AD NUMBER
AD874880
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; Jun 1970. Other requests shall be referred to Air Force Aero Propulsion Lab., Wright-Patterson AFB, OH 45433.
AUTHORITY
AFAPL ltr, 12 Apr 1972

AFAPL-TR-70-57

UNCLASSIFIED

STABILITY MARGIN DEFINITION

BRIAN BRIMELOW, SQUADRON LEADER, R.A.F.

TECHNICAL REPORT AFAPL-TR-70-57

JUNE 1970

[redacted]

STATEMENT #2 UNCLASSIFIED

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of

AIR FORCE AERO PROPULSION LABORATORY
DIRECTORATE OF LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

attn APTA.

UNCLASSIFIED

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

[redacted]

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

AFAPL-TR-70-57 June 1970

ERRATA - September 1970

The following corrections are applicable to AFAPL-TR-70-57, Stability Margin Definition, June 1970:

Notice page

Delete the second paragraph, "This document has been approved for public release and sale; its distribution is unlimited."

Title page

Delete the statement "This document has been approved for public release and sale; its distribution is unlimited." Substitute the following statement: "This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio."

Page iii

Delete the last sentence of the Abstract and substitute the following: "Both internal and external effects are considered and the interactions between inlet and engine stability coefficients are discussed."

DD Form 1473

Item 6. Delete "15 June 70" and substitute "June 1970"

Item 7a. Insert "18"

Item 9a. Report number should read "AFAPL-TR-70-57"

Item 12. Insert "Air Force Aero Propulsion Laboratory
Wright-Patterson Air Force Base, Ohio 45433."

Air Force Aero Propulsion Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base,
Ohio

AFAPL-TR-70-57

STABILITY MARGIN DEFINITION

BRIAN BRIMELOW, SQUADRON LEADER, R.A.F.

[redacted]

BLANK PAGE

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I

INTRODUCTION

The stability of the many components of the propulsion system must be considered jointly in order to establish the overall stability of the system. Because of the nature of the problem, events which in themselves take a minor percentage of the overall stability margin, can and often do cause stall. Consequently, it is all too easy in subsequent stall investigations to expend more effort working on the event which tripped the stall and may be minor, rather than the more fundamental phenomena which have used up ninety-nine point nine percent of the stability margin. To avoid wasting time on the various straws which can break the camel's back, it is necessary to develop a thorough accounting system, which will track quantitatively every destabilizing parameter from the early stages of development until the aircraft is withdrawn from service.

Computer simulation of propulsion components and systems is essential to the analysis of stability margins. The math models for these simulations must however rely on test data for many of the component characteristics, and simulation predictions must be checked according to a systematic development plan. The primary role of the computer math model is to synthesize the actions and interactions of the many component parts into an aggregate system response for a specified situation. The aggregate system for the required stability evaluation may comprise a compressor, an engine with its controls, an inlet with its controls, the complete propulsion system, or the propulsion system with a flight dynamics model of the aircraft. All of these systems levels have been modeled for a variety of stability analysis purposes.

II

PROPULSION SYSTEM SIMULATION

The most important models for compatibility design and evaluation are the dynamic models for the engine with controls and the engine/inlet combination (with engine and inlet controls). It is with these models that all factors contributing to surge may be brought together in the right combination and order dictated by the imposed disturbance, controls limitations and tolerance stacking effects. The applications of these models to controls design and mode selection is of importance because of the effect which the controls have on the dynamic mismatch between engine and inlet. Of course the mismatch is important to both the engine and inlet stability margins: mismatch is often a source of distortion and turbulence at the compressor and may cause buzz or unstart of the inlet.

Dynamic simulation of engine/control combinations can be utilized to define operation of the engine and to assess the stability margins and controls schedules during transient excursions. They are normally used by engine manufacturers during a development program to develop the controls, monitor component requirements and to coordinate systems design with the aircraft manufacturer(s). The simulations can be developed to predict propulsion system responses to all of the required transients (rotor speed, augmentation changes and all inlet generated or propagated disturbances). The inlet generated or propagated disturbances (from aircraft maneuvers, wind gusts, weapon firing, etc.) include steady state spatial distortion, time-variant distortion, inlet temperature distortion, and Reynolds number effects. To evaluate these latter conditions and any high-frequency multi-dimensional flow disturbances, predetermined correlations in component performance and stability characteristics must be included in the mathematical model. Test data and other analytical procedures can be used to obtain the required correlations between distortion, etc. and the changes in component performance and stability margin.

The use of a nonlinear dynamic model of the engine and control has gained wide acceptance in the industry. This technique requires the definition of the engine component performance and stability characteristics in the form of compressor maps, turbine maps, burner stability limits, etc. The performance maps of each of the components can be modified to reflect the effects of distortion and turbulence. Figure 1 describes the performance information required for a split compressor turbofan engine. Each of the components is treated as a lumped element, and major gas storage elements are treated as lumped volumes. The choice of volume lumpings shown by Figure 2 is for illustrative purposes only, the final number of volumes chosen is a function of the frequency response required.

The dynamic coupling between components in the engine simulator is accomplished by two basic relationships: (1) rotor speed of each spool is obtained from the time integration of the imbalance in torque (divided by rotor inertia) between the turbine and compressor on that rotor; and (2) pressure between components is obtained by time integration of the airflow imbalance (as modified by volume, specific heat ratio, and temperature according to the ideal gas law) between interfaces of the control volume. The more precise models for higher frequency must incorporate energy conservation equations (especially for burner and augmentor) involving enthalpy flows at interfaces and dynamic combustion equations. The computerized dynamic math model indicated in Figure 1, with variations as described above, is useful in the study of stability margin variations resulting from the interaction of provisional controls definitions and a variety of system disturbances. The dynamic response for this type of model can usually be made good to approximately 20 hertz. Effects requiring higher frequency response must be accounted for by modification of the basic maps.

III

STABILITY PREDICTION VALIDITY

Propulsion system simulations have demonstrated the capability to follow actual engine transients. The mathematical capability and understanding of the relevant thermodynamic relationships can therefore be considered to be in hand. However, the margin as assessed by the simulation will only be accurate provided the input empirical data is correct. Some of the data input requirements are straightforward, for example, component performance maps, engine volumes and areas, control schedules and component inertias. Unfortunately, some of the required data is less straightforward; this in general consists of the modification necessary to the basic maps forced by component interactions and the effect of changes in external environment. It is the degree to which these interactions and modifications can be accounted for that makes the difference between a simulation which is an interesting toy and a simulation which is a powerful and practical technique for keeping track of propulsion system stability.

Past experience can be used initially for factors such as Reynolds Number effects on compressor performance, but this can be such a significant effect that subsequent test verification is required. Some map changes, however, may require a major test program to support the necessary modifications. Figure 3 shows a basic fan map as tested on a rig. Figures 4 and 5 show the changes in the map of the same fan when the splitter cowl which separates engine core flow from the fan duct flow is placed close to the fan and the two streams are separately back-pressured. Figure 4 shows the change in the map when the fan duct stream is back-pressured. Figure 5 shows the change in the fan map when the core stream is back-pressured. In actual engine operation, not only will the surge line change as a function of engine operating condition, but the operating line will be similarly effected. Clearly a modification of this type to the simulation is a difficult programming job. However, in the long run it is preferable and less prone to error than attempting to track by hand the continuously changing margin through an engine transient, particularly since all other destabilizing influences must be monitored at the same time.

For many applications the key parameter in determining propulsion system stability is the index used to describe the flow field at the engine face. The history of distortion indices has been somewhat checkered. Many early indices were claimed by their inventors to be applicable to all engines. This was a fallacy but index inventors often stuck by their numbers as though their personal integrity and their company's position depended on proving the index was valid. Figure 6 and Figure 7 show comparisons of two pairs of distortion indices. The pair in Figure 6 includes a dynamic head (Q) term and the pair in Figure 7 do not. Each point represents a different distortion pattern. An index of a particular value is supposed to represent a given increment of surge pressure ratio loss. It is clear, therefore, that if the indices are applicable to all engines a relationship should exist between the indices which should be single valued. This single valued relationship does not exist unless a given form of pattern is specified, hence one index is not generally applicable and the probability is that neither are. The situation was further confused by the fact that in the early days distortion on aircraft was measured using steady state instrumentation. Hence, even when an index was tailored to a particular engine, there was no correlation with flight test data because the engine was seeing distortion patterns which were quite different from those recorded by the instrumentation. At this point the index inventors were accused of running a numbers game. This feeling is in no way dissipated when some of the "confusion factors" which go into indices are investigated. As an example, consider the use of the dynamic head Q. This is claimed to be a normalizing factor, since it compensates at part speed for the fact that a given level of delta pressure corresponds to a greater change in velocity than that same delta pressure at high speed.

Figure 8 shows the loss of surge pressure ratio of the fan as a function of speed (i.e., flow) and a distortion index. Figure 9 shows the same data except that this time the distortion index has been normalized (i.e., allegedly compensated for change in flow) by use of a Q/Pt factor. More interesting games can be played using this factor when considering fan amplification or attenuation of distortion. Figure 10 shows a distortion transfer coefficient (distortion out/distortion in) plotted in terms of an index based on delta pressure in/delta pressure out and the same index normalized by a Q factor. In this case, two different stations were used for calculating the input Q. Although the component performance is the same for each plot, the apparent performance to the uncritical eye can be greatly improved by suitable choice of index.

Despite the problems associated with distortion indices, it is clear that the flow field at the compressor face must be described by a numerical system if quantitative assessment of available margin is to be achieved. Bearing in mind the apparent component improvement implied by the previous example, it is extremely apparent that any system of stability resolution is dependent on complete visualization of the flow processes of each of the components involved. However, organization of the program requires the interfacing of many technical parameters to form the quantitative basis for assessment of stability margin. It is essential, however, to remember and watch for the pitfalls associated with distortion indices. The man who offers to sell distortion indices and the man who offers to sell the Brooklyn Bridge may not be out of the same stable, but it would be as well to check.

The first step in establishing a workable quantitative relationship between distortion and surge margin loss is to establish the fan response to steady state distortion. Several functions must be considered. First, sensitivity -- the rate of loss of surge pressure ratio with both circumferential and radial distortions must be found from rig tests. Distortion sensitivity will in general vary from hub to tip. In some cases, this is a very pronounced effect and the index should account for it. The extent and number of lobes of a circumferential distortion has a major effect, also the pressure gradient as the blades enter and leave a low pressure zone may be significant. The loss of surge pressure ratio associated with these phenomena should be investigated using controlled classical patterns. All the effects should then be added together and the index system checked, using more complex patterns which are typical of actual inlet distortion. At the same time, the fan transfer coefficients (i.e., the relationship between distortion in and distortion out) should be established. Unless the distortion into the compression system behind the fan can be accurately determined knowing only the conditions in front of the fan, diagnosis or assessment of overall engine stability is extremely difficult. Furthermore, it is impossible to screen inlet data for distortion levels potentially dangerous to the engine without adequate knowledge of the fan transfer coefficients. These coefficients should account for both radial distortion and the extent depth and lobe pattern of circumferential distortion. In addition to the pressure stability coefficients, it is necessary to account for the temperature distortion which is introduced by the different fan work inputs in the high and low pressure zones of the inlet flow field.

The stability coefficients for the subsequent units in the compression system should be established in the same way as for the fan. However, two additional points must be bourne in mind. The clean surge line must be established with the radial profile imposed which is normally delivered by the forward unit (or units), and the imposed distortion must be calculated after applying the transfer coefficients for the forward units to the relevant section of the inlet flow.

Once a credible numerical description has been developed for the inlet flow field, it is possible to proceed with analysis of a real dynamic environment. The patterns which the engine is encountering or can be expected to encounter must be determined. In a full scale test, the relevant patterns may be found by examining a moving time-average of the instantaneous distortion measured by high response instrumentation. The test data and instrumentation requirements on which this analysis technique is based are described in Reference 1. This analysis technique eliminates the error which was introduced when inlet-distortion data was based on the readings of steady state or very low response instrumentation, but there are other problems of environmental definition. When only inlet model data is available, i.e., in the early stages of system development, great care must be taken to account for scale effects. The effects of model size, acoustic frequency scaling and Reynolds Number must be applied. A fuller discussion of dynamic distortion scaling may be found in other references.

So far in the discussion of the data requirements for a stability stack up, only passing references have been made as to the time phasing of the input requirements. In the early stages much of the input to the stability model will be based on the engine manufacturers' experience and research projections. As the program develops, these projections must be replaced by hard test rig data which must then be updated whenever subsequent tests are run.

IV

CONCLUSION

It is currently possible to combine in a propulsion system dynamic model the empirical and theoretical data necessary to determine the available transient stability margin at various flight conditions. The data requirements for such a model are massive, but they are essential for satisfactory stability development, and none of the data requirements necessitate techniques outside the current state-of-the-art. In addition to stability tracking, the model provides at any stage in the development program a guide as to the work remaining to be done and a check on the progress of the work already accomplished.

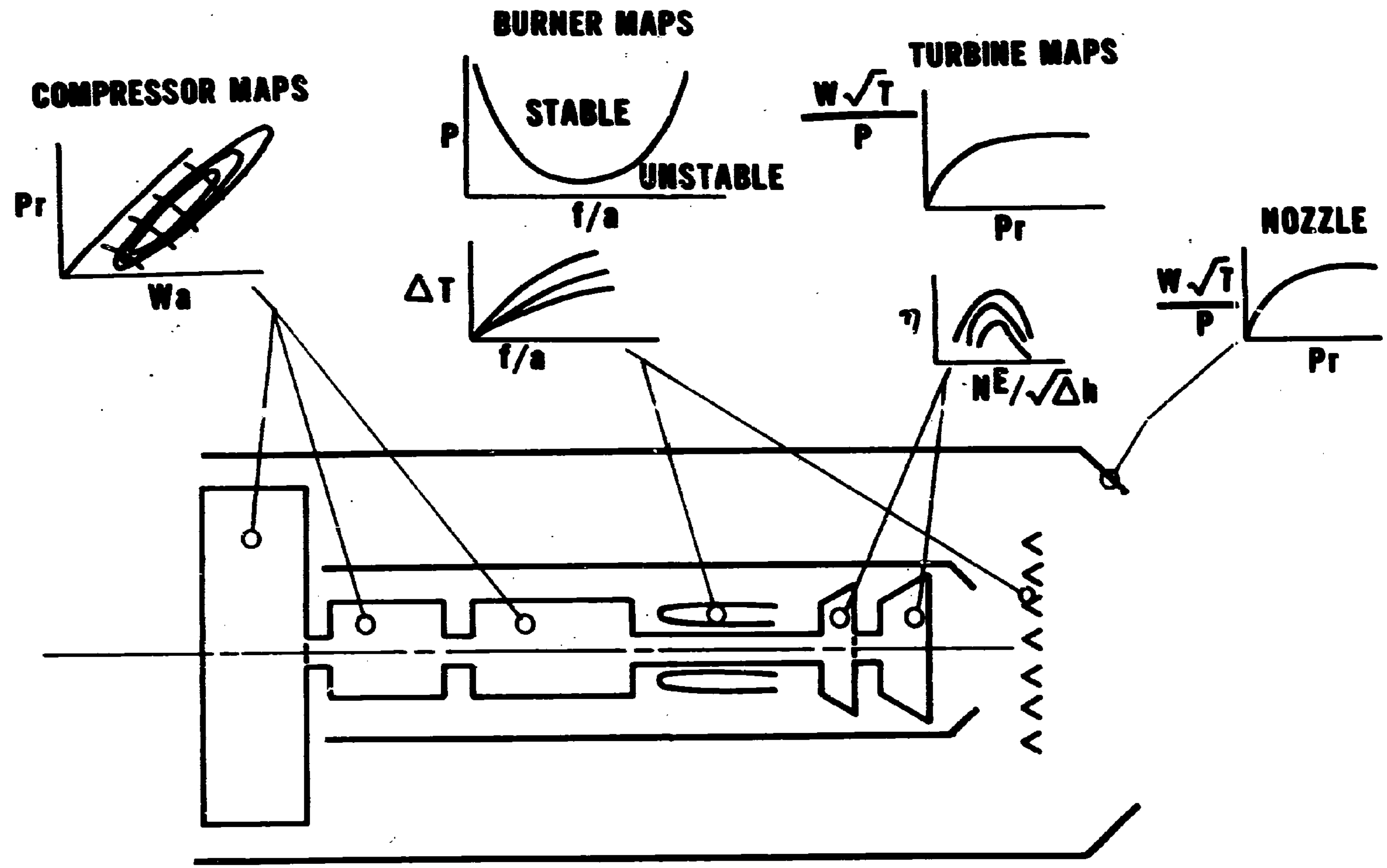

FIGURE 1 PERFORMANCE MAPS REQUIRED FOR DYNAMIC ENGINE SIMULATION

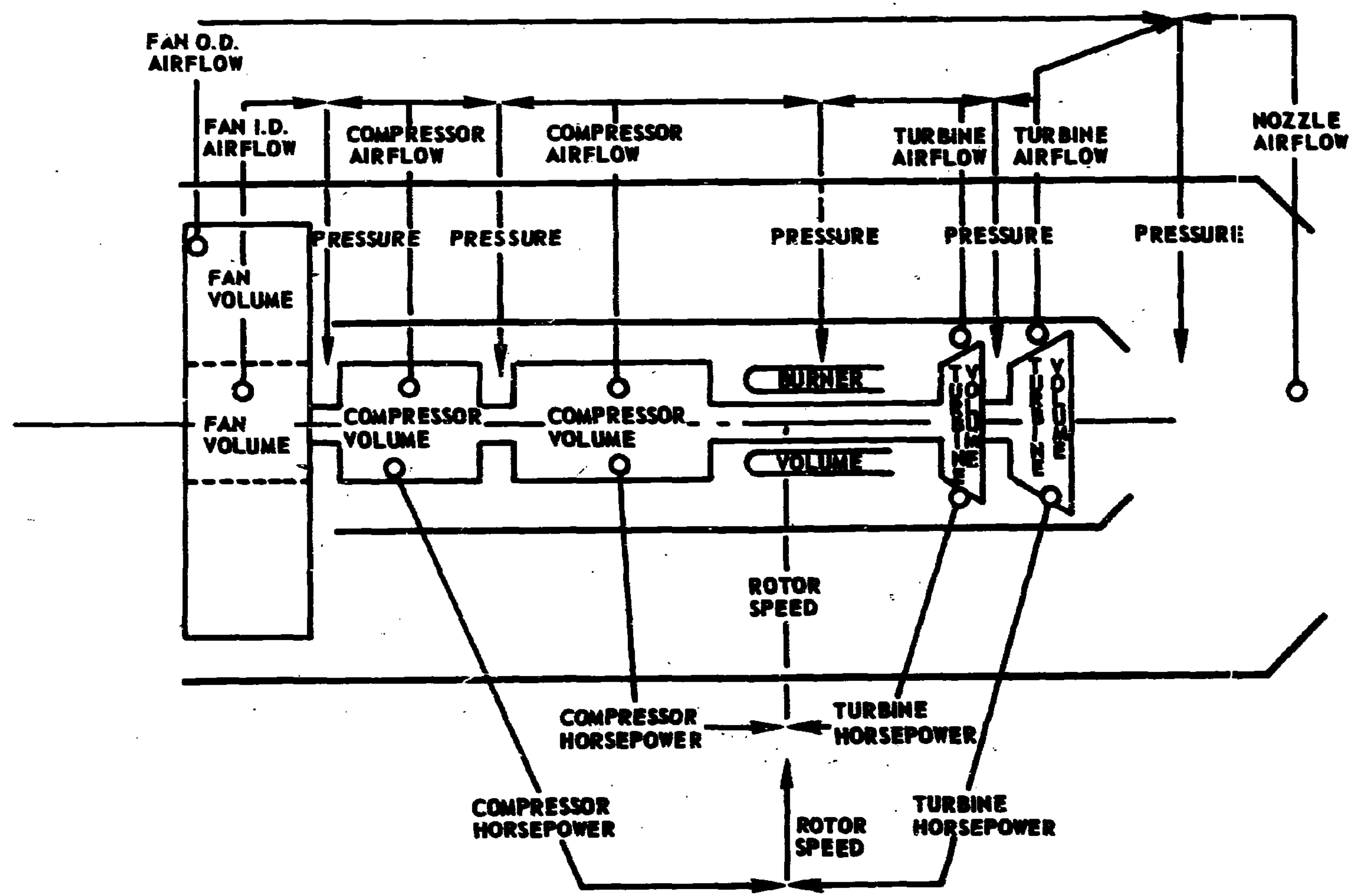

FIGURE 2 TYPICAL LUMPED-VOLUME ELEMENTS AND COUPLING FOR A DYNAMIC ENGINE SIMULATION

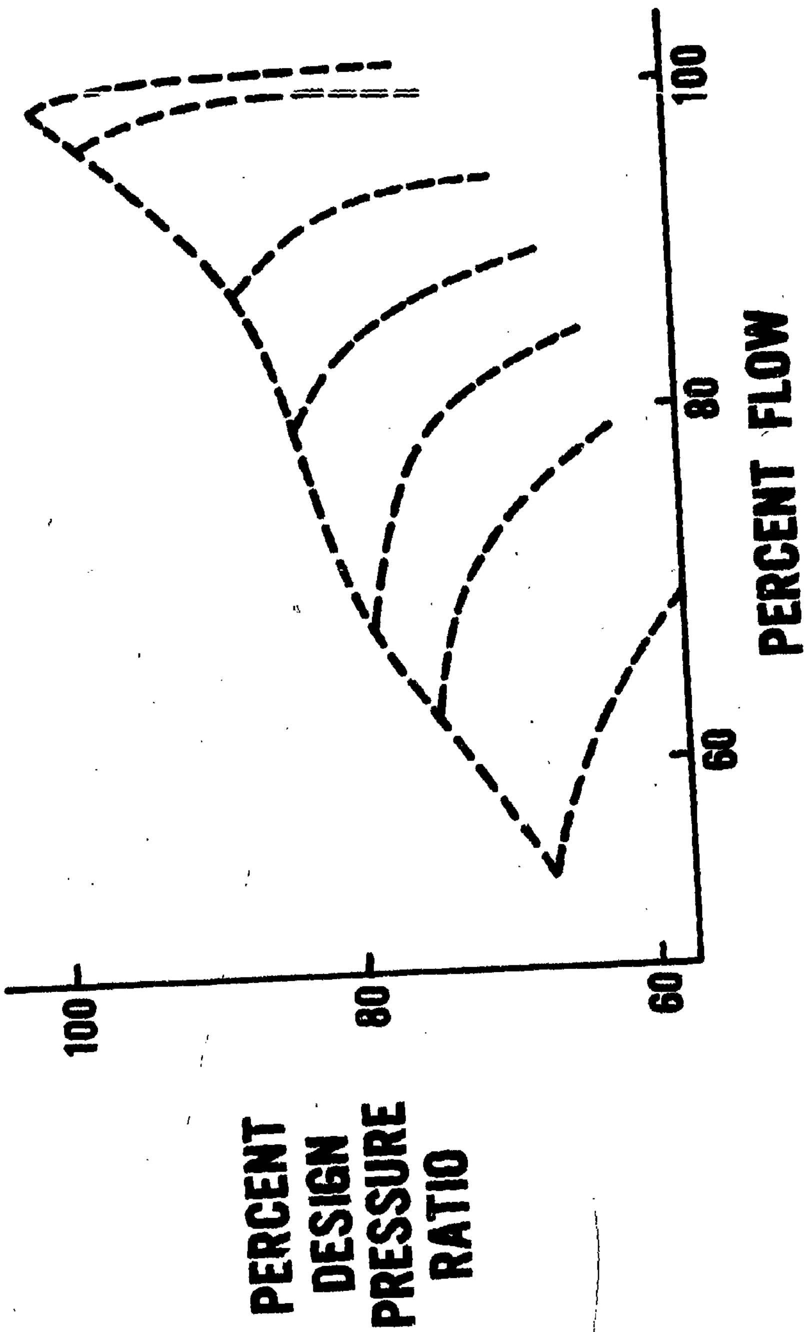

FIGURE 3 TYPICAL FAN MAP

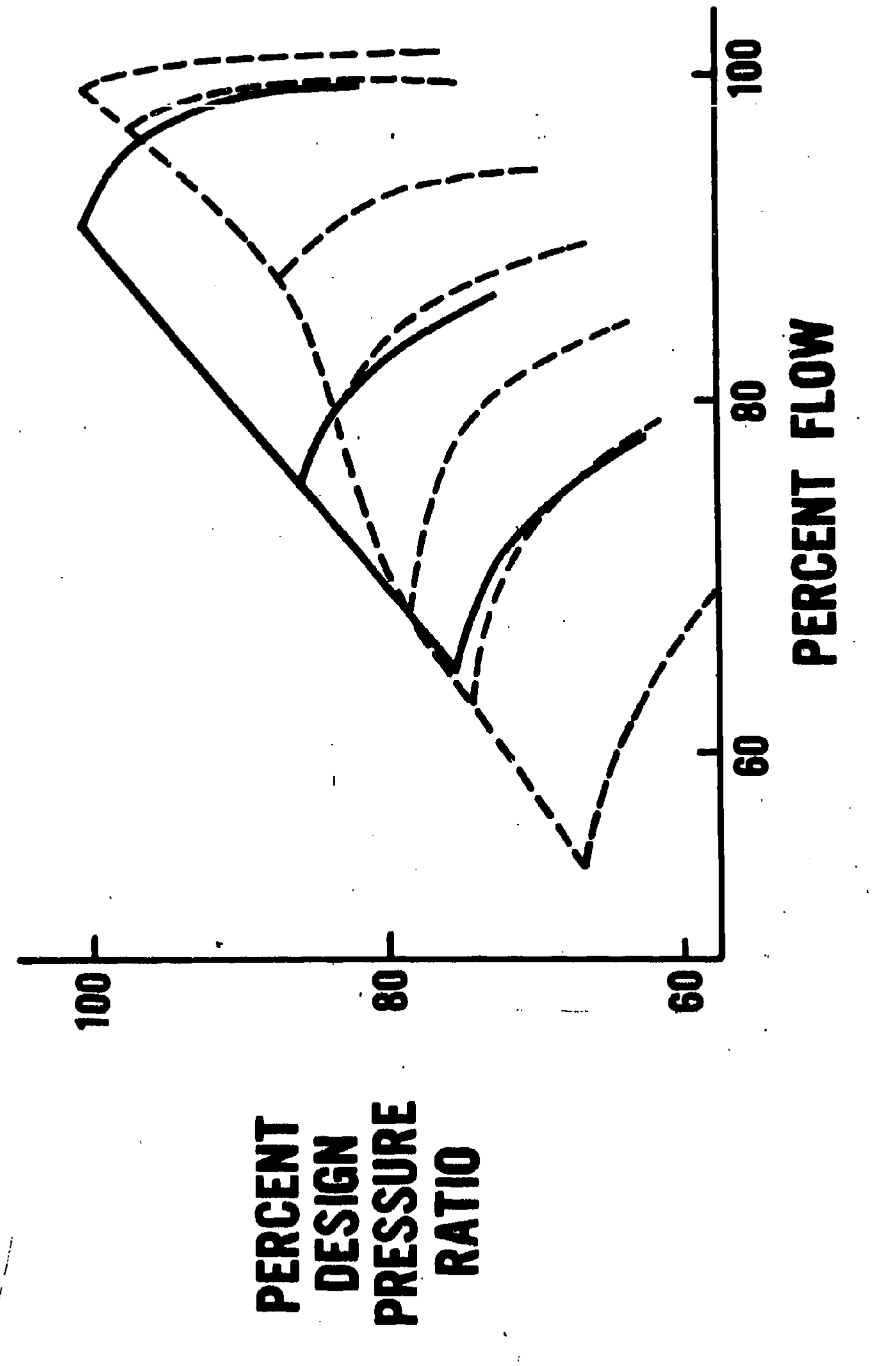

FIGURE 4 EFFECT OF O.D. BACK PRESSURE

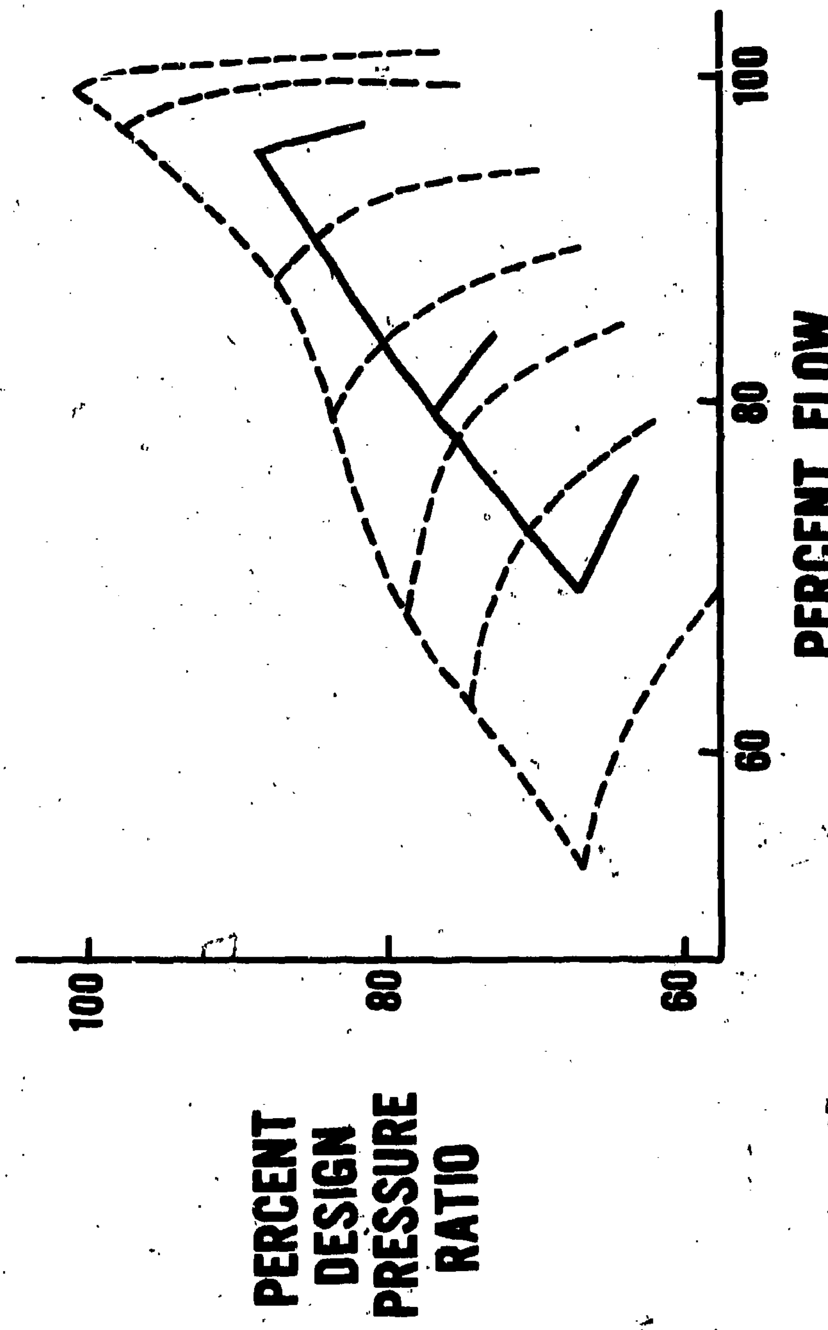

FIGURE 5 EFFECT OF I.D. BACK PRESSURE

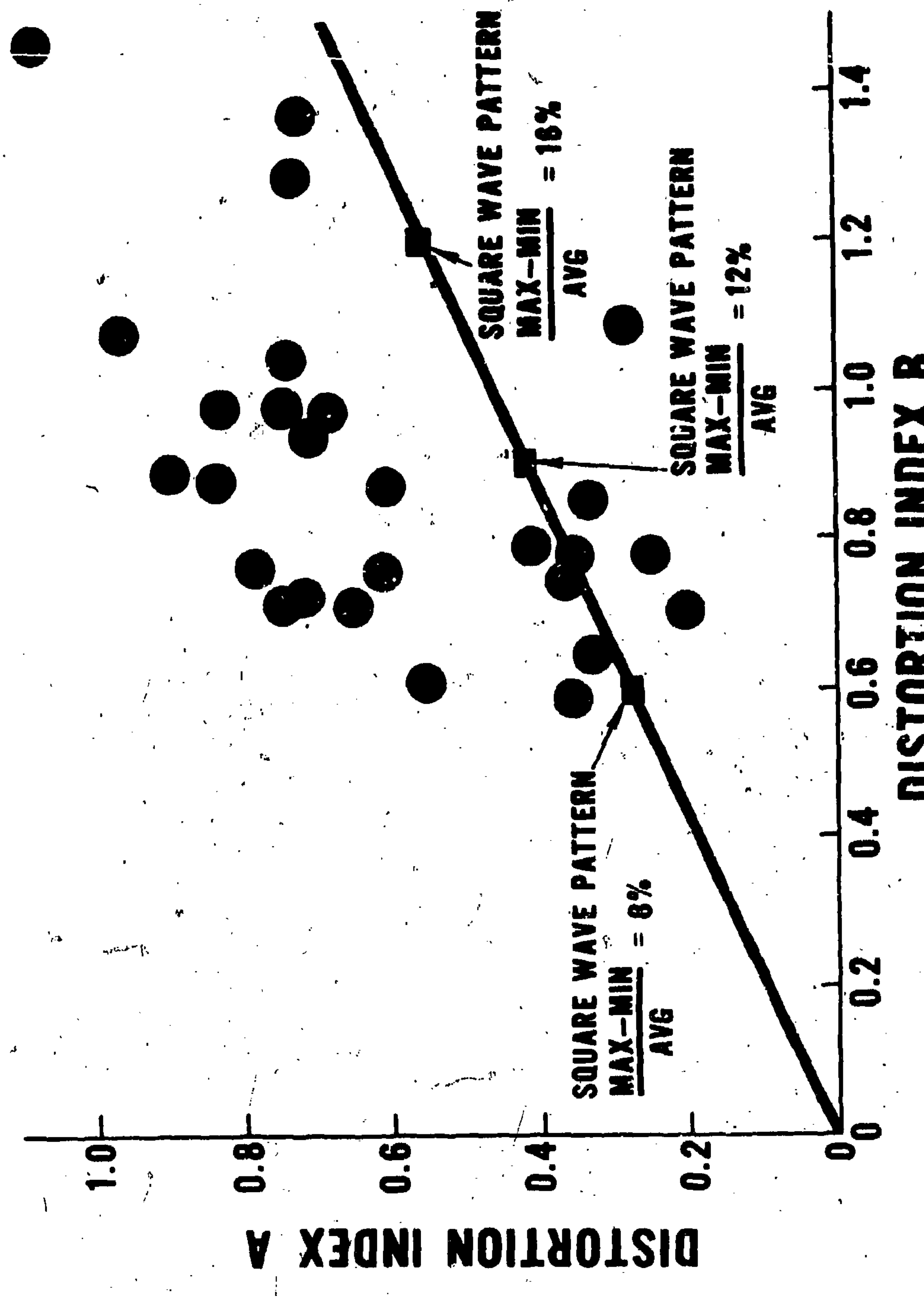

FIGURE 6 OVERALL DISTORTION INDEX COMPARISON INCLUDING Q FACTOR

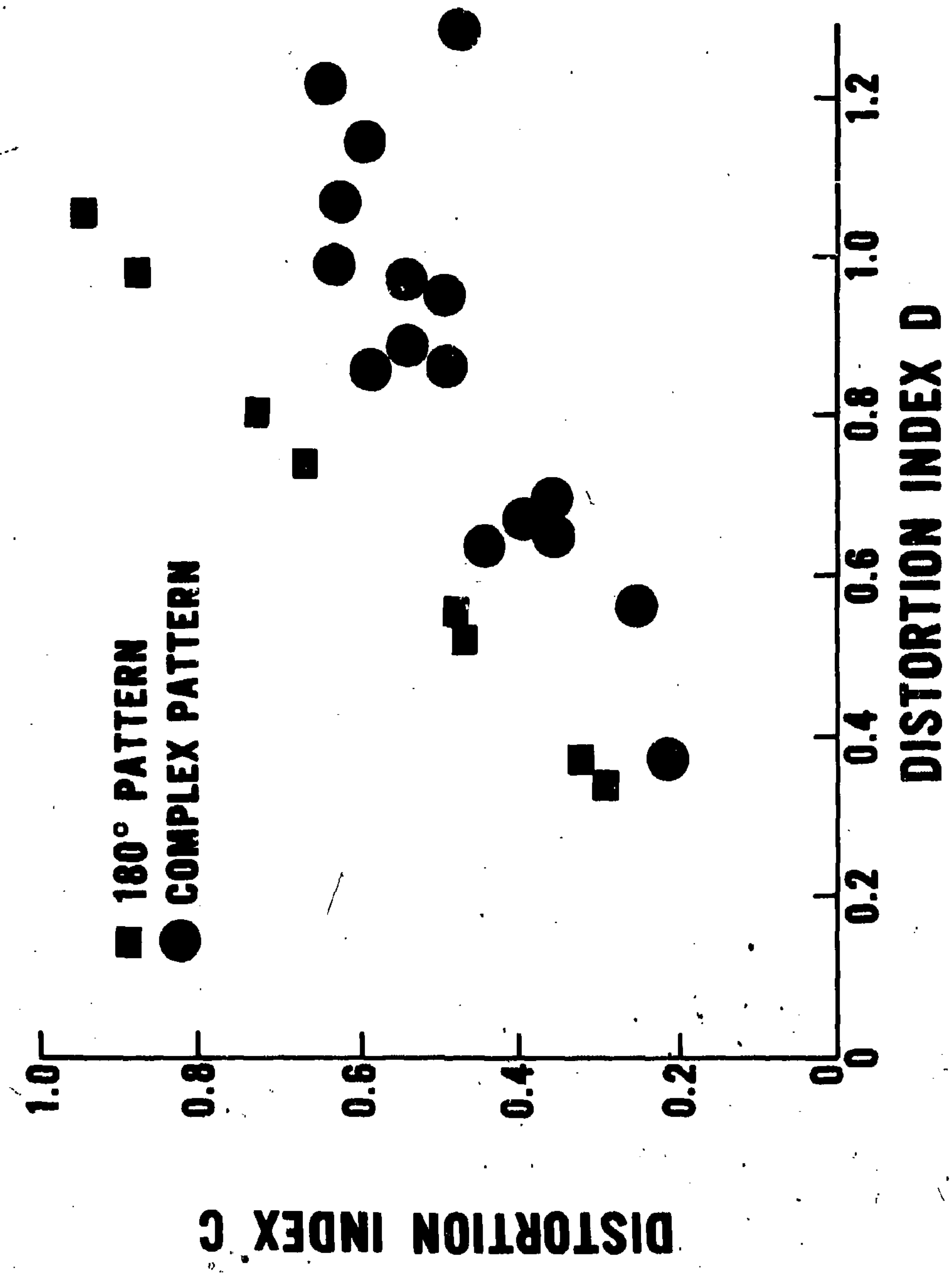

FIGURE 7 CIRCUMFERENTIAL DISTORTION INDEX COMPARISON
NO Q FACTOR

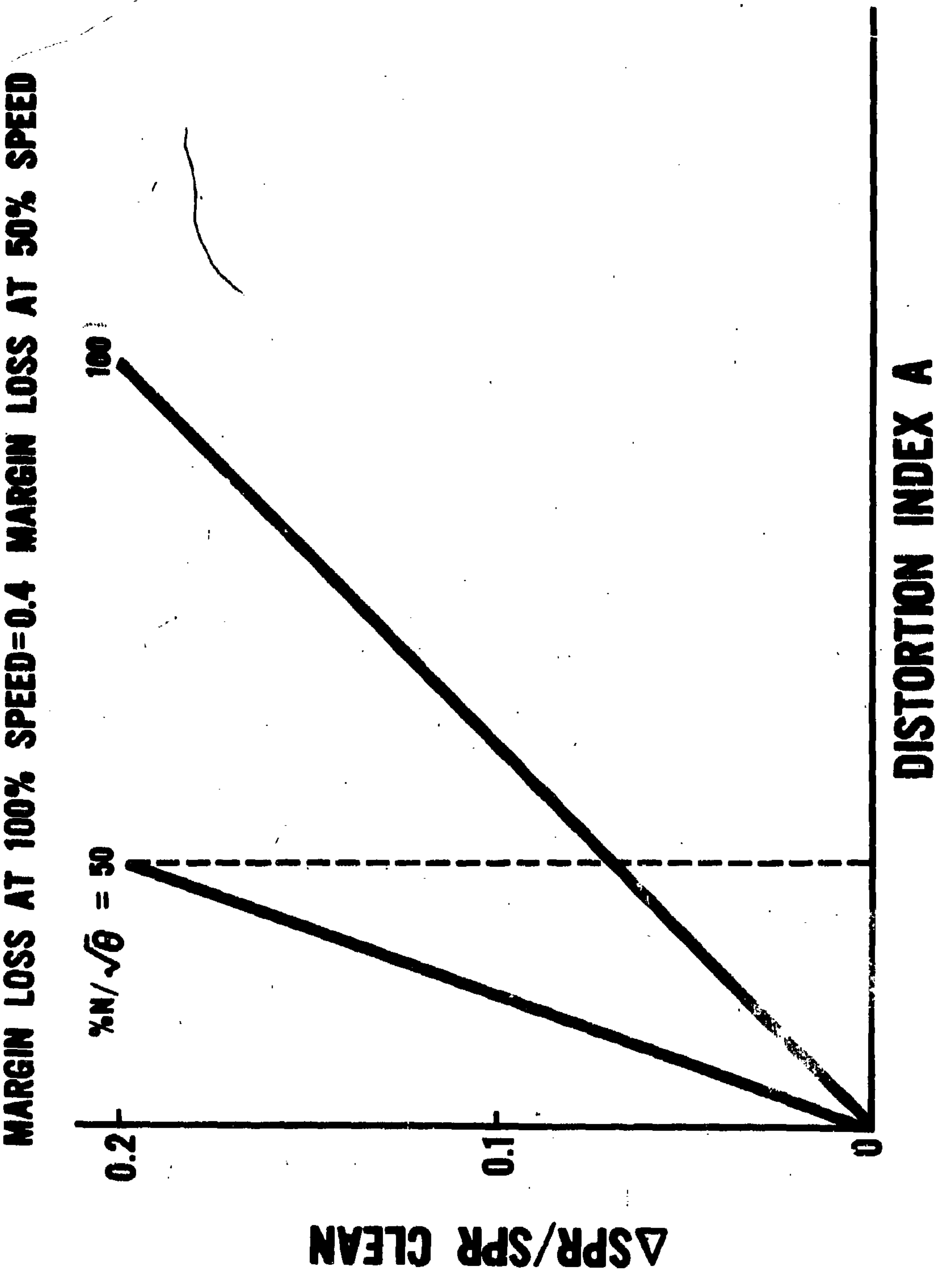

FIGURE 8 VARIATION OF SPR WITH DISTORTION AND SPEED

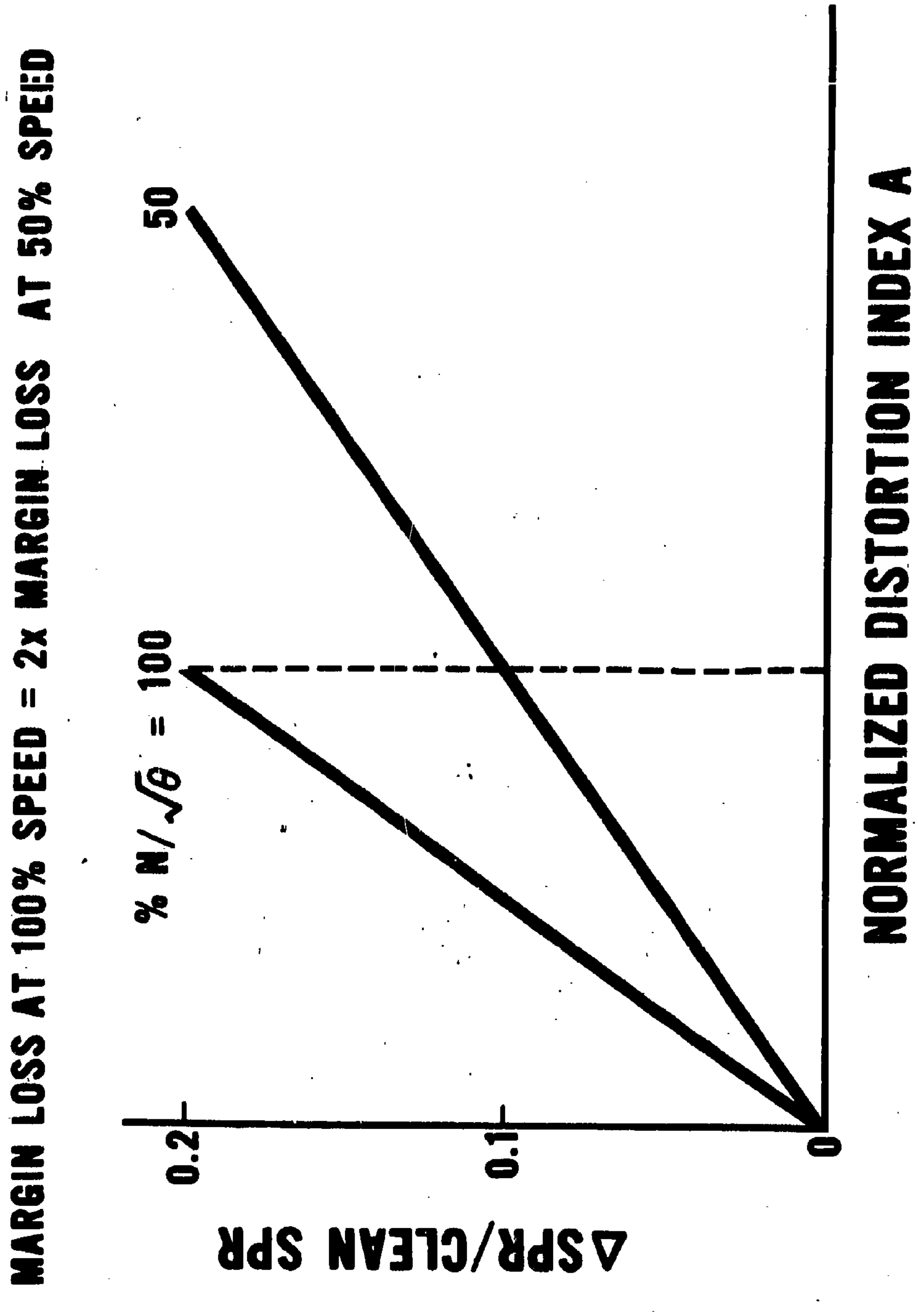

FIGURE 9 VARIATION OF SPR WITH DISTORTION AND SPEED NORMALIZED BY Q

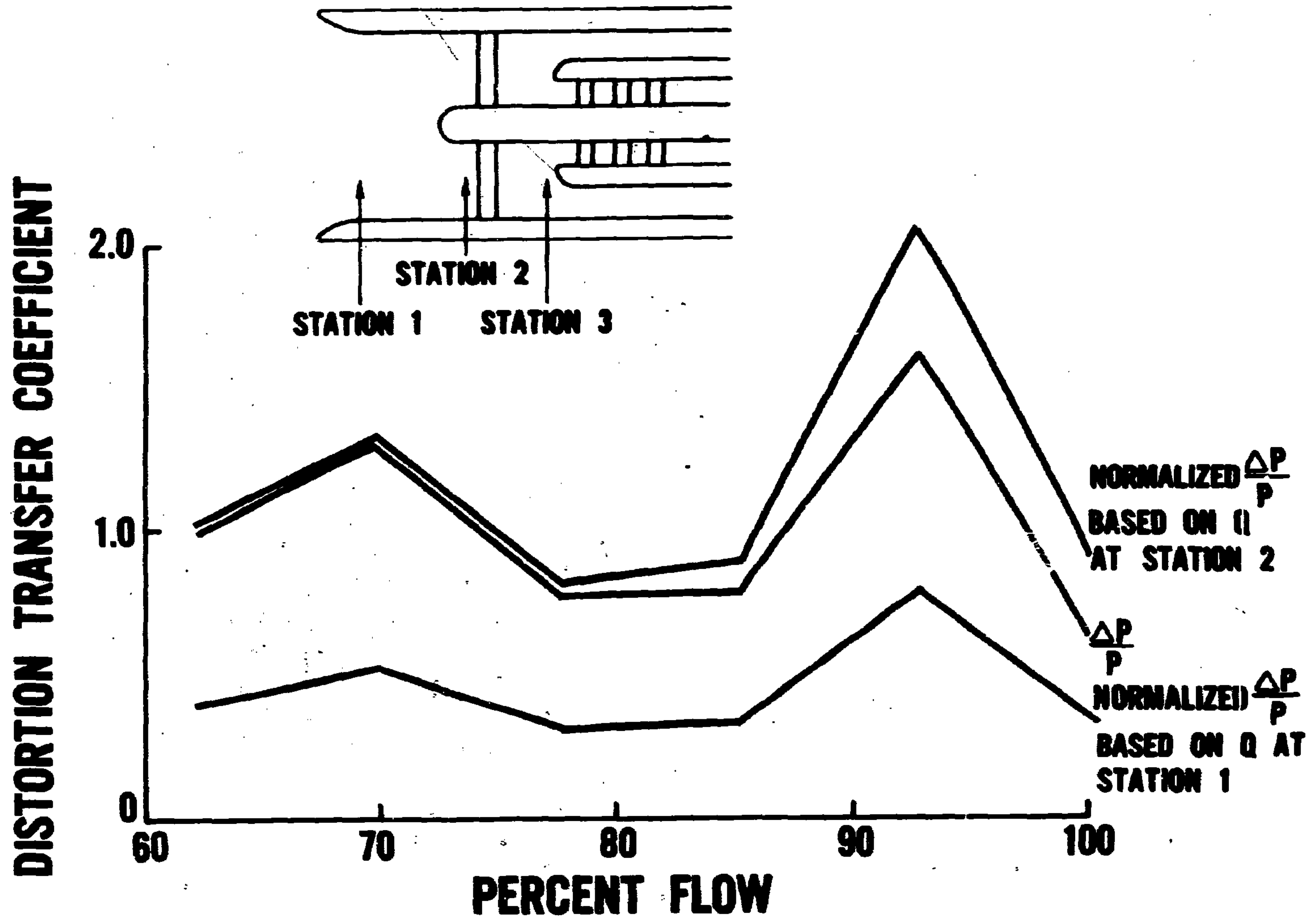

FIGURE 10 EFFECT OF Q ON DISTORTION TRANSFER COEFFICIENT

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) AFAPL (AFTA)	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE

STABILITY MARGIN DEFINITION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

From a presentation given at AIAA Conference, 15 June 70, San Diego, CA

5. AUTHOR(S) (First name, middle initial, last name)

Brian Brimelow, Sqn Ldr, R.A.F.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
15 June 70		

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 3066	AFAPL-TR-70-
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. [redacted]

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

The available stability margin of a turbine propulsion system is a function of a wide range of parameters, many of which are time dependent. Both internal and external effects are considered and the interactions between inlet and engine stability coefficients are discussed. ( )

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
STABILITY MARGIN						
OVERALL STABILITY MARGIN						
ENGINE/INLET STABILITY						
STABILITY COEFFICIENTS						
TRANSIENT STABILITY MARGIN						
INLET STABILITY						
TURBINE ENGINE STABILITY						
INLET DISTORTION						

UNCLASSIFIED
Security Classification