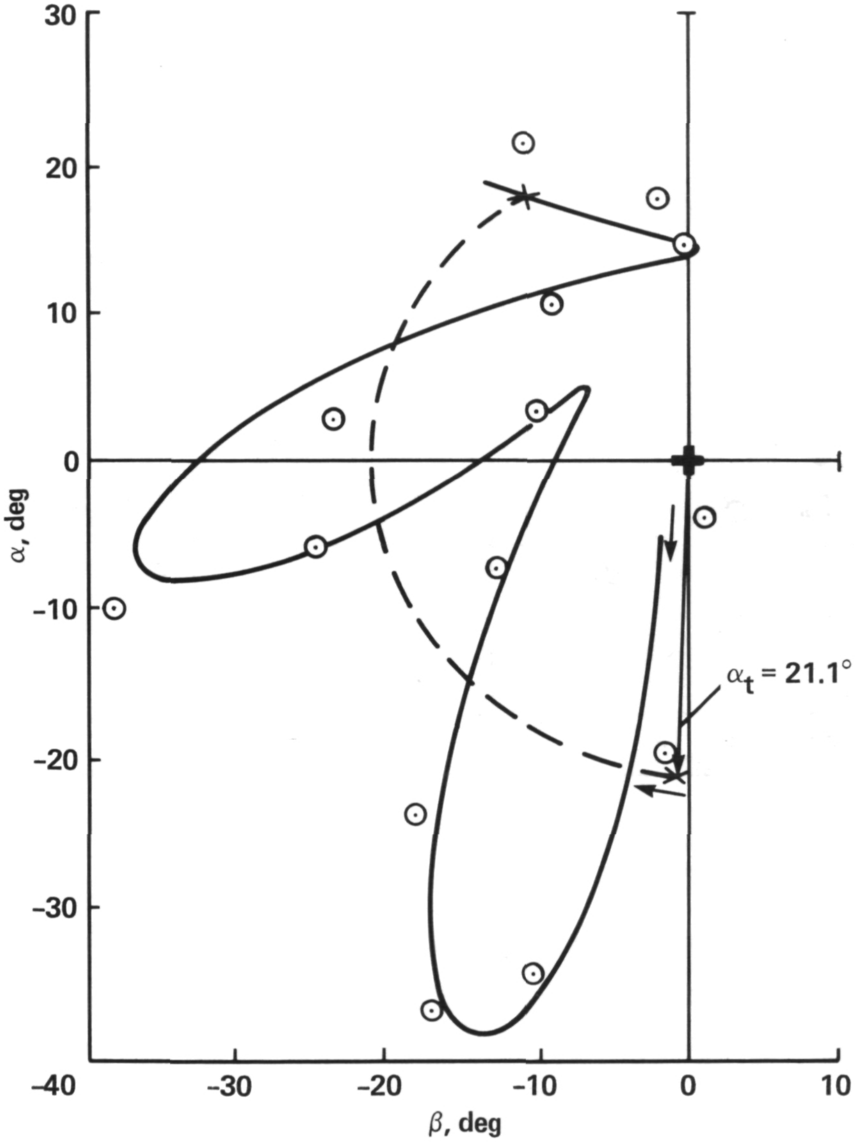
(d) Test 1802

Figure 2.– Continued.



(e) Test 1814

Figure 2.– Continued.



(f) Test 1815

Figure 2.– Concluded.

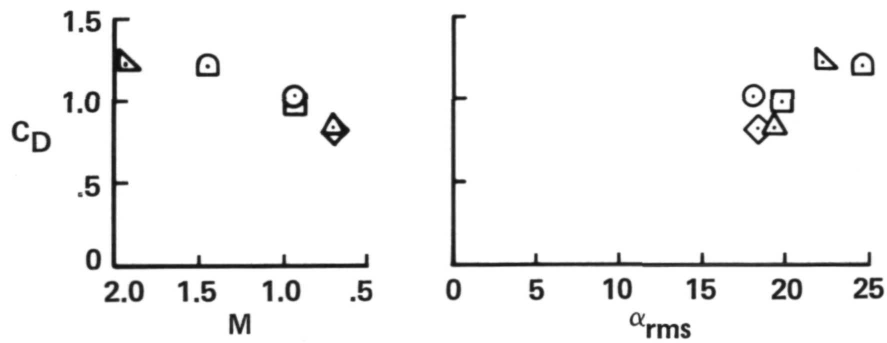


Figure 3.– Drag coefficient versus Mach number and α_{rms}.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-84309		

4. Title and Subtitle	5. Report Date
THE EFFECT OF ASYMMETRIC ABLATION ON TRIM ANGLE OF ATTACK	May 1983
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Robert L. Kruse	A-9164
	10. Work Unit No.
9. Performing Organization Name and Address	T-4221
NASA Ames Research Center Moffett Field, Calif. 94035	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code 506-51-21-01-00-21

15. Supplementary Notes

Point of Contact: Robert L. Kruse, Ames Research Center, Moffett Field, Calif. 94035, Mail Stop: 237-1, (415) 965-6094

16. Abstract

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17. Key Words (Suggested by Author(s))	18. Distribution Statement
Blunted cone	Unclassified - Unlimited Subject Category – 02

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	16	A02

*For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1983

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