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HIGH ANGLE OF ATTACK FLYING QUALITIES AND DEPARTURE CRITERIA DEVELOPMENT

AN INFORMAL REPORT BY

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ABSTRACT

The need for flying qualities and criteria for advanced aircraft is highlighted by the results of a recent survey, and the evolution of USAF high-angle-of-attack flying qualities requirements is documented.

The objectives and some preliminary results of three current AFFDL contracted efforts are presented. Inhouse efforts are also summarized. The goal of the AFFDL high-angle-of-attack program is to correlate desired aircraft behavior with intelligent flying qualities requirements and in turn relate these to suitable design methods. Results will be incorporated into the MIL-PRIME-Standard and Handbook.

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HIGH-ANGLE-OF-ATTACK FLYING QUALITIES AND DEPARTURE CRITERIA DEVELOPMENT

by

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Flight in the high-angle-of-attack regime is as common today as it was during man's first attempts at flight. All aircraft experience some degree of high-angle-of-attack flight during the take-off and landing phases while modern fighter aircraft experience even higher angles of attack in air combat maneuvering. During these types of maneuvers, the nonlinear high-angle-of-attack aerodynamic characteristics are likely to be the dominant factors in terms of maneuverability and safety of flight. It is important, therefore, to have a definitive set of flying qualities requirements for this flight regime and the capability to design aircraft which meet or exceed these requirements.

The need for a definitive set of requirements was apparent from the results of a survey (Ref. 1) on the future of research on flying qualities and criteria for highly augmented aircraft. Some important findings of this survey are summarized below:

a. Out of the 41 respondents, 90% indicated that there is a need for more research to better define flying qualities for highly augmented aircraft.

b. Of the above 90%, 92% of the response indicated that for highly maneuverable aircraft, this need was either important or critical, with 32% mentioning a need for more research in high-angle-of-attack and stall/spin characteristics specifically.

c. When asked to rate the importance of several areas of flying qualities research, 73% rated research on the limit-of-performance regions (such as high-angle-of-attack maneuvering) as high with 54% rating research on nonlinear flight regimes (such as large-amplitude maneuverability) as high.

With such a high percentage of the responses indicating the need for more research in high-angle-of-attack flying qualities, one must wonder how this regime is treated in the current flying qualities specification, MIL-F-8785B(ASG), "Flying Qualities of Piloted Aircraft" (Ref. 2).

One of the results of the December 1971 Stall/Post-Stall/Spin Symposium (Ref. 3) was the change in emphasis from requirements for developed spins and their recovery to the need for departure resistance. This redirection was reflected in the March 31, 1971 Amendment 1 to MIL-8785B. This amendment was largely qualitative in its characterization of the desirable high-angle-of-attack flying qualities. It emphasized resistance to departure and simple recovery along with loss-of-control warning. Some of these qualitative requirements were also accompanied by quantitative limits on such variables as sideslip, oscillatory bank angle, stall onset rate, etc. Most of these quantitative aspects were also incorporated in MIL-S-83691 (USAF), 31 March 1971 (Table I) and MIL-S-83691A (USAF), 15 April 1972, "Stall/Post-Stall/Spin Flight Test Demonstration Requirements for Airplanes," (Ref. 4). When Amendment 2 to MIL-F-8785B, 15 April 1973, was prepared, the quantitative requirements were deleted and its stall/post-stall/spin requirements remained primarily qualitative in nature. Amendment 2 does contain the current high-angle-of-attack flying qualities requirements (Ref. 5).

Since the evolution of the above amendments to the present specification, there have been major developments in flight control system design including new control devices, aerodynamic designs, air combat tactics, and an enhanced appreciation for the desirability of high-angle-of-attack flight. The current specification does not reflect any of these major developments. The proposed Amendment 3 to MIL-F-8785B, while still qualitative in nature, does begin to address some of the aforementioned developments. However, with the approach of the "MIL-PRIME-STD" and the supporting Handbook ("MIL-HDBK"), significantly more quantitative research is required in order to satisfactorily determine desirable high-angle-of-attack flying qualities requirements and appropriate design criteria. The AFFDL has a series of ongoing and planned research and development efforts that will attempt to provide some of the needed quantitative data. Each of these efforts is summarized below.

IDENTIFICATION OF KEY MANEUVER-LIMITING FACTORS, AFFDL CONTRACT NO. F33615-76-C-3072, SYSTEMS TECHNOLOGY, INC.

OBJECTIVE/APPROACH:

The objectives of this effort are to identify key design parameters that limit high-angle-of-attack maneuverability for several high-performance fighter aircraft and to postulate fundamental aerodynamic and control system design methodologies that will alleviate the limiting conditions. The key parameters and the design methodology will be validated and further investigated in a manned simulation of the aircraft and control system dynamics used in the analysis. Methods and criteria will be developed for evaluation of handling qualities describing high-angle-of-attack maneuvering flight. Consideration will be given to the following factors:

a. Applicability of the Cooper-Harper rating scale to the pilot tasks associated with high-angle-of-attack maneuvering flight in and about the limiting conditions. Potential definition of a scale more suited to description of handling qualities near the limiting conditions.

b. Fixed-base vs. moving-base simulation. Displays and instrumentation required for evaluation of handling qualities associated with the high-angle-of-attack maneuvering flight.

c. Definition of simulation tasks required to best evaluate handling qualities associated with the high-angle-of-attack maneuver-limiting conditions.

The results of this study will be used to formulate generalized design guides, handling qualities criteria and requirements for high-angle-of-attack maneuvering flight which can be incorporated into MIL-F-8785B.

PROGRESS:

This contract was awarded to Systems Technology, Inc. (STI), in May 1976, to investigate the F-4 and F-14 aircraft. The limiting conditions for each aircraft and associated causal factors were identified, but have not been validated through a manned simulation. For the F-4, the limiting factors and associated causal factors are:

wing rock

- unstable Dutch roll
- nonlinear aerodynamic interaction

yaw SAS ineffective

$\omega_r > \omega_d$

$\omega_{SR} < 1/T_{\theta_3}$

- improve via

$a_y \rightarrow \delta_r$

$p \rightarrow \delta_a$

roll control via lateral stick

- divergent because ω_ϕ^2 negative

- correct with stick-rudder crossfeed

nose slice divergence

- nonminimum-phase zero, $N^{\theta}_{\delta_e}$

- due to N'_{α}, L'_{α}

- open loop or push stick to recover.

For the F-14, the limiting factors and associated causal factors are:

wing rock

- unstable Dutch roll (small C_{ℓ_p}, negative C_{n_p}, small negative C_{n_β})

roll reversal

- negative $C_{n_{\delta a}}(\omega^2_{\phi})$

key flight control consideration (preliminary analysis)

- augment C_{ℓ_p} via roll rate CAS

- augment C_{n_β}, C_{n_p} via sideslip stability augmentor

- reduce $C_{n_{\delta a}}$ via aileron to rudder interconnect.

Although STI has not performed the manned simulation, they have developed the definition of simulator tasks, a tentative departure rating scale, and a questionnaire for the overall assessment of the configuration. The simulation tasks are presented in Table II. The pilot rating scale is shown in Figure 1 with the assessment questionnaire presented in Table III.

Overall program results will be available in August 1979.

HIGH-ANGLE-OF-ATTACK DESIGN GUIDES AND FLYING QUALITIES CRITERIA, AFFDL CONTRACT NO. F33615-78-C-3604, SYSTEMS TECHNOLOGY, INC.

OBJECTIVE/APPROACH:

This effort consists of both gathering and analyzing existing data required to provide new and/or improved high-angle-of-attack flying qualities requirements and design guides. An extensive literature survey and a comprehensive series of personal visits to various organizations in the aeronautical community will be used to revise high-angle-of-attack flying qualities specifications. The design guides effort consists of gathering high-angle-of-attack design guides from several sources and performing appropriate analysis for verification. This effort will include both aerodynamic and control system design methodologies. Aerodynamic data and flight characteristics will be used for correlation with existing or potential new guides. Results will be presented in compendium form. Future areas for technical development will be suggested and justified. Consideration will be given to the relationship of application of guides to obtaining adequate flying qualities.

PROGRESS:

This contract was awarded to Systems Technology, Inc. in April 1978. The extensive literature search and survey of designers and users are currently being conducted.

THE DEVELOPMENT OF AN AIRCRAFT DEPARTURE CRITERION AND ASSOCIATED DESIGN CHARTS, CONTRACT NO. N62269-77-C-0106/DEPARTURE TRENDS FOR CCV AIRCRAFT, CONTRACT NO. F33615-78-C-3600, BIHRLE APPLIED RESEARCH, INC.

OBJECTIVE/APPROACH:

The objective of the NADC effort was to generate design charts and associated boundaries for identifying departure and uncoordinated roll-reversal flight characteristics as a function of three aerodynamic parameters: C_{ℓ_β}, C_{n_β}, and $C_{n_{\delta a}}$, including several variations in each.

The objective of the AFFDL effort is to investigate departure characteristics of an aircraft that is statically unstable in pitch and to determine if significant trends can be correlated with aerodynamic characteristics and variations in the flight control system. Three levels of static instability will be studied using the aerodynamic characteristics developed for the NADC contract as a basis for this investigation. Since the basic configuration did not require a flight control system, the contractor is required to design a simple longitudinal system to artificially provide the original level of static stability. The resulting control system will also include a simple angle-of-attack limiting system. The effects of the C_{ℓ_β}, C_{n_β}, and $C_{n_{\delta a}}$ variations developed in the NADC effort and the influence of the developed flight control augmentation system will be determined for the unstable configurations. The results of this effort will be correlated with those of the NADC effort to determine trends in the departure characteristics of statically unstable aircraft.

PROGRESS:

Both contracts were awarded to Bihrle Applied Research, Inc. The NADC effort was completed in July 1978, with a final report submitted at that time. The AFFDL contract was awarded in May 1978.

NADC CONTRACT - FINAL RESULTS (Ref. 6)

A departure boundary for each level of $C_{n_{\delta a}}$ is shown in Figure 2. For combinations of C_{n_β} and C_{ℓ_β} above the boundary, departure does not occur. For combinations below the boundary, departure occurs for the maneuvers used in this study. Using the bank angle information obtained in the development of the design charts, roll-reversal boundaries were developed. These boundaries, shown in Figure 3, are not departure boundaries but uncoordinated roll-reversal boundaries requiring the pilot to apply rudder to coordinate the maneuver.

AFFDL CONTRACT

Since the contract was begun in May, limited progress can be reported at this time. The effects of variations in C_{m_q} and C_{m_β} were investigated in order to determine their influence on the departure boundaries developed under the NADC effort. Preliminary results indicate the following:

a. Reducing the C_{m_q} level could result in a significant alteration of the departure boundaries.

b. A positive C_{m_β} level could alter the departure boundary slightly.

c. A negative C_{m_β} would more seriously change the boundary.

AERODYNAMIC HYSTERESIS EFFECT ON FLYING QUALITIES - INHOUSE EFFORT

OBJECTIVE/APPROACH:

One of the second-order (nonlinear) effects that may significantly change an aircraft's flying qualities at high angles of attack is aerodynamic hysteresis. By making the aerodynamic coefficients double-valued functions, changes occur in derivative definition and zero β data (trim requirements, control power). The objective of this effort has been to determine the effects of an idealized hysteresis loop and to define hysteresis uncovered in wind tunnel data (AFFDL-TM's 76-75-FGC and 78-91-FGC). Future efforts will involve further wind tunnel studies and mathematical definition of the phenomenon and its effects on pilot-in-the-loop simulations.

PROGRESS:

Hysteresis has been shown to be a potential cause of wing rock (TM-76-74) and some examples of its existence in wind tunnel data have been found (TM-78-91). Further work may be appended to wind tunnel tests or simulations as the opportunities arise. Work in the area by other organizations will be encouraged and supported if resources are available.

ROLL/PITCH INERTIAL COUPLING OF A STATICALLY UNSTABLE AIRCRAFT - INHOUSE EFFORT

OBJECTIVE/APPROACH:

The objective of this effort is to determine the effect of various levels of stability-axis yaw rate (αp-r) feedback on the roll/pitch coupling departures of a statically unstable lightweight-fighter configuration at low airspeeds and high roll rates. The influence that these levels have on other high-angle-of-attack maneuvers will also be assessed. Both digital computer and pilot-in-the-loop simulations will be used for the analysis. By varying the gain K on the K(αp-r) feedback loop, a check will be made to determine any change in the aircraft's roll characteristics and stabilator movement. The maximum stabilator displacement limit and the center of gravity location will be varied in order to identify their effects on the inertial coupling during the rolling maneuvers. The manned simulation task will provide additional evaluation through the investigation of several maneuvers. The simulation pilots will also rate the handling qualities of the aircraft for each maneuver using both the Cooper-Harper and several potential high-angle-of-attack rating scales.

PROGRESS:

A digital computer simulation at the AFFDL and a manned simulation at the AFFTC have been completed. Results from the two simulations have not been correlated at this time. Based on some preliminary comments from the AFFTC, the pilots have reacted favorably to the new rating scales. More detailed comments from the pilots will be forwarded to Systems Technology, Inc. to be included in their work on deriving a new high-angle-of-attack rating scale.

EVALUATION OF CRITERIA TO PREDICT LATERAL-DIRECTIONAL DIVERGENCE AT HIGH-ANGLES-OF-ATTACK - INHOUSE EFFORT

OBJECTIVE/APPROACH:

The $C_{n_{\beta_{DYN}}}$, aileron-alone and lateral-control departure parameters will be calculated for several levels of lateral-directional static stability characteristics. A comparison will then be made in an attempt to correlate these parameters with computer-generated departure susceptibility time histories of a statically unstable lightweight-fighter configuration incorporating an advanced flight control system. The calculated departure parameters will also be compared to the migration of the roots of the lateral-directional characteristic equation. Based upon the results of this investigation, conclusions on the use of the departure parameters in the presence of a flight control system and recommendations for future work will also be made.

PROGRESS:

Two C_{n_β}, C_{ℓ_β} combinations were defined that would result in significantly different lateral-directional stability characteristics. These combinations were used to develop the $C_{n_{\beta_{DYN}}}$ (Fig. 4), aileron-alone (Fig. 5) and lateral-control departure parameters. These parameters by themselves and with the crossplot of $C_{n_{\beta_{DYN}}}$/aileron-alone departure parameter (Fig. 6) and $C_{n_{\beta_{DYN}}}$/lateral-control departure parameter were used to predict where lateral-directional departures will occur.

In order to assess the ability of these parameters to predict departures for this configuration, a digital computer simulation was conducted using the two C_{n_β}, C_{ℓ_β} combinations. The simulation was performed with the longitudinal and lateral-directional control system feedbacks open and also with the lateral-directional feedbacks closed. These two levels of augmentation were investigated in order to determine if significant changes in the departure characteristics would be obtained. The simulation task involved a simple 360° roll about trim points at high angles of attack. The resulting motions were analyzed and correlated with the predicted departure characteristics. These same motions were also correlated with the root migration of the lateral-directional characteristic equation (Figs. 7, 8).

Final analysis and correlation of this effort has not been completed at this time. Results, when available, will be published in AFFDL-TM-78-56-FGC.

DEPARTURE CRITERIA VALIDATION AND EVALUATION - PROPOSED INHOUSE EFFORT

OBJECTIVE/APPROACH:

Criteria relating departure from controlled flight to various stability and control parameters have been developed (Refs. 6, 7) using certain "typical" configurations and for varying degrees of linearization. In order for the aircraft designer to confidently use these criteria, they must be validated for different flight maneuvers and stability and control characteristics. In addition, the designer needs to know which parameters are most crucial for departure resistance or recovery. He also needs to know how accurately they need to be calculated during the design phase. Existing computation methods (e.g., Datcom, FLEXSTAB) are currently not appropriate for use in the high-angle-of-attack regime. An evaluation will therefore be made to determine the most crucial design parameters in terms of a configuration's departure sensitivity as well as how accurately they must be determined by revised computation methods in terms of variations with angle of attack and sideslip.

The models, maneuvers, and assumptions used in determining the various departure criteria will be compared and contrasted with other available knowledge. Where appropriate, further criteria development or validation will be made via sensitivity analyses on a six-degree-of-freedom computer program. Aircraft mathematical models will also be devised to test for the most crucial designer-estimated parameters. These models will include non-linearities with angle of attack and sideslip. The sensitivity of the resulting aircraft motion and departure susceptibility to variations in the estimated parameters will be determined.

BENEFITS:

Besides providing guidance to aircraft designers on what makes a departure-resistant configuration, this effort will also contribute to two other elements of the Flight Dynamics Laboratory's stability and control research. It will identify the most crucial parameters which need to be predicted with a quantifiable accuracy by improved design predictions techniques. In addition, an understanding of discrepancies between stability and control parameters derived from prediction methods, wind-tunnel measurements, and flight tests will be developed for the high-angle-of-attack regime in conjunction with a broad, new stability and control data discrepancies effort.

CONCLUSION:

In summary, the Control Dynamics Branch of the Flight Dynamics Laboratory is undertaking to identify and solve some of the major problems that degrade the flying qualities of military aircraft in the high-angle-of-attack regime. Closed-loop linearized work that applies to task-oriented flying qualities is being done by contractors such as STI. Open-loop nonlinear analysis pertaining to departure susceptibility is being done both in-house and on contract. Problems involving statically unstable aircraft are also being addressed. Work sponsored by other government agencies will be monitored through the DOD/NASA Stall/Spin Coordinating Committee.

Over the next few years, we hope to develop a good understanding of the state of the art in high-angle-of-attack flying qualities, airframe and flight control system design, and departure resistance criteria. This will enable us to correlate the desired aircraft behavior at high angles of attack with intelligent flying qualities specifications. The end product will be much needed quantitative requirements and guidance to incorporate into the coming Mil-Prime-Standard and its Handbook.

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4. Sharp, P. S., and C. E. McElroy, Background Information and Users Guide for MIL-S-83691, AFFTC-TD-73-2, March 1974.

5. MIL-F-8785B, Amendment 2, 16 September 1974. "Proposals for Revising MIL-F-8785B 'Flying Qualities of Piloted Aircraft' Volume I, Proposed Revisions," AFFDL-FGC-Working Paper, August 1977.

6. Bihrle, William, Jr., and Barnhart, B., Design Charts and Boundaries for Identifying Departure Resistant Fighter Configurations, NADC-76154-30, July 1978.

7. Weissman, Robert, Criteria for Predicting Spin Susceptibility of Fighter-Type Aircraft, ASD-TR-72-48, June 1972.

TABLE I

FLIGHT TEST DEMONSTRATION MANEUVERS

Test Phase	Maneuver Requirements					
	Control Application	Entry Conditions[1]				
		Smooth AOA Rate[4]		Abrupt AOA Rate[5]		Tactical[6]
		One g	Accelerated[3]	One g	Accelerated[3]	
A Stalls	Pitch control applied to achieve the specified AOA rate, lateral/directional controls neutral or small lateral/directional control inputs as normally required for the maneuver task. Recovery initiated after the pilot has a positive indication of: (a) A definite g-break, or (b) a rapid angular divergence, or (c) the aft stick stop has been reached and AOA is not increasing.	Class: I, II, III, IV	Class: I, II, III, IV	Class: I, II, III, IV	Class: I, IV	Class: I, IV
B Stalls with Aggravated Control Inputs	Pitch control applied to achieve the specified AOA rate, lateral/directional controls as required for the maneuver task. When condition (a), (b), or (c) from above has been attained, controls briefly misapplied,[7] intentionally or in response to unscheduled aircraft motions, before recovery attempt is initiated.	Class: I, II, III, IV	Class: I, II, III, IV	Class: I, II, III, IV	Class: I, IV	Class: I, IV
C Stalls with Aggravated and Sustained Control Inputs	Pitch control applied to achieve the specified AOA rate, lateral/directional controls as required for the maneuver task. When condition (a), (b), or (c) has been attained, controls are misapplied[7,9], intentionally or in response to unscheduled aircraft motions, and held for 3 seconds[8,9] before recovery attempt is initiated.	Class: I, II, III, IV	Class: I, II, III, IV	Class: I, II, III, IV	Class: I, IV	Class: I, IV
D Spin Attempts[2,10] (this Phase required only for training aircraft which may be intentionally spun and for Class I and IV aircraft in which sufficient departures or spins did not result in Test Phases A, B, or C to define characteristics)	Pitch control applied abruptly, lateral/directional controls as required for the maneuver task. When condition (a), (b), or (c) has been attained, controls applied in the most critical positions to attain the expected spin modes of the aircraft and held for up to 15 seconds before recovery attempt is initiated, unless the pilot definitely recognizes a spin mode.			Class: I, IV	Class: I, IV	Class: I, IV

TABLE II
TASK DEFINITIONS FOR RATING
HIGH-ANGLE-OF-ATTACK MANEUVERS

1. Straight Ahead Stall
   a. Keep wings level.
   b. Maintain constant heading.
   c. Continue stick ramp until one of the following occurs:

      (1) Definite g-break occurs
      (2) Aft stick limit is reached
      (3) Aircraft departs

      These events shall constitute the definition of "stall" in the following task descriptions.

2. Constant Attitude Stall
   a. Pitch to and maintain constant value of pitch attitude.
   b. Reduce power until stall occurs.
   c. Maintain constant heading.
   d. Keep wings level.

3. Bank-to-Bank Turns
   a. Establish 60-degree bank turn.
   b. Reverse direction using rapid roll rate to 60 degrees in other direction.
   c. Hold pitch attitude approximately constant.
   d. Repeat maneuver increasing pitch attitude each time until stall occurs.
   e. When stall occurs recover to wings-level flight with heading approximately equal to heading at stall.
   f. Rating should pertain to Task 3e

4. Wind-Up Turns
   a. Initiate moderate roll rate.
   b. Maintain altitude approximately constant by increasing back pressure until stall occurs.
   c. When stall occurs, recover to wings-level flight with heading approximately equal to heading at stall.
   d. Rate Task 4c.

5, 6 Track Target (5→steady climb; 6→bank-to-bank turns)
   a. Employ maximum effort to stay on target's tail; however, do not consider ability to keep pipper on target in ratings.
   b. When aircraft stalls, your task is to recover to wings-level flight in same general direction as when stall occurred in the minimum time.
   c. Angular excursions should start decreasing shortly after recovery controls are applied.
   d. Performance should take into account the peak angular and angular rate excursions at stall.

TABLE III
OVERALL ASSESSMENT OF CONFIGURATION

1. Departure Resistance

   a. Extremely susceptible to departure.

   b. Susceptible to departure.

   c. Resistant to departure.

   d. Extremely resistant to departure.

2. Departure Warning

Discuss warning characteristics with respect to accomplishment of mission. Some aspects of this are:

   a. Does warning allow me to utilize a greater portion of the flight envelope?

   b. Does warning interfere with the primary task?

   c. Is warning consistent across all types of entry? Is this type of consistency even desirable?

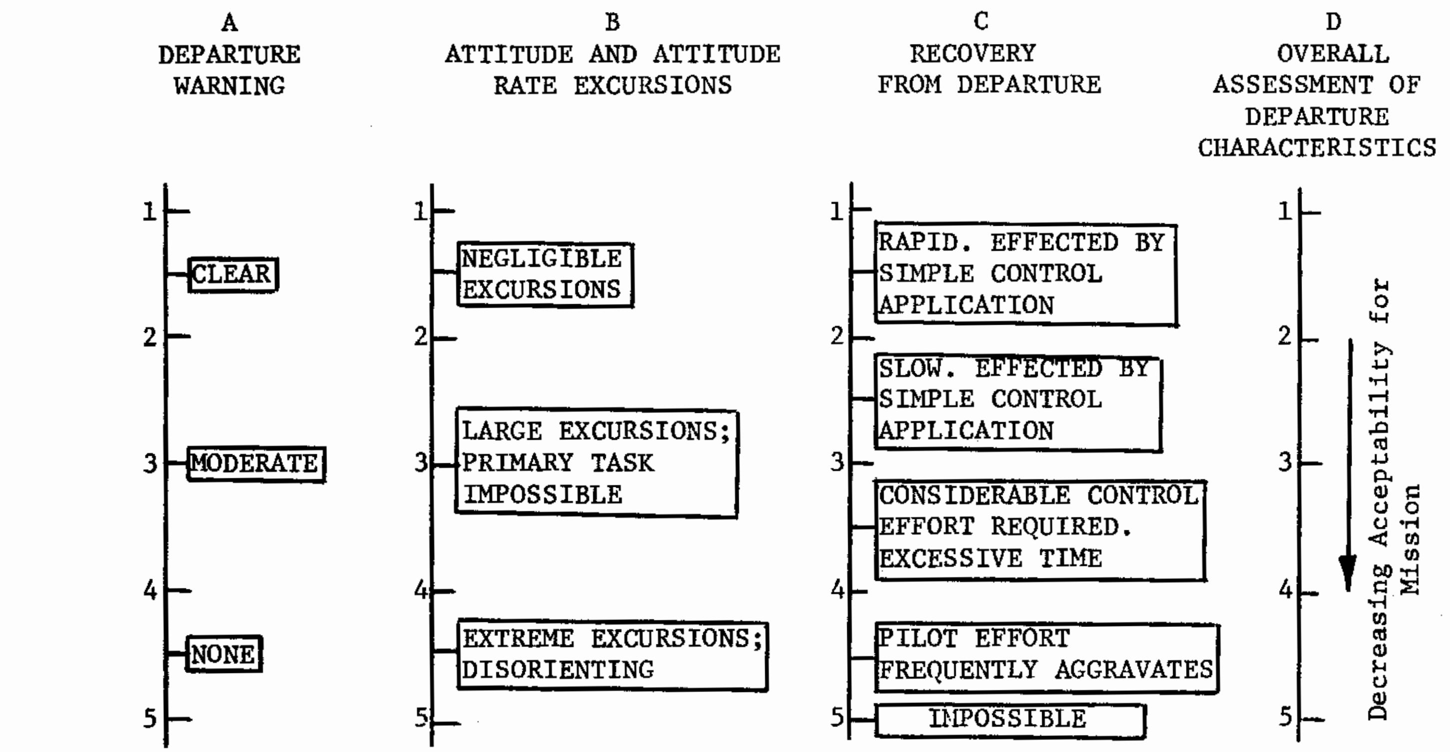
   d. Are the departure modes of this aircraft predictable?

3. Departure Recovery

Is there a unique recovery technique that always works?

4. Departure Severity

Are departure motions ever large enough to constitute a mission hazard worthy of a flight restriction?



- Describe warning
- Did warning interfere with primary task? If so, to what extent?

- Describe departure sequence
  1. Nose slice
  2. Wing rock
  3. Rolling departure
  4. Pitch up

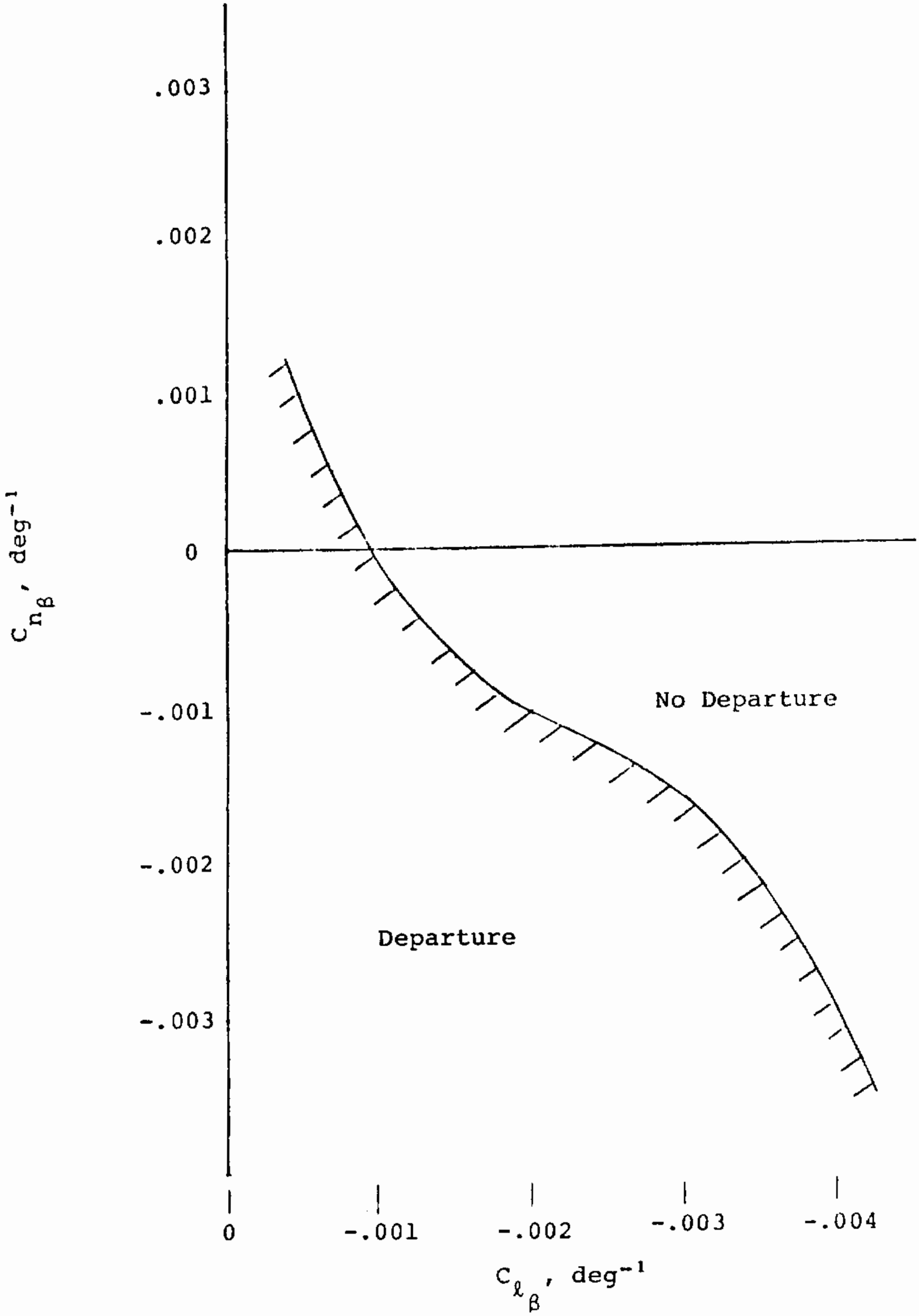
- What was primary departure variable? ($\theta, \dot{\theta}, \psi, \dot{\psi}, \phi, \dot{\phi}$)

- Was attitude loss primarily due to a path divergence or to attitude excursions?

- Fighter
- Trainer

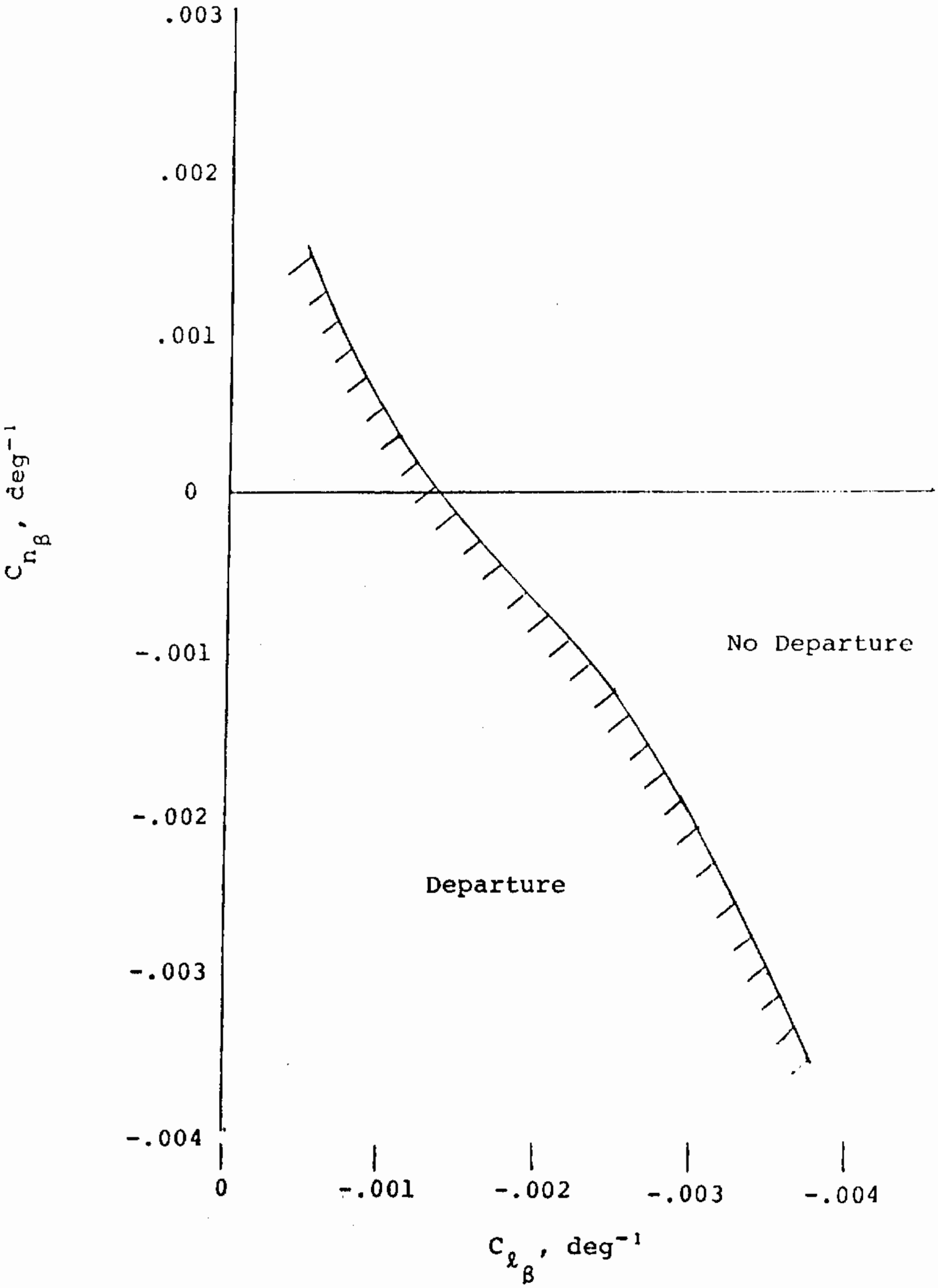
FIGURE 1

TENTATIVE DEPARTURE RATING SCALE



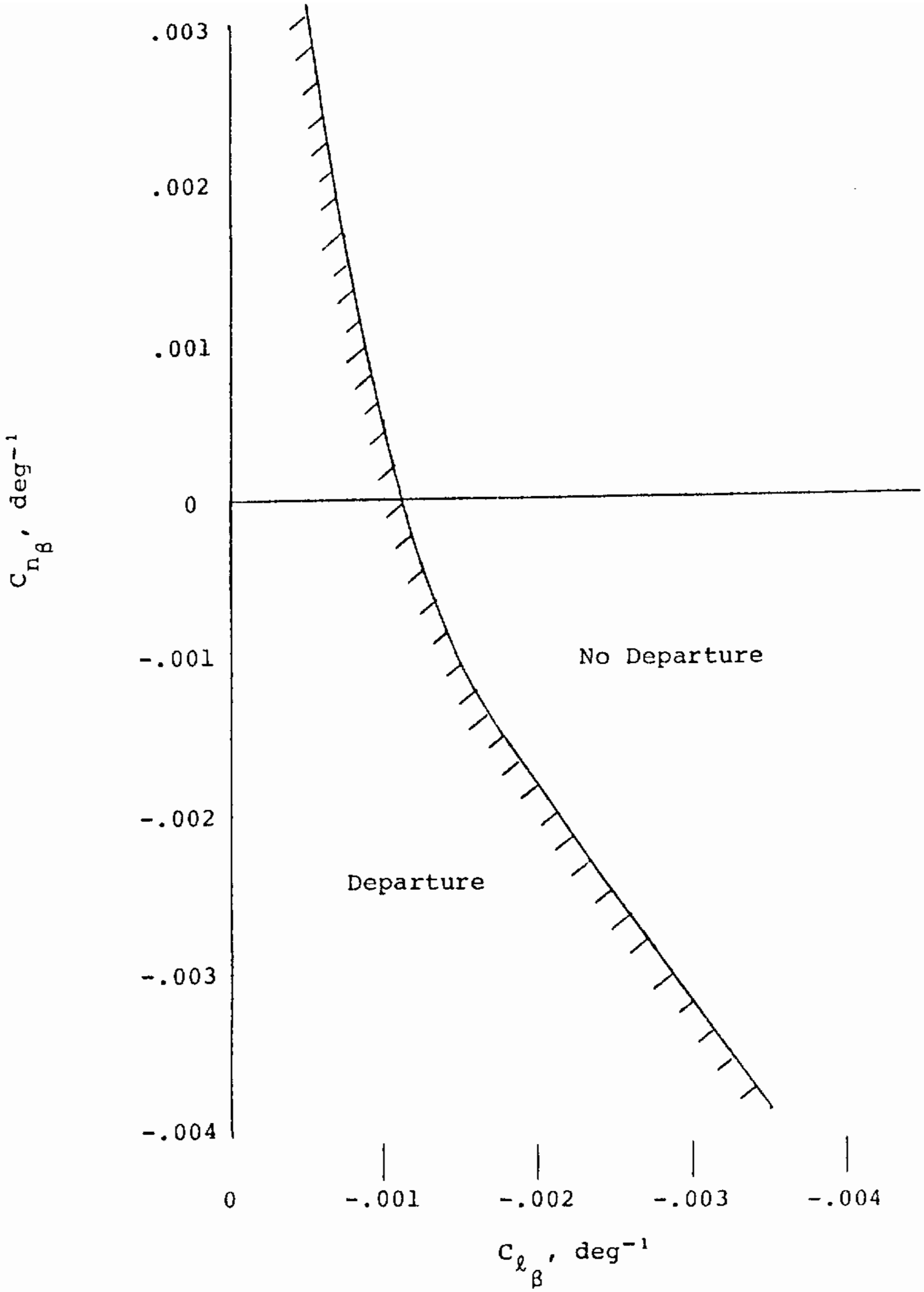
(a) Adverse $C_{n_{\delta_a}}$

Figure 2.- Departure boundaries. (From Ref 6)



(b) Neutral $C_{n_{\delta_a}}$

Figure 2.- Continued.



(c) Proverse $C_{n_{\delta_a}}$

Figure 2.- Concluded.

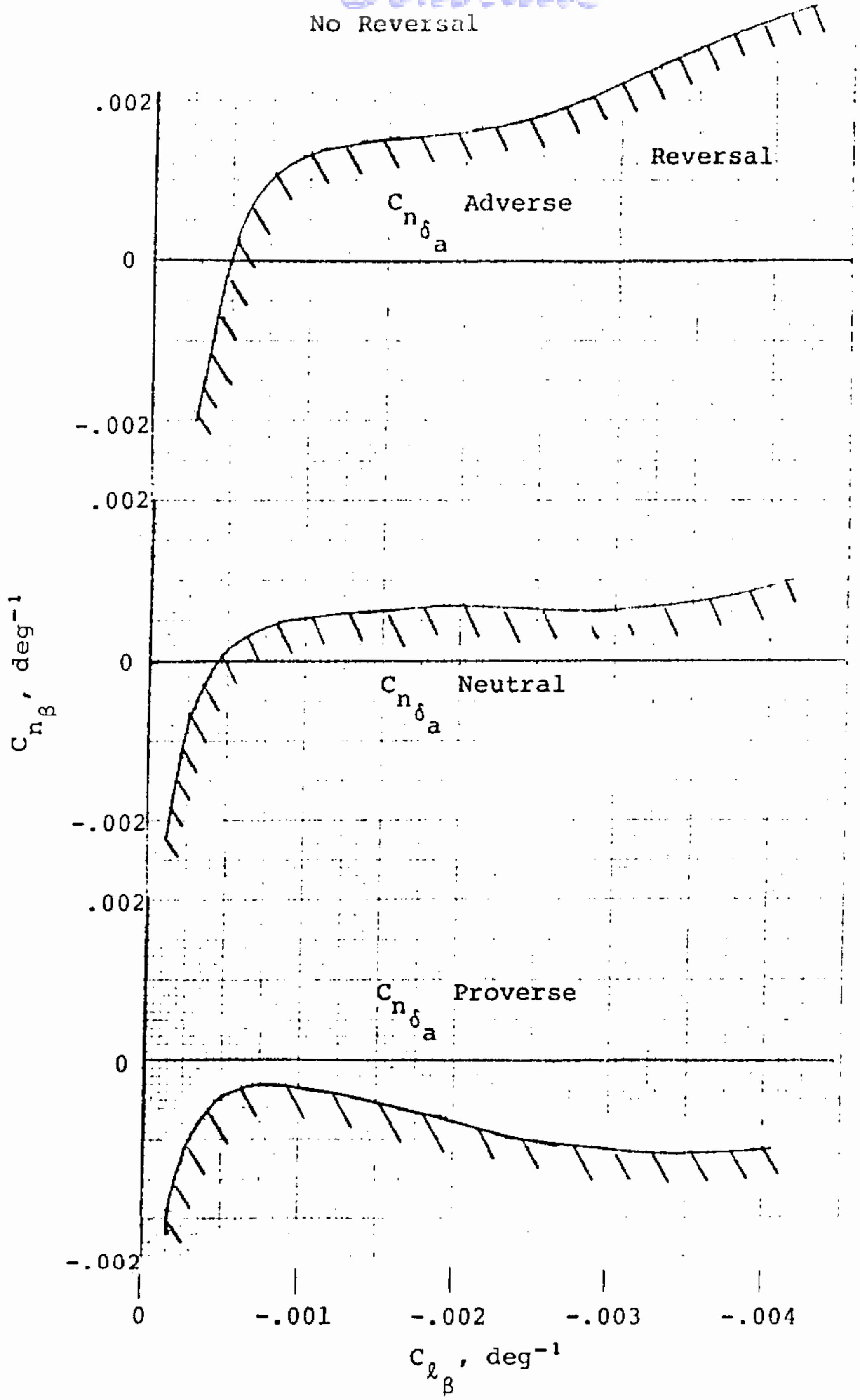
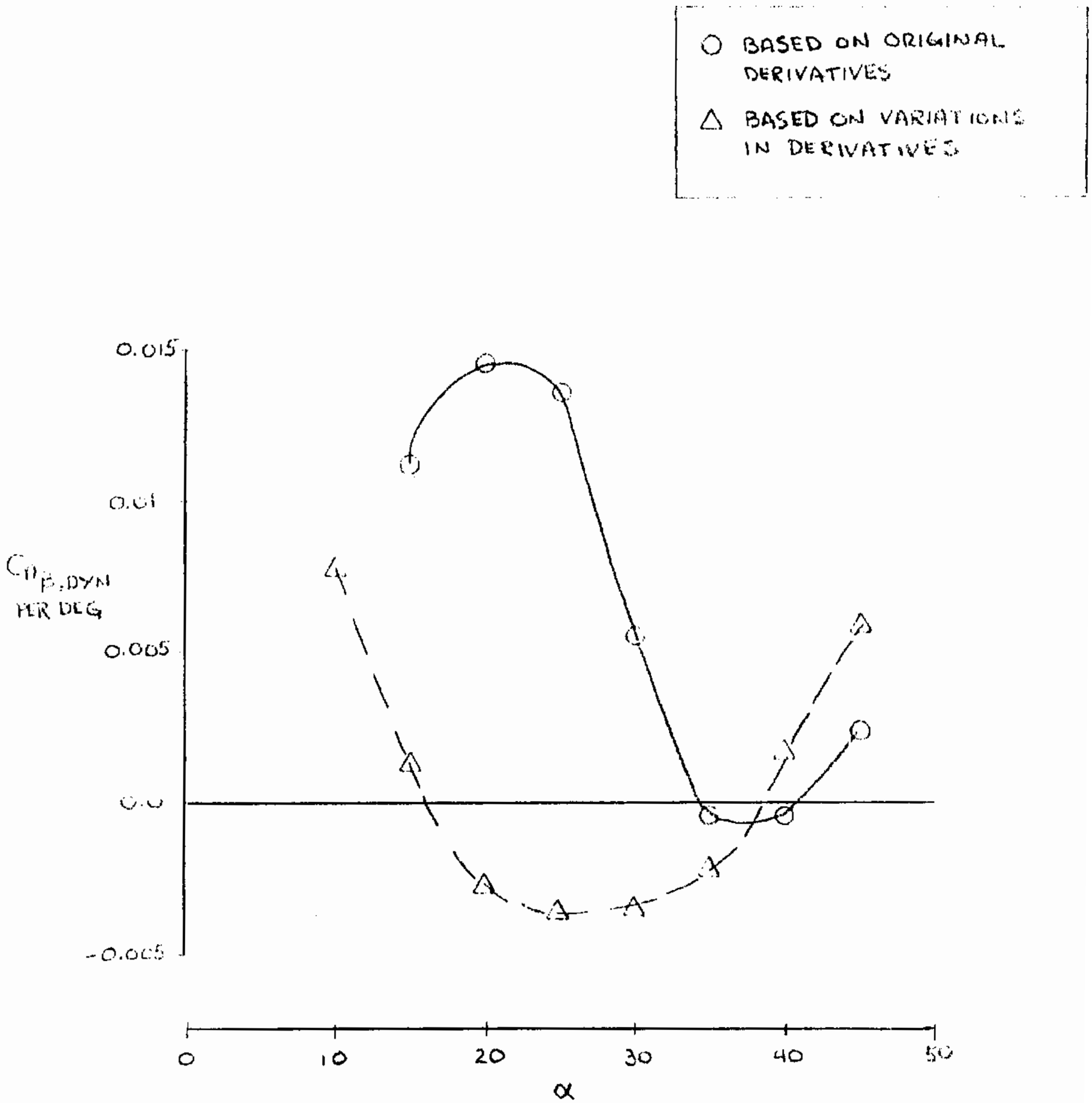
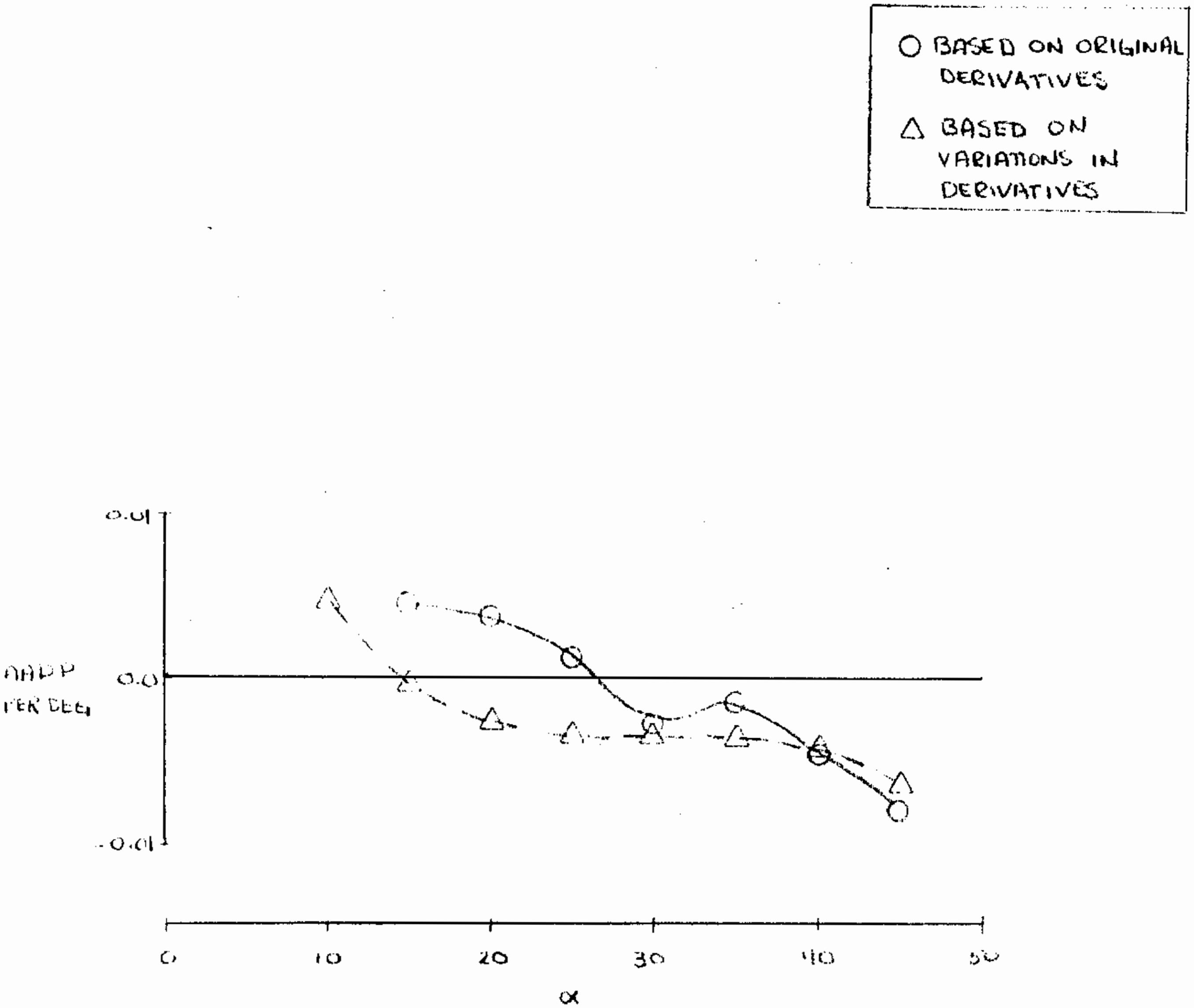


Figure 3 - Uncoordinated roll-reversal boundary. (From Ref. 6)



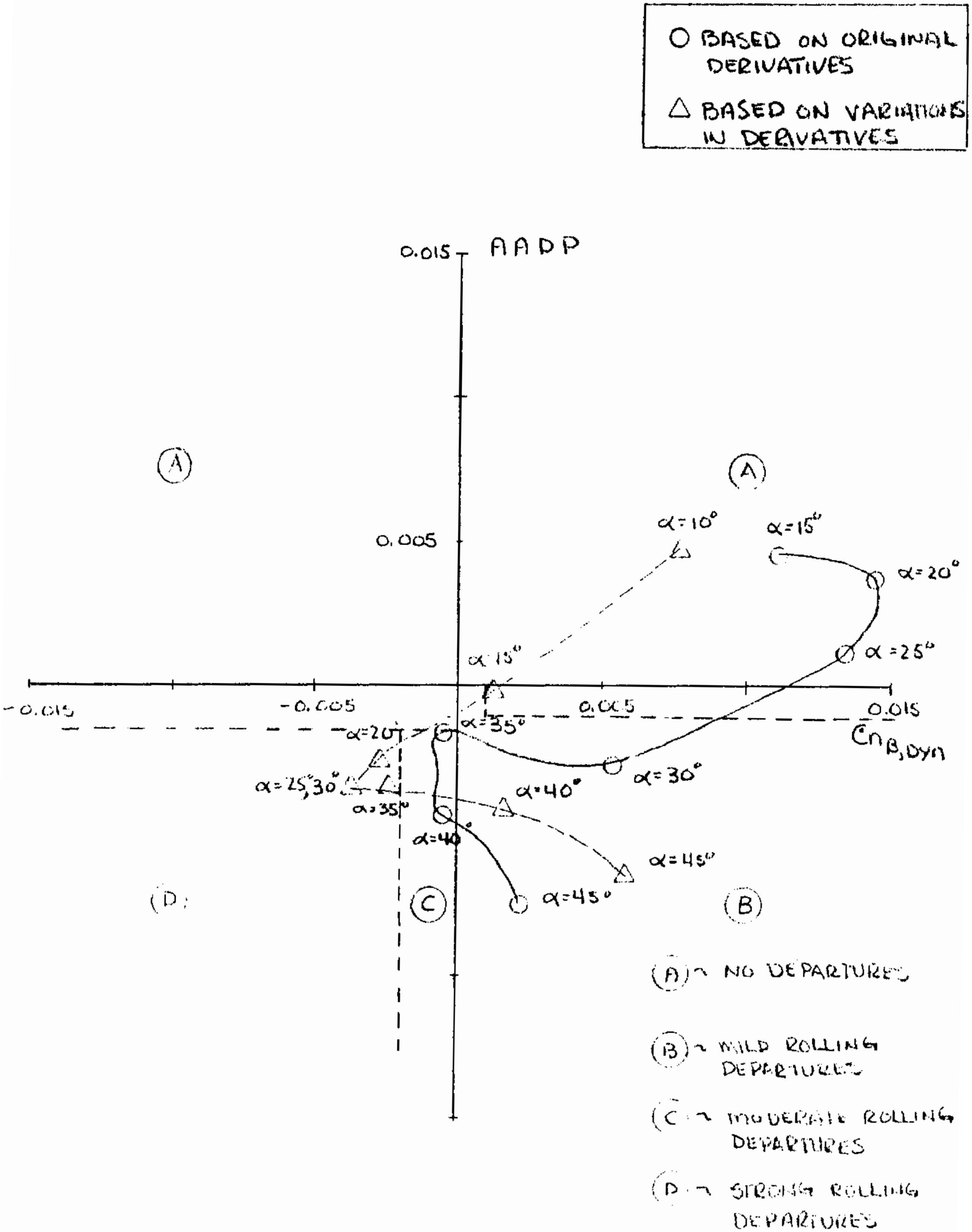
Variation of $Cn_{\beta,DYN}$ with angle of attack

Figure 4



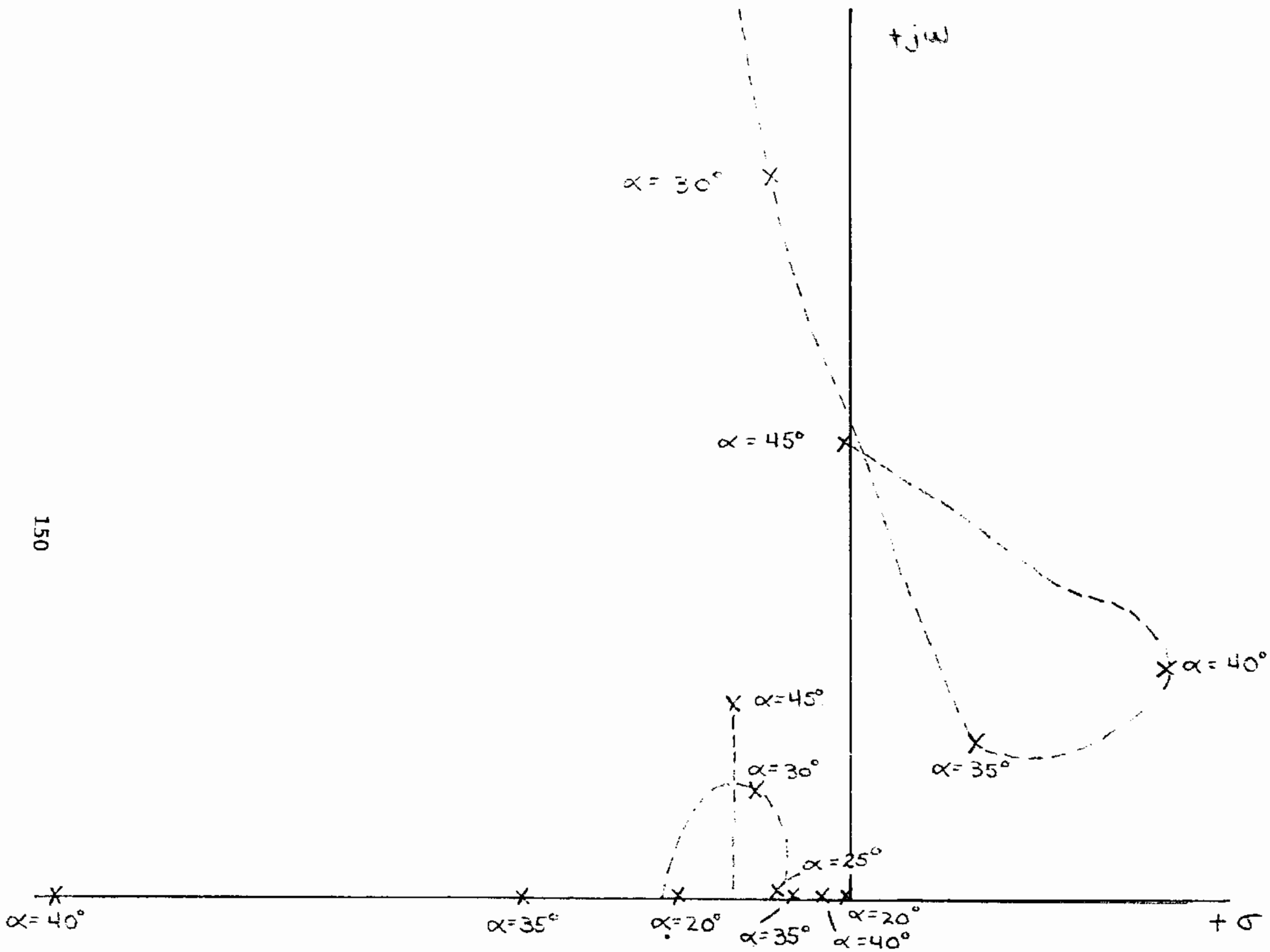
VARIATION OF AAPP WITH ANGLE OF ATTACK.

Figure 5



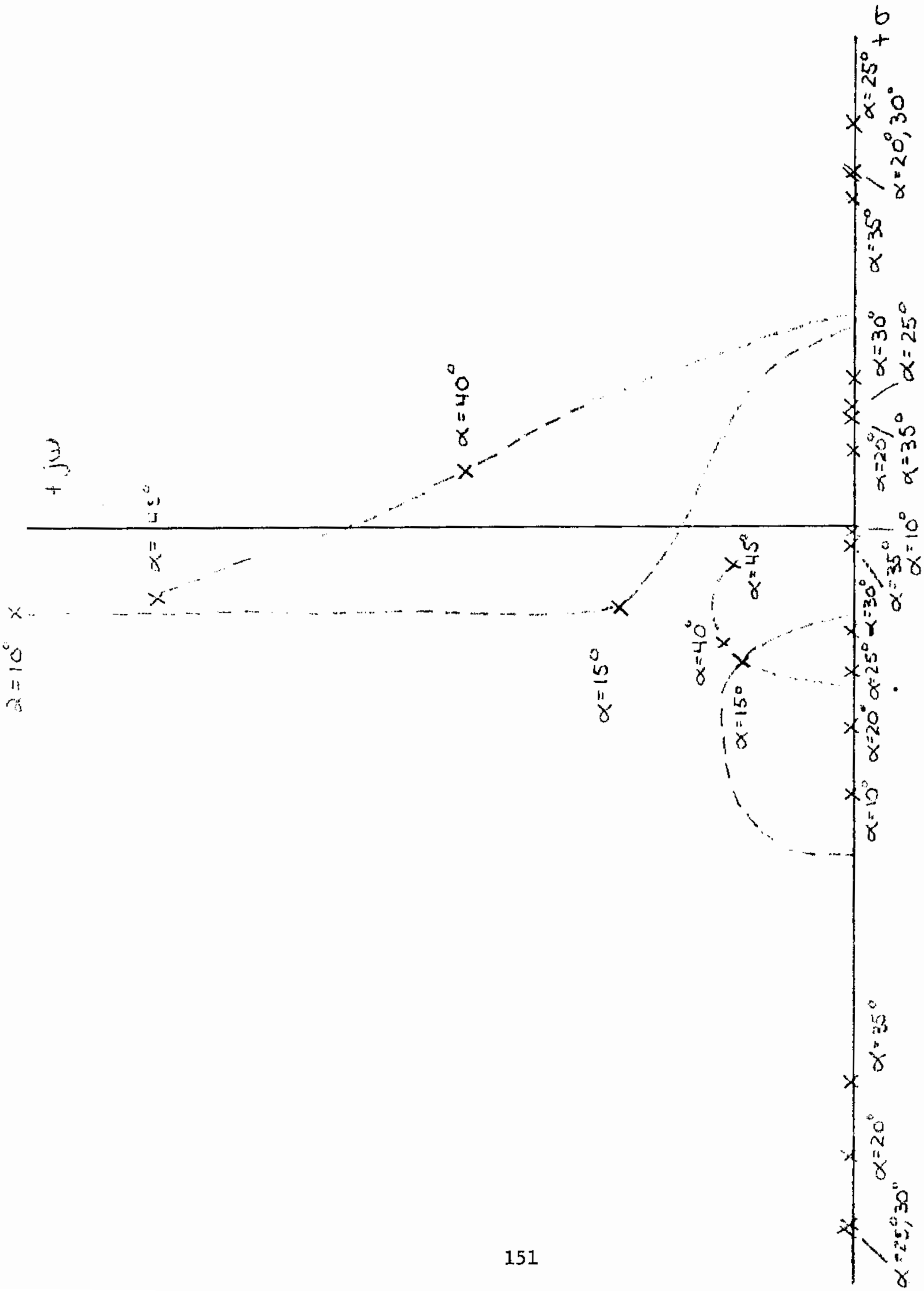
AADP - $Cn_{\beta,Dyn}$ (FROM REF. 7)

Figure 6



ROOT MIGRATION BASED ON ORIGINAL DERIVATIVES

Figure 7



ROOT MIGRATION BASED ON VARIATIONS IN DERIVATIVES

Figure 8

Presentation Questions and Answers

Author's Note: Table I, which was taken from MIL-S-83691 (31 March 1971), has been changed by MIL-S-83691A (15 April 1972) to include additional testing requirements under test phase D, Spin Attempts. This phase now includes smooth AOA rate entry conditions for Class I and IV airplanes. Control Application for this phase now requires that pro-spin controls be held until the airplane has undergone at least three spin turns. See Reference 4 for details.

Question: (Dr. Beam, OSAF) You talk of recovery from spins but there is some discrepancy in defining a fully developed spin. Is this in terms of a stable rate?
Answer: Departure is defined (Ref. 4) as "the event in the post-stall flight regime which precipitates entry into a post-stall gyration, spin, or deep stall condition.... Departure is synonymous with complete loss of control." A Post-Stall Gyration is an "uncontrolled motion about one or more airplane axes following departure.... The PSG is differentiated from a spin by the lack of a predominant, sustained yawing motion..." While spin recovery is important, our research emphasizes departure resistance and other handling qualities.

Question: (Frank Carlson, Boeing) What part is aerodynamic hysteresis playing in your current evaluation of stall/spin?
Answer: In conjunction with the Arnold Engineering Development Center, we are documenting the occurrence of hysteresis in lateral/directional wind tunnel test data. This information can be used in determining its effect on flying qualities through analysis and simulation. Longitudinal hysteresis is not being considered.

Question: (Don Cichy, Rockwell/Columbus) Are you applying Mehra's work in catastrophe theory to your departure criteria effort?
Answer: No. His work is documented in a June, 1977 Office of Naval Research report ONR-CR215-248-1, Global Stability and Control Analysis of Aircraft at High Angles of Attack. It is not yet developed to the point that direct comparisons can be made with our departure criteria efforts.