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WIND TUNNEL TEST RESULTS ON A FLIGHT PATH ACCELEROMETER AT SUBSONIC AND SUPERSONIC SPEEDS

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ARO, Inc.

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NOTICES

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FOREWORD

The work reported herein was done at the request of the Air Force Flight Test Center (AFFTC), Air Force Systems Command (AFSC), under Program Element 65701F, Project 6903, Task 55.

The test results were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract F40600-72-C-0003. The tests were conducted on December 6, 1971, and January 24, 1972, under ARO Project No. VA0078, and the final data reduction was completed on February 2, 1972. The manuscript was submitted for publication on February 17, 1972.

This technical report has been reviewed and is approved.

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ABSTRACT

A test program was conducted to obtain the damping characteristics of the vanes and provide a flow calibration of the newly developed Flight Path Accelerometer (FPA). Earlier calibration results identified an interference problem from the sideslip vane strut on the angle-of-attack vanes, and, consequently, the sideslip vane was moved rearward, thus necessitating additional calibration tests. The test program was conducted in the von Kármán Gas Dynamics Facility (VKF) Supersonic Wind Tunnel (A). The tests were conducted at Mach numbers from 0.3 to 3.0 over a free-stream Reynolds number range, based on boom diameter, from 0.004×10^6 to 1.5×10^6. The angle of attack ranged from -3 to 20 deg. The triangular vanes with 0.71 aspect ratio were statically and dynamically stable over the entire Mach number range and had a maximum sideslip position error of 2 deg at Mach numbers from 1.5 to 3.0.

CONTENTS

ILLUSTRATIONS

NOMENCLATURE

AR	Aspect ratio, ($AR = b^2/S$)
b	Vane span length, 2.5 in.
C_m	Pitching-moment coefficient, pitching moment/$q_\infty S\bar{c}$

Cm_α	Pitching-moment derivative coefficient, $\frac{\partial C_m}{\partial \alpha}$, 1/radian
Cm_q	$\partial C_m/\partial(q\bar{c}/2V_\infty)$ Local damping-in-pitch derivatives, 1/radian
$Cm_{\dot{\alpha}}$	$\partial C_m/\partial(\dot{\alpha}\bar{c}/2V_\infty)$ Local damping-in-pitch derivatives, 1/radian
$\bar{c}$	Vane mean aerodynamic chord, 4 in.
d	Boom diameter, 0.271 ft
M_∞	Free-stream Mach number
p_o	Tunnel stilling chamber pressure, psia
q	Model angular pitch rate, radians/sec
q_∞	Free-stream dynamic pressure, psia
Re/ft	Free-stream unit Reynolds number per foot
Re_d	Free-stream Reynolds number based on boom diameter
S	Vane planform area, 8.75 in.^{2}
T_o	Tunnel stilling chamber temperature, °R
V_∞	Free-stream velocity, ft/sec
α	Vane angle of attack during dynamic tests
$\dot{\alpha}$	Time rate of change of α, radians/sec
α_t	Angle of attack of model centerline as indicated by the wind tunnel instrumentation, deg
β_e	Sideslip position error, $\beta_t - \beta_i$, deg
β_i	Sideslip angle of model centerline as indicated by the model instrumentation, deg
β_t	Sideslip angle of model centerline as indicated by the wind tunnel instrumentation, deg
ϕ	Model roll angle, deg

SECTION I
INTRODUCTION

In 1970 the Air Force Flight Test Center (AFFTC) at Edwards Air Force Base, California, obtained a Flight Path Accelerometer (FPA) to be used in the flight testing of newly developed aircraft. Calibration tests to determine the position error of the angle-of-attack and sideslip vanes of the FPA were attempted in the AEDC Propulsion Wind Tunnel Facility (PWT) Aerodynamic Wind Tunnel (4T) in July 1970. These tests were unsuccessful because of excessive vane oscillation caused by vane dynamic instabilities. Viscous dampers were added to the FPA system, and a successful calibration was obtained. However, the viscous dampers increased the response time of the vanes to an unacceptable value. The problem was solved by von Kármán Gas Dynamics Facility (VKF) personnel by changing the aerodynamic shape of the vane.

Several sets of vanes were designed by VKF, and the optimum vane design was determined by a wind tunnel test program (Ref. 1); a position error calibration was also obtained for the selected vane design. The new vane design had both good damping and position error characteristics except at Mach number 1.1 where a shock from the strut mount of the angle-of-sideslip vane impinged on the angle-of-attack vanes and created a position error of approximately 1 deg at zero angle of attack. To avoid this problem the angle-of-sideslip vane was moved rearward 6 in. and new subsonic and transonic calibration data were obtained (Ref. 2). The present test program was conducted to obtain new calibration data at supersonic Mach numbers and the damping characteristics of the vanes at subsonic and supersonic Mach numbers.

SECTION II
APPARATUS

2.1 TEST ARTICLE

Details of the full-scale FPA are shown in Fig. 1. It is designed for installation on the nose boom of aircraft undergoing flight testing. The boom is equipped with two angle-of-attack vanes and one angle-of-sideslip vane. The vanes are mounted on shafts which ride internally on precision, low-friction ball bearings. The vanes rotate freely within specified limits on their respective hinge lines and, therefore, remain aligned with the local flow direction regardless of the boom angle of attack.

The vane shape, a triangular planform with a cut tip, was selected from earlier tests (Ref. 1) because of its damping characteristics and simplicity.

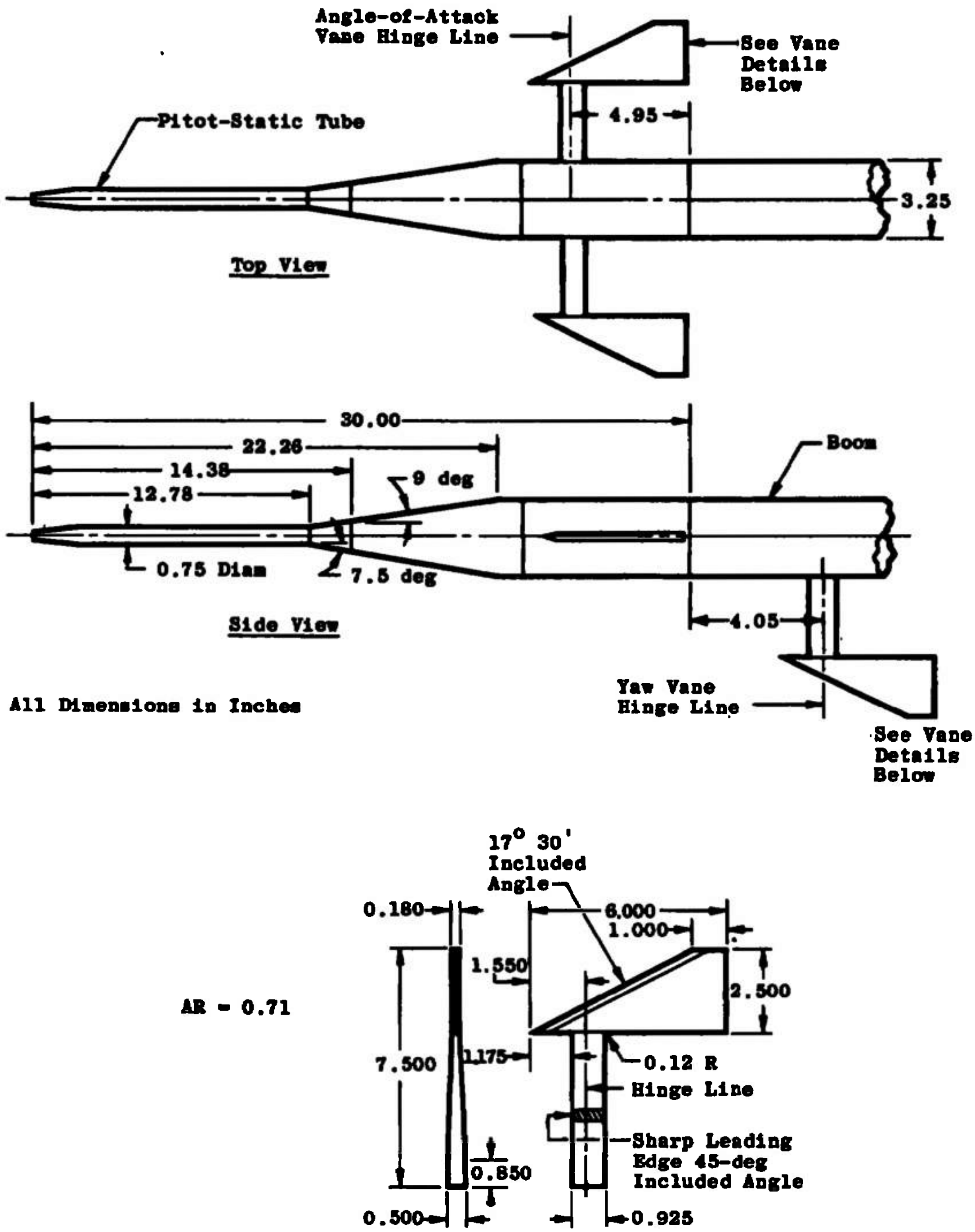

Fig. 1 Details of the Flight Path Accelerometer

2.2 WIND TUNNEL

Supersonic Wind Tunnel (A) is a continuous, closed-circuit, variable density wind tunnel with an automatically driven, flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel can provide supersonic Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 750°R ($M_\infty = 6$). Minimum operating pressures range from about one-fourth to one-twentieth of the maximum at each Mach number. The tunnel can also provide subsonic Mach numbers. In most instances Mach number changes may be made without stopping the tunnel. The model can be injected into the tunnel for a test run and then retracted for model changes without stopping the tunnel flow.

2.3 INSTRUMENTATION

The instrumentation contained in the FPA housing includes an angle-of-attack synchro, an angle-of-sideslip synchro, two accelerometers, a temperature sensor, and total and static pressure lines. The angle-of-attack and sideslip synchros measure the indicated angle of attack and sideslip of the FPA by measuring the angle of rotation of the vane shaft with respect to the FPA housing. The two accelerometers are mounted on the angle-of-attack vane shaft. The sensitive axis of one is normal to the shaft and in the plane of the vanes and is referred to as the longitudinal accelerometer. The sensitive axis of the other is normal to the plane of the vanes and is referred to as the normal accelerometer.

The outputs of the accelerometers and temperature sensor were not required for these tests and were not recorded. The outputs of the angle-of-attack and sideslip synchros and the reference voltage were recorded on the standard Tunnel A d-c readout equipment. The boom angle of attack was recorded using the standard tunnel sector readout.

SECTION III
TEST PROCEDURE

3.1 TEST TECHNIQUE

The pitch oscillation data were obtained by deflecting the angle-of-attack vanes to 5 deg by an air jet directed at the vane from below and behind and then rapidly shutting off the jet. The decay of the angle of attack for this phase of the tests was recorded, by using an oscillograph and the Tunnel A digital instrumentation, at the rate of 350 points per second. The vane damping data were obtained in Tunnel A at the conditions listed below.

M_∞	p_o, psia	T_o, °R	Re/ft x 10^{-6}	q_∞, psia
0.30	8.1	560	0.0132	0.50
0.51	6.0	↓	0.0144	0.90
0.71	4.8	↓	0.0156	1.20
1.50	15.3	↓	4.44	6.57
2.51	28.7	↓	5.40	7.29
3.00	36.6	↓	5.40	6.28

For the position error calibration the boom was set to the specified angles in Tunnel A and the readings from the FPA were recorded under static conditions. The position error calibration was obtained at the nominal conditions below.

M_∞	p_o, psia	T_o, °R	Re/ft x 10^{-6}	q_∞, psia
1.5	13.5	560	3.96	5.79
2.0	16.2	↓	3.96	5.80
2.5	20.8	↓	3.96	5.32
3.0	28.9	↓	4.20	4.96

3.2 DATA PRECISION

Uncertainties (bands which include 95 percent of the calibration data) in the basic tunnel parameters, p_o, T_o, and M_∞, were estimated from repeat calibrations of the instrumentation and from the repeatability and uniformity of the test section flow during tunnel calibration. These uncertainties were then used to estimate uncertainties in other free-stream properties using the Taylor series method of error propagation (Ref. 3). Because the entire test section has not been calibrated subsonically, only the centerline Mach number distributions were used in calculating the uncertainties in the subsonic test conditions.

	±Uncertainty, percent				
M_∞	M_∞	p_o	T_o	q_∞	Re_d
0.3	3.33	0.25	0.72	6.26	3.1
0.5	1.96	0.33	↓	3.26	1.8
0.7	1.40	0.42	↓	1.96	1.3
1.5	0.67	0.74	↓	0.76	1.26
2.0	0.50	0.62	↓	0.76	1.22
2.5	0.31	0.48	↓	0.96	1.27
3.0	0.40	0.35	↓	0.68	1.18

Measurements of the model attitude in pitch and yaw using the tunnel sector are precise within ±0.05 deg based on repeat calibrations. The data were corrected for tunnel flow angularity. Based on repeatability the maximum uncertainty is 5 and 10 percent for C_{m_α} and $C_{m_q} + C_{m_{\dot{\alpha}}}$, respectively.

SECTION IV
RESULTS AND DISCUSSION

4.1 RESULTS OF DYNAMIC TESTS

The variations of the static and dynamic pitching-moment derivative coefficients at zero angle of attack with Mach number are presented in Fig. 2. The data show that the vanes are both statically and dynamically stable for both the subsonic and supersonic Mach numbers tested. Although no stability data were obtained at transonic speeds, earlier tests (Ref. 1) were conducted on the FPA at the transonic Mach numbers to obtain calibration data, and no instabilities were found during these tests. Therefore, the triangular planform area vanes (see Fig. 1) now used on the FPA are both statically and dynamically stable over the required FPA flight regime. The theoretical values shown with the data in Fig. 2 show acceptable agreement.

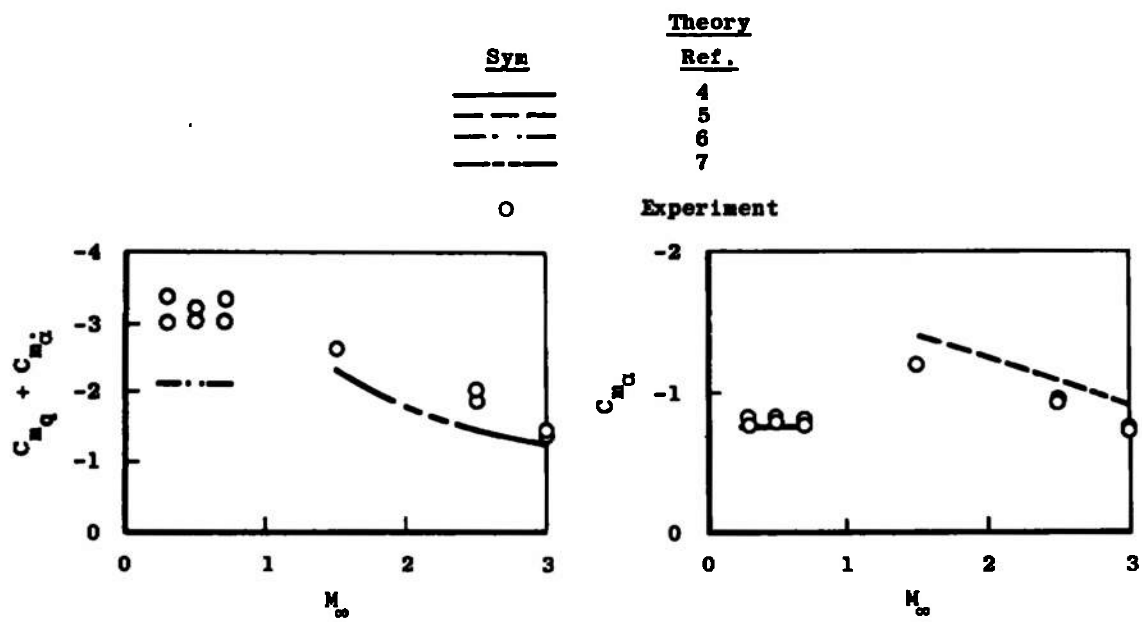

Fig. 2 Variation of the Static and Dynamic Pitching-Moment Derivatives with Mach Number at Zero Angle of Attack

4.2 FLOW CALIBRATION RESULTS

As discussed earlier in Section I, previous calibration tests (Ref. 1) conducted on the FPA indicated that a shock from the angle-of-sideslip vane strut impinged on the angle-of-attack vanes at a Mach number of 1.1. This disturbance caused an undesired position error of approximately 1 deg at zero angle of attack. A simple solution to the problem was to move the angle-of-sideslip vane downstream. This change of position for the angle-of-sideslip vane could not influence the angle-of-attack vane calibration at supersonic Mach numbers obtained in Ref. 1 because the angle-of-attack vanes were already forward of the sideslip vane (the sideslip vane was previously 6 in. forward of its current position, shown in Fig. 1), and any shock from the sideslip vane strut was swept downstream of the angle-of-attack vanes for Mach numbers greater than 1.3. Of course, it was necessary to repeat the angle-of-sideslip vane calibration because it is influenced by the flow over the angle-of-attack vanes. New subsonic and transonic calibration results for both the angle-of-attack and sideslip vanes are reported in Ref. 2.

The variations of the angle of sideslip indicated by the FPA, β_i, with the true sideslip angle of the FPA boom, β_t, are shown in Fig. 3. In general, the FPA indicates sideslip angles that are too large. The sideslip data for the combined attitude (roll angles of 30 and 60 deg) indicate that the FPA-indicated sideslip angles are definitely affected by combined attitude. Apparently, the effect of combined attitude on the indicated sideslip angle is caused by flow interference from the angle-of-attack vanes which are mounted at a more forward axial position on the boom.

The position error data for the pure sideslip indicated angle (no combined attitude) are shown plotted in Fig. 4 versus their corresponding indicated angles. The position errors are nonlinear with indicated angle for all Mach numbers tested. The position errors for all Mach numbers except 2.0 are similar in that they have a negative initial slope and then peak at a sideslip error (β_e) less than 2 deg. The Mach number 2 position errors have a positive initial slope and then decrease to negative values of β_e with increasing sideslip angles (β_i).

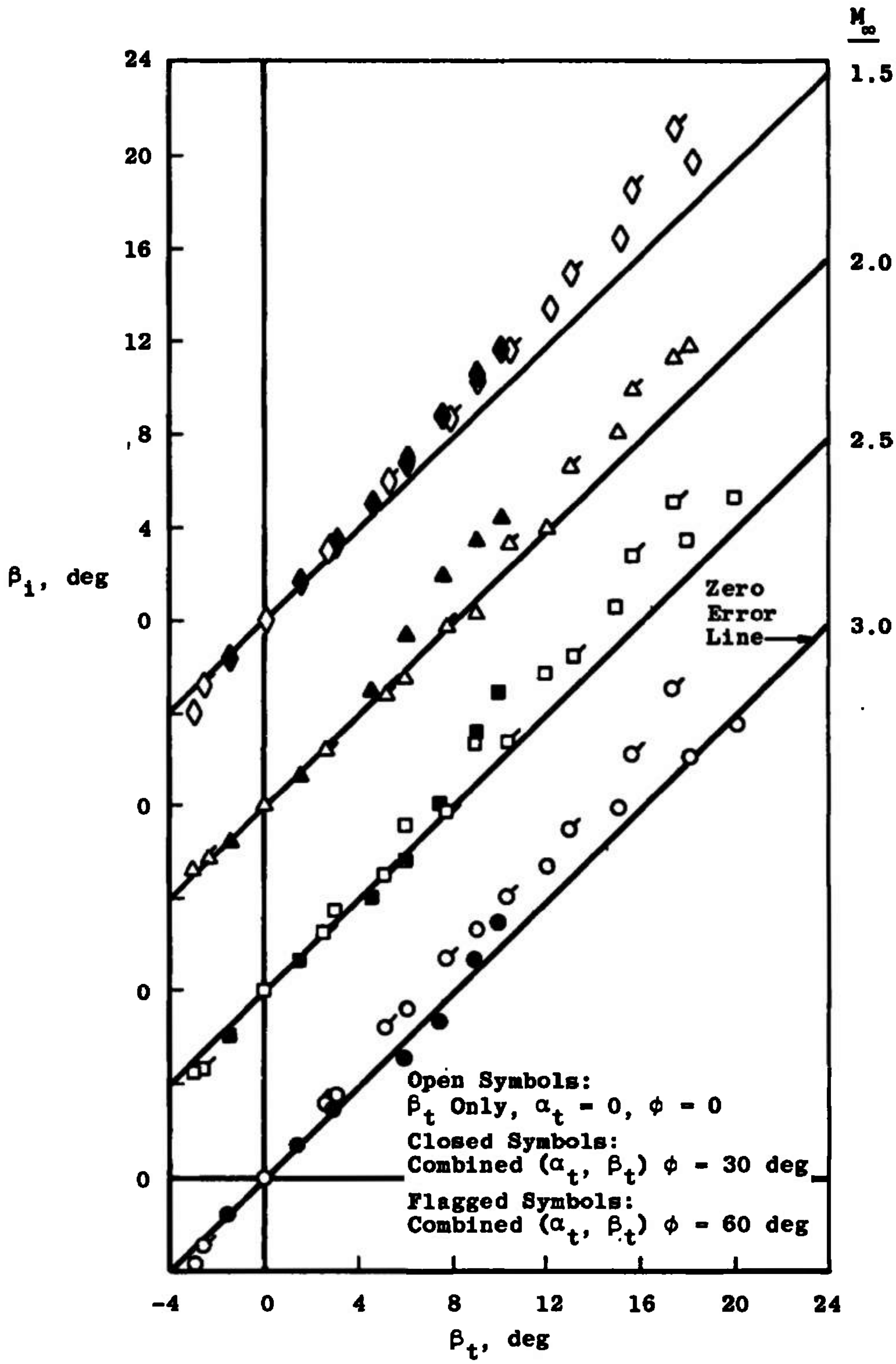

Fig. 3 Variation of the Indicated Angle of Sideslip, β_i, with the Actual Sideslip Angle, β_t

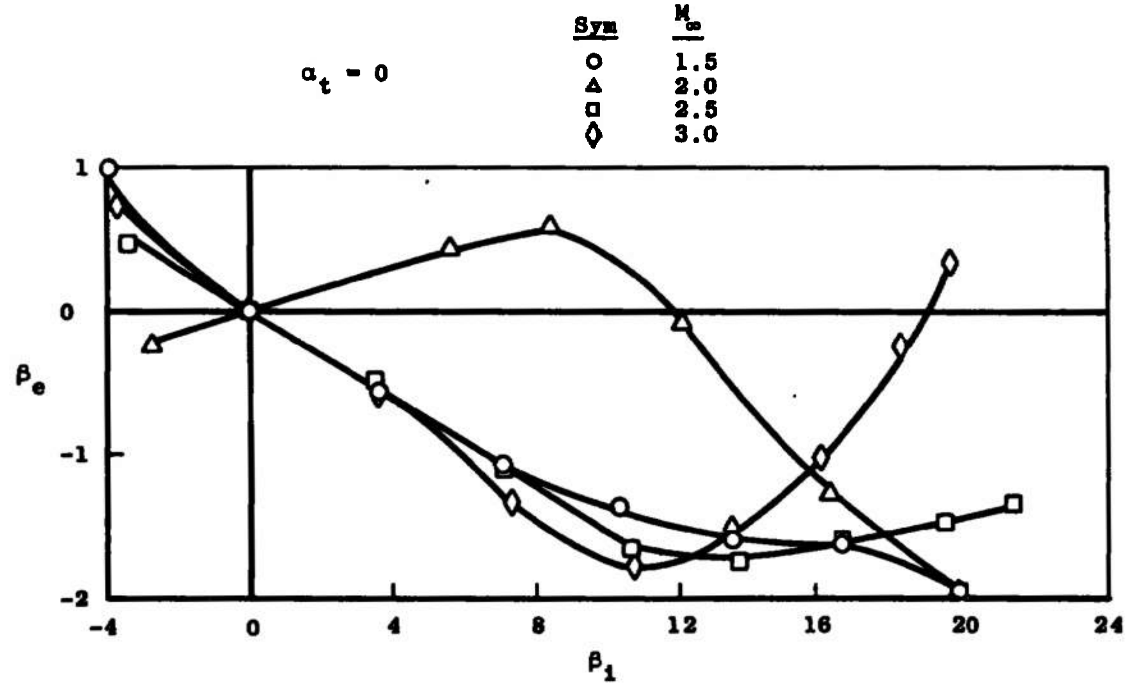

Fig. 4 Variation of the Sideslip Position Error, β_e, with Indicated Angle, β_i

SECTION V
CONCLUDING REMARKS

A program has been conducted at the Arnold Engineering Development Center to design, fabricate, and calibrate angle-of-attack and angle-of-sideslip vanes for a newly developed Flight Path Accelerometer. The current test program was conducted to obtain the vane damping characteristics at subsonic and supersonic Mach numbers and to obtain a new flow angle calibration for the vanes at supersonic Mach numbers necessitated because the sideslip vane had to be moved aft on the Flight Path Accelerometer body. The results from the current test program indicate the following:

1. The vanes are both statically and dynamically stable at Mach numbers up to 3.
2. The angles indicated by the sideslip vane are affected by combined attitude.
3. At Mach numbers from 1.5 to 3.0 the sideslip vanes had a maximum sideslip position error of 2 deg for pure sideslip (α_t = 0) over the indicated sideslip angle range from 0 to 21 deg.

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