APPENDIX B:

AFFTC PARAMETER IDENTIFICATION EXPERIENCE

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The following paper was not presented at the symposium, but was judged pertinent for inclusion in the proceedings in light of discussions concerning flight-test procedures and techniques.

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AFFTC
PARAMETER IDENTIFICATION EXPERIENCE

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ABSTRACT

One of the fundamental tasks of engineering and science, is the extraction of information from data. Parameter identification is a discipline that provides tools for the efficient use of data in the estimation of constants appearing in mathematical models of physical phenomena.

The application of parameter identification techniques to aircraft flight testing is simply the process of obtaining quantitative measures of various aircraft characteristics. In general, the parameters may relate to aerodynamic, structural, performance, or other types of characteristics. Typically, the flight-determined characteristics are compared with predicted values to verify or point out deficiencies in the predictions. They are used to substantiate design goals, to assess control system performance, to verify and improve piloted simulators, and to establish design criteria.

This paper presents an overview of AFFTC experience with parameter identification and presents the major results of such application with respect to accuracy, contributions of otherwise unobtainable information, cost effectiveness, and problems encountered.

INTRODUCTION

The Air Force Flight Test Center has been engaged in the determination of the coefficients of "model" equations (stability and control derivatives) which describe the flight characteristics of air vehicles since 1948. In addition, from 1948 to 1961, no less than twenty-two publications on the subject were authorized by the National Aeronautics and Space Agency (NASA, then NACA), the United States Air Force and other agencies (reference 1).

The advantages and benefits of developing a complete mathematical description of an air vehicle's stability and control characteristics has been long recognized by the flight test community. They include (reference 2):

1. Improved verification of performance criteria,

2. Improved dependability of extrapolated flight characteristics.

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3. Enhanced system development and optimization of vehicle performance,

4. More accurately represented engineering and operational simulators, and

5. The reduction of the amount of flight test time required to adequately assess the flight characteristics of an air vehicle.

Despite the recognition of the desirability of accomplishing such a task, early parameter identification efforts were limited to the synthesizing of major stability derivatives from data produced by small, linear control inputs. The manual matching of analog computer outputs with flight test traces (analog matching), using linear equations of motion was the most commonly used method of determining these major derivatives (reference 3). Although good results were (and are) achieved, this technique was time consuming and was strongly dependent on the sophistication of the operator. The development of faster, more accurate methods has been accomplished in recent years using improved mathematical techniques well suited for automated computer application. The remainder of this paper concerns the use and application of an automated parameter identification scheme as applied to flight test data at the AFFTC.

The particular parameter identification technique which has been widely used at the AFFTC is the Modified Maximum Likelihood Estimator (MMLE) developed by Kenneth W. Iliff and Lawrence W. Taylor, Jr. of the NASA Dryden Flight Research Center, Edwards AFB, Calif. Experience with this method has been restricted to identification of parameters of linear mathematical models.

Over the past several years this method has been applied on ten major test programs; X-24B, YF-16, YF-17, A-9, A-10, YC-14, YC-15, F-15, F-16, and B-1. The uniqueness of application at the AFFTC has been in its use as the first application of parameter identification as a production analysis tool. The AFFTC has processed more than 1500 maneuvers in limited amounts of time using parameter identification techniques.

PARAMETER IDENTIFICATION EXPERIENCE

The current philosophy of evaluating aircraft at the AFFTC directs aircraft testing efforts toward three major areas; system development, compliance with performance criteria, and minimum testing required. Use of parameter identification techniques has yielded significant improvements toward meeting these goals over previous test methods employed. Due to the nature of this technique, identification of detailed mathematical models is accomplished, thus increasing the information available by which the overall system can be more effectively analyzed and developed.

Test Optimization:

The aircraft flight test maneuvers required for parameter identification are of a different type than is used to obtain the more classical test data and thereby provide an independent test whose results can be directly correlated with classical testing. The independence of test techniques also allows for an optimum test plan to be developed which utilizes both the new and more classical test methods, thereby minimizing the overall flight test time required. From an implementation point of view, we feel that we have demonstrated significant reductions in the amount of flight test time necessary to define the stability and control characteristics of an air vehicle. During the evaluation of several prototype and production aircraft, records were maintained with respect to the amount of dedicated flight time devoted to classical stability and control maneuvers and those flight hours devoted to parameter identification of STABility Derivative EXtraction (STABDEX) maneuvers.

Table 1

A COMPARISON OF CLASSICAL AND STABDEX
FLIGHT REQUIREMENTS FOR A TYPICAL CONFIGURATION

	Classical	STABDEX
Total Maneuvers	159(89)	117(53)
Total Flight Hours	20.8(11.7)	4.2(1.9)
Maneuvers per Flight Hour	7.6(7.6)	27.9(27.9)
Parameters per Maneuver	2.9(2.9)	10.5(10.5)
Parameters per Flight Hour	22(22)	293(293)

NOTE: Numbers in parentheses are for an idealized flight test program.

Table 1 is a listing of the actual experience during one of these programs in which both classical and STABDEX methods were used. The numbers in parentheses are an estimate of an idealized test program, based on hindsight, which could have been flown to obtain the same data. Two points are obvious. The first is that efficient test planning can effect a significant reduction in flight test time regardless of the analysis method used. The second is that the total flight time can be reduced nearly 75% by the application of STABDEX techniques. It must be noted that the flight time indicated in the tables is not exactly representative of the total flight time required since the evaluation of characteristics such as the variation of pitch control force and deflection with velocity and certain roll performance parameters must be obtained by classical techniques. On the other hand, in a properly implemented active control system, the longitudinal short period frequency and damping ratios can only be quantified by STABDEX techniques.

Accuracy:

The most fundamental and commonly asked question concerning parameter identification techniques is; how accurate are the results? The term accuracy implies an absolute measure of the error between an estimate and the true value. This of course is impossible to compute since the true value is unknown; however, there are several indicators that have been used which lend confidence and credibility to the results obtained by the application of parameter identification to test data. The three basic indicators of accuracy in the results are; (1) repeatability, (2) correlation, and (3) statistical error analyses.

Figures 1 through 4 shows data which were obtained from an aircraft using the MMLE computer program. Each data point plotted vs angle of attack (α), represents an independent test condition. The data exhibits significant repeatability where data were obtained at similar test conditions. Since these tests were independently conducted and evaluated, the repeatability exhibited lends confidence that the technique yields consistent results. The data presented here is typical of the results obtained on many other test programs conducted at the AFFTC. The vertical lines presented on these plots represent "confidence" levels as computed by the MMLE program. These "confidence" levels will be discussed later.

Figures 5 and 6 are typical examples of the correlation obtained between classical and STABDEX techniques. The data symbols plotted on figure 5 were measurements taken directly from steady-heading sideslip maneuvers, while the faired lines depict data obtained through calculation using STABDEX data. Figure 6 shows similar data; however, this data was obtained over a wide range of flight conditions and is graphic evidence that the STABDEX technique yields nearly identical results as does the classical steady-heading sideslip maneuvers.

A third technique which has been used to validate STABDEX data is the comparison of in flight measured frequency response estimates; that is, measured estimates of the aircraft transfer function, with the Laplace transformation of the equations of motion, where the Laplace transforms are computed using STABDEX data. The result is a direct comparison between measured and computed aircraft transfer functions in the frequency domain. With respect to the dominant model parameters, the results of this technique showed the method to be sensitive enough to easily verify the STABDEX derived model.

In the computational scheme employed in the MMLE program, there exists the capability (under certain conditions and restrictions) to calculate the statistical variance of the estimated parameter value with respect to the true value. This has been shown to be easily accomplished provided one also obtains a measure of the noise associated with the inflight measured variables. If this can be accomplished, a correction may be made to the "confidence" level which is computed by the MMLE program and which results in an estimate of the variance. The correction factor to be multiplied is N/2B where N is the sample rate and B is the measured frequency bandwidth of the noise (reference 4). This technique has not been employed to date in a production test program; however, we feel that application of this technique will become standard practice. It should be noted that the "confidence" level which is calculated has been used as a relative measure of goodness and parameter sensitivity as can be seen from figures 1 through 4.

Flight Test Parameter Identification Comparisons with Wind Tunnel:

Prior to first flight, wind tunnel estimates remain our primary indicators of how an aircraft will behave. However, there have been several instances where wind tunnel estimates failed to adequately predict aircraft response particularly where initial placard limits were to be established. It is not surprising that differences between wind tunnel estimates and flight test data occur in the rotary derivatives, but, the area of concern, in my opinion, is in the variation experienced in the major derivatives. Figures 7 and 8 are examples of the differences experienced between wind tunnel estimates and flight test data for two major derivatives. Figure 7 shows the wind tunnel estimate for the static margin parameter (C_{m_α}) and shows zero static margin actually occurred near 22.5 degrees angle of attack as opposed to the predicted 14.5 degree angle of attack crossover point. Figure 8 shows the directional stability parameter (C_{n_β}) to be much more stabilizing than predicted. These data have been verified by the techniques mentioned earlier. This discussion is not intended as a condemnation of wind tunnel data or methods, but, rather serves to point out the need for flight testing and increased communication between the flight test and wind tunnel communities.

Parameter Identification and Configuration Effects:

One of the most powerful results of the STABDEX method is in the ability to model relatively small changes in the aircraft's response characteristics due to changes in the aircraft's shape or configuration. Figures 9 and 10 show data obtained for one prototype aircraft. Data shown in figure 9 represents a comparison of static lateral-directional stability characteristics with a change in external stores loading (configuration effect), while the data in figure 10 depicts a change in static lateral-directional stability characteristics with dynamic pressure variations (flexibility effects). It has been our experience that as long as any physical change in the aircraft occurs and produces a measurable change in aircraft response, application of the STABDEX technique has yielded accurate mathematical models of the phenomena.

OTHER CONTRIBUTIONS OF PARAMETER IDENTIFICATION

The examples I have given are only a few of the many which have been encountered in recent years. There are many contributions which have been made through the use of parameter identification which have enhanced our ability to analyze, evaluate, and optimize aircraft performance. One of the advantages in developing a mathematical model of the aircraft is the ability to extrapolate a measured parameter to the next most hazardous flight condition, thereby enhancing safety and mission effectiveness. This has been practiced on more than one test program with great success, particularly near the extremes of the flight envelope. On one prototype test program of a multiengine aircraft, data was obtained during engine-out approaches to stalling maneuvers while maintaining wings level and zero sideslip. The raw measurements of aileron deflection were corrected for aileron required due to rudder deflection yielding the aileron requirement due to an engine-out rolling moment. The measured data were corrected by application of the inflight determined roll control effectiveness parameters (control derivatives) $C_{l_{\delta_r}}$ and $C_{l_{\delta_a}}$ Figure 11 illustrates the results of those calculations for one configuration tested. The data presented shows how the STABDEX data was utilized to compute and extrapolate the aileron requirements for an engine-out situation to the worst case flight conditions, thereby establishing a margin of safety which would have been difficult or impractical to establish otherwise.

Many evaluations which have been recently accomplished would have been impossible to conduct without the use of parameter identification. This is becoming more and more commonplace with the trend toward active control systems. The two most obvious of all contributions of parameter identification are in the evaluation and optimization of the flight control systems associated with the aircraft, and our ability to provide accurate mathematical models for engineering or operational training simulators.

CONCLUDING REMARKS

The flight test community at the AFFTC has had significant success with the method of parameter identification. Our successes have included the reduction and optimization of flight test programs, improvement in our ability to verify performance criteria, enhanced system development and optimization of vehicle performance, and improvement in the dependability of measured flight characteristics which has also led to more accurately represented simulations. We are committed to the continued use and development of parameter identification techniques, and expect further improvements in flight testing will occur with the development of nonlinear model identification programs and broader applications.

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5. Maine, Richard E. and Iliff, Kenneth W., "A FORTRAN Program for Determining Aircraft Stability and Control Derivatives from Flight Data," NASA TN D-7831, National Aeronautics and Space Administration, Washington, DC, Apr 1975.

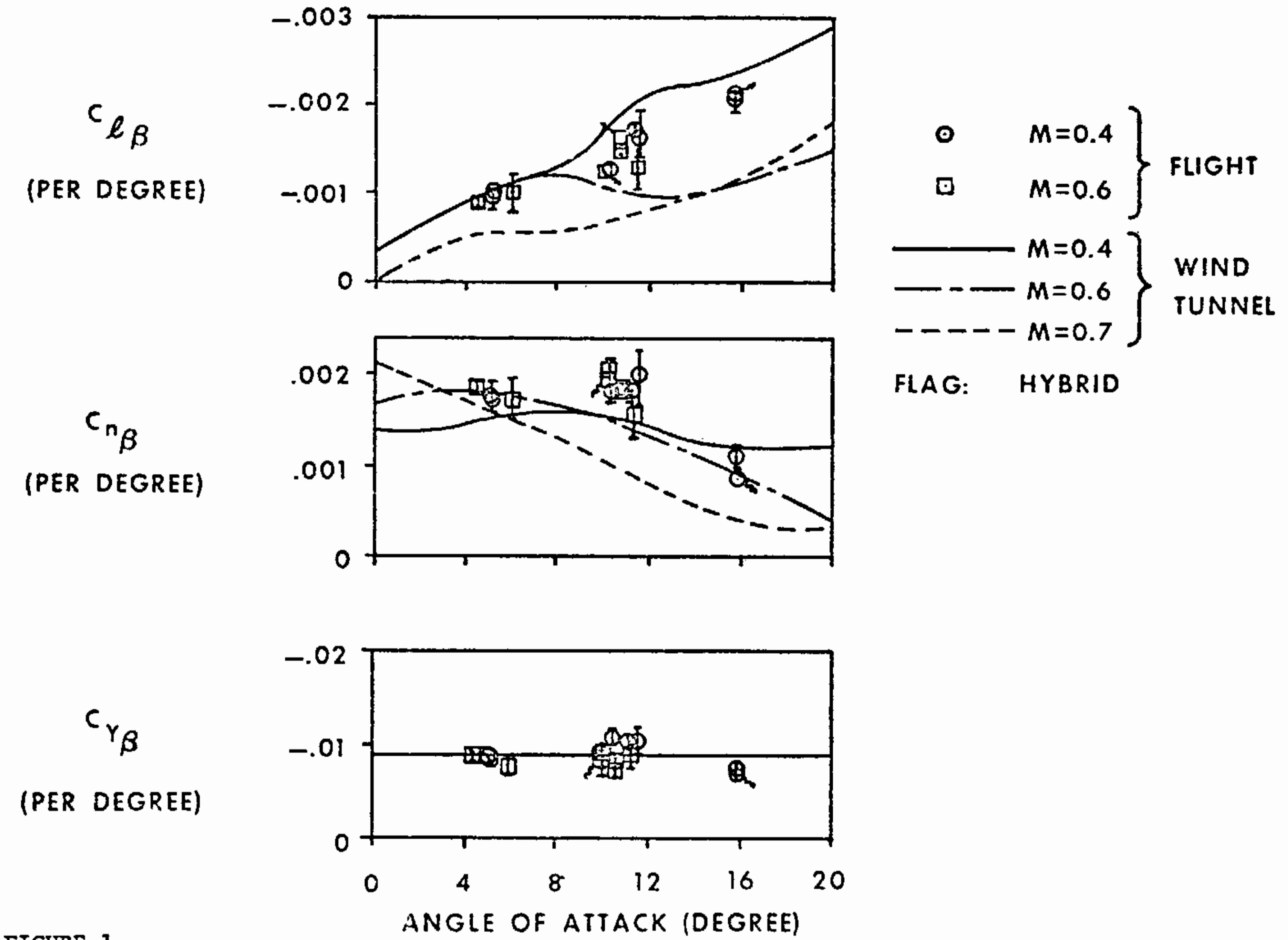
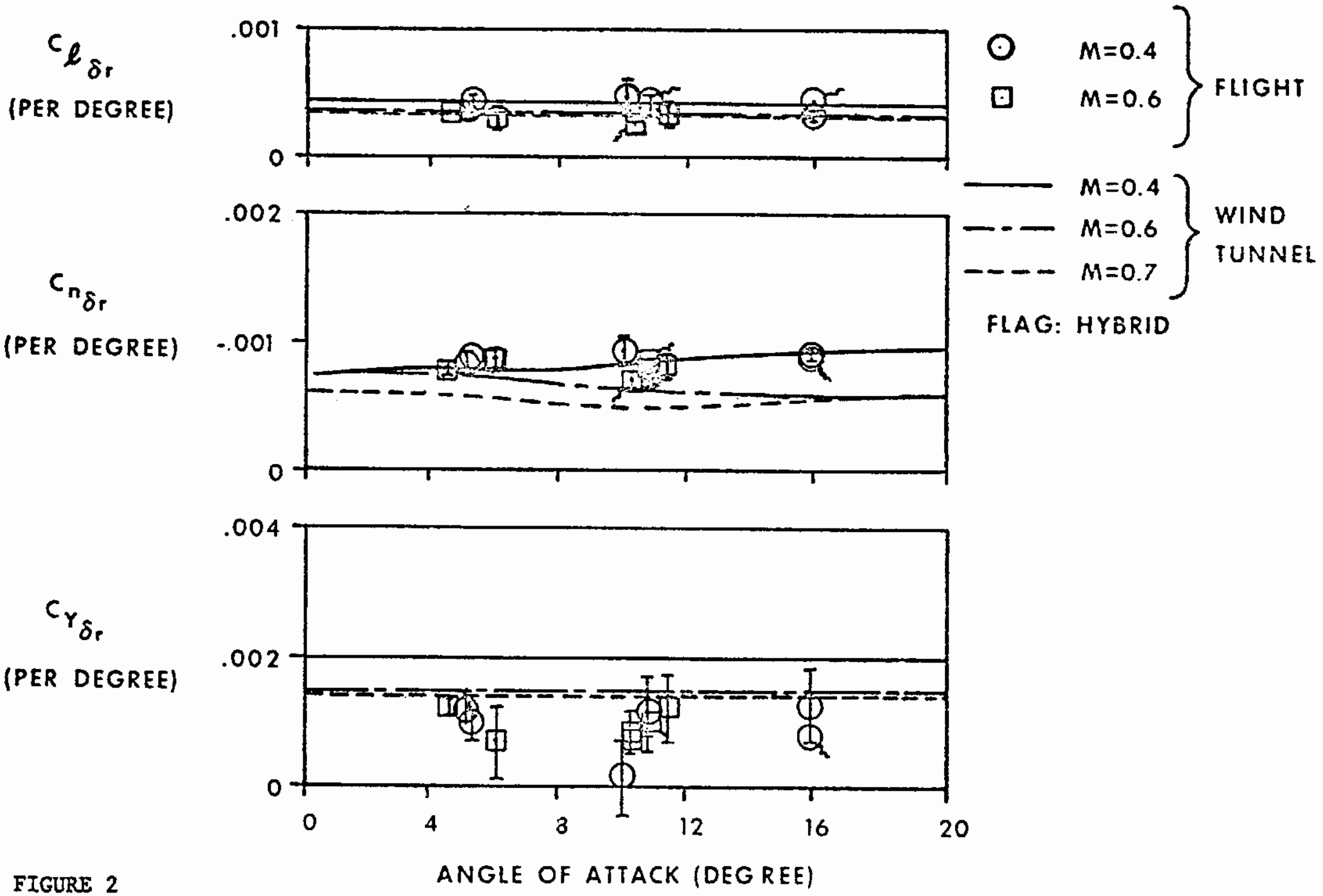

C_{ℓ_β}
(PER DEGREE)
−.003
−.002
−.001
0
C_{n_β}
(PER DEGREE)
.002
.001
0
C_{Y_β}
(PER DEGREE)
−.02
−.01
0
0
4
8
12
16
20
ANGLE OF ATTACK (DEGREE)
M=0.4
M=0.6
FLIGHT
M=0.4
M=0.6
M=0.7
WIND TUNNEL
FLAG: HYBRID

FIGURE 1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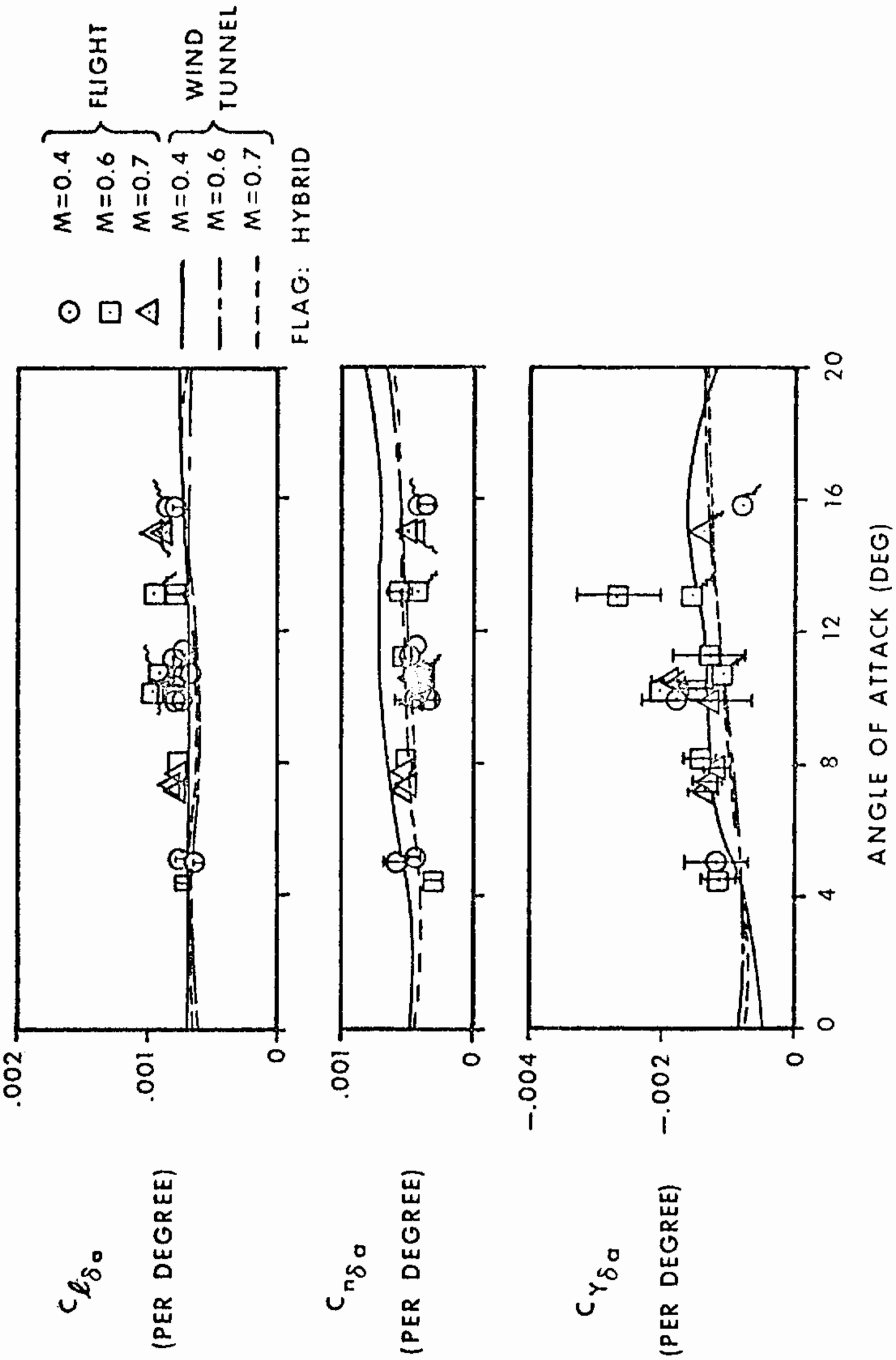
0
$C_{n_{\delta r}}$
(PER DEGREE)
.002
-.001
0
$C_{Y_{\delta r}}$
(PER DEGREE)
.004
.002
0
0
4
3
12
16
20
ANGLE OF ATTACK (DEGREE)
M=0.4
M=0.6
FLIGHT
M=0.4
M=0.6
M=0.7
WIND TUNNEL
FLAG: HYBRID

FIGURE 2


$C_{\ell_{\delta a}}$ (PER DEGREE)
$C_{n_{\delta a}}$ (PER DEGREE)
$C_{Y_{\delta a}}$ (PER DEGREE)
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.001
0
.001
0
−.004
−.002
0
0
4
8
12
16
20
ANGLE OF ATTACK (DEG)
⊙ M=0.4
⊡ M=0.6
△ M=0.7
FLIGHT
M=0.4
M=0.6
M=0.7
WIND TUNNEL
FLAG: HYBRID

FIGURE 3

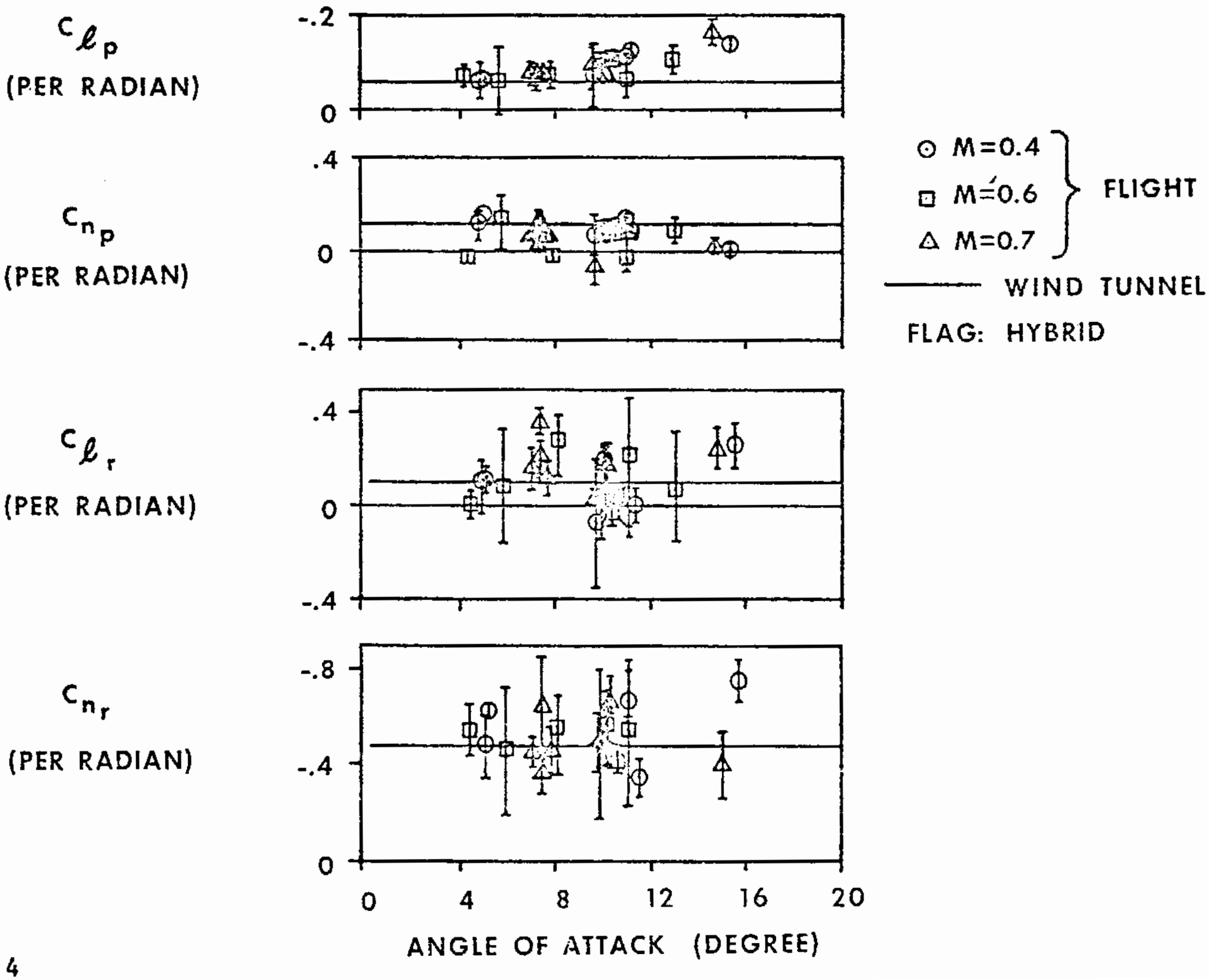

C_{ℓ_p}
(PER RADIAN)
C_{n_p}
(PER RADIAN)
C_{ℓ_r}
(PER RADIAN)
C_{n_r}
(PER RADIAN)
-.2
0
.4
0
-.4
.4
0
-.4
-.8
-.4
0
0
4
8
12
16
20
ANGLE OF ATTACK (DEGREE)
⊙ M=0.4
◻ M=0.6
△ M=0.7
FLIGHT
WIND TUNNEL
FLAG: HYBRID

FIGURE 4

STEADY HEADING SIDESLIP CHARACTERISTICS

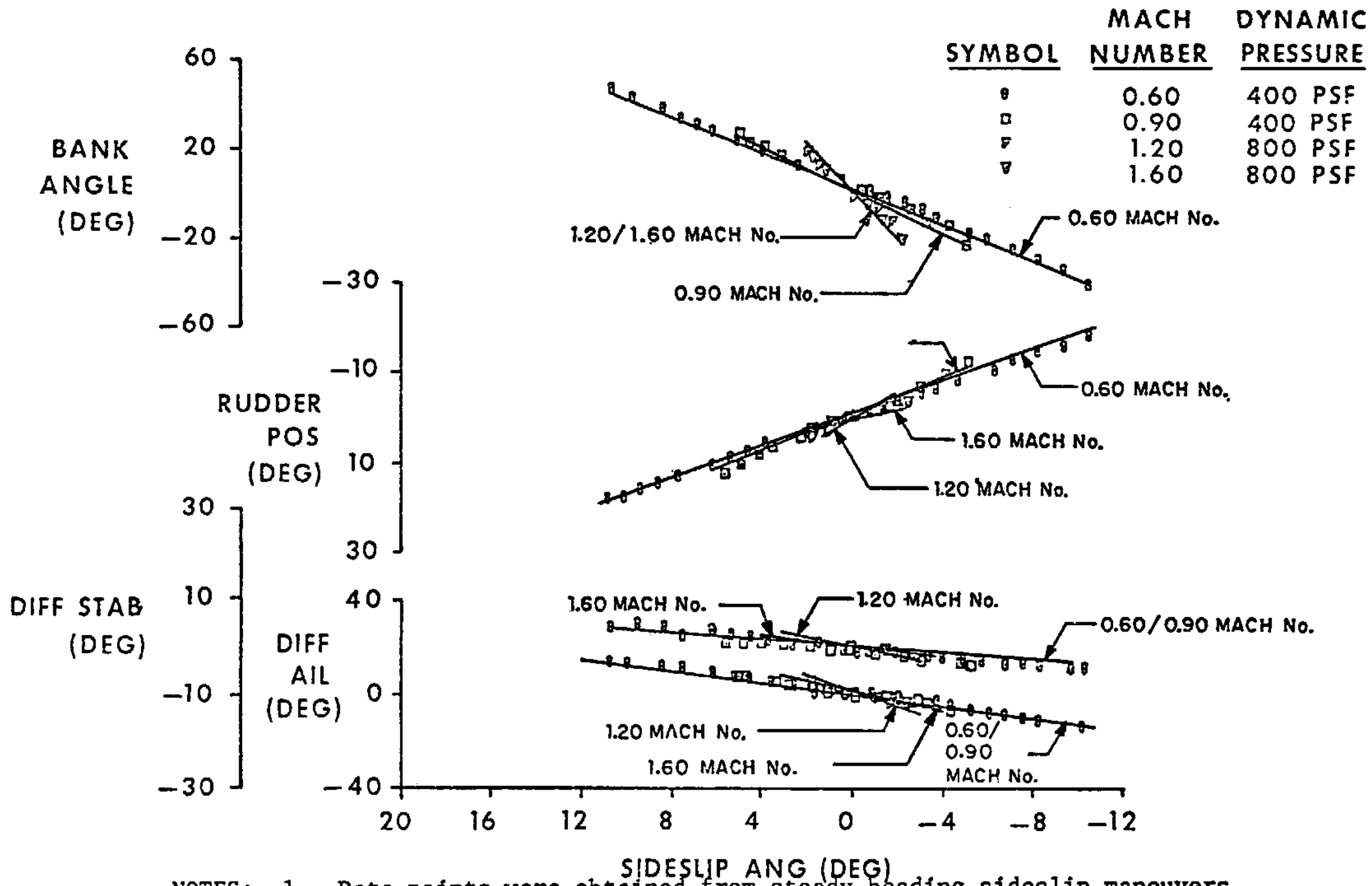
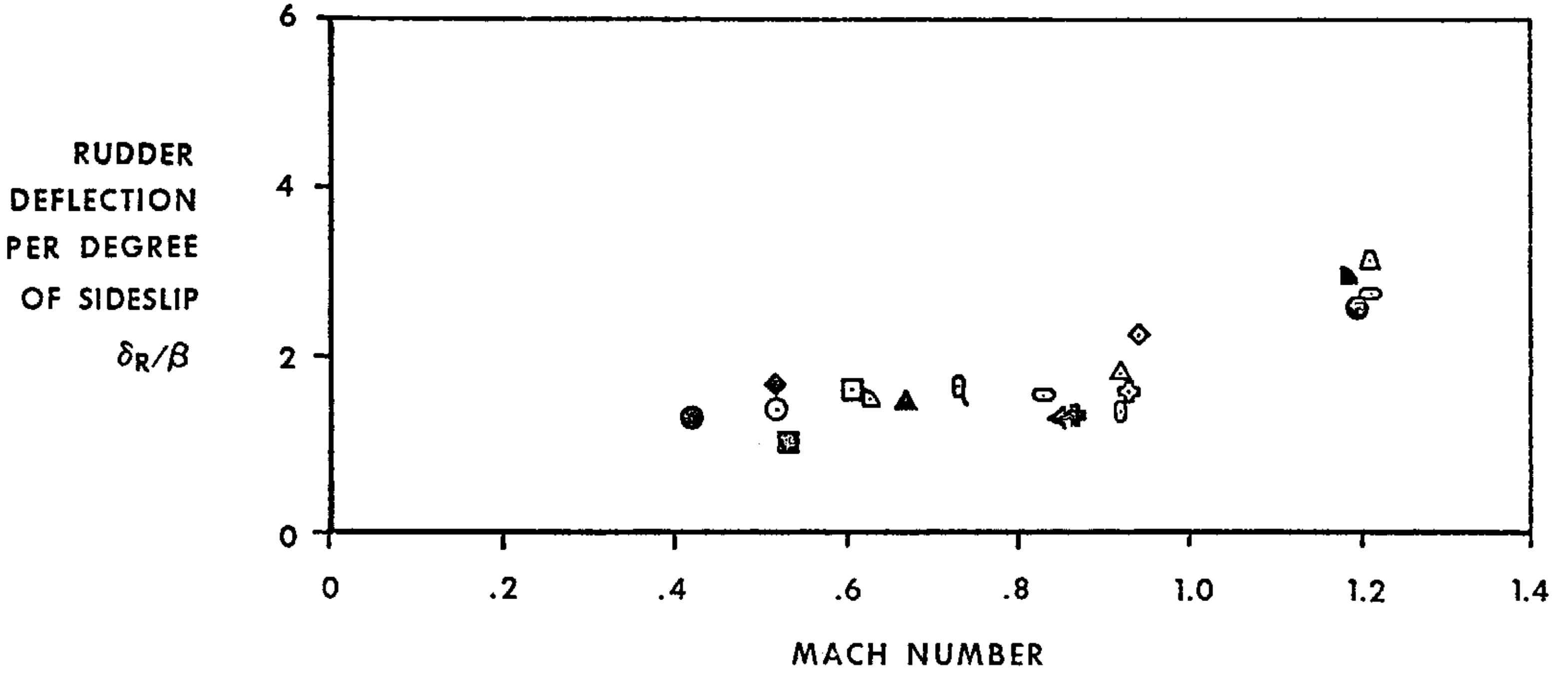


FIGURE 5

NOTES:
1. Data points were obtained from steady-heading sideslip maneuvers.
2. Fairings depict slopes defined by stability derivative data.

STATIC DIRECTIONAL STABILITY



NOTES: 1. Solid Symbols denote $\delta_r/_\beta$ calculated from inflight determined stability derivatives.

2. Open symbols denote $\delta_r/_\beta$ obtained from wings level and constant heading sideslips.

FIGURE 6

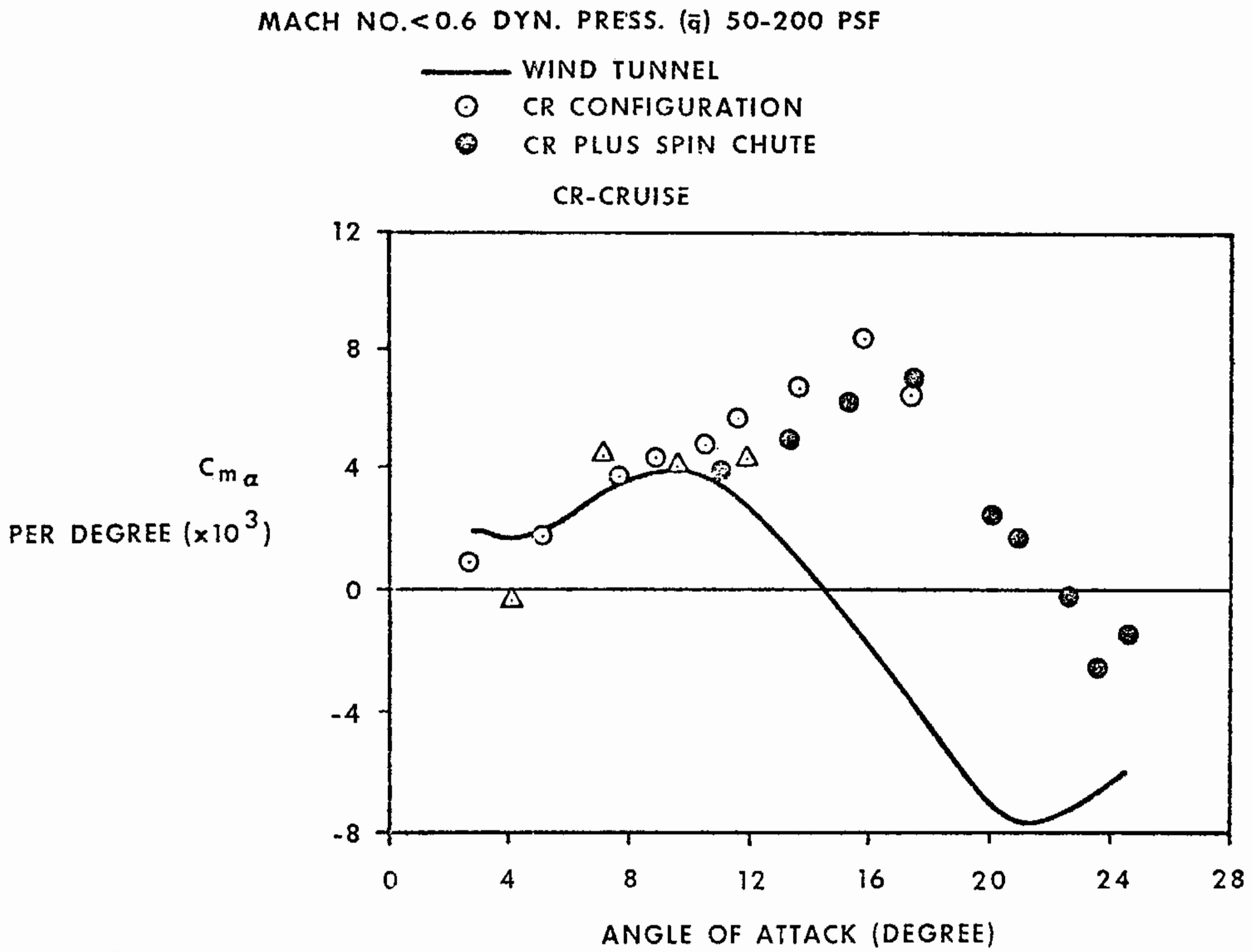

MACH NO.< 0.6 DYN. PRESS. (q̄) 50-200 PSF
WIND TUNNEL
⊙ CR CONFIGURATION
● CR PLUS SPIN CHUTE
CR-CRUISE
C_{m_α}
PER DEGREE (x10^3)
12
8
4
0
-4
-8
0
4
8
12
16
20
24
28
ANGLE OF ATTACK (DEGREE)

FIGURE 7

NOTES:

1. Test data are in the body axis, wind tunnel data are in the stability axis.
2. Fairings from wind tunnel estimates.

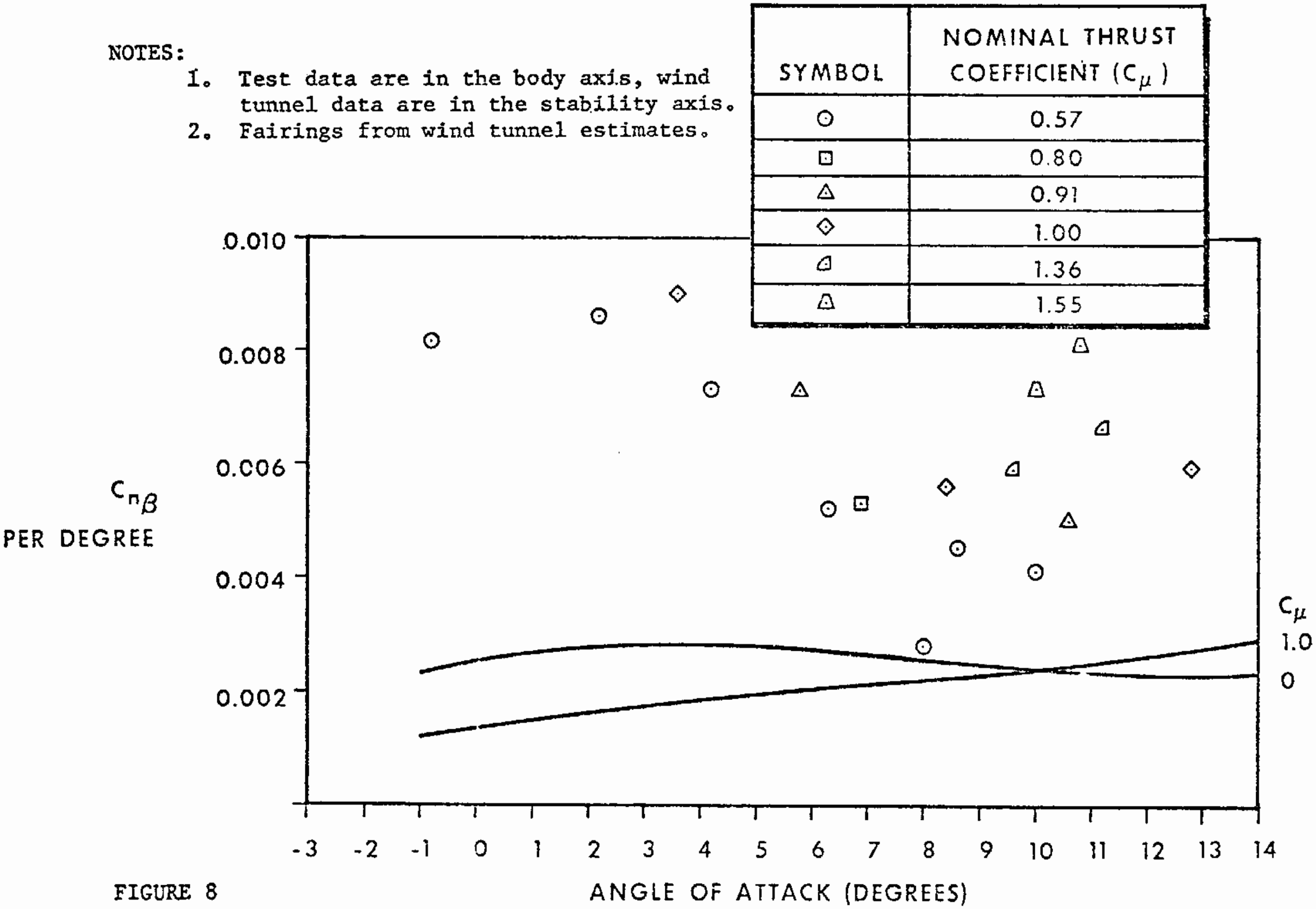


FIGURE 8

STATIC LATERAL-DIRECTIONAL STABILITY COMPARISON

LOADING 3

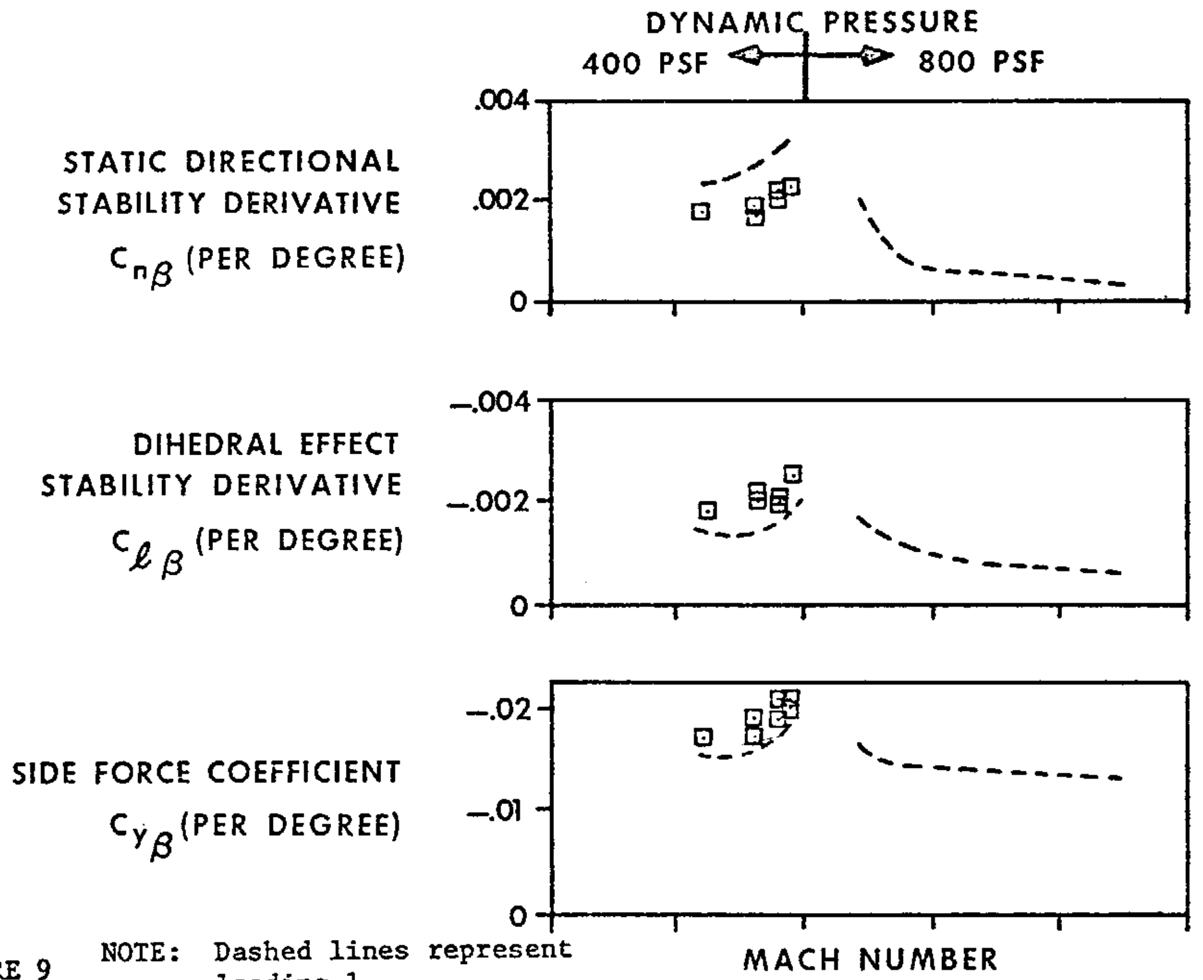
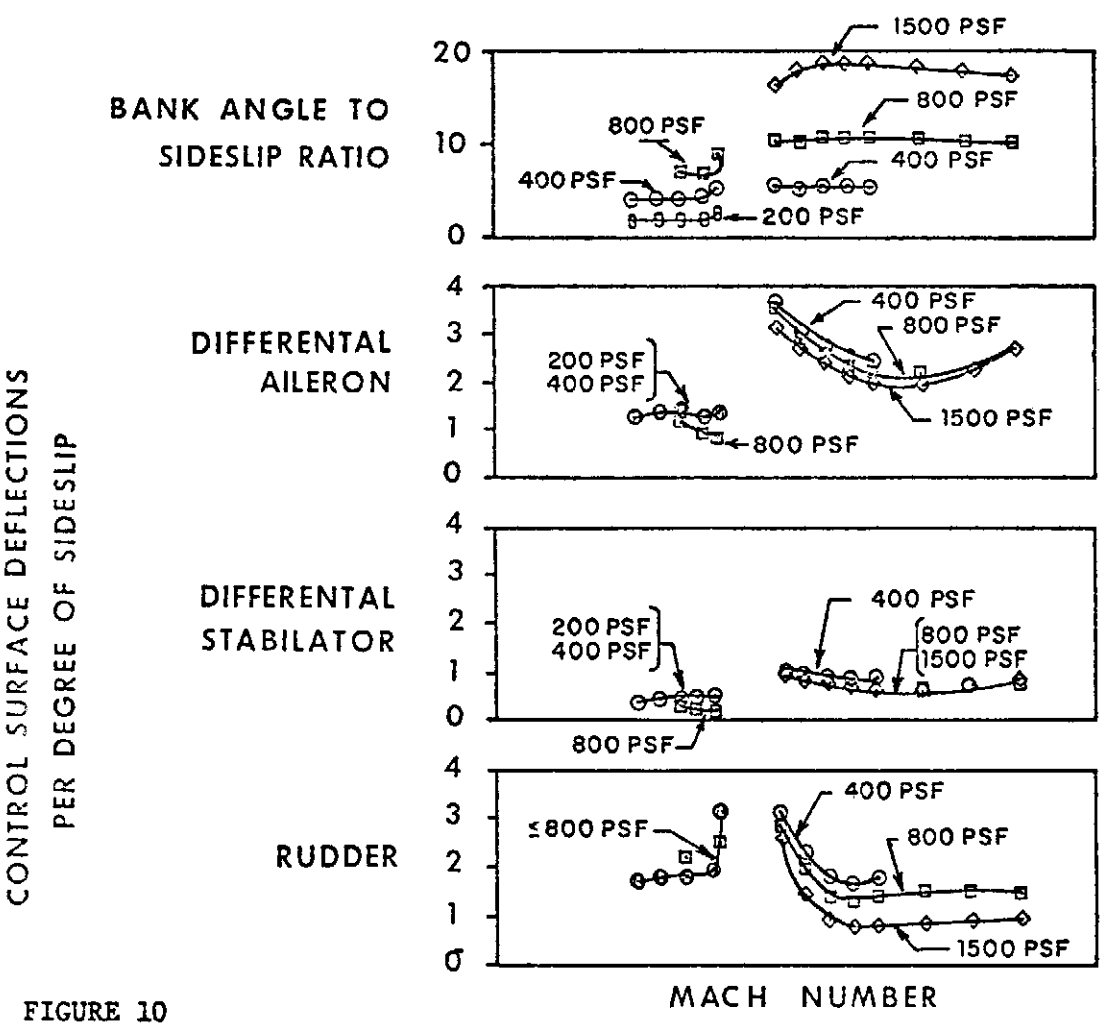


FIGURE 9

NOTE: Dashed lines represent loading 1.

STATIC LATERAL-DIRECTIONAL STABILITY



SYMBOL	DYNAMIC PRESSURE
⊖	200 PSF
○	400 PSF
□	800 PSF
◇	1500 PSF

NOTES:

1. Data points were computed from stability derivative data.
2. Fairings represent data point fairings

FIGURE 10

ASYMMETRIC THRUST CONTROL REQUIREMENTS - AILERON

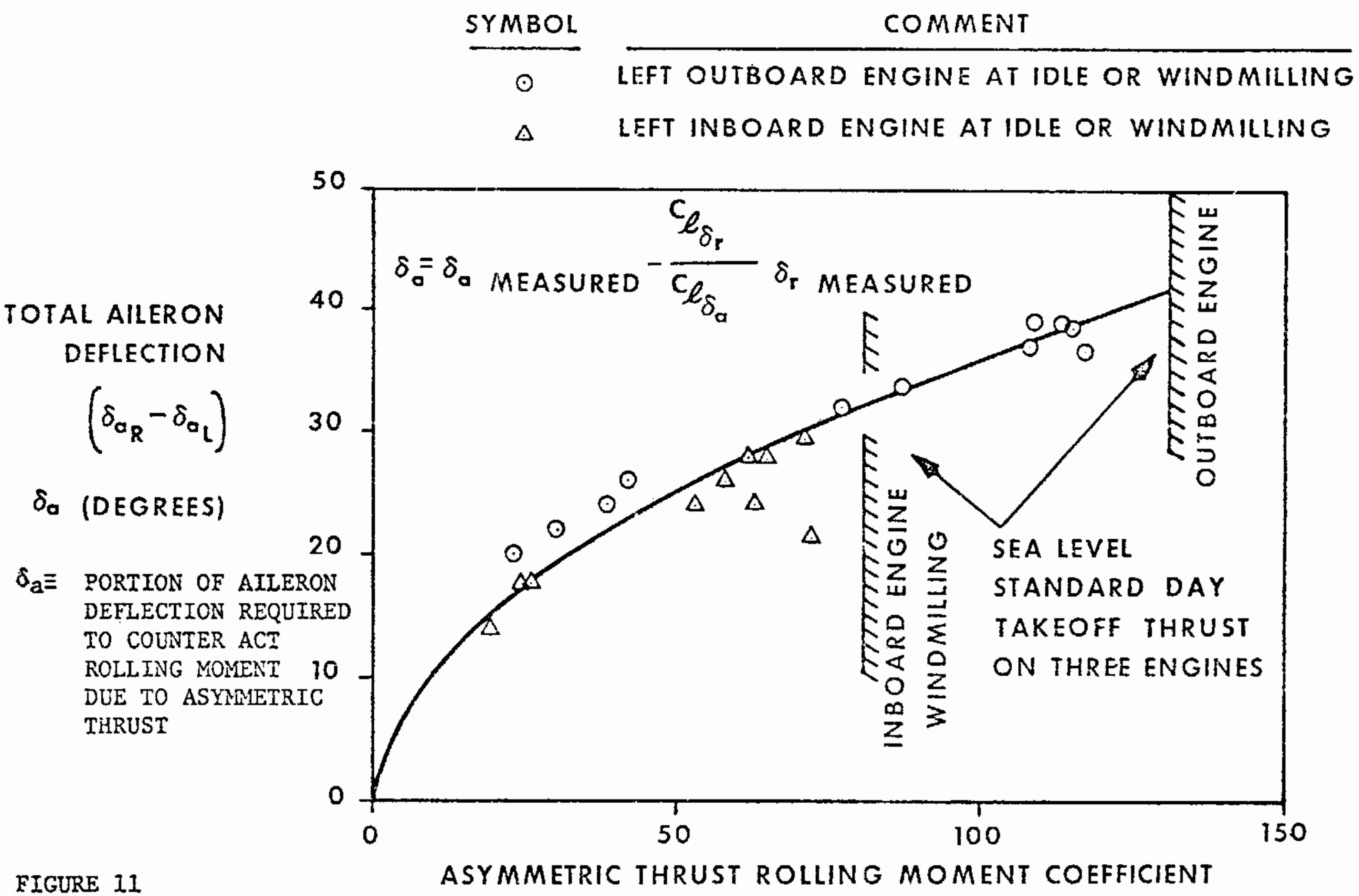


FIGURE 11

*U.S.Government Printing Office: 1979 — 657-002/408