AEDC-TR-79-77

An Evaluation of Statistical Methods for the Prediction of Maximum Time-Variant Inlet Total Pressure Distortion

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ARO, Inc.

September 1980

Final Report for Period October 1, 1978 – September 24, 1979

ARNOLD ENGINEERING DEVELOPMENT CENTER
ARNOLD AIR FORCE STATION, TENNESSEE
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

APPROVAL STATEMENT

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FOR THE COMMANDER

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AEDC-TR-79-77	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): AN EVALUATION OF STATISTICAL METHODS FOR THE PREDICTION OF MAXIMUM TIME-VARIANT INLET TOTAL PRESSURE DISTORTION	5. TYPE OF REPORT & PERIOD COVERED: Final Report - October 1, 1978 to September 24, 1979
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): M. E. Sanders and R. J. Christenson, ARO, Inc., a Sverdrup Corporation Company	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Arnold Engineering Development Center/DOT, Air Force Systems Command, Arnold Air Force Station, Tennessee 37389	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Program Element 65807F
11. CONTROLLING OFFICE NAME AND ADDRESS: Arnold Engineering Development Center/DOS, Air Force Systems Command, Arnold Air Force Station, Tennessee 37389	12. REPORT DATE: September 1980
	13. NUMBER OF PAGES: 53
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE: N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available in Defense Technical Information Center (DTIC)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

statistical analysis	duct inlets	attitude
statistical processes	data reduction	predictions
distortion	Mach number	measurement
pressure	mass flow	turbulence
rocket engines	models	on line systems

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An analysis was conducted to determine the accuracies and limitations of three statistical methods used to predict engine-face maximum time-variant total pressure distortion. The statistical methods have all been proposed as low-cost alternatives to the time-consuming and costly deterministic method generally used for reducing engine-face time-variant total pressure data. The statistical methods are evaluated by comparing their predicted

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20. ABSTRACT (Continued)

distortion values and patterns to those measured with the deterministic method. Data comparisons from tests of four different inlet models, covering a wide range of Mach numbers, mass flow ratios, model attitudes, and distortion factors, were used during the analysis. The results show good agreement between the measured and predicted values for all three statistical methods. The distortion pattern predictions, however, were inadequate at conditions with high total pressure fluctuation (turbulence). It is recommended that improvements continue to be made in the statistical methods, particularly adjustments for high-turbulence conditions, and that the Melick method be used as an on-line distortion analysis tool for inlet performance tests.

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PREFACE

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), at the request of the Directorate of Technology, AEDC. The analysis was performed by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), operating contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee, under ARO Project Number P32G-23C. The Air Force project manager was Mr. Elton Thompson, Directorate of Technology. Data analysis was completed on August 10, 1979, and the manuscript was submitted for publication on September 24, 1979.

CONTENTS

ILLUSTRATIONS

TABLES

1.0 INTRODUCTION

During early stages of aircraft development, inlet/engine compatibility is assessed from total pressure distortion factors acquired from subscale model inlet performance tests. During later stages, the turbine engine is tested and evaluated with engine-face total pressure distortion patterns derived from wind-tunnel-inlet performance tests. The present, or deterministic, method for determining the distortion factors and patterns is to process and analyze a large quantity of inlet high-response total pressure data. From this data set the maximum distortion factors and patterns that occur for a sufficient duration (on the order of one compressor revolution) are then selected. This method of determining maximum distortion factors and patterns is both time-consuming and costly, and it requires significant data-management skill.

The accurate, rapid, and economical evaluation of maximum time-variant distortion is a high-priority development item for sub- and full-scale inlet performance tests in wind-tunnel facilities. Because of the expense and the time delays of the present method, a study has been made to evaluate statistical techniques that can be used to modify, supplement, or replace the present method. The three statistical techniques based on the work of Jacocks (Ref. 1), Melick (Ref. 2), and Motycka (Ref. 3) appear to reduce the time required to evaluate maximum time-variant distortion data. The objective of the work reported herein was to review the concepts of the three statistical techniques and to determine their advantages and disadvantages. The statistical predictions of the methods were evaluated by comparisons to the deterministic results over a broad range of model scales, Mach numbers, model attitudes, and inlet airflows.

2.0 INLET TOTAL PRESSURE DISTORTION METHODOLOGY

2.1 GENERAL DISCUSSION

During the past 15 years, a substantially expanded effort has been required to properly assess aircraft inlet/engine compatibility because of two related developments: the advent of the high-performance fighter aircraft and the use of turbofan engines. Because of its enlarged Mach number-altitude-attitude operating envelope, the high-performance aircraft has experienced increases in the nonuniformity and unsteadiness of the flow delivered to the engine. In addition, the turbofan engine has been introduced as the power plant for these highly maneuverable vehicles, and experience has shown that the turbofan engine is more sensitive than the turbojet engine to distorted inlet flow. These factors have resulted in minimal engine-surge margins, with the major portion of the available engine-surge margin allocated to inlet distortion.

Because of measurement ease, inlet flow nonuniformity is described by both airframe and engine manufacturers in terms of total pressure distortion. Typically, eight rakes of total pressure probes with five to six probes per rake (Fig. 1) are used to measure the total pressure profile at the inlet/engine interface plane. Complicated indicators of the engine-face distortion, distortion factors have been formulated that are, in turn, correlated to engine surge line degradation. Definitions of some of the more commonly used distortion factors are presented in Table 1.

Experience with the B-70 and F-111 programs (Refs. 4 and 5) demonstrated the engines' sensitivity to the inlet time-variant total pressure distortion, with minimum engine-response times comparable to the compressor rotation period. Thus, for proper evaluation, measurements of the engine-face total pressures are required with high-response transducers whose outputs are generally recorded on 14-track analog tapes in multiplexed, constant-bandwidth FM mode. To obtain the time-variant or instantaneous distortion values, the pressure data recorded on FM tape must be frozen in time, digitized at relatively high frequency (several thousand samples per second), and distortion factors calculated for each time slice (see Fig. 2). The largest distortion value found in a discrete time interval, normally 30 sec, is referred to as the maximum time-variant distortion. Such measurement of maximum time-variant distortion is generally known as the deterministic method. The process is shown schematically in Fig. 3.

In terms of manpower and cost, the inlet/engine compatibility and inlet performance tests at the AEDC Propulsion Wind Tunnel (PWT) require about 40 percent more resources than do any other types of routine tests. The high cost is a direct result of the effort required to define the maximum time-variant distortion over a wide range of test conditions. The increase in required test program resources, caused by the addition of dynamic instrumentation, can be attributed almost entirely to determination of the compressor-face maximum time-variant distortion in the conventional manner. Because dynamic instrumentation requires nearly 30 sec to tape data at each test condition, the time required for such data acquisition is approximately double that of other tests. Cost factors, therefore, mandate the development of an alternate method of determining inlet maximum time-variant distortion.

2.2 RANDOM-DATA CHARACTERISTICS OF ENGINE-FACE TOTAL PRESSURE DATA

A representation of the random-data characteristic of the total pressure fluctuations may be seen in Fig. 4, which shows the result of screening and subsequently processing several minutes of inlet data by the deterministic method, in the vicinity of the time of maximum time-variant distortion. For comparison, the steady-state and maximum time-variant distortion pressure patterns are shown as well as the time histories of each measured total pressure ratioed to the local steady-state pressure. The normalized pressure waveforms about the time of maximum distortion show little spatial correlation and the work of other investigators has shown that increasing the total pressure fluctuation values causes greater dissimilarity between the maximum distortion pattern and the steady-state pattern. Moreover, the basic randomness of the time-dependent flow results in a distortion pattern at the time of maximum time-variant distortion that is one sample from a population of patterns. Hence, the engine-face pressure pattern corresponding to the maximum time-variant distortion is not repeatable. If the test conditions shown in Fig. 4 were repeated, the only reproducible data would be the steady-state pressures or other time-averaged parameters.

Since the total pressure fluctuations appear to be random and since the various distortion factors are functions of these pressures, it follows that every distortion factor considered in a time sequence represents a stochastic process. Any instantaneous sample from that process is only one sample possible from an infinite population. In particular, the one observed maximum time-variant distortion within a finite observation or data-acquisition time interval is just that — one observation. It should be admitted that, if an engine surges as a result of the distortion, then that one observation assumes special significance. Nevertheless, through recognizing that the turbulent inlet flow is fundamentally random, several investigators have concluded that a statistical analysis of the flow is essential for its proper interpretation.

3.0 DESCRIPTION OF STATISTICAL METHODS

3.1 JACOCKS METHOD

The Jacocks method (Ref. 1) uses Gumbel's extreme-value statistics to extrapolate the random variable (distortion factor) to the expected maximum value for any time period. The method (Fig. 5) requires steady- and dynamic-pressure measurements at the engine/inlet interface and a continuous computation of the distortion factor, computation that generally requires an Analog Distortion Calculator (ADC). The analog-computed distortion factor is passed through peak detectors that sample the signal over a given time interval, register and transmit to a digital computer the maximum value of the distortion parameter during the time interval, and then reset for the next data segment. This procedure is repeated over the record length of the time-variant data, generally 30 sec. The Jacocks method uses the ADC-detected peaks, in conjunction with Gumbel's extreme-value statistics, to predict the expected maximum distortion value.

The method also requires a digital computer. A FORTRAN listing of the program is presented in Ref. 1; a card deck may be made available to approved requesters by AEDC. The various subroutines have not been optimized from the standpoint of computer time; execution time on the IBM System 370/165 (including plotting) averages about 3 sec for processing 60 peak values. The required core size for the program is about 17K words, depending on the data source(s).

3.2 MELICK METHOD

The Melick method (Ref. 2) uses fundamental principles of fluid dynamics to describe the characteristics of the turbulent inlet flow. The inlet total pressure fluctuations are modeled by hypothesizing that the measured total pressure fluctuations result from a random distribution of discrete vortices convected downstream by the mean flow. A solution to the one-dimensional, time-dependent, incompressible Navier-Stokes equations is used to represent mathematically the flow properties of an isolated vortex, and statistical parameters are used to extend the analysis to account for a random distribution of discrete vortices. The necessary input quantities are

1. unfiltered root-mean-square (rms) value of total pressure fluctuations for each of the dynamic probes to be used in the prediction (from 4 to 40 high-response total pressure probes),

2. the ratio of the filtered to unfiltered total pressure fluctuation rms value for each of the dynamic measurements,

3. airflow velocity and static pressure at the engine face,

4. data analysis time, engine cutoff frequency, and filter cutoff frequency, and

5. steady-state total pressure distribution at the engine face.

The Melick method (Fig. 6) can be used to predict maximum time-variant distortion in an on-line mode of operation in the wind tunnel. The time-variant pressure signal from each of the high-response transducers is carried through two parallel branch networks. One branch carries the original signal through an rms network which yields the rms value (σ) of the time-dependent measurement. The other branch carries the original signal through a preselected filter and then through an rms network. This yields a reduced value of the rms signal (σ_{l_c}); the ratio of the two rms values (σ_{l_c}/σ) is a measure of the size of the low total pressure region.

To obtain a typical representation of the time-dependent flow activity over the engine face, several high-response total pressure probes can be used and the results averaged. From 4 to 40 high-response total pressure probes are generally used. The capability to use a less-than-full complement of high-response total pressure probes represents a cost advantage of the Melick method. Execution time averages about 3 sec per point on an IBM System 370/165. The required core size for the program is about 22K words.

3.3 MOTYCKA METHOD

Motycka (Ref. 3) devised a system that uses random numbers to synthesize the time-variant inlet distortion from statistical properties of inlet total pressure data. The necessary input quantities are

1. steady-state total pressure distribution at the engine face (40 probes),

2. filtered total pressure fluctuation rms value for each probe location, and

3. data analysis time and engine cutoff frequency.

Figure 7 is a schematic of the data reduction system required for the Motycka method. The output from all high-response probes is sampled by an rms meter. An Amplitude Probability Density (APD) curve is generated for each probe by using the rms reading and the steady-state total pressure and assuming a normal distribution (Fig. 8a). A cumulative probability function (ΣAPD) is calculated by integrating the APD function (Fig. 8b). Random numbers are then scaled to a range from 0 to 1.0 and converted to pressure readings, as shown in Fig. 8b. The equal time step between pressures is assigned as a function of the frequency range of interest. Each pressure is recorded, and a digitized pressure-time trace is created. This process is repeated for each probe location. The resulting pressure-time traces are then reduced in the exact manner as the digitized data obtained by the deterministic method.

The computer program used was prepared at AEDC. It was based on the descriptions given in Ref. 3. For the AEDC version of the Motycka program, execution time averages about 90 sec on the IBM System 370/165 and requires about 30K words of core. The Motycka method can be used on-line to predict maximum time-variant distortion, although the results presented herein were obtained during off-line analysis.

4.0 EVALUATION OF STATISTICAL METHODS

Maximum time-variant distortion values and patterns for four inlet tests were predicted with the three statistical techniques. These results were compared to the values and patterns obtained with the deterministic method. Statistical and measured distortion values are presented for (1) the General Electric (GE) factors IDC and IDR, (2) the Pratt and Whitney Aircraft (PWA) factors KA2, KΘ, and KRA, and (3) the Williams Research Corporation (WRC) factor AMPC, all defined in Table 1. Table 2 summarizes the test conditions for the four inlet tests.

4.1 EVALUATION OF PREDICTED DISTORTION VALUES

The statistical methods are evaluated by plotting the statistical predictions against the deterministic values. In addition to a line of perfect agreement, ±10-percent-deviation lines are included on each comparison plot. In the experience of the authors, a deviation of only ±10 percent constitutes excellent agreement. No attempt was made to evaluate the underlying principles of the various methods. Rather, the aim of this evaluation was to assess the accuracy and limitations of the three statistical methods.

4.1.1 Jacocks Method

Comparisons for the distortion factors IDC and IDR are shown in Fig. 9 for a 30-sec data analysis time. The data shown are constituted of all test points for which both predicted and measured values were available. Most of the data fall close to but outside the +10-percent error line for the distortion factor IDC. For the distortion factor IDR, the predicted values are scattered about the line of perfect agreement, with most of the data within ±10-percent error. The average deviations for IDC and IDR, respectively, are 15.1 and 10.0 percent. The requirement of an ADC is decidedly a disadvantage of the Jacocks method. Of the four test programs, only one uses a real-time ADC for on-line data analysis. Therefore, data comparisons of the Jacocks method are limited to those in Fig. 9.

4.1.2 Melick Method

Comparisons of predicted and measured values for the distortion factors IDC, IDR, KA2, KΘ, KRA, and AMPC are shown in Fig. 10. The data were acquired from all four inlet tests described in Table 2. To improve its prediction of the distortion factor IDC, the Melick method was modified at AEDC. The modification consisted of replacing the theoretically derived statistics of IDC with empirically derived statistics. Nonetheless, the data in Figs. 10a and b show that the predicted IDC values are in excellent agreement with the measured results, with average deviations of 6.6 and 6.5 percent of Tests A and B, respectively.

The predicted IDR values agree well with the measured results from Test B (Fig. 10d). However, the Test A results (Fig. 10c) show that the predicted IDR values are as much as 50 percent low. The existence of so many data beyond the $\pm$10-percent error band was attributed to the high inlet total pressure fluctuations produced at high angles of attack (α) and sideslip (β). At these conditions, the engine-face radial distortion (IDR) switched from tip to hub radial, whereas the radial distortions for most of the data in Figs. 10c and d are tip radial. These results suggest that the nature of the total pressure fluctuations should be considered in formulating the statistics of the distortion factors. For the case of tip radial dominated flow distortion, the total pressure fluctuations are primarily boundary-layer radiated noise. For hub radial dominated flow distortion, the total pressure fluctuations are amplified by flow separation and/or shock-boundary-layer interactions. Therefore, the statistics for IDR should be modified as were those for IDC for the high total pressure fluctuation condition that exists during flow separation and shock-boundary-layer interactions.

Comparisons of the measured and Melick-predicted values for the Pratt and Whitney distortion factors KA2, KΘ, and KRA are presented in Figs. 10e, f, and g, respectively. Good agreement is observed for KA2 (Fig. 10e) and for most of the KRA data (Fig. 10g). The predictions for the circumferential distortion factor, KΘ (Fig. 10f), are poor in the lower KΘ range but excellent in the higher KΘ range.

In addition, the Melick method was modified to include the statistics of the WRC circumferential distortion factor, AMPC. The AMPC statistics were empirically derived with the procedure that was used for IDC. Melick predictions for the WRC parameter AMPC are presented in Figs. 10h and i for Tests C and D, respectively. There is reasonably good agreement between the measured and predicted values despite the fact that a limited data base was used in the derivation of the AMPC statistics.

In general, excellent correlation between the Melick-predicted distortion values and the measured values was found for the distortion factor IDC. For the other distortion factors (IDR, KA2, KΘ, KRA, and AMPC) poor to good agreement was observed. The excellent correlation resulting from the modification of the IDC statistics suggests that similar improvements in the correlation of the other distortion factors would result if the same modification approach were to be used for the other parameters.

4.1.3 Motycka Method

Comparisons of the values predicted with the Motycka method to the measured test data for the distortion factors IDC, IDR, KA2, KΘ, KRA, and AMPC are shown in Fig. 11. These data were acquired during the four inlet tests.

The predictions for GE distortion factors IDC and IDR for Tests A and B are shown in Figs. 11a through d. The results of the Motycka method are very much like those of the Melick method: excellent correlation for IDC but an inability to properly account for hub radial distortion for IDR.

For the PWA and WRC distortion factors (Figs. 11e through i), the Motycka method tends to predict values lower than the measured values. This tendency suggests that the assumption of a normal distribution for each total pressure probe is invalid for a significant portion of the data base (i.e., the three-sigma criterion is too stringent). However, the results show good correlation for much of the data in Fig. 11. The method appears promising and warrants further study.

4.2 EVALUATION OF PREDICTED DISTORTION PATTERNS

The Jacocks method has no provisions for predicting maximum time-variant total pressure distortion patterns. The Melick method predicts maximum time-variant distortion patterns by adjusting the steady-state patterns for total pressure fluctuations. The Melick-predicted distortion patterns are determined by a procedure totally separate from that used to make the distortion value predictions. In contrast, the Motycka method predicts a maximum time-variant distortion pattern from the pressure-time histories created by the statistical properties and by the random number generator.

Comparisons of the measured and predicted time-variant distortion patterns are presented in Fig. 12 for selected conditions from Test D. These results typify the several hundred distortion patterns generated from the four inlet tests. The comparisons are presented as a function of engine-face total pressure fluctuation rms values. The Motycka prediction of the distortion patterns is obviously superior to the Melick predictions. As a matter of fact, the Motycka-predicted patterns correlate excellently to the measured patterns except at the high total pressure fluctuation conditions of Figs. 12e and f. The data show that the agreement between the measured and predicted patterns decreases significantly as the separated-flow condition within the inlet duct worsens, a factor which increases total pressure fluctuation. These results emphasize the need to consider the nature of the inlet total pressure fluctuations when formulating statistical techniques.

5.0 CONCLUSIONS AND RECOMMENDATION

Table 3 summarizes the advantages and disadvantages of the three statistical methods. None of the three techniques is accurate enough to replace the current deterministic method for all conditions, although the Melick method could be improved by modifying the distortion factors statistics, thus bringing the deviations to within ±10 percent of the deterministic values. At present, however, the distortion pattern predictions from the Melick method are unacceptable.

Of the three statistical methods investigated, the Motycka method shows the most promise. The Motycka-predicted distortion values and patterns agree closely with those measured; however, the method must be modified to account for the nature of the inlet total pressure fluctuations. Also, the excessive time required by the method for digital computer execution (90 sec per point for 0.5-sec data analysis time) (see Table 3) is a disadvantage of the method, and further modification to the Motycka method might significantly increase this time requirement.

The Jacocks method predicts distortion values with reasonable accuracy, but the ADC requirement makes the method unsuitable for most inlet test programs. Improvement might result from combining the extreme-value statistics of the Jacocks method with the Motycka method since this analysis shows that the three-sigma criterion assumed in the Motycka method yields distortion values lower than the measured values.

At present, the Melick method is recommended for use during early subscale model inlet tests for the determination of maximum time-variant distortion values. Good correlation was found for most test conditions. The method is simple and easy to implement, and it requires less than a full array (normally 40) of engine-face total pressure probes. Also, the Melick method can be used as an on-line data analysis tool for configuration selection and test direction at any stage of aircraft development. However, as the aircraft configuration is finalized, the distortion values and patterns should be determined with the more accurate, conventional manner.

REFERENCES

1. Jacocks, J. L. and Kneile, K. R. "Statistical Prediction of Maximum Time-Variant Inlet Distortion Levels." AEDC-TR-74-121 (ADA004104), January 1975.

2. Melick, H. C., Ybarra, A. H., and Bencze, D. P. "Estimating Maximum Instantaneous Distortion from Inlet Total Pressure RMS and PSD Measurements." NASA TMX-73,145, June 1976.

3. Motycka, D. L. "Determination of Maximum Expected Instantaneous Distortion Patterns from Statistical Properties of Inlet Pressure Data." AIAA Paper 76-705, July 1976.

4. Kimzey, W. F. and Lewis, R. J. "An Experimental Investigation of the Effects of Shock-Induced Turbulent In-Flow on a Turbojet Engine." Presented at AIAA 2nd Propulsion Joint Specialist Conference, United States Air Force Academy, Colorado Springs, Colorado, June 13-17, 1966.

5. Rall, F. T. "Aircraft and Propulsion Operational Considerations Related to Inlet Design." In *Proceedings*. 27th AGARD Conference, September, 1967.

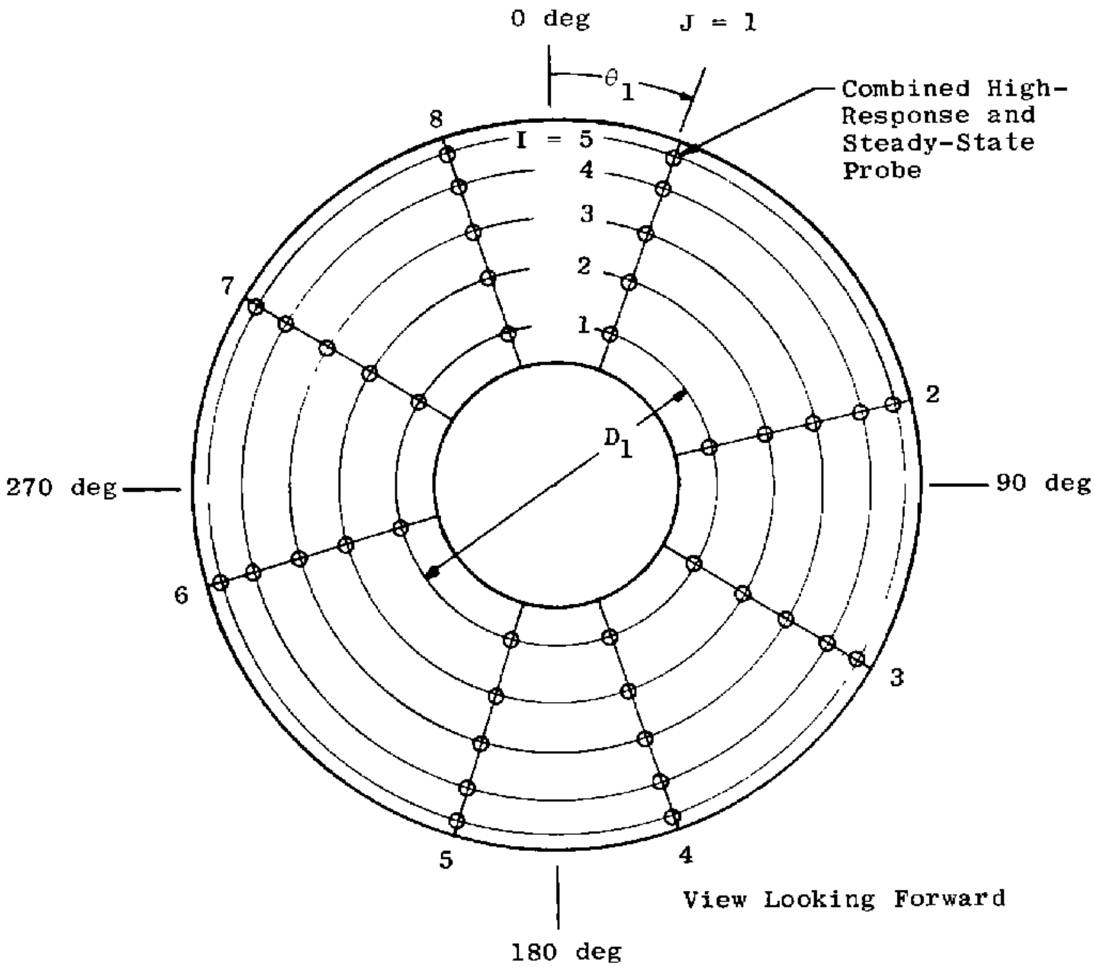


Figure 1. General engine-face probe geometry and nomenclature.

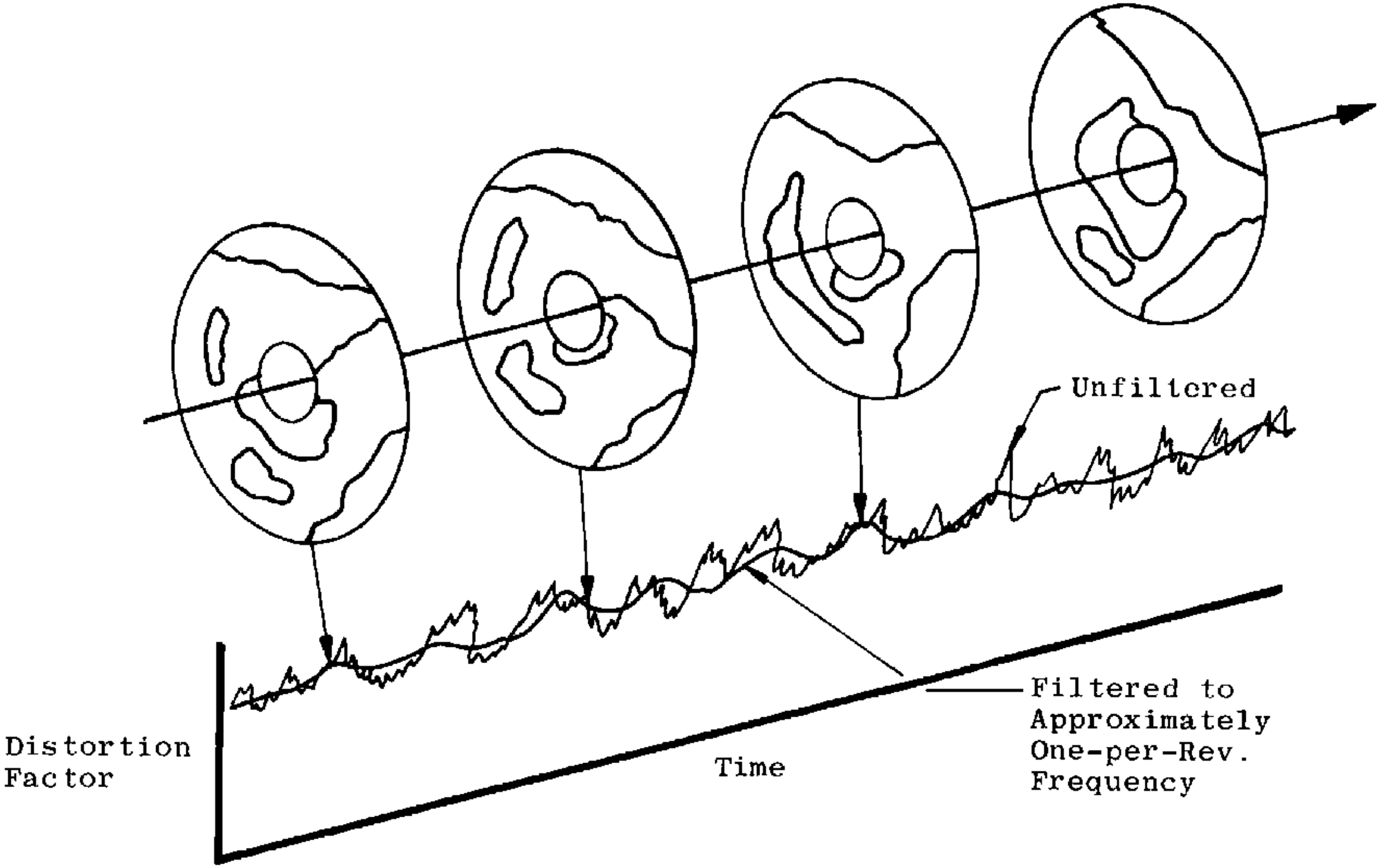


Figure 2. Flow-field description by time-dependent distortion factor method.

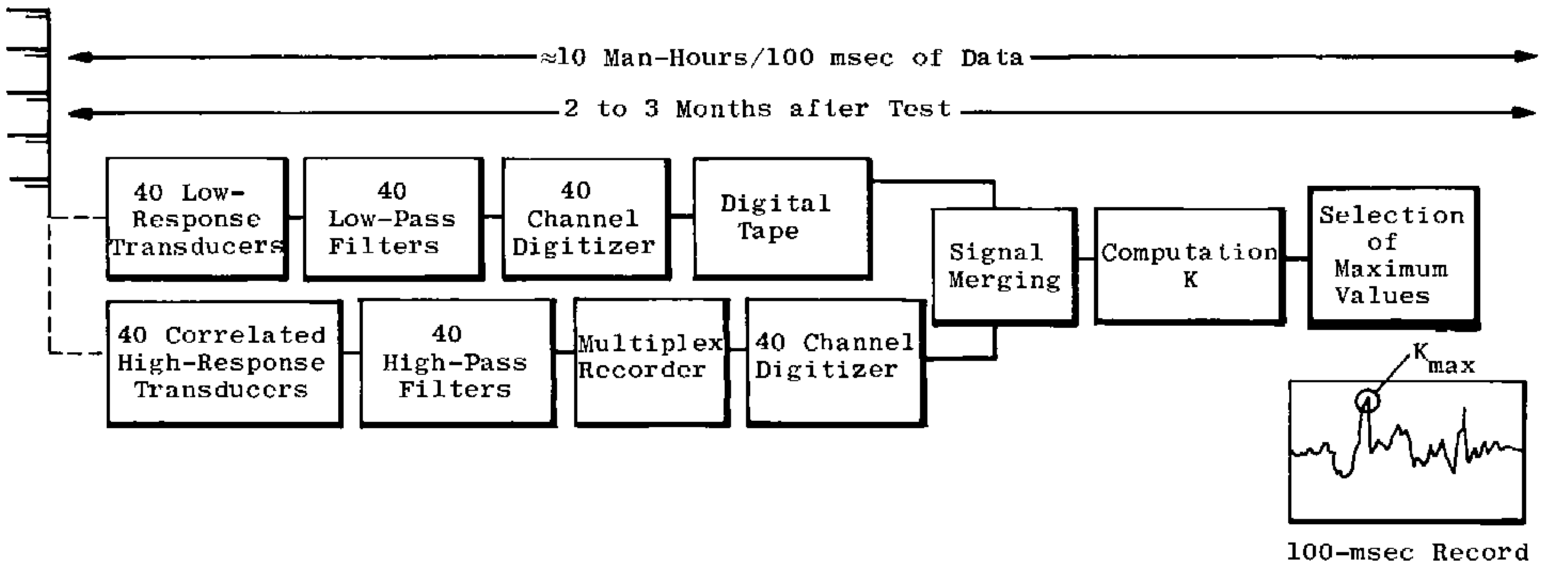


Figure 3. Deterministic method for processing time-variant distortion data.

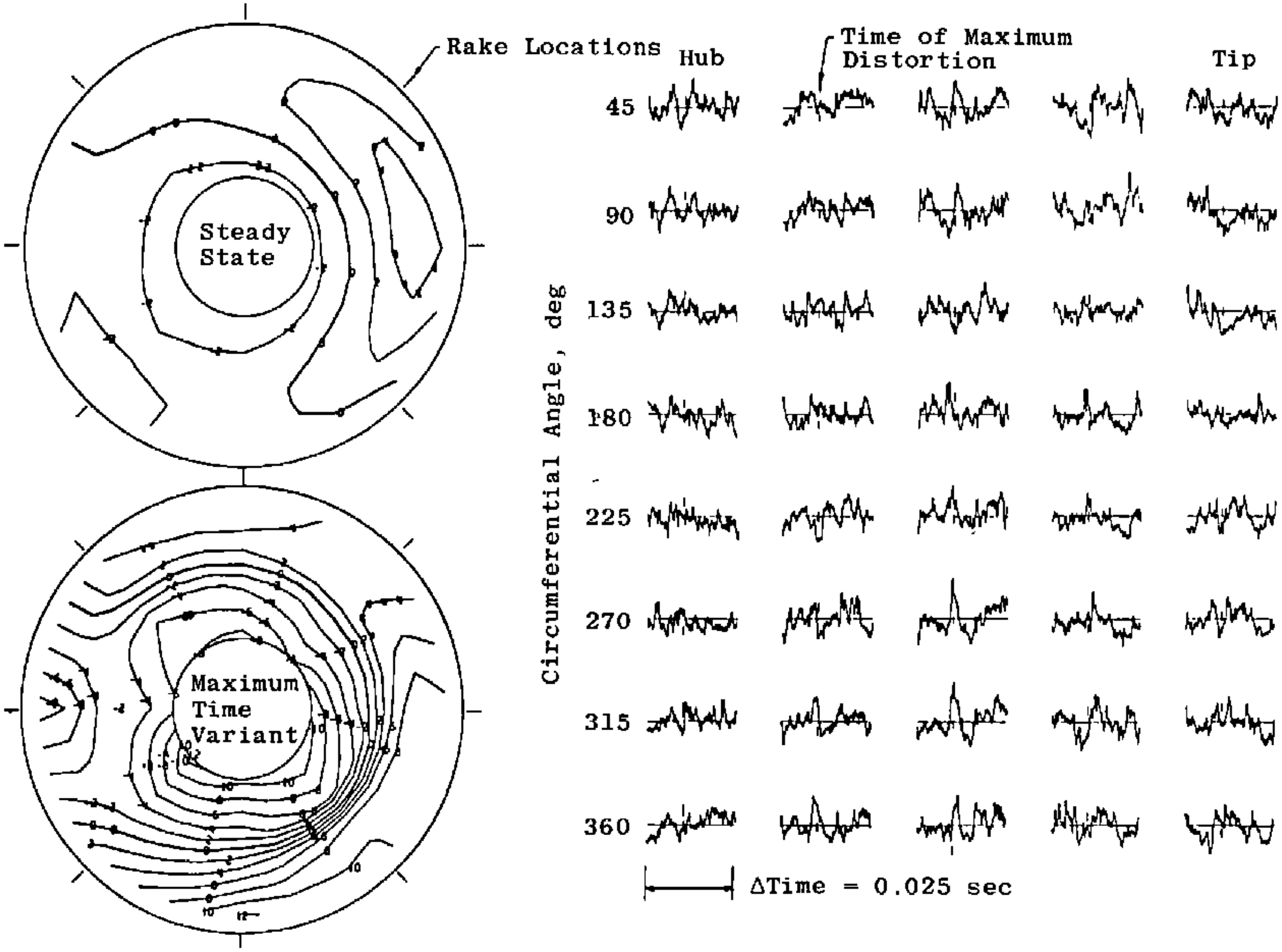


Figure 4. Typical engine-face total pressure waveforms at the time of maximum distortion.

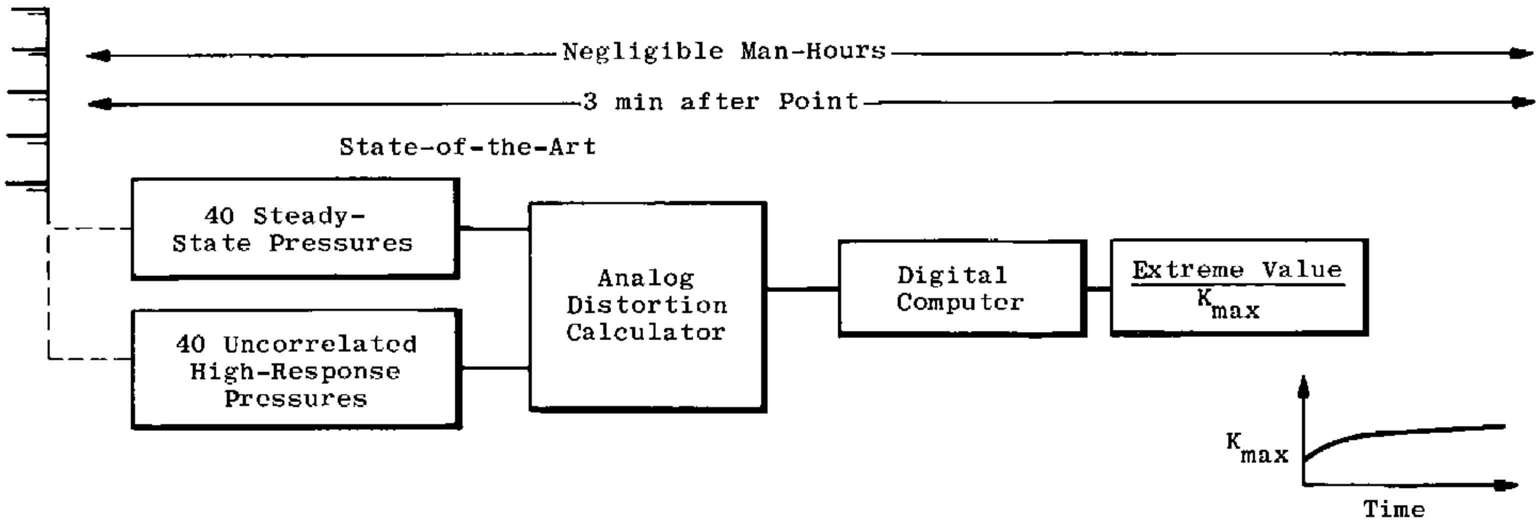


Figure 5. Jacocks statistical method for processing time-variant distortion data.

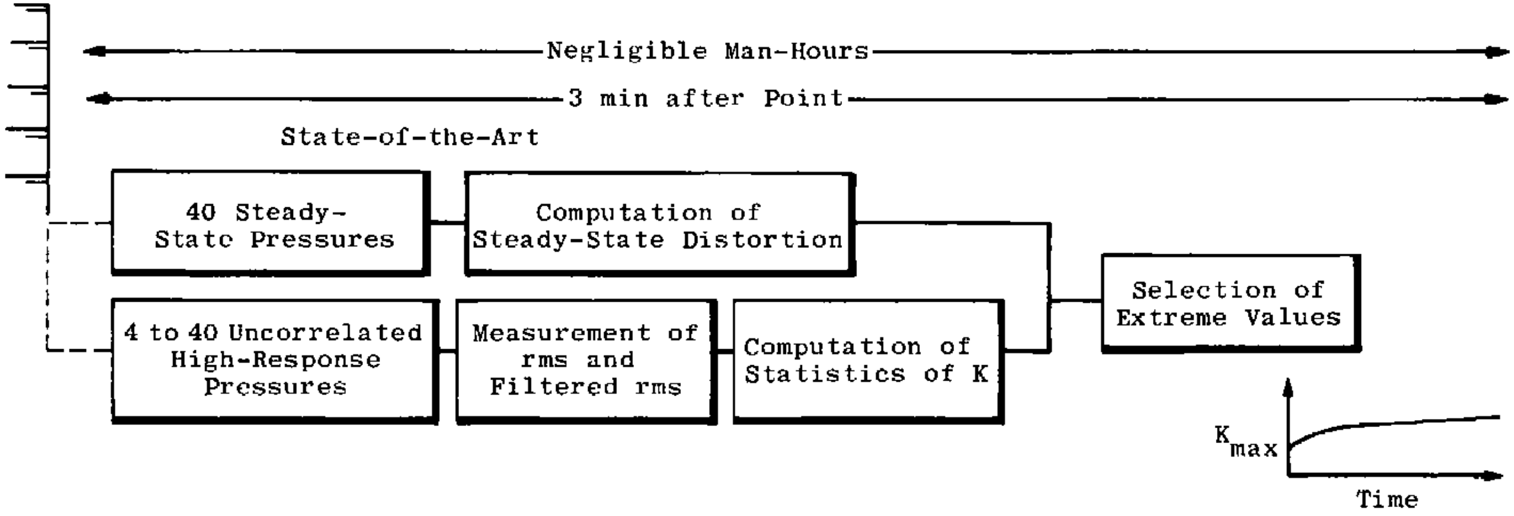


Figure 6. Melick statistical method for processing time-variant distortion data.

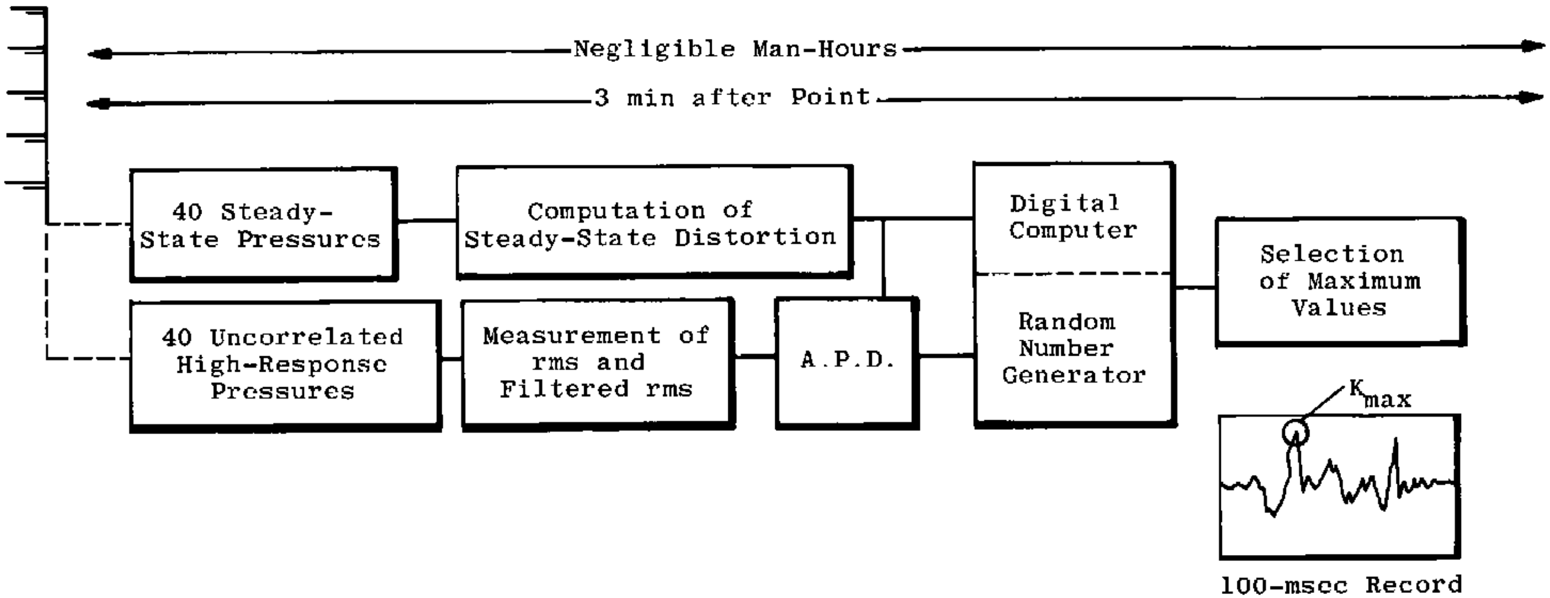
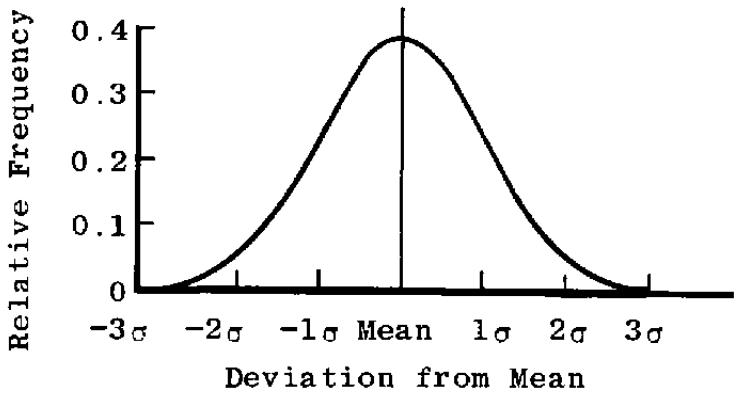
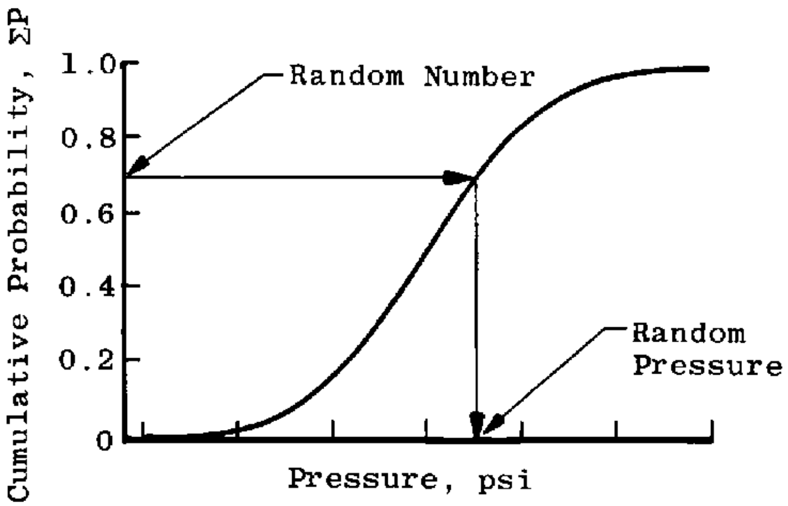


Figure 7. Motycka statistical method for processing time-variant distortion data.

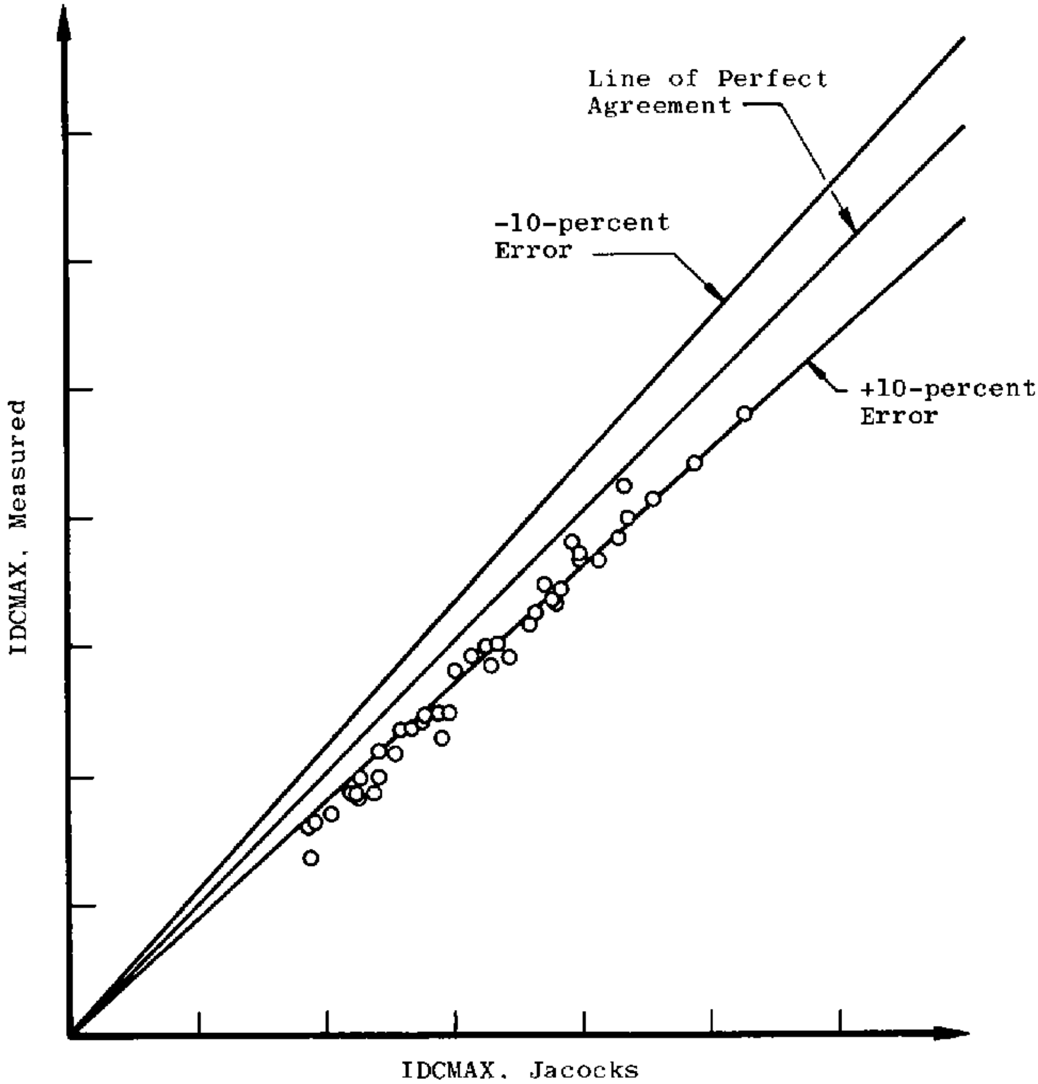


a. Amplitude probability density (A. P. D.)



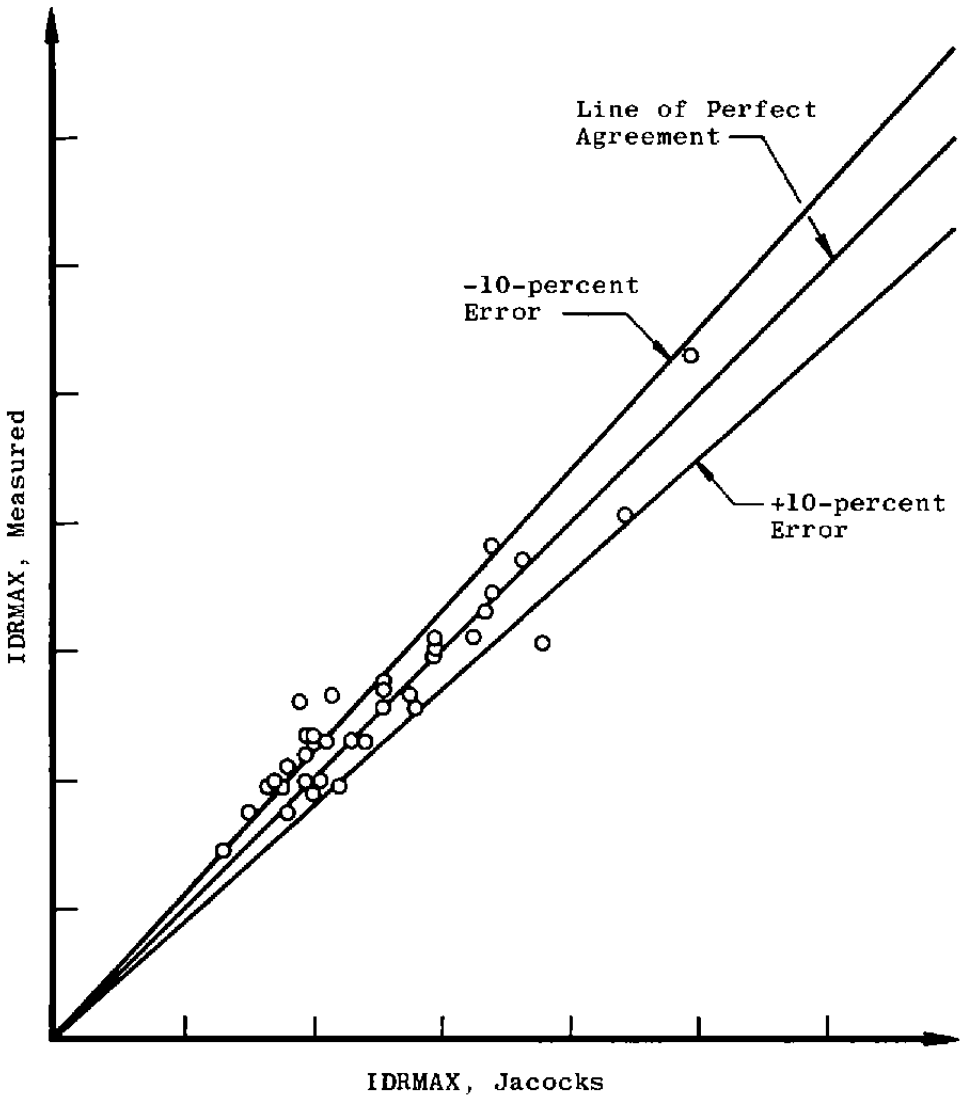
b. Cumulative probability

Figure 8. Statistical parameters used in the Motycka method.

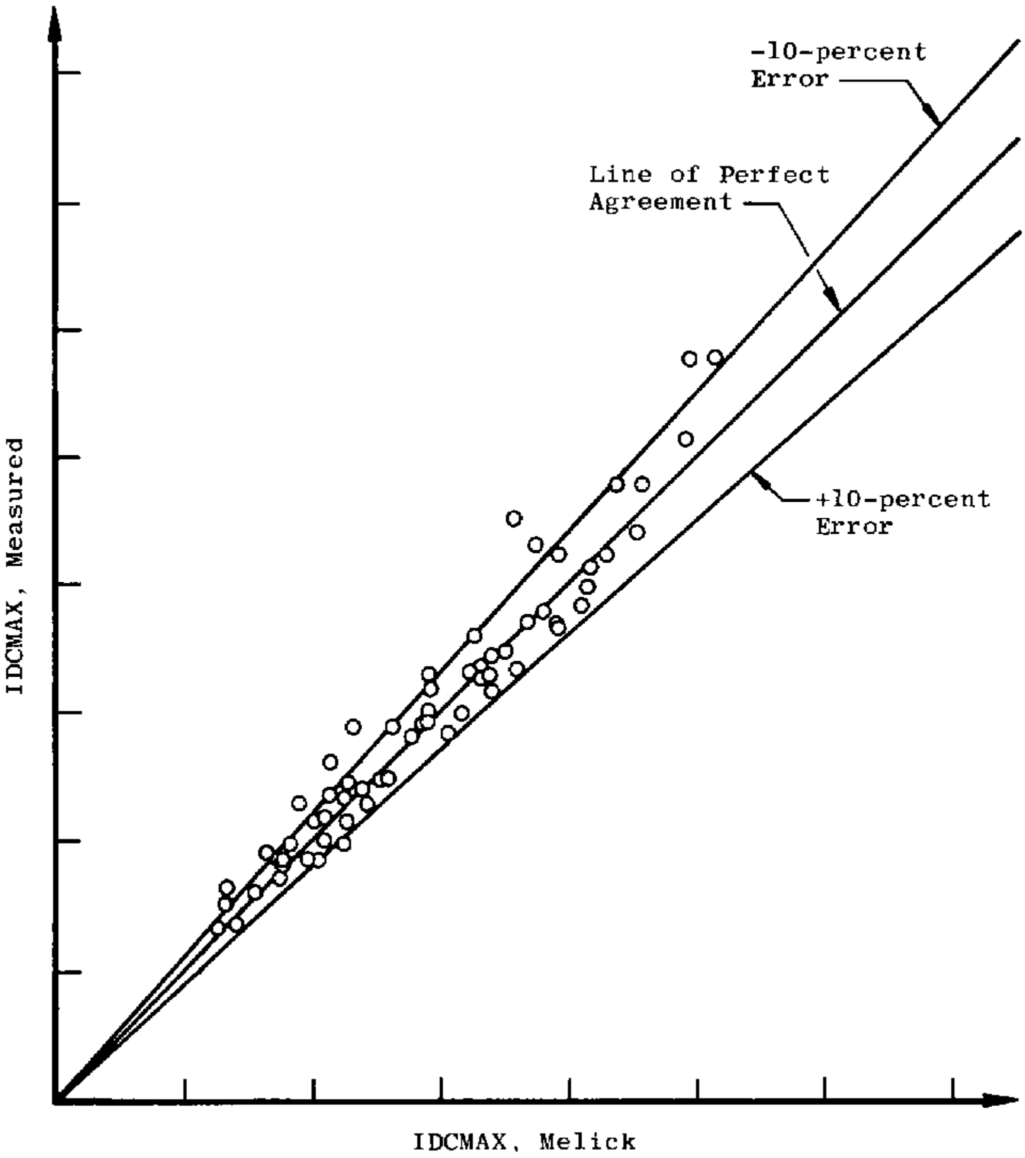


a. Distortion factor IDC

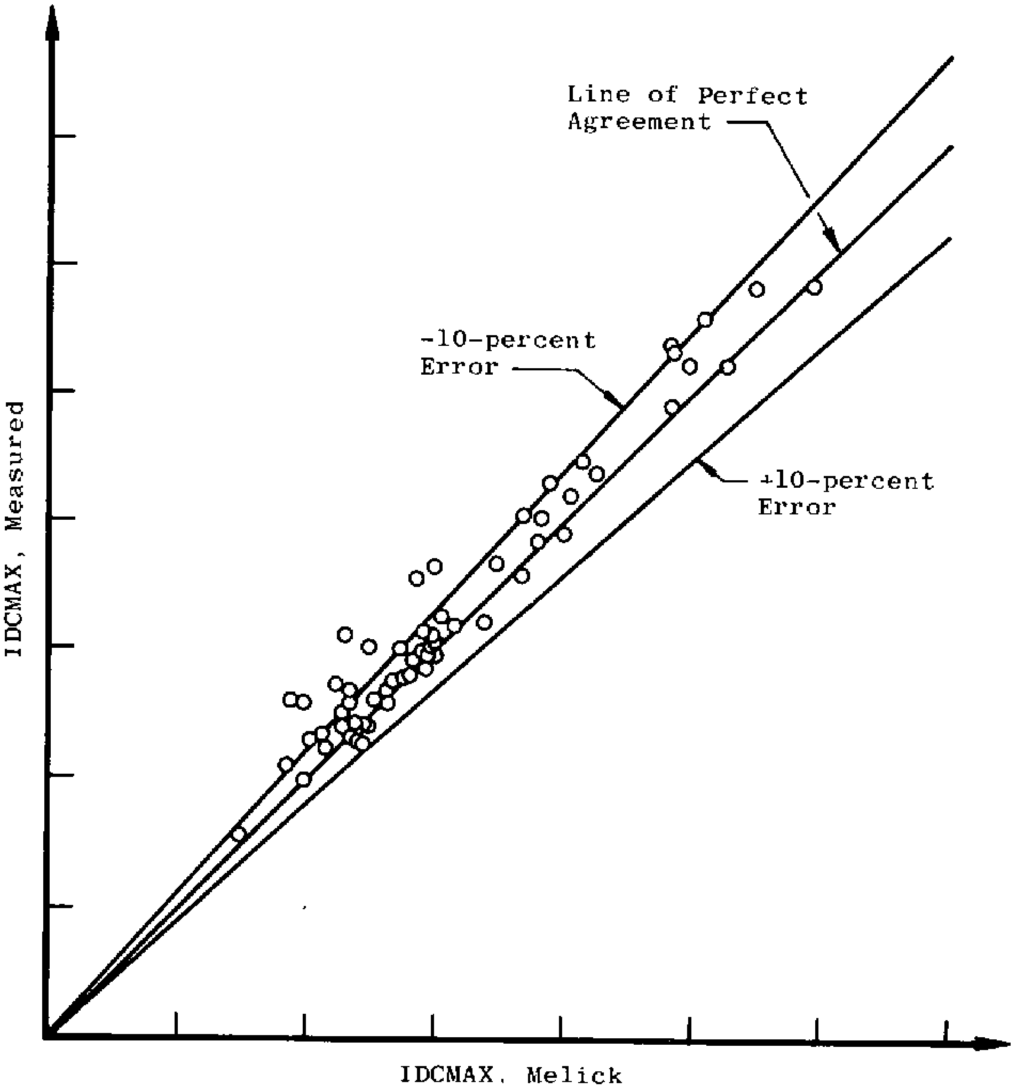
Figure 9. Comparison of measured maximum time-variant distortion values with the Jacocks method.



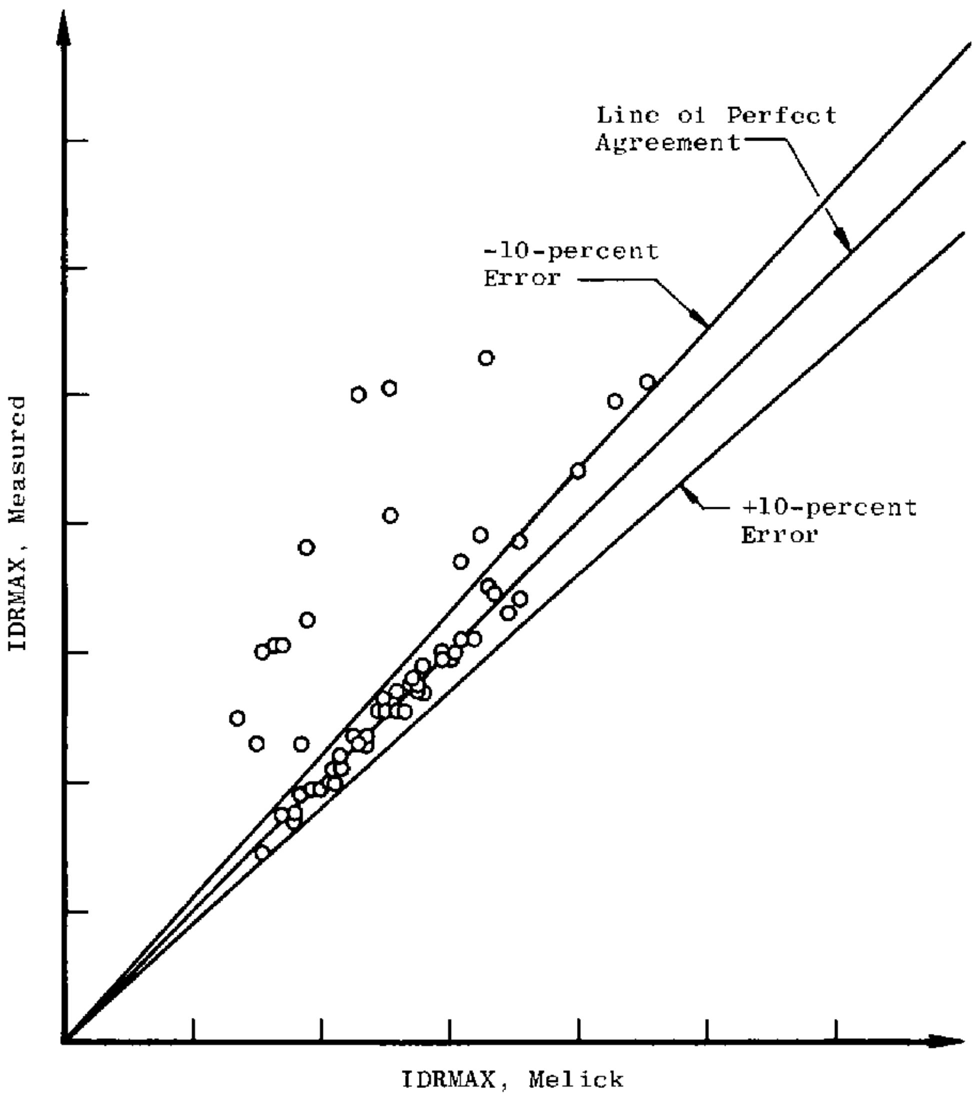
b. Distortion factor IDR
Figure 9. Concluded.



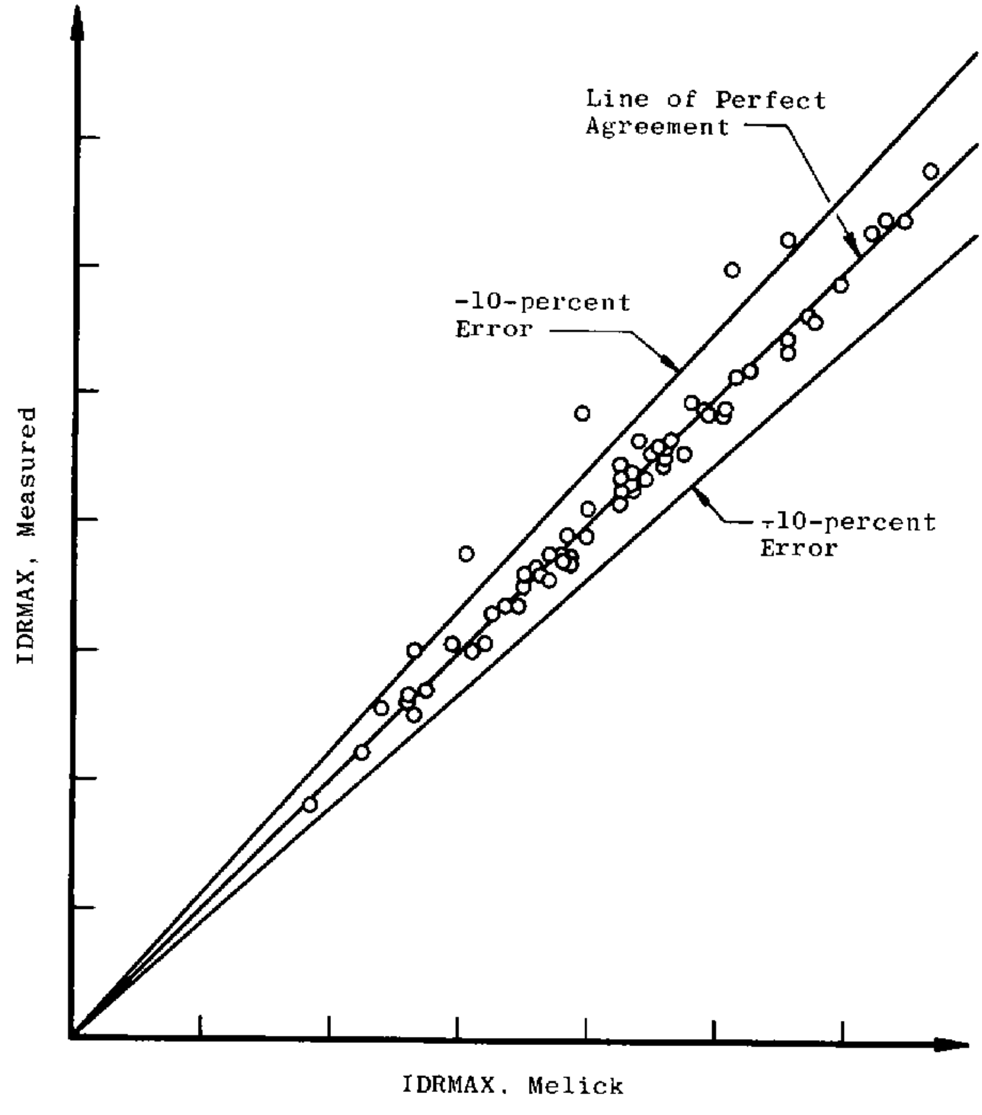
a. Test A, distortion factor IDC
Figure 10. Comparison of measured maximum time-variant distortion values with the Melick method.



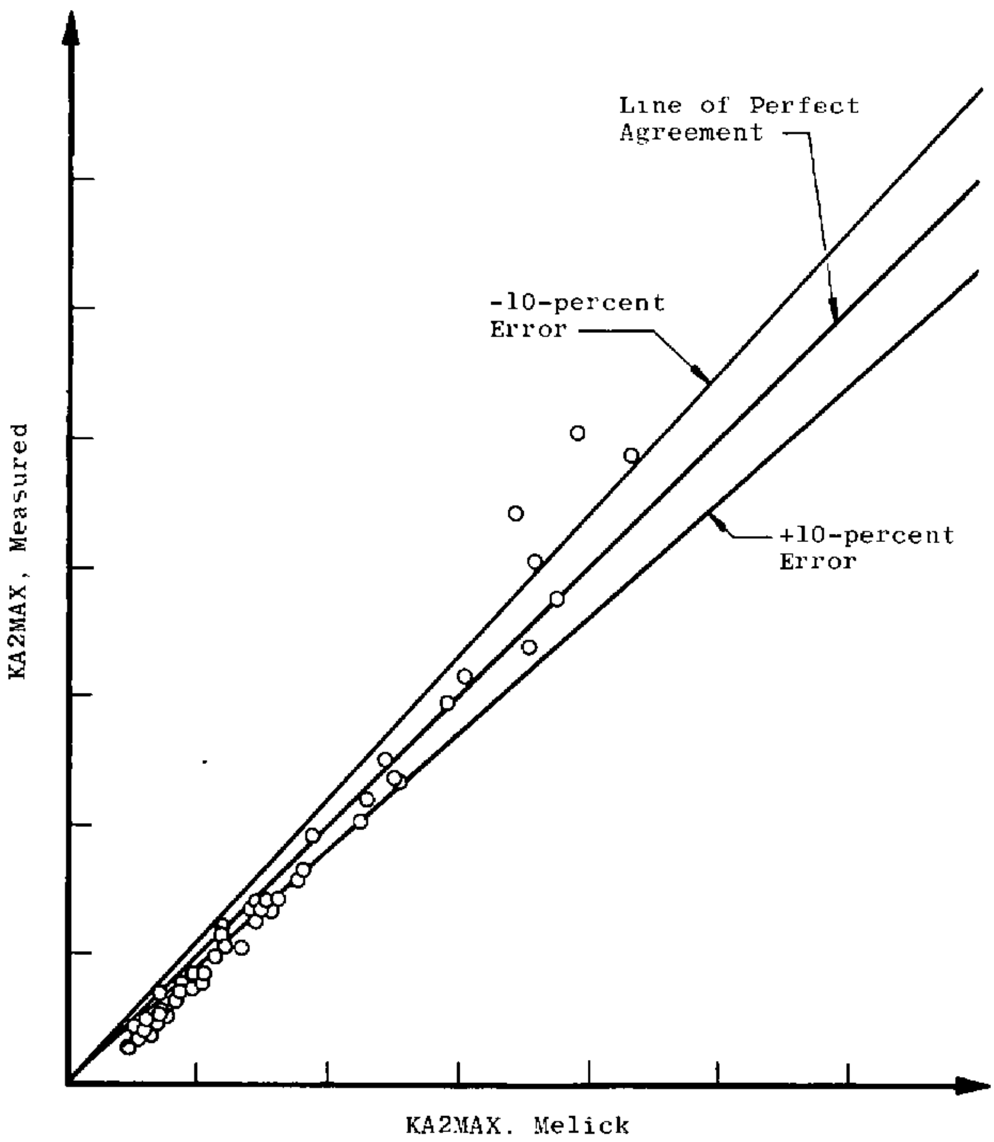
b. Test B, distortion factor IDC
Figure 10. Continued.



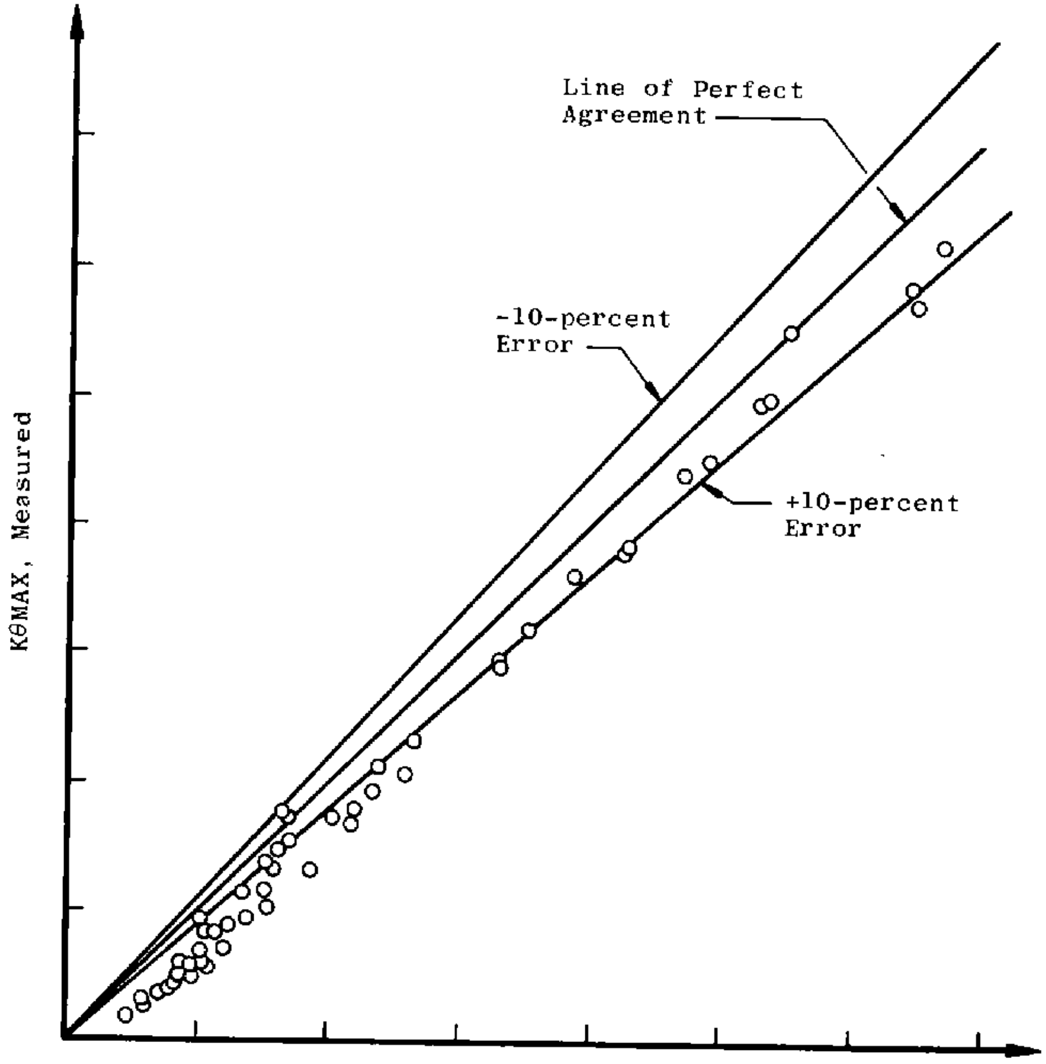
c. Test A, distortion factor IDR
Figure 10. Continued.



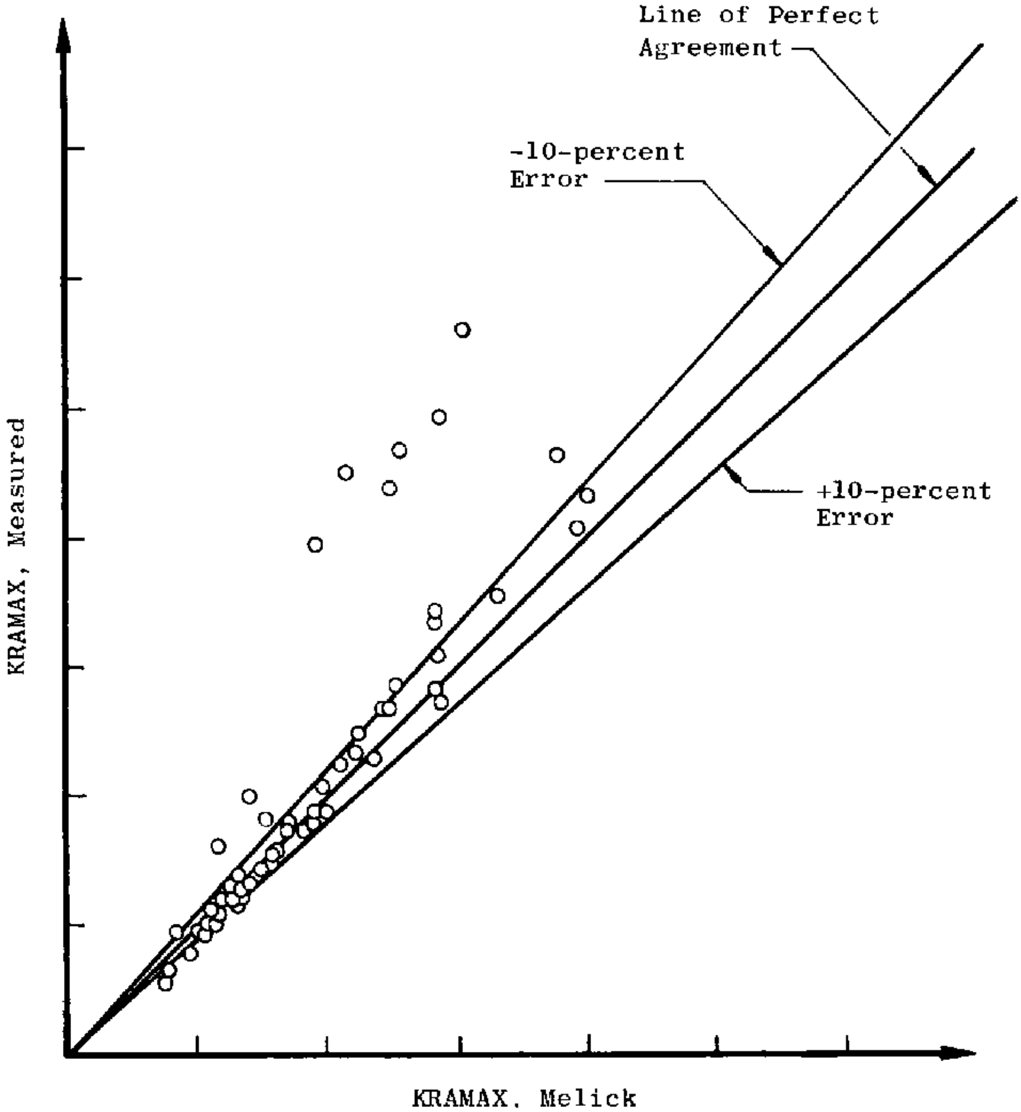
d. Test B, distortion factor IDR
Figure 10. Continued.



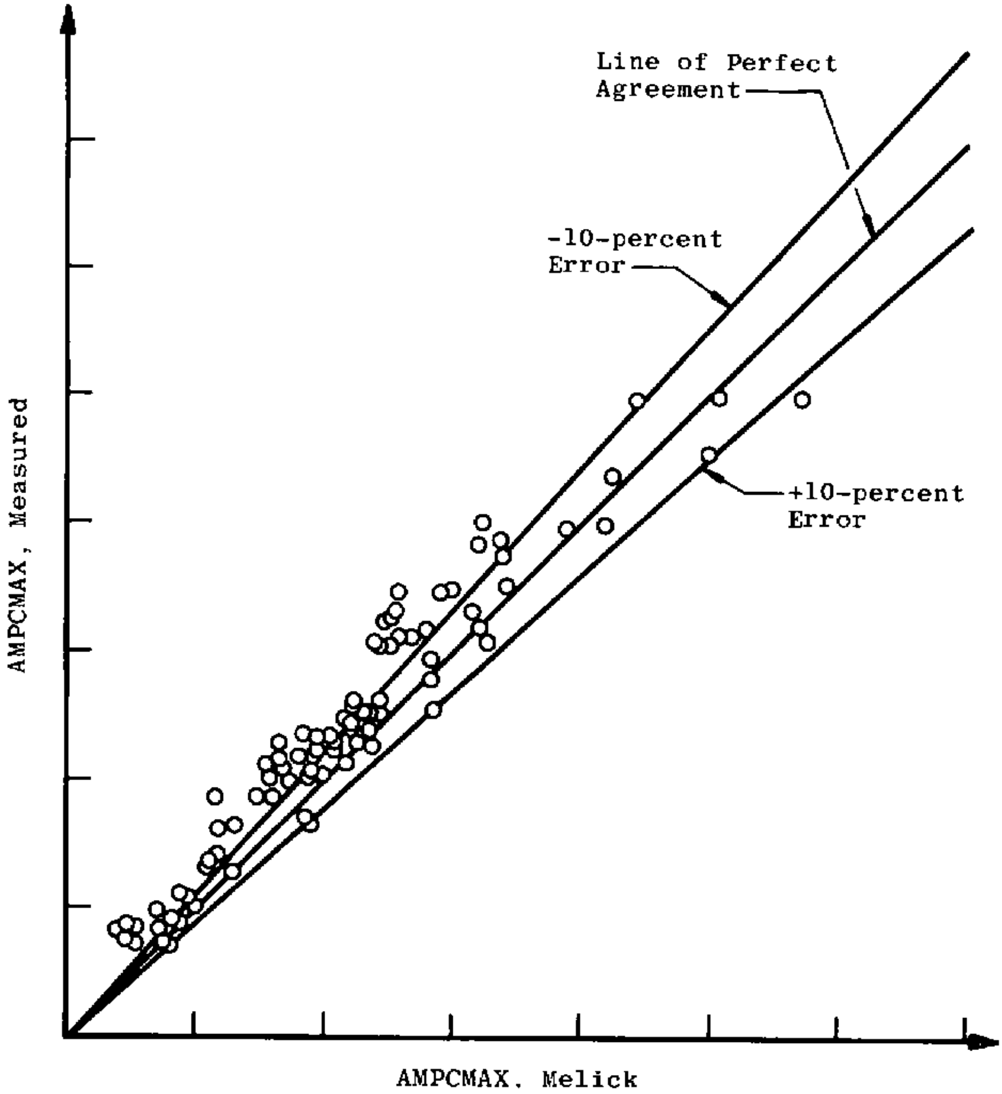
e. Test B, distortion factor KA2
Figure 10. Continued.



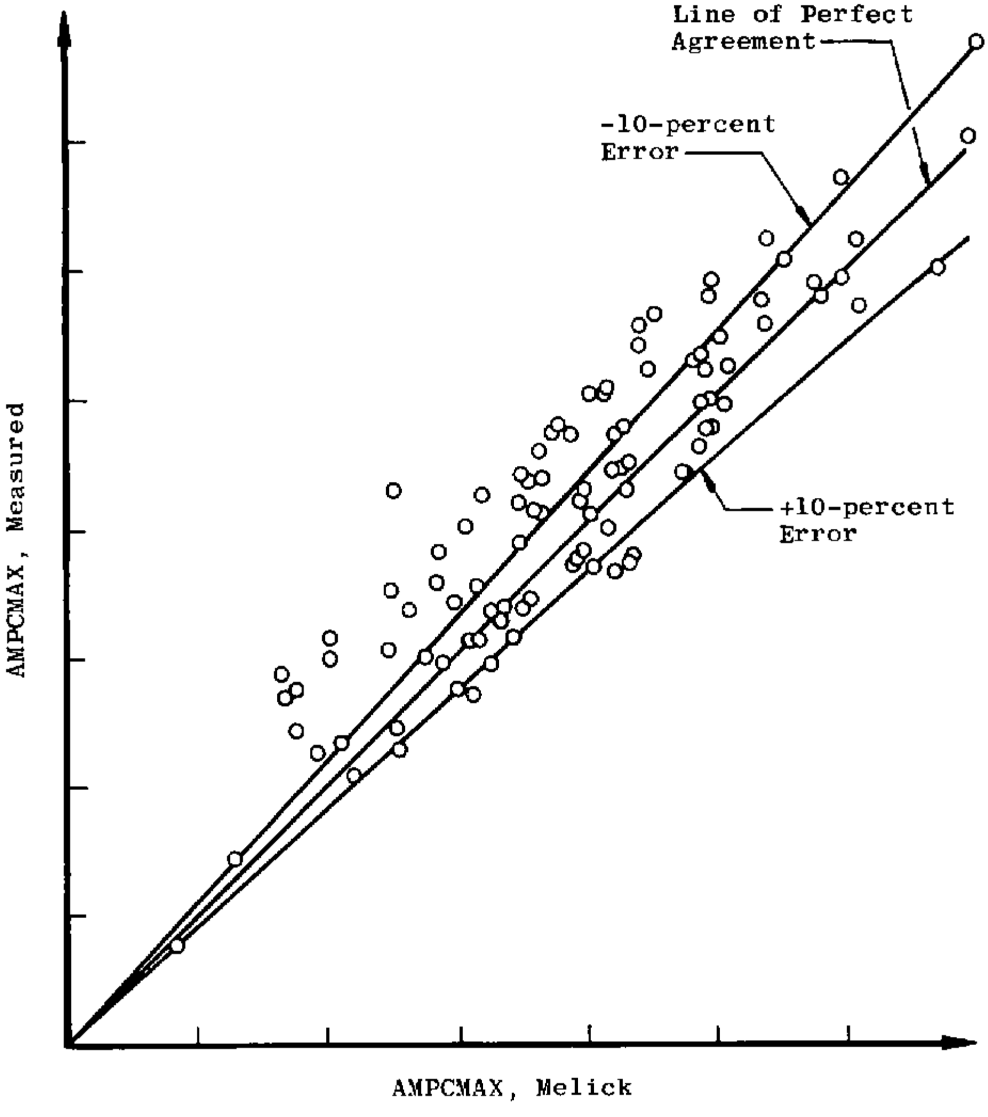
f. Test B, distortion factor $K\theta$
Figure 10. Continued.



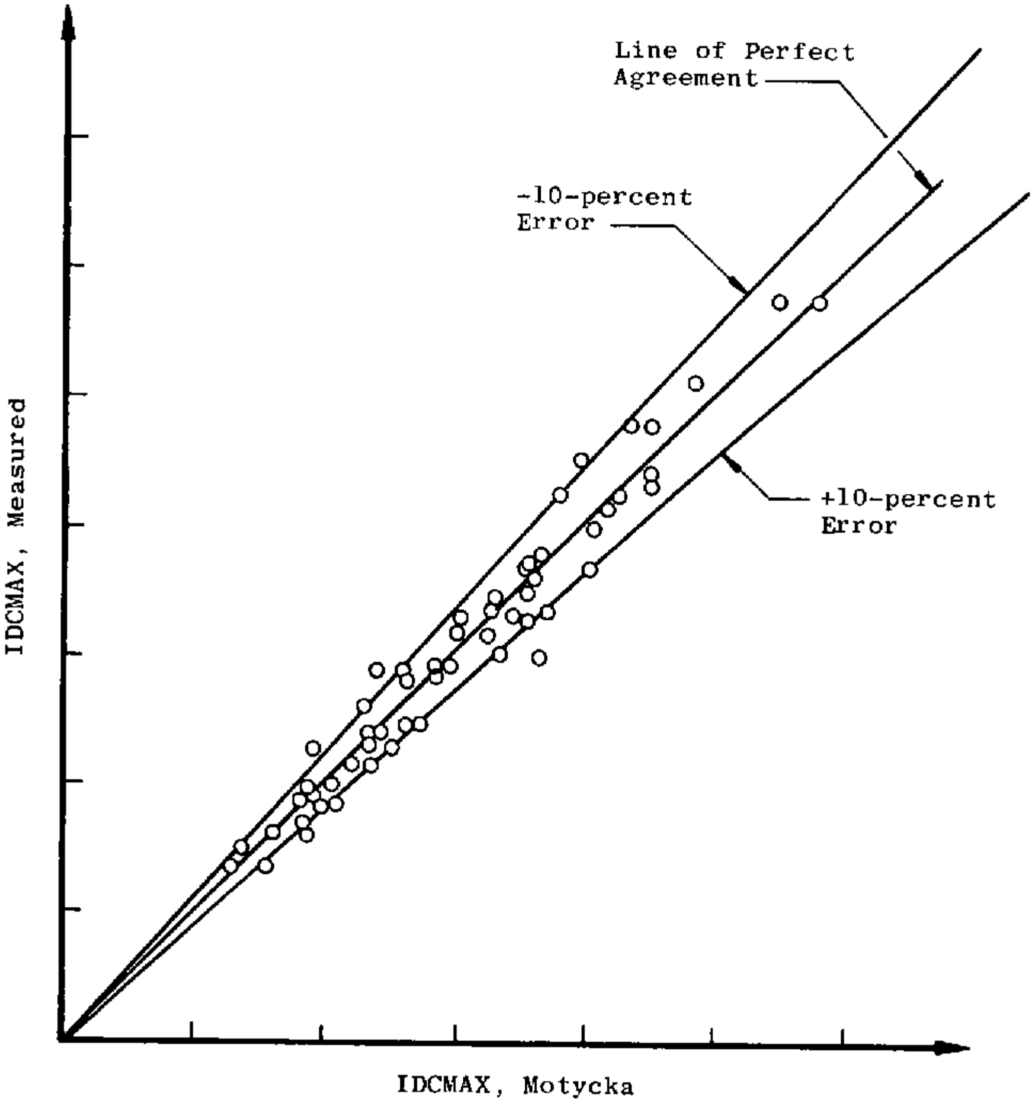
g. Test B, distortion factor KRA
Figure 10. Continued.



h. Test C, distortion factor AMPC
Figure 10. Continued.

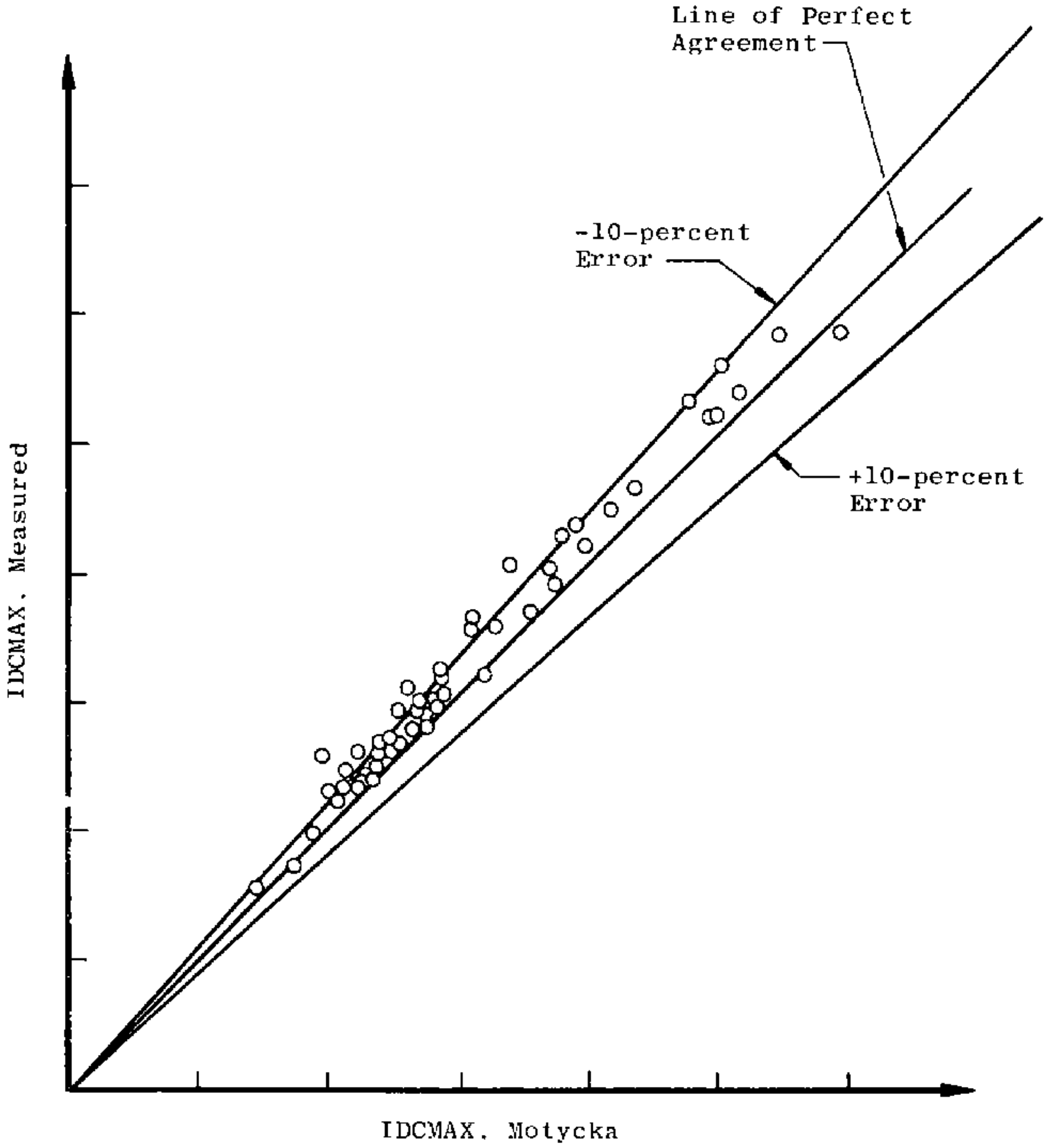


i. Test D, distortion factor AMPC
Figure 10. Concluded.

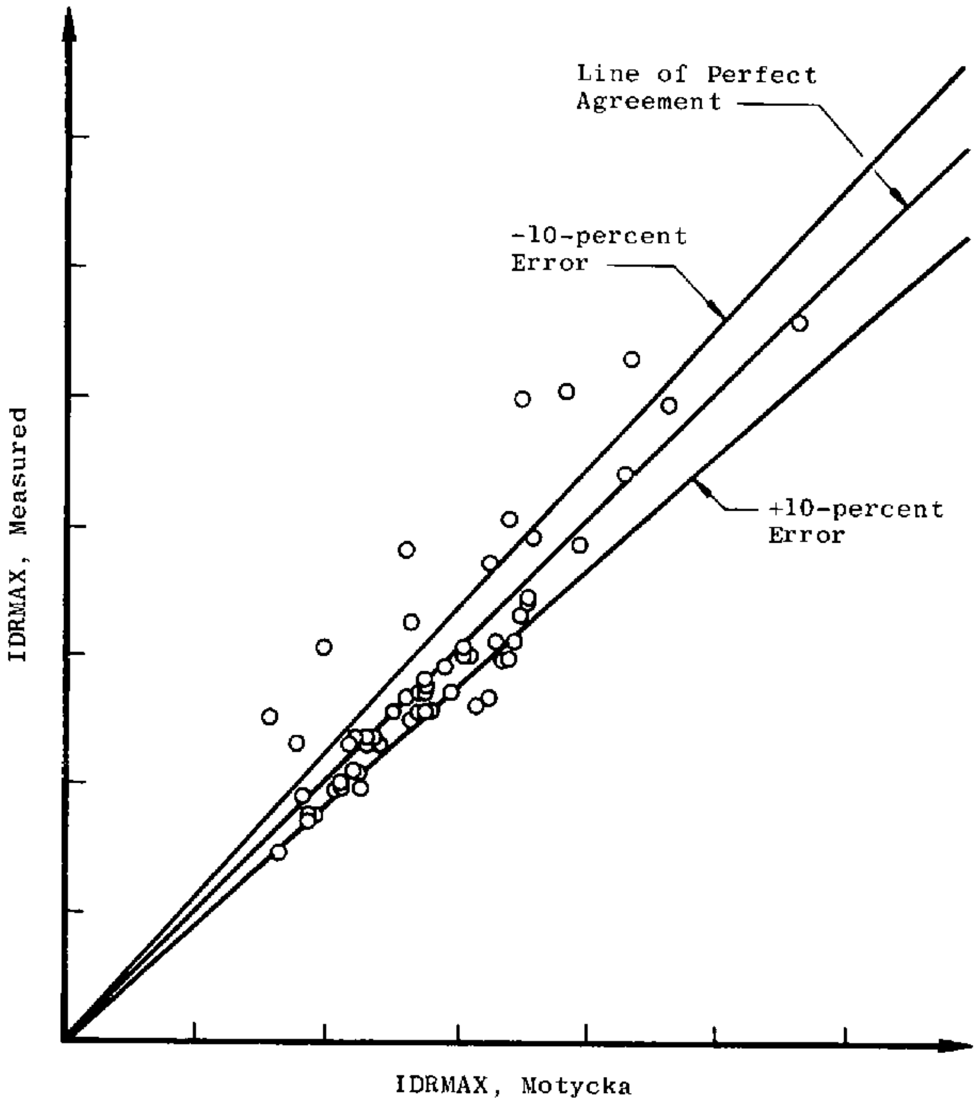


a. Test A, distortion factor IDC

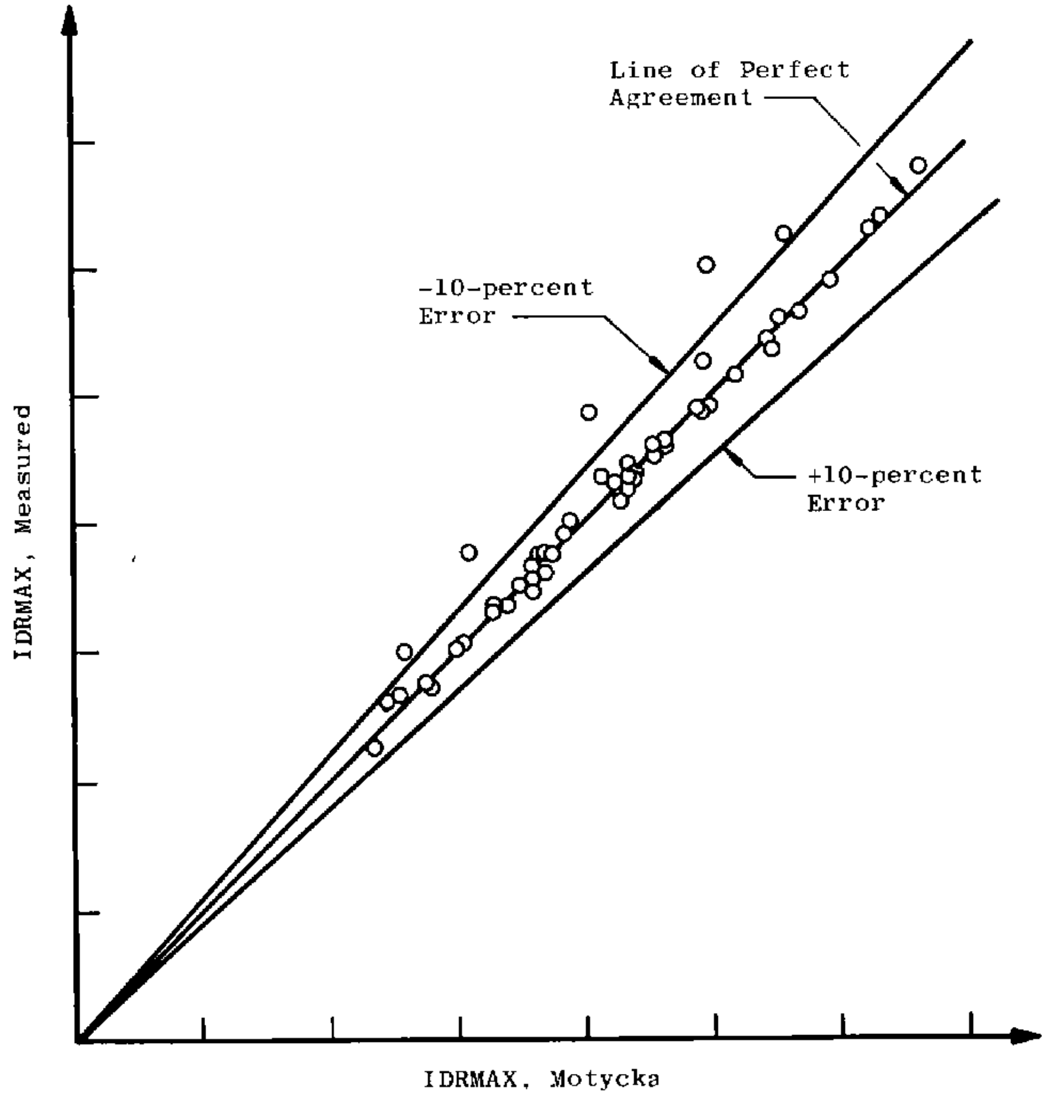
Figure 11. Comparison of measured maximum time-variant distortion values with the Motycka method.



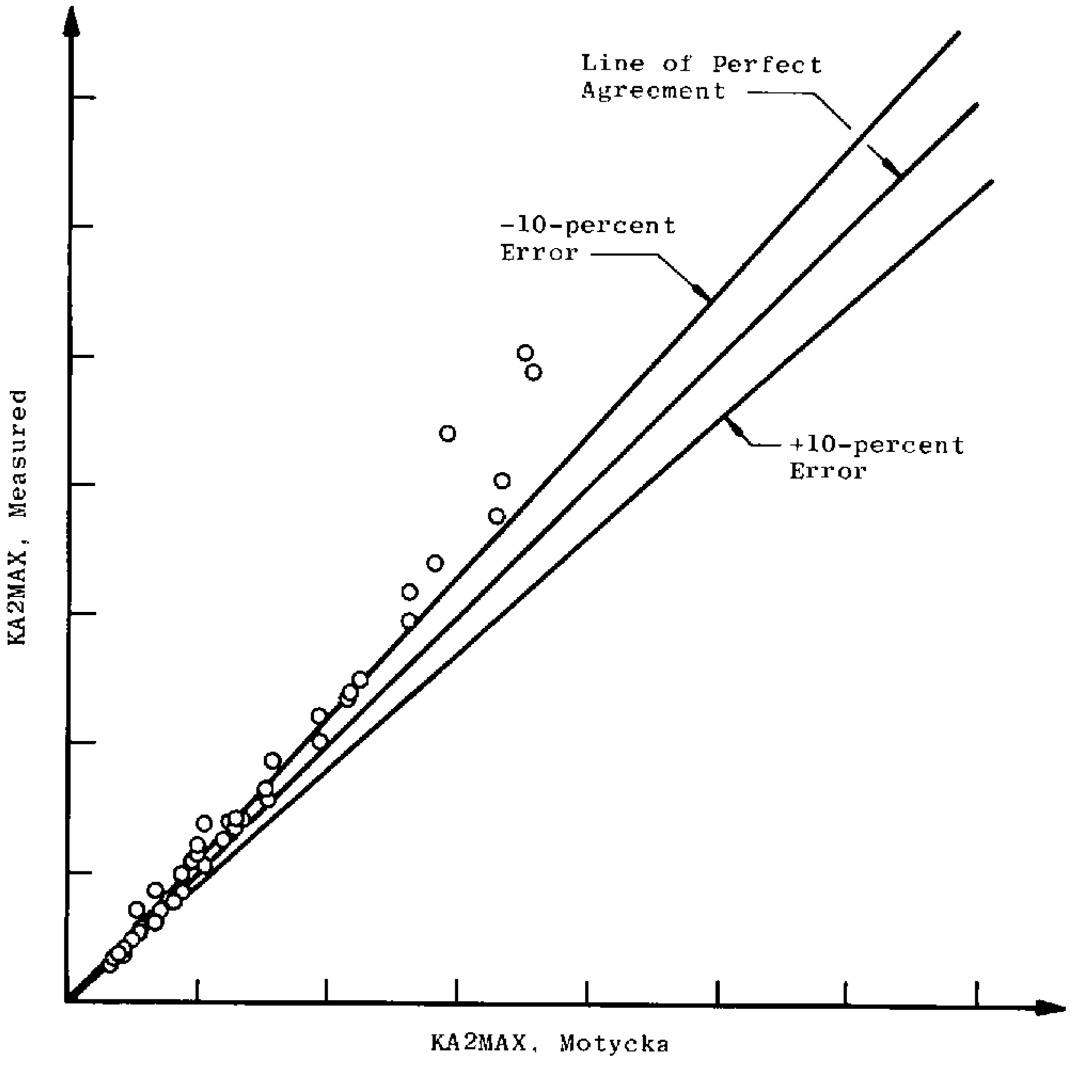
b. Test B, distortion factor IDC
Figure 11. Continued.



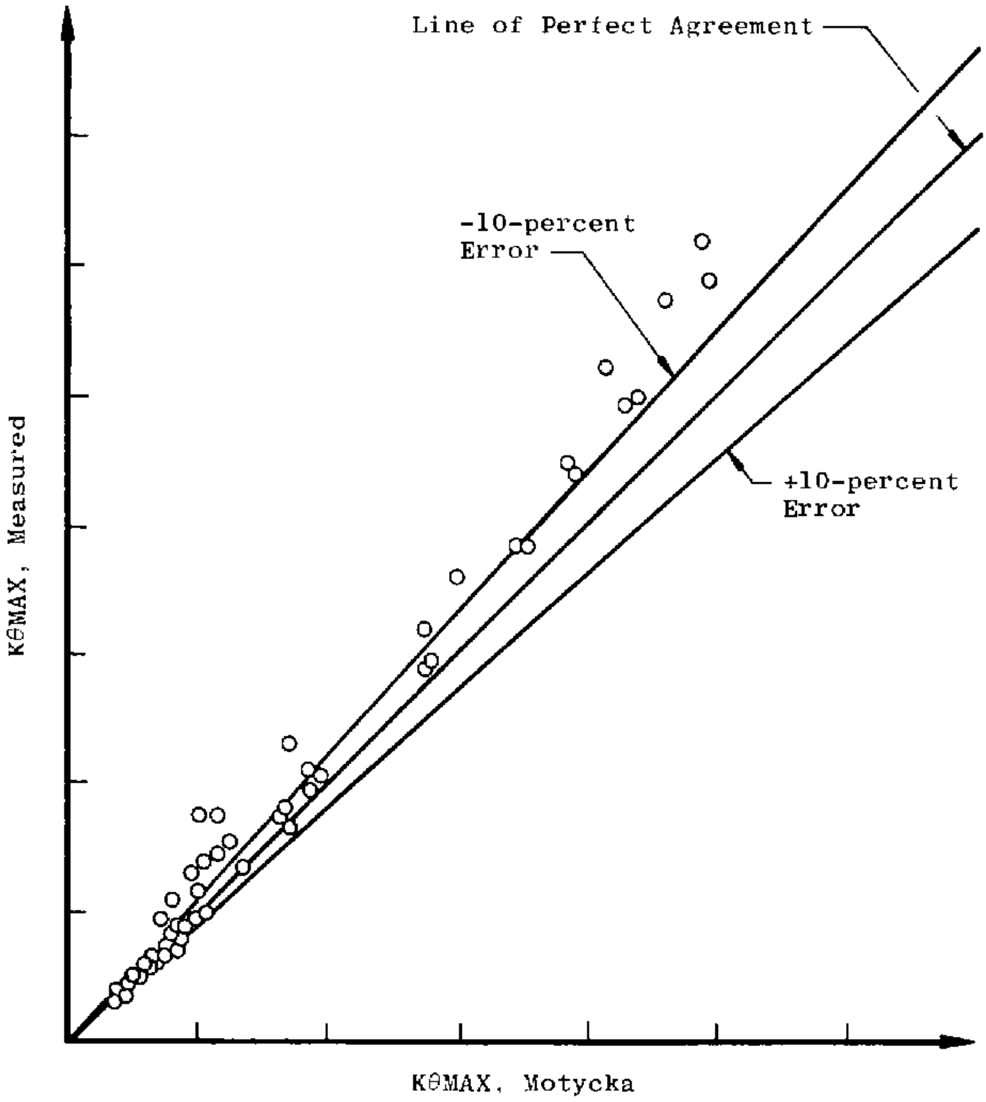
c. Test A, distortion factor IDR
Figure 11. Continued.



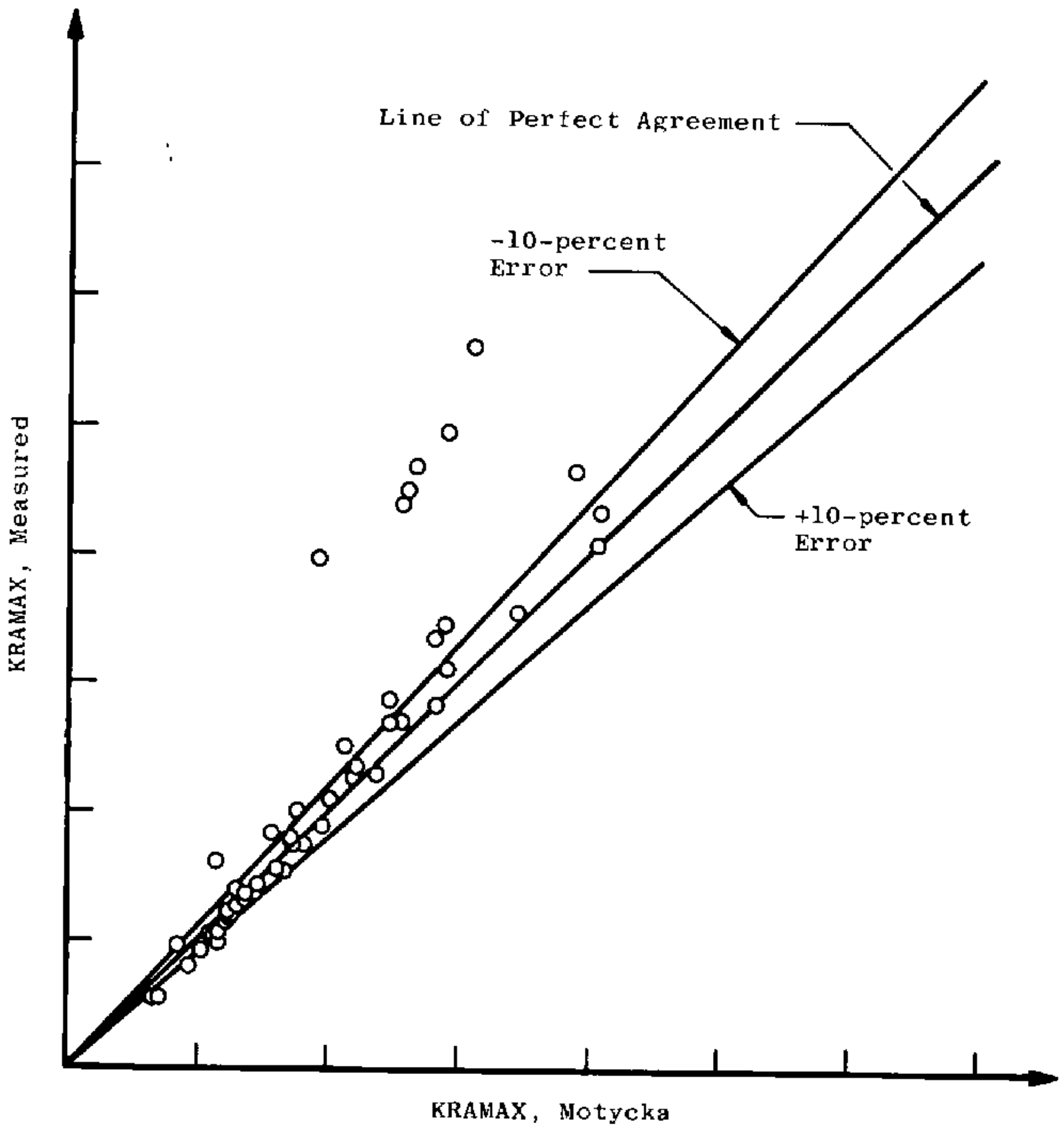
d. Test B, distortion factor IDR
Figure 11. Continued.



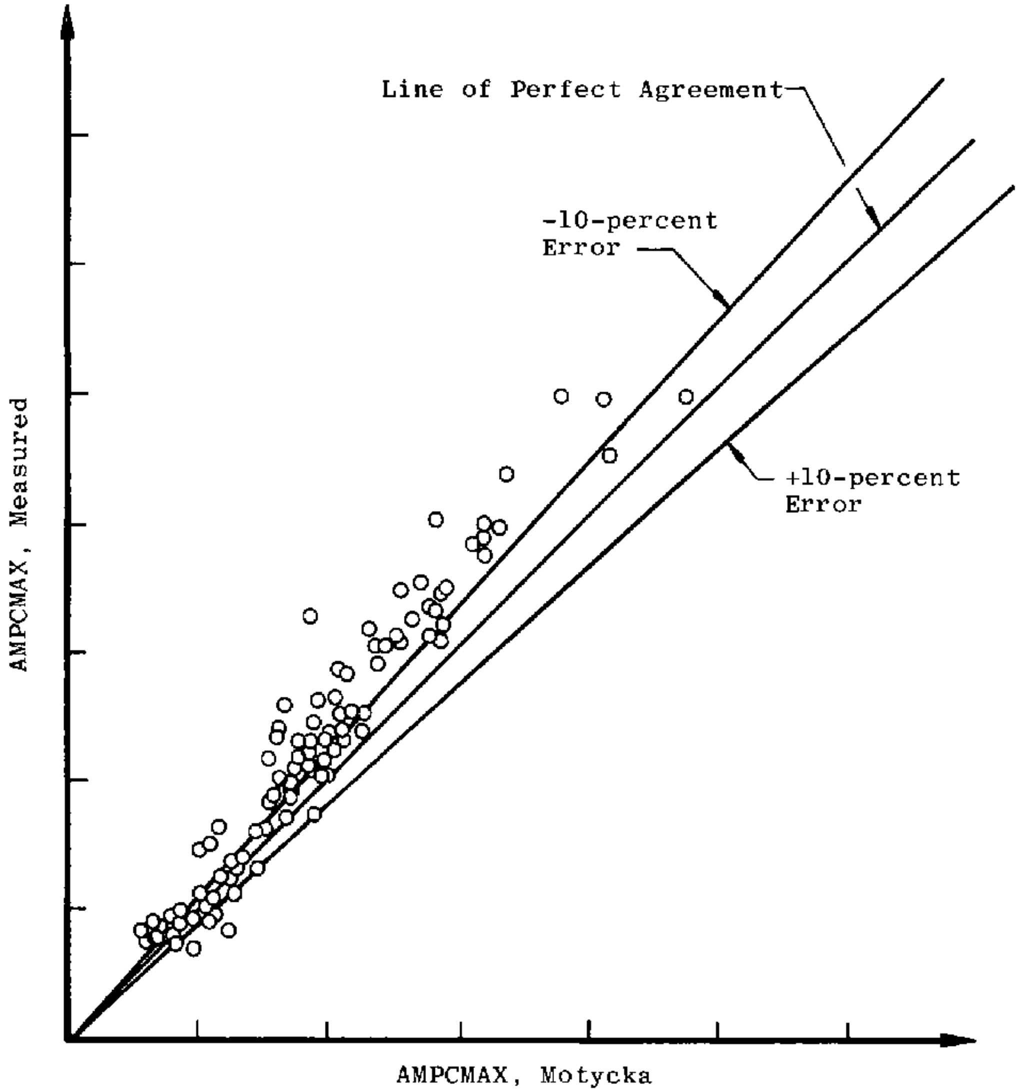
e. Test B, distortion factor KA2
Figure 11. Continued.



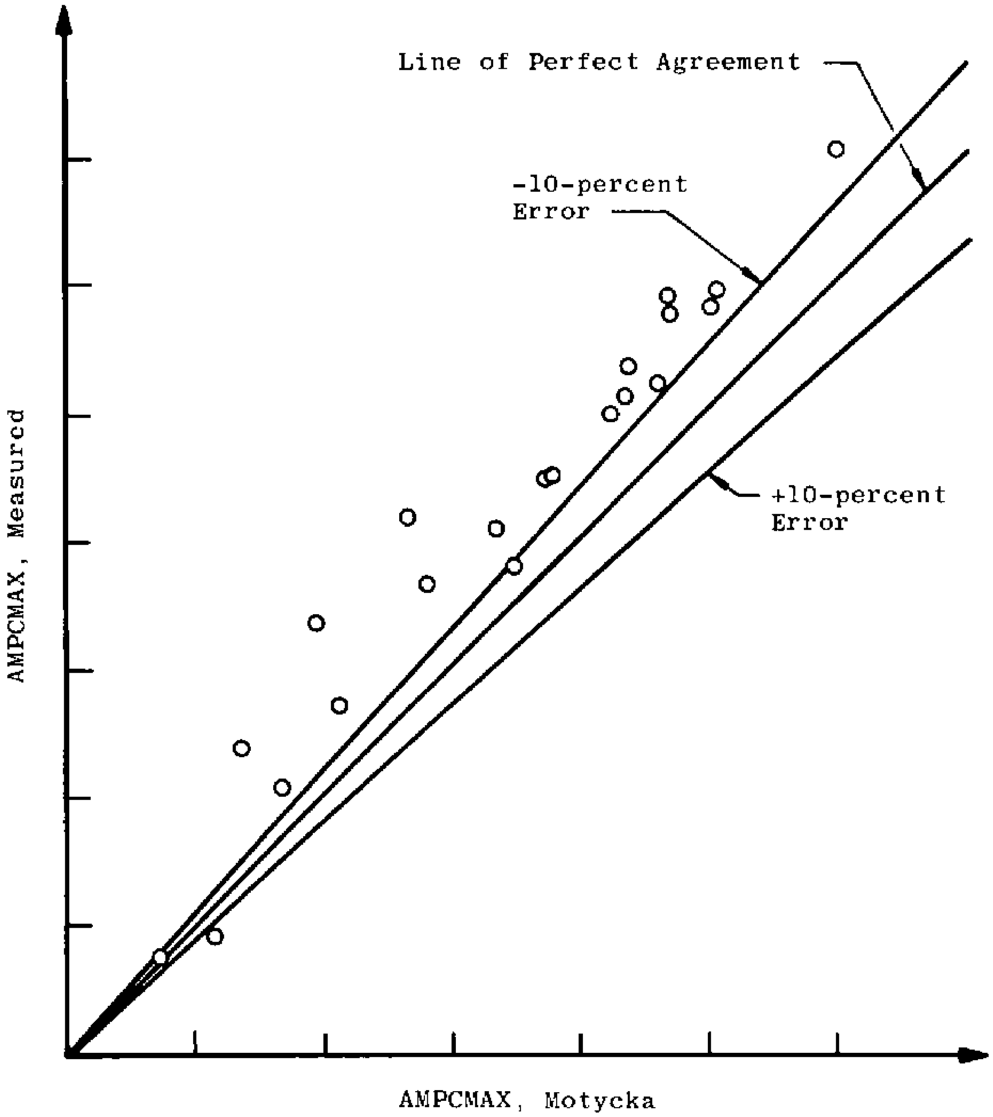
f. Test B, distortion factor Kθ
Figure 11. Continued.



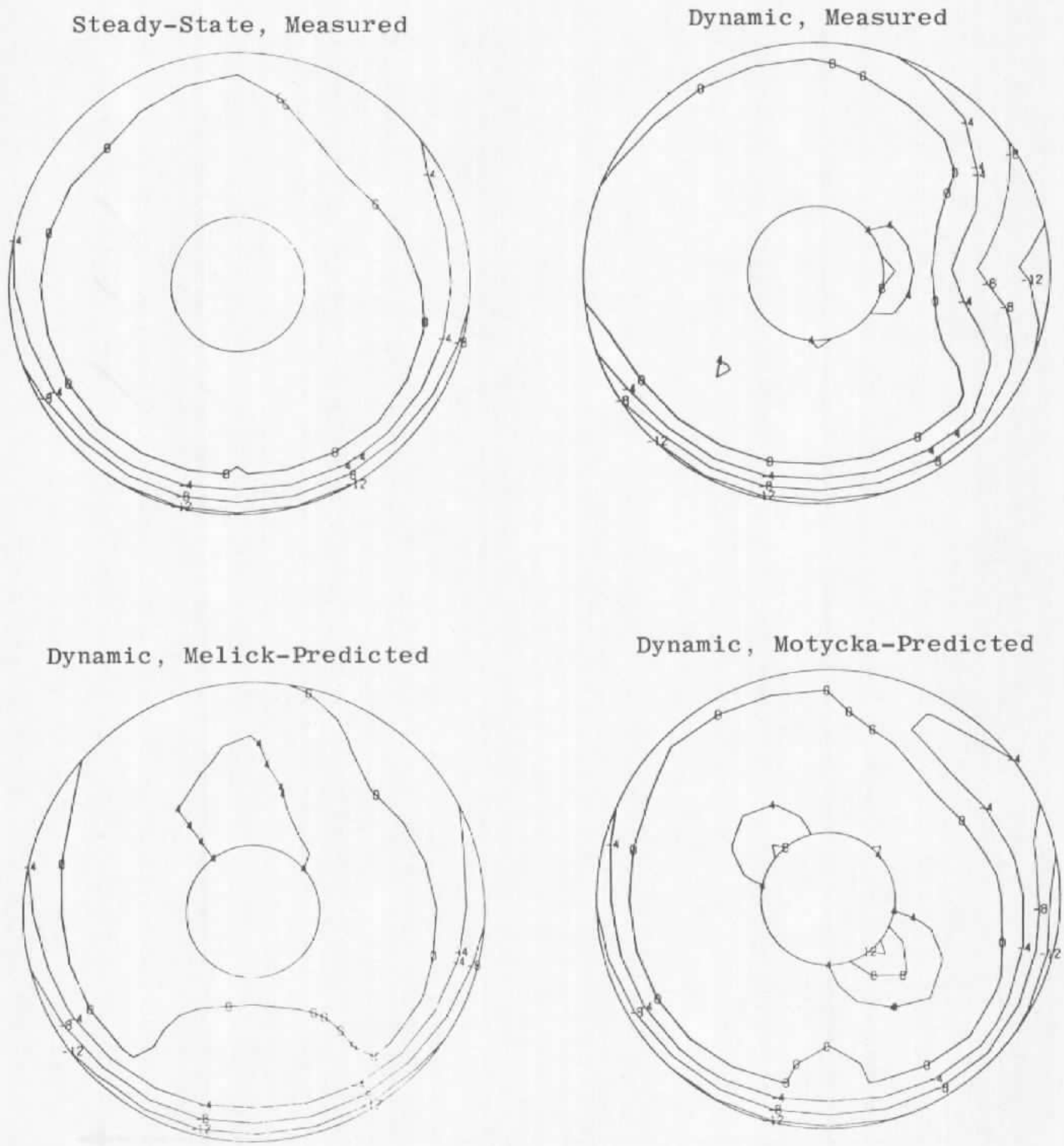
g. Test B, distortion factor KRA
Figure 11. Continued.



h. Test C, distortion factor AMPC
Figure 11. Continued.



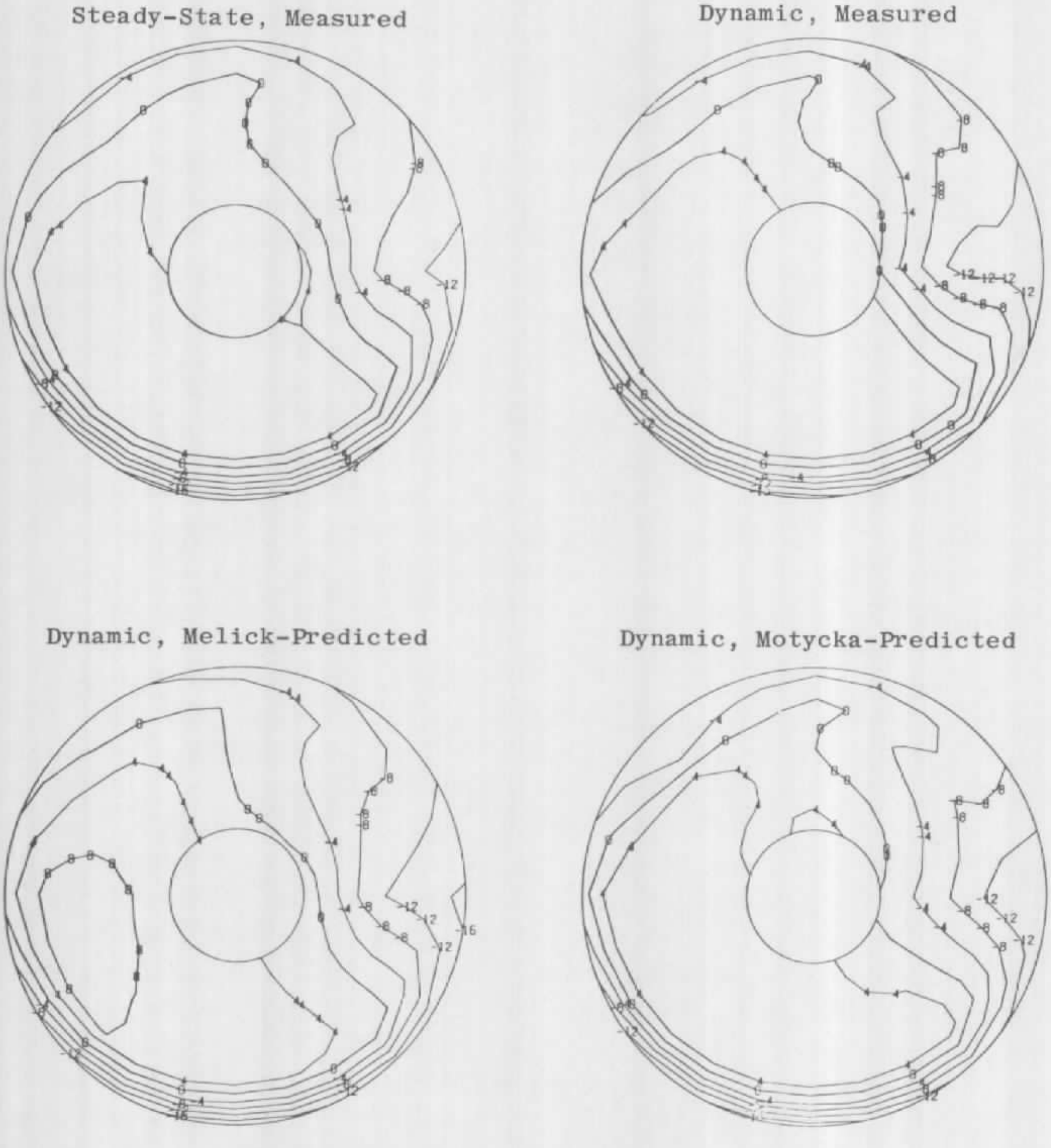
i. Test D, distortion factor AMPC
Figure 11. Concluded.



Note: Isobar lines are in terms of percent deviation from average pressures.

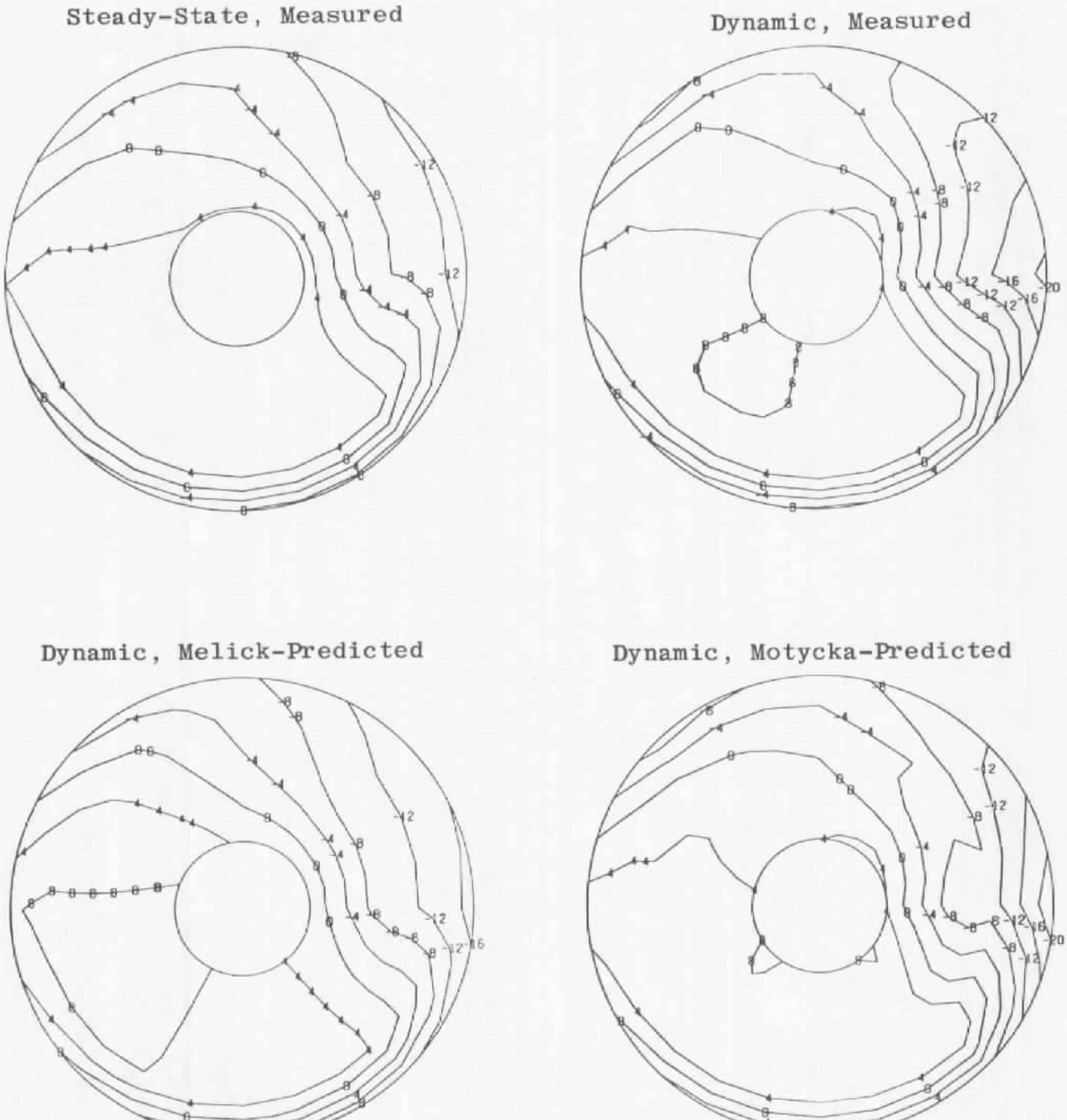
a. Tu = 0.012

Figure 12. Comparison of measured maximum time-variant distortion patterns with the statistical methods, Test D.



Note: Isobar lines are in terms of percent deviation from average pressures.

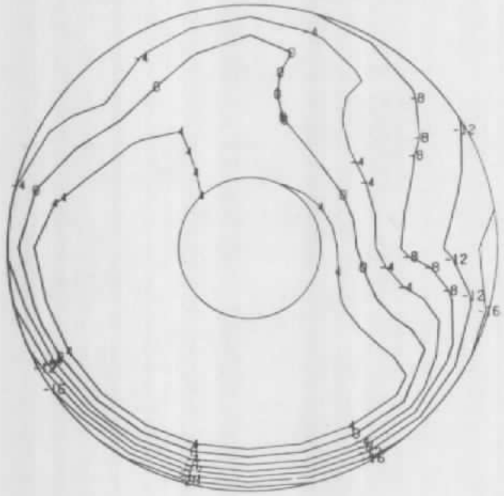
b. Tu = 0.015
Figure 12. Continued.



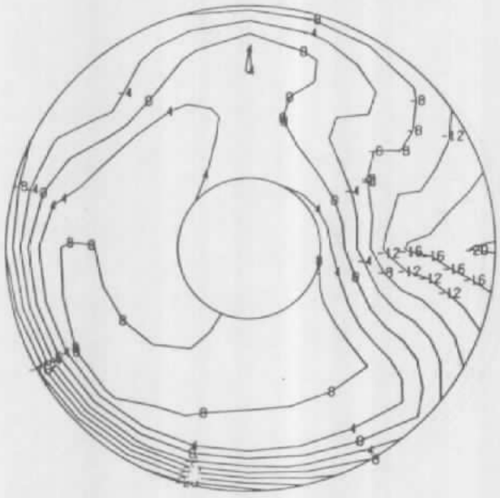
Note: Isobar lines are in terms of percent deviation from average pressures.

c. Tu = 0.016
Figure 12. Continued.

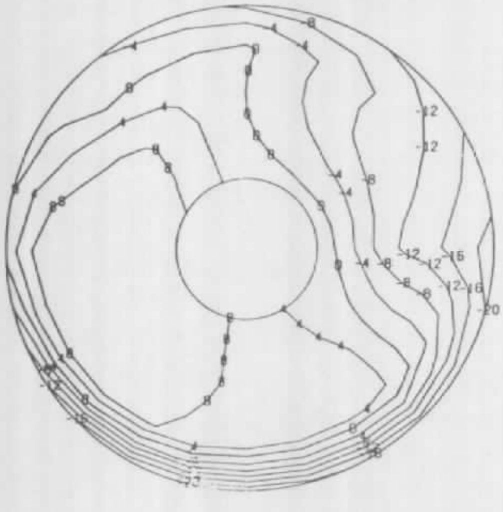
Steady-State, Measured



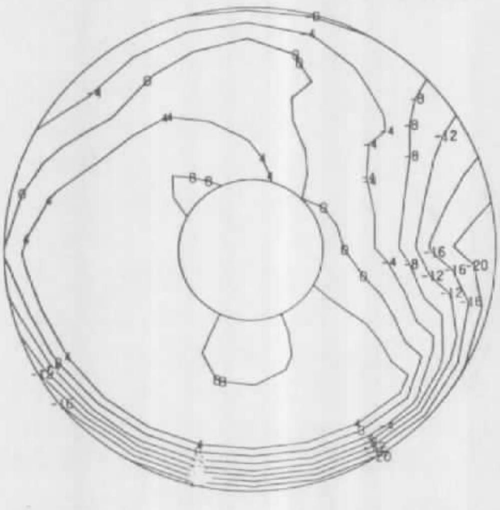
Dynamic, Measured



Dynamic, Melick-Predicted



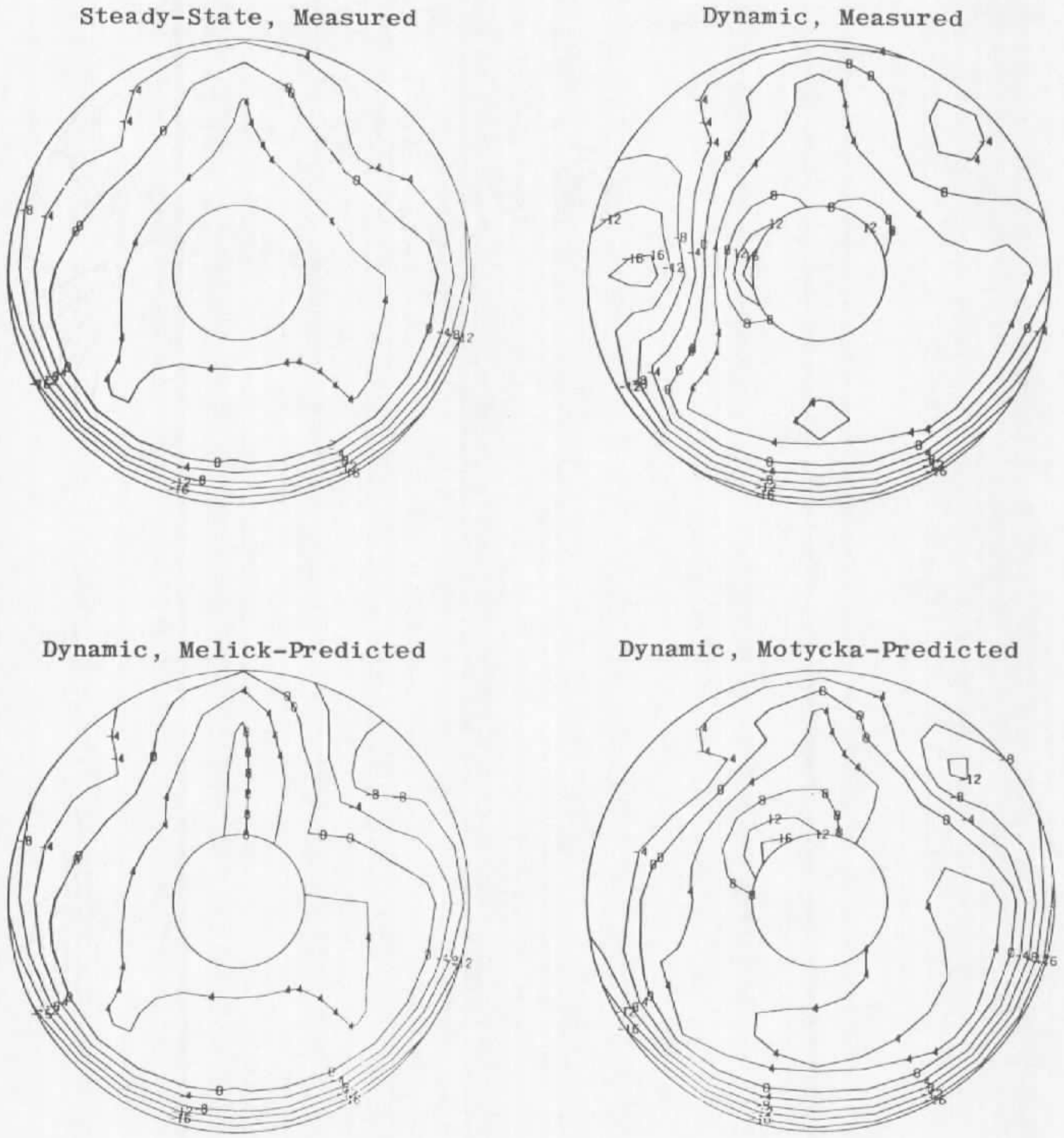
Dynamic, Motycka-Predicted



Note: Isobar lines are in terms of percent deviation from average pressures.

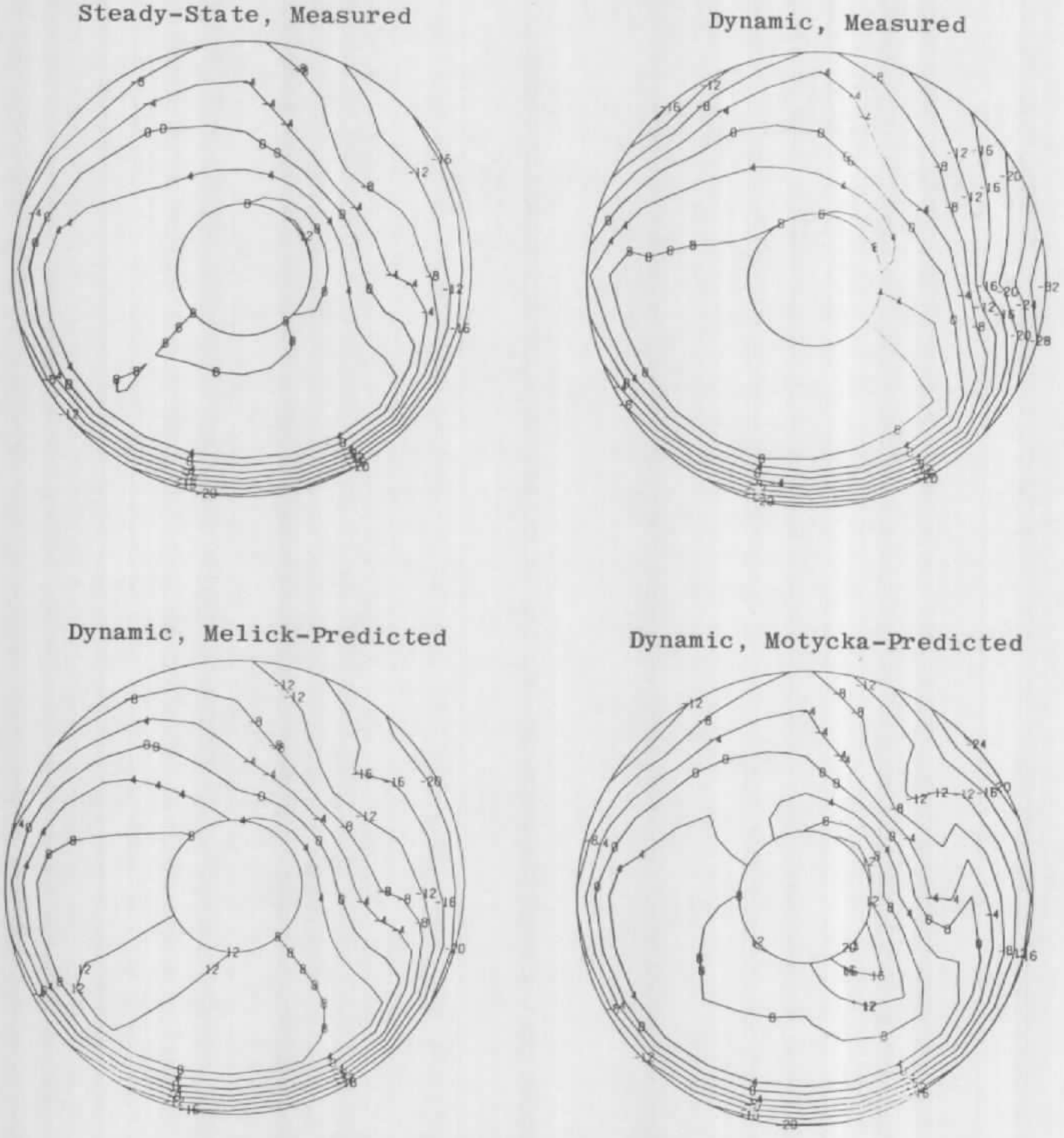
d. Tu = 0.019

Figure 12. Continued.



Note: Isobar lines are in terms of percent deviation from average pressures.

e. Tu = 0.023
Figure 12. Continued.



Note: Isobar lines are in terms of percent deviation from average pressures.

f. Tu = 0.023
Figure 12. Concluded.

Table 1. Definition of Distortion Factors

Factor	Equation	Supplemental Equations	Definitions
IDC	$IDC = \max\left[\frac{1}{2}(IDC_1 + IDC_2), \frac{1}{2}(IDC_4 + IDC_5)\right]$	$IDC_j = \frac{(\bar{P}_t)_j - (P_{t,\,min})_j}{\bar{P}_t}$	$(\bar{P}_t)_j$ = average total pressure for ring j $(P_{t,\,min})_j$ = minimum total pressure reading in ring j $\bar{P}_t$ = average total pressure at engine face
IDR	$IDR = \max(IDR_1, IDR_5)$	$IDR_j = \frac{\bar{P}_t - (\bar{P}_t)_j}{\bar{P}_t}$	
Kθ	$K\theta = \frac{\sum_{j=1}^{NR}(A_1)_j(1/D_j)}{(\bar{q}/\bar{P}_t)\sum_{j=1}^{NR}(1/D_j)}$	$(A_1)_j = \sqrt{(a_1^2 + b_1^2)_j}$ $(a_1)_j = \left[\frac{1}{M}\sum_{i=1}^{M}\frac{p_{t_i}}{\bar{P}_t}\cos(\theta_i)\right]_j$ $(b_1)_j = \left[\frac{1}{M}\sum_{i=1}^{M}\frac{p_{t_i}}{\bar{P}_{t_i}}\sin(\theta_i)\right]_j$	$\bar{P}_t$, $(\bar{P}_t)_j$ = see above $\bar{q}$ = average dynamic pressure at engine face M = number of rakes $(P_{t_i})_j$ = individual total pressure, rake i, ring j θ = angular position of P_{t_i} $\frac{(P_{t,\,base})_j}{\bar{P}_t}$ = base radial profile for ring j; normally equal to 1.0 for all j x = ring diam. exp, normally equal to 1.0 b = radial distortion weighting factor; normally equal to 1.0 D_j = diameter of ring j
KRA	$KRA = \sum_{j=1}^{NR}\left\lvert\frac{\Delta p_{t_j}}{\bar{P}_t}\right\rvert\frac{\bar{P}_t}{\bar{q}}\frac{1}{D_j{}^x}$	$\frac{\Delta p_{t_j}}{\bar{P}_t} = \frac{(\bar{P}_t)_j}{\bar{P}_t} - \frac{(P_{t,\,base})_j}{\bar{P}_t}$	
KA2	$KA2 = K\theta + b(KRA)$		
AMPC	$AMPC = \frac{(\bar{P}_t)_{i,max} - (\bar{P}_t)_{i,min}}{\bar{P}_t}$		$(\bar{P}_t)_{i,max}$ = largest rake average $(\bar{P}_t)_{i,min}$ = smallest rake average
AMPR	$AMPR = \frac{\bar{P}_{t_{inner}} - \bar{P}_{t_{outer}}}{2\bar{P}_t}$	$\bar{P}_{t_{inner}} = (\bar{P}_t)_1 + (\bar{P}_t)_2$ $\bar{P}_{t_{outer}} = (\bar{P}_t)_4 + (\bar{P}_t)_5$	$(\bar{P}_t)_j$ = ring average pressure

Table 2. Summary of Test Data Used in Comparisons

Test	Model Scale	Mach Number	α, deg	β, deg
A	0.192	0.55 to 1.55	-5 to 44	-5 to 15
B	0.150	0 to 1.5	-10 to 60	0 to -30
C	1.000	0.45 to 0.80	-8 to 8	0 to -4
D	1.000	0.45 to 0.80	-8 to 8	0 to -4

Table 3. Summary of Statistical Methods

Jacocks Method	Melick Method	Motycka Method
Advantages 1. Accurate predictions 2. On-line capability 3. Computer deck available	Advantages 1. Reasonably accurate predictions of distortion values 2. On-line capability 3. Limited instrumentation 4. Computer deck available	Advantages 1. Reasonably accurate predictions of distortion values and patterns 2. On-line capability 3. Computer deck available
Disadvantages 1. Requires use of ADC 2. No pattern prediction capability 3. Requires a high-response total pressure probe for each steady-state probe	Disadvantages 1. Poor pattern prediction capability	Disadvantages 1. Requires a high-response total pressure probe for each steady-state probe 2. Excessive execution time

NOMENCLATURE

AMPC	Williams Research Corporation engine-face circumferential total pressure distortion (see Table 1)
AMPCMAX	Maximum time-variant value of AMPC
AMPR	Williams Research Corporation engine-face radial total pressure distortion (see Table 1)
AMPRMAX	Maximum time-variant value of AMPR
IDC	General Electric engine-face circumferential total pressure distortion (see Table 1)
IDCMAX	Maximum time-variant value of IDC
IDR	General Electric engine-face radial total pressure distortion (see Table 1)
IDRMAX	Maximum time-variant value of IDR
KA2	Pratt and Whitney engine-face total pressure distortion (see Table 1)
KA2MAX	Maximum time-variant value of KA2
KRA	Pratt and Whitney engine-face radial total pressure distortion (see Table 1)
KRAMAX	Maximum time-variant value of KRA
KΘ	Pratt and Whitney engine-face circumferential total pressure distortion (see Table 1)
KΘMAX	Maximum time-variant value of KΘ
K_{max}	Maximum value of arbitrary distortion factor
M_∞	Free-stream Mach number
Tu	Ratio of average engine-face rms total pressure fluctuation to average engine-face total pressure

α	Model angle of attack, deg
β	Model angle of sideslip, deg
σ	Root-mean-square average of a time-dependent function