SAE Aerospace
An SAE International Group

AEROSPACE INFORMATION REPORT

SAE AIR4979 REV. A

Issued 1996-08
Reaffirmed 2004-11
Stabilized 2012-05

Superseding AIR4979

Estimation of Measurement Uncertainty in Engine Tests Based on NATO AGARD Uniform Engine Test Program

RATIONALE

The overall objectives and approach described in this document were intended to provide guidance and benchmarking. Readers may refer to this approach and practice guidance for application, comparison, or extension to their specific related tasks, using the appropriate technical data, requirements and the most current applicable references. The general approach and guidance are considered stable in regards to the above stated intent.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE E-33 In-Flight Propulsion Measurement Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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INTRODUCTION

In 1979, the Uniform Engine Test Program (UETP) was formed to organize and direct an international turbojet engine testing program and to analyze the test results. In 1991, SAE Subcommittee E-33C accepted the challenge from Dr. James Mitchell to take advantage of a rare opportunity to evaluate the intrinsic interfacility systematic errors. Posttest uncertainties were compared and are presented in AIR4979. For this task, the subcommittee was originally co-chaired by Dr. Robert Abernethy and James Thompson. In 1992, the chairmanship was assumed by Mike McGonigle. The committee benefited from multinational membership, including some original members of the AGARD-UETP. A list of contributing individuals and their sponsoring organizations is listed below:

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TABLE OF CONTENTS

1. SCOPE 4

2. REFERENCES 4

2.1 Applicable Documents 4
2.1.1 SAE Publications 4
2.1.2 ANSI Publications 5
2.1.3 ASME Publications 5
2.1.4 Applicable References 5
2.2 Symbols 7
2.3 Subscripts 7
2.4 Acronyms 7
2.5 Glossary of Terms 8

3. INTRODUCTION 10

4. MEASUREMENT UNCERTAINTY METHODOLOGY BACKGROUND 11

5. MEASUREMENT PRACTICES AND UNCERTAINTY ANALYSIS 16

5.1 General Overview of the Measurement Uncertainty Process 16
5.2 The Measurement Uncertainty Process for the Uniform Engine Test Program 19
5.2.1 Definition of Defined Measurement Processes 19
5.2.2 Elemental Error Assessment 20
5.2.3 Measurement Uncertainty Components 21
5.2.4 Performance Parameter Components 23
5.2.5 Uncertainty 24
5.2.6 Validation of the Uncertainty 24
5.2.7 Interfacility Comparisons 25
5.3 Summary 28

6. STATISTICAL ANALYSIS OF UETP RESULTS 28

6.1 UETP Test Processes and Analysis 28
6.2 AGARD's Concerns 37
6.3 Statistical Methods 38
6.3.1 Standard Error of Estimate (SEE), (Random Uncertainty) 38
6.3.2 Pooled Standard Error of Estimate 39
6.3.3 Sample Size 40
6.3.4 Systematic Uncertainty 40
6.4 Analysis Procedure 41
6.4.1 Selection of Curve-Fit Polynomial 42
6.4.2 Explanation of Table and Plot Terms 43

TABLE OF CONTENTS (Continued)

7. COMPARISON OF PRETEST UNCERTAINTY ESTIMATES WITH POSTTEST ANALYSIS RESULTS 46

7.1 Random Uncertainty 46
7.2 Systematic Uncertainty 46
7.3 Total Uncertainty 46
7.4 Discussion 46

8. CONCLUSIONS 51

Appendix A - Uncertainty/Error Propagation 53
Appendix B - Summaries of Elemental Measurement Process Components and Practices 61
Appendix C - Tabular Presentation of UETP Pretest Uncertainty Results 67
Appendix D - Plots of UETP Test Data and Statistical Analysis Results 69
Appendix E - Determination of Posttest Interfacility Systematic Uncertainties 120

1. SCOPE:

The primary objective of this document is to describe the systematic and random measurement uncertainties which may be expected when testing gas turbine engines in a range of different test facilities. The documentation covers a "traditional" method for estimating pretest uncertainties and a "new" method for computing and comparing posttest uncertainties. To determine these posttest uncertainties, data generated during the AGARD Uniform Engine Test Program (UETP) were analyzed and compared to the pretest estimates.

The proposed procedure provides a mechanism for determining the expected accuracy of test results obtained from facilities which were not previously cross calibrated. Furthermore, the method can be used to assist in making cost-effective management decisions on the level of validation/cross calibration necessary when bringing a test facility on line.

This document is also intended to act as a guide for improving uncertainty analyses in a broad spectrum of related industries. Measurement uncertainty and measurement system approaches and practices for the UETP are presented in a systematic format. Readers can use these uncertainty approaches and practices for comparison to their own measurement systems.

The approach chosen was to analyze three of the UETP test conditions at eight test facilities along with the individual measurement system approaches and practices. The test program provided a wide range of performance measurements and corresponding pretest uncertainty estimates encompassing a variety of test and measurement approaches and practices. Included in the analysis are the basic gas turbine performance measurements of temperature, pressure, airflow, fuel flow, area, speed, thrust, and typical performance parameter functions and associated uncertainty estimates.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

2.1.1.1 AIR1678 Uncertainty of In-Flight Thrust Determination

2.1.1.2 SP-674 In-Flight Thrust Determination and Uncertainty", Aerospace Technology Conference and Exposition, Report No, SAE-AIR 1703, Long Beach, California, October 13-16, 1986.

2.1.1.3 R.B. Abernethy, "SAE In-Flight Propulsion Measurement Committee E-33: Its life and work", SAE in Aerospace Engineering Volume 1, No. 1. July 1981.

2.1.1.4 R.B. Abernethy, "Uncertainty Methodology for In-Flight Thrust Determination". SAE paper 831438, October 1983, see also SAE paper 831439 for application.

2.1.1.5 J.H. Roberts, W.R. Beyerly, M.W. Mason, J.R. Glazier, and R.H. Wiley. "PW4084 Engine Testing in Altitude & Sea Level Test Facilities," SAE Paper No. 942140 Aerotech, Los Angeles, California, October 3-6,1994.

2.1.2 ANSI Publications: Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

2.1.2.1 ISO TC30 SC9 "Fluid Flow Measurement Uncertainty," Draft of January 1985. (Revision to ISO 5168).

2.1.2.2 ISO 90 International Organization for Standardization,"Guide to the Expression of Uncertainty in Measurement", 1993.

2.1.2.3 ANSI/ASME PTC 19.1, "Measurement Uncertainty", Performance Test Codes Supplement, 1985.

2.1.2.4 ANSI/ASME MFC-2M, "Measurement Uncertainty for Fluid Flow in Closed Conduits", 1983.

2.1.3 ASME Publications: Available from ASME, 345 East 47th St., New York, NY 10017-2330.

2.1.3.1 R.B. Abernethy, R.P. Benedict, R.P. Dowdell, "ASME Measurement Uncertainty", ASME paper 83WA/FM-3.

2.1.4 Applicable References:

2.1.4.1 R.B. Abernethy and B.G. Ringhiser, "The History and Statistical Development of the New ASME-SAE-AIAA-ISO Measurement Uncertainty Methodology," AIAA paper 85-1403, July 8, 1985.

2.1.4.2 J.W. Thompson, W.F. Kimzey and W.O. Boals, "An Overview of the Application of Standard Measurement Uncertainty Methodology to Propulsion Testing," AGARD Conference Proceedings No. 429, September 1987.

2.1.4.3 R.B. Abernethy, "ICRPG Handbook for Estimating the Uncertainty in Measurements Made With Liquid Propellant Rocket Engine Systems," JANNAF (formerly ICRPG) Performance Standardization Working Group Report CPIA No. 180 (AD 851 127), April 1969.

2.1.4.4 R.B. Abernethy and J.W. Thompson, Jr., "Handbook Uncertainty in Gas Turbine Measurements," AEDC-TR-73-5 February 1973.

2.1.4.5 AIAA Thrust-Drag Editorial Board, chaired by E.E. Covert, "Measurement and Prediction of Thrust and Drag from Transports to Fighters," 1985.

2.1.4.6 D.L. Colbert, B.D. Powell, and R.B. Abernethy, "The ICRPG Measurement Uncertainty Model," AIAA paper No. 69-734.

2.1.4.7 R.B. Abernethy, and J.W. Thompson, Jr., "Uncertainty in Gas Turbine Measurements," AIAA paper No. 73-1230.

2.1.4.8 R.B. Abernethy, "Uncertainty in Gas Turbine Measurements," Revised 1980 Edition, ISA I-483-3.

2.1.4.9 R.B. Abernethy and R.P. Benedict, "Measurement Uncertainty: A Standard Methodology," ISA paper 1984, 0-87664-806-5/84.

2.1.4.10 International Organization for Standardization, "International Vocabulary of Basic and General Terms in Metrology", 2nd Edition, 1993, (Geneva, Switzerland)

2.1.4.11 W.G. Steele, R.P. Taylor, R.E. Burrell, and H.W. Coleman, "Use of Previous Experience to Estimate Precision Uncertainty of Small Sample Experiments," AIAA Journal, Vol.31, No.10, October 1993, pp. 1891-1896.

2.1.4.12 W. G. Steele, R.A. Ferguson, R.P. Taylor, and H.W. Coleman, "Comparison of ANSI/ASME and ISO Models for Calculation of Uncertainty," ISA Transactions, 1994.

2.1.4.13 K.K. Brown, H.W. Coleman, W.G. Steele, and R.P. Taylor, "Evaluation of Correlated Bias Approximations in Experimental Uncertainty Analysis," AIAA Paper No. 94-0772, 32nd Aerospace Sciences Meeting, Reno, NV, January 1994.

2.1.4.14 M.J. Price, "Uncertainty of Derived Results on X-Y Plots", Proceedings of the 39th International Instrumentation Symposium, 1993, Paper #93-107, May 1993.

2.1.4.15 J.G. Mitchell, "Uniform Test Engine Testing Programme General Test Plan", AGARD/PEP, Jan 82, revised Jun 83.

2.1.4.16 J.P.K. Vleghert, "Measurement Uncertainty within the UETP", AGARDograph 307 May 89.

2.1.4.17 J.W. Bird, "Measurement Uncertainty Analysis For The Uniform Engine Test Program", National Research Council of Canada, Institute For Mechanical Engineering, Ottawa, Ont. TR-ENG-006, 1990.

2.1.4.18 AGARD-AR-248, "The Uniform Engine Test Programme", AGARD Advisory Report No. 248, February 1990.

2.1.4.19 W.J. Dixon, and F.J. Massey, "Introduction to Statistical Analysis", 2nd Edition, 1957, McGraw-Hill, p 176.

2.1.4.20 A.J. Duncan, "Quality Control and Industrial Statistics", R.D. Irwin Inc., Revised 1959.

2.1.4.21 J.H. Roberts, J.L. Lewis, D.H. Glicken, " Engine Thrust Measurement Uncertainty," Paper No. AIA-85-1404, AIAA/SAE/ASME/ASEE 21ST Joint Propulsion Conference, Monterey, California, July 10, 1985.

2.2 Symbols:

b - Elemental systematic uncertainty
B - Total systematic uncertainty
D - Desired test condition
DMP - Defined measurement process
FNR - Corrected net thrust
NL - Low pressure compressor speed
NLR - Corrected low pressure compressor speed
NH - High pressure compressor speed
NHR - Corrected high pressure compressor speed
NL/NH - Rotor speed ratio
P2 - Engine inlet total pressure
P7 - Nozzle exit total pressure
P5/P2 - Engine pressure ratio (also referred to as P5Q2)
P7/P2 - Engine pressure ratio (also referred to as P7Q2)
R - Correction to reference test condition (SLS)
s - Sample standard deviation
$S_{\bar{x}}$ - Total random uncertainty
SFCR - Corrected specific fuel consumption
t - Student's t parameter
T2 - Engine inlet total temperature
T7 - Nozzle exit total temperature
T7/T2 - Engine temperature ratio
U - Uncertainty
WAIR - Corrected engine airflow
WFR - Corrected fuel flow

2.3 Subscripts:

95 - 95% confidence band
99 - 99% confidence band
Add - additive model
RSS - Root-sum-square model

2.4 Acronyms:

AEDC - Arnold Engineering Development Center
AGARD - Advisory Group for Aerospace Research & Development(NATO)
AIR - Aerospace Information Report
AIAA - American Institute of Aeronautics and Astronautics
ANSI - American National Standards Institute
ASME - American Society of Mechanical Engineers

2.4 (Continued):

BIPM - International Bureau of Weights and Measures
CEPr - Centre d'Essais des Propulseurs
CIPM - International Committee for Weights and Measures
ICRPG - Interagency Chemical Rocket Propulsion Group(JANNAF)
ISA - Instrumentation Society of America
ISO - International Standards Organization
NAPC - Naval Air Propulsion Center
NATO - North Atlantic Treaty Organization
NASA - National Aeronautics and Space Administration
NASA1 * First entry test
NASA2 * Second entry test
NIST - National Institute for Standards and Technology
NRCC - National Research Council of Canada
PEP - Propulsion and Energetics Panel
RAE(P) - Royal Aircraft Establishment(Pyestock)
SAE - Society of Automotive Engineers
TAG - Technical Advisory Group
TUAF - Turkish Air Force Supply and Maintenance Centre
UETP - Uniform Engine Test Program
USAF - United States Airforce
WG - Working Group

2.5 Glossary of Terms:

Definitions for statistical terms such as standard deviation and variance are available in reference 2.1.4.19.

GRAND MEAN: The average of the averages.

$\overline{N}$: A composite sample size when the sample sizes of a number of groups being combined are not equal.

POOLED: Term used to describe the combination of data from different data sources.

POOLED SEE: A statistic calculated from the SEE's of several facilities.

POOLED STANDARD DEVIATION: The square root of averaged sample variances (pooled variance) which gives an estimate of overall population standard deviation.

POOLED VARIANCE: A weighted average of k variances where the degrees of freedom are used as weights.

2.5 (Continued):

RANDOM ERROR: A random variable, assumed to come from a Gaussian distribution, which lies somewhere within the limits $\pm t_{95} S_{\bar{X}}$ or $\pm t_{95} SEE/\sqrt{N}$ (where t is Students' t, extracted from statistical tables, $S_{\bar{X}}$ is the standard deviation of the mean and SEE is the Standard Error of Estimate). The presence of such errors is shown by the scatter of points about a mean value, $S_{\bar{X}}$, or about a curve-fit, $SEE/\sqrt{N}$.

(NOTE: Random Error is also known as the "Precision" Error)

RANDOM UNCERTAINTY: The uncertainty associated with a random error.

RANGE: The range is the difference between the maximum and minimum curve-fit values at one particular value of the independent variable.

S_{CORR} : The corrected deviation of the facility-to-facility variation; used in this AIR to estimate the systematic uncertainty.

STANDARD ERROR OF ESTIMATE: The standard deviation of the residual scatter of points about a curve-fit. It is calculated by statistical methods from the analysis of data.

(NOTE: Standard Error of Estimate is also known as "Residual Standard Deviation)

SYSTEMATIC ERROR (B): A constant error of unknown value.

(NOTE: Systematic Error is also known as "Fixed" or "Bias" Error)

SYSTEMATIC UNCERTAINTY: The uncertainty associated with a systematic error.

UNCERTAINTY: Uncertainty is the half-range of an interval within which the true value is expected to lie.

Uncertainty has two components, systematic uncertainty and random uncertainty which may be combined in alternative ways. Thus, for example, the uncertainty of a single point is either (see Equation 1):

$$U_{Add} = \pm(B + 2S_{\bar{X}}) \qquad \text{(Eq.1)}$$

or

$$U_{RSS} = \pm\sqrt{B^2 + (2S_{\bar{X}})^2}$$

or

$$U_{95} = \pm 2\sqrt{\left(\frac{B}{2}\right)^2 + (S_{\bar{X}})^2}$$

3. INTRODUCTION:

In 1979, the AGARD Propulsion and Energetics Panel (PEP) embarked on a program to test two J-57 turbine engines at several facilities in North America and Europe in pursuit of the following goals:

"1. To provide a basis for upgrading the standards of turbine engine testing within AGARD countries by comparing test procedures, instrumentation techniques, and data reduction methods, thereby increasing confidence in performance data obtained from engine test facilities and

2. To compare the performance of an engine measured in ground level test facilities and altitude facilities at the same nondimensional conditions and establish the reasons for any observed differences."

Working Group 15, entitled the Uniform Engine Testing Program (UETP), was formed to organize and direct an international turbojet engine testing program and to analyze the test results. Tests were conducted in five countries (eight test facilities) in both altitude simulation facilities and sea-level test beds. The tenacity of Working Group 15 members and the continued support of the PEP membership and AGARD National Delegates permitted the program to reach a successful conclusion.

An experiment was designed to meet the objectives of the UETP as defined by the PEP of AGARD. Two specially modified J57-PW-19W turbine engines were selected as the test articles. Test objectives were tailored to be compatible with the capability and availability of eight different engine test facilities located in five NATO countries.

The design of the experiment included the specification of the test article, the matrix of variables, the experimental measurements, and the formats of the test reports. In addition, the design included the definition of three key methodologies, i.e., test, data processing, and measurement uncertainty, to the extent necessary to meet the objectives of the UETP, and to maximize the level of confidence in the comparative engine performance measurements from each facility. This approach was consistent with a basic requirement of the UETP, which was to utilize local test facility practices to the maximum extent possible.

In the application of the measurement uncertainty methodology, estimates of the systematic errors must be based on judgment unless there are data for interfacility comparisons. The UETP database represents a rare opportunity to identify systematic and random uncertainties commensurate with basic measurement system approaches and practices for turbine engine measurement. In addition, a description of practices and procedures with examples would provide the basis for improving the application of error assessment to measurement systems, internationally, in a broad spectrum of industries.

3. (Continued):

An overview of the measurement uncertainty methodology, traditionally used for performing an analysis, is given in Section 4. Section 5 outlines a traditional approach for carrying out an uncertainty analysis in addition to a summary of the measurement process adopted by the UETP participants for computing pretest uncertainty estimates. The estimates, which covered three different subsonic test conditions for inlet pressures of 82.7, 20.7, and 101.3 kPa, are summarized in Tables C1, C2 and C3 of Appendix C. These estimates give an indication of the magnitude of the measurement uncertainty of gas turbine performance parameters commensurate with the measurement system practices and approaches employed during the UETP.

Subcommittee E-33C found that the data made available by the UETP provided valuable information about the systematic uncertainty of engine parameters measured in various test facilities. The committee, using well established statistical tools and curve-fitting techniques, devised a method for estimating the facility-to-facility systematic uncertainties of engine parameters. The method for estimating the systematic uncertainties is described in Section 6.

A comparison of the UETP facility uncertainties and the SAE interfacility uncertainty results are given in Section 7. Interfacility uncertainty results for selected performance parameters are listed in Appendix E and can be interpreted as an estimate of the systematic uncertainties resulting from differences in the measurement practices of various "world class" test facilities. These systematic uncertainties are also indicators of those areas which may need improvements to meet the measurement requirements of specific tests.

The calculation procedure devised by Subcommittee E-33C and outlined in this document may be used as a guide for estimating a facility-to-facility systematic uncertainty for gas turbine performance parameter functions. The method can be applied to check the validity of pretest uncertainty estimates. This document can also be used as a guide for determining the magnitude of the uncertainty associated with a defined measurement process.

4. MEASUREMENT UNCERTAINTY METHODOLOGY BACKGROUND:

The uncertainty methodology selected by the UETP was established in the early 1900s at the National Bureau of Standards. Over the years, it has been developed into a standard methodology accepted by many technical societies both nationally and internationally. The history of this development has been well documented by Abernethy and Ringhiser (Reference 2.1.4.1), and by Thompson, et al (Reference 2.1.4.2).

An early milestone in the methodology history occurred in 1969; the Interagency Chemical Rocket Propulsion Group (ICRPG), now known as JANNAF, presented the ICRPG Handbook (Reference 2.1.4.3) at the joint SAE-ASME-AIAA Propulsion Conference. The need for an uncertainty methodology standard for evaluation of the performance of liquid propellant rocket engines was seen by the group due to the numerous methods in use at the time, which made it difficult to make comparisons between engine manufacturers. Widespread acceptance of this handbook by not only the rocket propulsion community but also the turbine community prompted the USAF Applied Propulsion Laboratory to produce the "Handbook Uncertainty in Gas Turbine Measurements"(Reference 2.1.4.4) in 1973. This document was also reprinted by the ISA in 1980.

4. (Continued):

To date, the SAE (Reference 2.1.1.1, 2.1.1.3, and 2.1.1.4), ASME (Reference 2.1.2.3, 2.1.2.4, and 2.1.3.1), AIAA (Refence 2.1.4.5, 2.1.4.6, and 2.1.4.7), ISA (Reference 2.1.4.8 and 2.1.4.9), ISO (Reference 2.1.2.1), USAF (2.1.4.4), and JANNAF (2.1.4.3) have all produced reports supporting this methodology as an industry standard for determining measurement uncertainty. The SAE (Reference 2.1.1.4) report gives the application of the methodology to in-flight thrust uncertainty determination while ASME and ISO have applied it to fluid flow uncertainty determination.

In 1978, recognizing the lack of an internationally accepted standard for the expression of uncertainty in measurement, the International Committee for Weights and Measures (CIPM) made a request to the International Bureau of Weights and Measures (BIPM) to address the problem. After preparing a detailed questionnaire and receiving responses from 21 national laboratories, the BIPM convened a Working Group, staffed by experts from 11 national standards laboratories, to develop a recommendation. Their recommendation INC-1 (1980), "The Expression of Experimental Uncertainties", provided a brief outline of approach. This recommendation was subsequently adopted by the CIPM in October 1981. The CIPM then requested the International Organization for Standardization (ISO) to develop a detailed guide based on the Working Group recommendation. The ISO assigned the task to the ISO Technical Advisory Group on Metrology (TAG 4), which established Working Group 3 (ISO/TAG 4/WG 3), comprising members from four international organizations. The Working Group developed a comprehensive reference document on the general application of the CIPM approach titled "Guide to the Expression of Uncertainty in Measurement (Reference 2.1.2.2)".

The methodology is structured to combine statistical and engineering concepts in a manner which can be systematically applied to each step in the measurement system uncertainty assessment procedure. The essential steps in the procedure as provided in AIR1678 are discussed in Section 5. Basic to the process is the classification of measurement errors into one of two components: systematic (fixed or bias) uncertainty or random (precision) uncertainty.

The elemental systematic uncertainty, b, is most often determined from special tests or engineering judgements which involve nonstatistical methods. The systematic uncertainties are estimates of the largest possible remaining systematic errors after all corrections have been made. The random uncertainty, s, can be determined by statistical analysis of variations in repeated measurements. These variations are characterized by the population standard deviation, σ. The sample standard deviation, s, is the computed estimate of the population standard deviation, σ:

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad \text{(Eq.2)}$$

where:

n = number of measurements
x_i = individual measurements
$\bar{x}$ = is the sample average

4. (Continued):

and

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} \qquad \text{(Eq.3)}$$

Once the elemental uncertainties have been determined they must be combined into systematic and random components for each measurement of interest. Maintaining separate components is necessary for propagating measurement uncertainties to performance parameters, and for uncertainty reporting and validation. The total systematic uncertainty (B) is the root-sum-square of k elemental systematic uncertainties.

$$B = \sqrt{b_1{}^2 + b_2{}^2 + b_3{}^2 + \ldots + b_k{}^2} \qquad \text{(Eq.4)}$$

and the total random uncertainty is the root-sum-square of the elemental standard deviations of the means, $S_{\bar{x}}$:

$$S_{\bar{x}} = \sqrt{S_{\bar{x}_1}{}^2 + S_{\bar{x}_2}{}^2 + S_{\bar{x}_3}{}^2 + \ldots + S_{\bar{x}_k}{}^2} \qquad \text{(Eq.5)}$$

A single number is needed to express the measurement uncertainty. In the methodology, documented by Abernethy and Thompson (Reference 2.1.4.4) two options are available: the additive U_{Add} model and the root-sum-squares U_{RSS} model. The equations for these two models are:

$$U_{Add} = \pm\left(B + t_{95} S_{\bar{x}}\right) \equiv U_{99} \qquad \text{(Eq.6)}$$

$$U_{RSS} = \pm\sqrt{B^2 + \frac{\left(t_{95} S_{\bar{x}}\right)^2}{n}} \equiv U_{95}$$

where:

n = number of independent tests or redundant measurements
t_{95} = the 95th percentile point for the two-tailed Student's "t" distribution
U_{99} = approximately 99% interval coverage
U_{95} = approximately 95% interval coverage

4. (Continued):

Reports of uncertainty analyses should include the systematic and random uncertainty and degrees-of-freedom associated with t_{95} and the measurement range over which the uncertainty is applicable.

In July 1992, knowing there was no uniform approach to the statement of uncertainty within the National Institute of Standards and Technology (NIST), its director, John W. Lyons, appointed an Ad Hoc committee to recommend a NIST policy on Uncertainty Statements. The Ad Hoc Committee recommended a specific policy for the implementation of the CIPM approach at the NIST. That policy has since been incorporated in the NIST Administrative Manual.

Currently, the committee responsible for the revision to the U.S. National Standard, ANSI/ASME PTC 19.1, "Measurement Uncertainty" has recognized the need to harmonize the revised National Standard document with the ISO Guide (Reference 2.1.2.2) and thereby, in conformance with the policy of the NIST. While, as outlined above, the methodology of this paper is consistent with the accepted approaches at the time the NATO AGARD Uniform Engine Test Program was initiated, the report terminology has been updated to be in harmony with the ISO Guide. Also, by following a simplified uncertainty model, as developed in the revision of ANSI/ASME 19.1, the reader can relate previously acquired data, uncertainty analyses, and parameter elemental error source tabulations to the ISO Guide methodology.

The ISO Guide methodology differentiates quite clearly between the terms "error" and "uncertainty". These definitions are taken from the "International Vocabulary of Basic and General Terms in Metrology (Reference 2.1.4.10)":

a. "error (of measurement) - result of a measurement minus a true value of the measurand.

b. uncertainty (of measurement) - a parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand. Note, the parameter may be, for example, a standard deviation or the width of a confidence interval."

Clearly, the intent is to differentiate an "error" and that which is only an estimate of error, which is, "uncertainty". Further, the term "bias", now called "systematic uncertainty", caused by the fixed error sources, is the difference between a measurement and the true value. The term "precision" meaning the closeness of agreement between repeated measurements of the same measurand is now described by the term "random uncertainty". The new nomenclature employing systematic and random uncertainty has been offered to reduce ambiguity associated with the use of the terms bias and precision.

The ISO Guide methodology differs from previous methodology in that it classifies uncertainties by the source of the information or data. If there are data to provide a calculated standard uncertainty the ISO Guide classifies the uncertainty as "Type A"; if on the other hand the estimate is based on means other than a statistical analysis of available data the ISO Guide classifies the uncertainty as "Type B".

4. (Continued):

Basic to the ISO Guide is the representation of each component of uncertainty (systematic and random) by an estimated standard deviation. For Type A uncertainties a standard deviation is calculated from the available data. For Type B, the standard deviation is determined by other than rigorous statistical methods.

This document as well as the revision to PTC 19.1 continues to emphasize the effects of error sources rather than the origin of the information. That is, if an error source causes dispersion (scatter) in the test results it is a random uncertainty source; whereas, if the error source does not cause test data dispersion it is a systematic uncertainty source. This document does not attempt to identify Type A or Type B elemental uncertainties, as this information was not readily available from the UETP data.

The simplified U_{95} uncertainty model with the following assumptions will meet the needs of most uncertainty analyses:

a. All systematic uncertainty sources are assumed normally distributed and are estimated as $2\,S_{\bar{x}}$ for 95% confidence.

b. All random uncertainty sources are assumed normally distributed and are estimated as, $S_{\bar{x}}$, the standard deviation of the sample mean, with degrees of freedom sufficiently large such that $t_{95}=2$ can be used as the multiplier.

c. The uncertainties are grouped as systematic or random, root-sum-squared to obtain as a result, B and $S_{\bar{x}}$, respectively.

d. The results are then root-sum-squared to obtain a 95% confidence interval as follows:

$$U_{95} = 2\sqrt{\left(\frac{B}{2}\right)^2 + (S_{\bar{x}})^2} \qquad \text{(Eq.7)}$$

The multiplier 2 is the Student's t_{95} which is taken as 2.00 for more than 30 degrees of freedom. For more detail or where the above simplified model does not meet the requirements of a complex analysis, the reader is directed to the ISO Guide (Reference 2.1.2.2), the revision to PTC 19.1, and to two documents by Steele (Reference 2.1.4.11 and 2.1.4.12) and another by Brown (Reference 2.1.4.13).

5. MEASUREMENT PRACTICES AND UNCERTAINTY ANALYSIS:

The first step in the conduct and analysis of an experiment is the specification and implementation of measurement requirements. An assessment of the uncertainty inherent in the desired analysis parameters and functional relationships should be done beforehand to ensure the feasibility and accuracy of the test in the planned facility. Following the testing for the experiment, this uncertainty analysis would be reviewed and updated, with the actual test data, to include deviations in procedure, failures in equipment or instrumentation and observed scatter or offsets in the test results. Particular assessments may be necessary if comparisons are to be made with other experiments in-house or at other facilities.

This whole scheme may be considered a measurement uncertainty process, for which a comprehensive description and some recommended practices are provided in the report references. The application of this process during the Uniform Engine Test Program is described to provide guidance and sample results for the test and analysis community.

5.1 General Overview of the Measurement Uncertainty Process:

The essential steps for providing an experimental process with relevant uncertainty estimates can be extended from AIR1678. Starting with a test plan, the steps are:

a. Establish the Defined Measurement Processes (DMP).

b. Conduct an Elemental Uncertainties Assessment (b,s).

c. Determine Measurement Uncertainty Components (B,S).

d. Propagate Measurement Uncertainty Components to the Performance Parameters required for analysis.

e. Calculate the Uncertainty for the Performance Parameters.

f. Improve the Measurement process, if possible, if the Uncertainty is too large.

g. Validate the Uncertainty with available test data.

h. Conduct interfacility comparisons, if applicable.

This process is illustrated in Table 1 which also notes the key elements and benefits of each step. Proper documentation of this process would include detailed methodology for each step, along with a summary of the major assumptions and limitations.

The test plan would normally identify the key performance parameters required for the analysis and may specify maximum or target uncertainties. It will also allow a determination of the intended use of the test data, i.e., run-to-run or facility-to-facility comparisons using single value or X-Y functions.

TABLE 1 - The Measurement Uncertainty Process

Step	Measurement Process	Key Elements	Benefits
1	Establish the defined measurement process	Duration, Averaging, Instrumentation	Uncertainty estimates are compatible with use of test results
2	Conduct an elemental uncertainty assessment	Audit of error sources for entire test process	Shows significant sources of error
3	Define measurement uncertainty components	Definition of measurements	Identifies critical measurement errors
4	Propagate measurement uncertainty components to the performance parameters required for analysis	Influence Coefficients	Finds measurements significant for final analysis
5	Calculate the uncertainty for the performance parameters	Uncertainty model and confidence interval	Shows test plan feasibility or compliance
6	Improve measurement process, if possible, if the uncertainty is too large	Test plan objectives, possible procedures and instrumentation	Achieve test plan compliance
7	Validate the uncertainty with available test data	Pretest estimate and test results	Confidence in estimates and test results
8	Conduct interfacility comparisons, if applicable	Compatible test plans, uncertainty processes, curve comparison method	Establish bias Test data validation

5.1 (Continued):

A Defined Measurement Process (DMP) description is prepared to make the uncertainty estimates compatible with the intended use of the test data. An uncertainty classification scheme can then be set up: uncertainties fixed during the DMP are systematic and those varying during the DMP are random. The duration of the measurement process, the planned type and number of instruments and the means of averaging or combining multiple readings must be included. Additional advice is provided in Appendix C of AIR1678.

5.1 (Continued):

The elemental uncertainty assessment is an audit of the entire measurement process covering all possible error sources. Contributions are investigated and quantified from the calibration, measurement and data processing necessary to derive a measurement in engineering units. AIR1678 lists some information sources as: calibration histories, previous tests with similar instrumentation, prior uncertainty analyses and expert opinions. The planned test techniques must be considered during this audit. The main steps in this assessment are:

a. Identify all contributing uncertainty sources for each measurement.

b. Classify each error source as systematic or random.

c. For each DMP: make the final classification of the errors as systematic or random.

These elemental uncertainty sources are then combined to calculate the systematic and random uncertainty components for the actual measurements. Uncertainties of performance parameters are obtained by propagating the systematic and random components of each parameter. This is done by deriving influence coefficients, i.e., partial derivatives of the performance parameters with respect to the measurements at a desired test condition, by:

a. Explicitly differentiating the governing equations for the performance parameters,

or

b. Running the data reduction programs used in the actual tests with input data sets pertubated by offsets of order of the expected uncertainty, e.g., ±0.5 to 1% in each of the measurements.

See Appendix A for a detailed discussion of items a and b.

The systematic and random estimates may be combined to provide an uncertainty for each of the performance parameters at the desired reference condition(s). This step requires the choice of an uncertainty model for combining the systematic and random estimates which determines the confidence interval for the results.

The pretest uncertainty analysis prepared during these preceding steps can be confirmed by comparison with a posttest analysis of the test data. This process serves to validate the test data and identify any test anomalies. Elemental random uncertainties can be calculated from repeat points and should be comparable to pretest estimates. The results of the tests should fall within the estimated pretest uncertainty intervals (AIR1678). If not, the reported uncertainty should be prepared from a synthesis of the pre and posttest analyses.

If the experiment involves various facilities, a means of comparison must be specified. A successful comparison will require nearly identical or compatible test plans and uncertainty analyses with detailed, pre-planned documentation. In general, the performance parameters will have to be compared using X-Y functional relationships (Reference 2.1.4.14).

5.2 The Measurement Uncertainty Process for the Uniform Engine Test Program:

This section details the implementation of this measurement uncertainty process during the Uniform Engine Test Program. This NATO AGARD sponsored program operated with a jointly developed test plan (Reference 2.1.4.15). Some of the details from the test plan are summarized below:

a. Two twin spool J57 turbojets (takeoff thrust 50.7 kN) were selected for the program - tests were conducted at eight facilities at altitude and sea-level conditions

b. Each run consisted of nine, double data points taken at steady state, at specified points over the high rotor speed range from bleed valve closed to maximum dry power

c. Reference instrumentation for speed, airflow, fuel flow, and turbine exit temperature and pressure was provided

d. Facility instrumentation (calibrated according to each facility's normal practices) which paralleled the reference set, was used for the performance comparisons

e. Interfacility performance comparisons were made at specified reference conditions using functional relationships (second order curve-fits) between corrected parameters:

(1) Rotor speed ratio (NL/NH) versus corrected high pressure compressor speed (NHR)

(2) Engine temperature ratio (T7/T2) versus engine pressure ratio (P7/P2)

(3) Corrected engine airflow (WA1R) versus corrected low pressure compressor speed (NLR)

(4) Corrected engine fuel flow (WFR) versus corrected high pressure compressor speed (NHR)

(5) Corrected net thrust (FNR) versus engine pressure ratio (P5/P2)

(6) Corrected specific fuel consumption (SFCR) versus corrected net thrust (FNR)

5.2.1 Definition of Defined Measurement Processes: No single DMP was specified in the UETP General Test Plan prepared by the participants. However, for carrying out the interfacility performance comparisons, the test plan was explicit in that:

a. Engine performance was to be reported over the nine power settings at each test condition with the facility's own instrumentation

b. Tabulation of pretest uncertainty estimates were to be prepared according to AEDC-TR-73-5 (Reference 2.1.4.4)

However, specification of the estimation methodology was not explicitly requested.

5.2.1 (Continued):

A summary of the DMP's which were specified by RAE(P) and AEDC is given in a report by Vleghert (Reference 2.1.4.16). RAE(P) declared their DMP as: A single engine performance curve-fitted by least squares to the test results for the nine engine power settings, for a single engine run, at the specified tests conditions. The estimated random uncertainties were based on the predicted data scatter that will occur about a curve-fit through the nine power settings. With this DMP, RAE(P) proposed to verify this precision with posttest analyses of the residual error of curve-fits of the test data. In addition, differences between a collection of curves with different test conditions and day-to-day variations were classed as systematic uncertainties.

AEDC's DMP considers the results for the entire test program at their installation. Consequently, the random uncertainties would include contributions from day-to-day variations.

NRC's DMP is described in a subsequent report (Reference 2.1.4.17) as a series of two test runs taken for the sea-level test condition (which was the only condition run at that facility). This DMP was compatible with the calibration period for the majority of their instrumentation.

Differences in the DMP's or the lack of documentation for the error classification at each UETP facility are cited by Vleghert (Reference 2.1.4.16) as a major obstacle to the direct comparison of elemental error assessments.

5.2.2 Elemental Error Assessment: The elemental uncertainty assessments required by the test plan proved to have insufficient detail to resolve the apparent differences in the uncertainty limits of the performance parameters. Subsequently, the UETP working group sponsored an uncertainty subcommittee which developed a set of elemental error audit forms. This comprehensive list of possible error sources for force, fuel flow, pressure, temperature, speed and area formed the basis for a re-submission of the facility uncertainty reports.

A summary of these elemental error reports and the audit sheets are provided by Vleghert (Reference 2.1.4.16). Some observations from his comparison of the methods are: error sources must be subgrouped for ready comparison with more guidance given for what is considered under each error, and "other effects" may be quite significant and must be included, e.g., sensor errors or errors of method. In addition, the choice of transducer error model (constant absolute versus constant percentage versus linear absolute error) particularly for pressure transducers will affect estimates when tests cover large portions of the full-scale range of the transducer. The determination of fuel properties may introduce large errors as various evaluation methods are available with differing accuracy definitions.

Audit sheets from the test reports of each participating facility have been further summarized to indicate key differences in the measurement processes. For each of the elemental measurements, the practices and system components used by the UETP facilities are compiled into tables in Appendix B.

In addition, a subsequent review of the elemental error reports of the various facilities revealed the following observations or guidelines:

5.2.2.1 Pressure: A summary of the pressure measurement practices of the UETP facilities is shown in Table B1, in Appendix B. Both single transducer per channel and multiplexed systems were used during the UETP. For the higher pressures (Test condition 3): systematic uncertainties were 0.1 to 0.3% of reading and random uncertainties were about an order of magnitude smaller. At the lower pressures of test condition 9, the choice of transducer error model was particularly significant: systematic uncertainties ranged from 0.1 to 1% with random uncertainties of 0.01 to 0.3%.

5.2.2.2 Temperature: The UETP temperature measurement practices are summarized in Table B2. Similar data acquisition and reduction methods were used by the UETP participants. However, reference junction and calibration methods varied. Systematic uncertainties varied even among those facilities using wire manufacturer specifications. For compressor inlet temperature, random uncertainties ranged from 0 to 0.12% and systematic uncertainties varied from 0.2 to 0.4%.

5.2.2.3 Area: No significant differences were observed in the practices for area measurement.

5.2.2.4 Rotor Speed: Table B3 covers the rotor speed measurement practices during the UETP. Measurement of rotor speed directly with pulse counts or period gave significantly lower uncertainties than the use of frequency to voltage converters, i.e., 0.02 compared to 0.2%. Random uncertainties varied from 0 to 0.15% likely for the same reason.

5.2.2.5 Force: The force measurement practices and uncertainties are given in Table B4. Signal conditioning and curve-fit errors ranged from small to major contributors to the total error in force. Thrust system hysteresis contributions varied between systematic and random, with zero entries signaling that this contribution was combined with another error source. The systematic uncertainty estimates ranged from 0.08 to 1.6% while the random varied from 0.05 to 0.8%.

5.2.2.6 Fuel Flow: Similar data reduction corrections were used by the various UETP participants (see Table B5). Most facilities had dual range turbine meters. However, the RAE(P) positive displacement meters had lower uncertainties than dual range turbine meter systems. Systematic uncertainties ranged from 0.1 to 0.6% while random varied from 0.03 to 0.5%, with the higher values associated with the lower fuel flow test condition.

5.2.3 Measurement Uncertainty Components: Each facility combined the elemental estimates into systematic and random uncertainties for the measurement parameters and propagated them into the engine performance calculations. In most cases, these calculations were specified in the UETP General Test Plan (Reference 2.1.4.15). However, facility-specific methods were used in the determination of gross thrust and fuel mass flow. In addition, the calculation of the uncertainties for spatially-averaged parameters varied. Except for one case, the standard error of the mean ($S_{\bar{x}} / \sqrt{N}$) was not applied. When spatial averaged thermocouples or pressure tubes became unserviceable different compensation methods were applied. No account was taken in the uncertainty estimates for such variations in the turbine exit total temperature or total pressure. However, the performance analysis methods of the UETP General Test Plan were sometimes altered to use another more reliable measurement, e.g., turbine exit static pressure instead of total pressure in the nozzle pressure ratio parameter (see AGARD-AR-248 (Reference 2.1.4.18)).

5.2.3 (Continued):

The results of the measurement uncertainty component, derived from the individual facility uncertainty reports are shown in Figure 1 with numerical values given in Table C1, in Appendix C.

For the UETP database, the systematic uncertainty estimates were generally 3 to 10 times the magnitude of the random uncertainty estimates. These interfacility differences are attributed to different instrumentation and data acquisition schemes and also variations in the uncertainty assumptions and methods used.

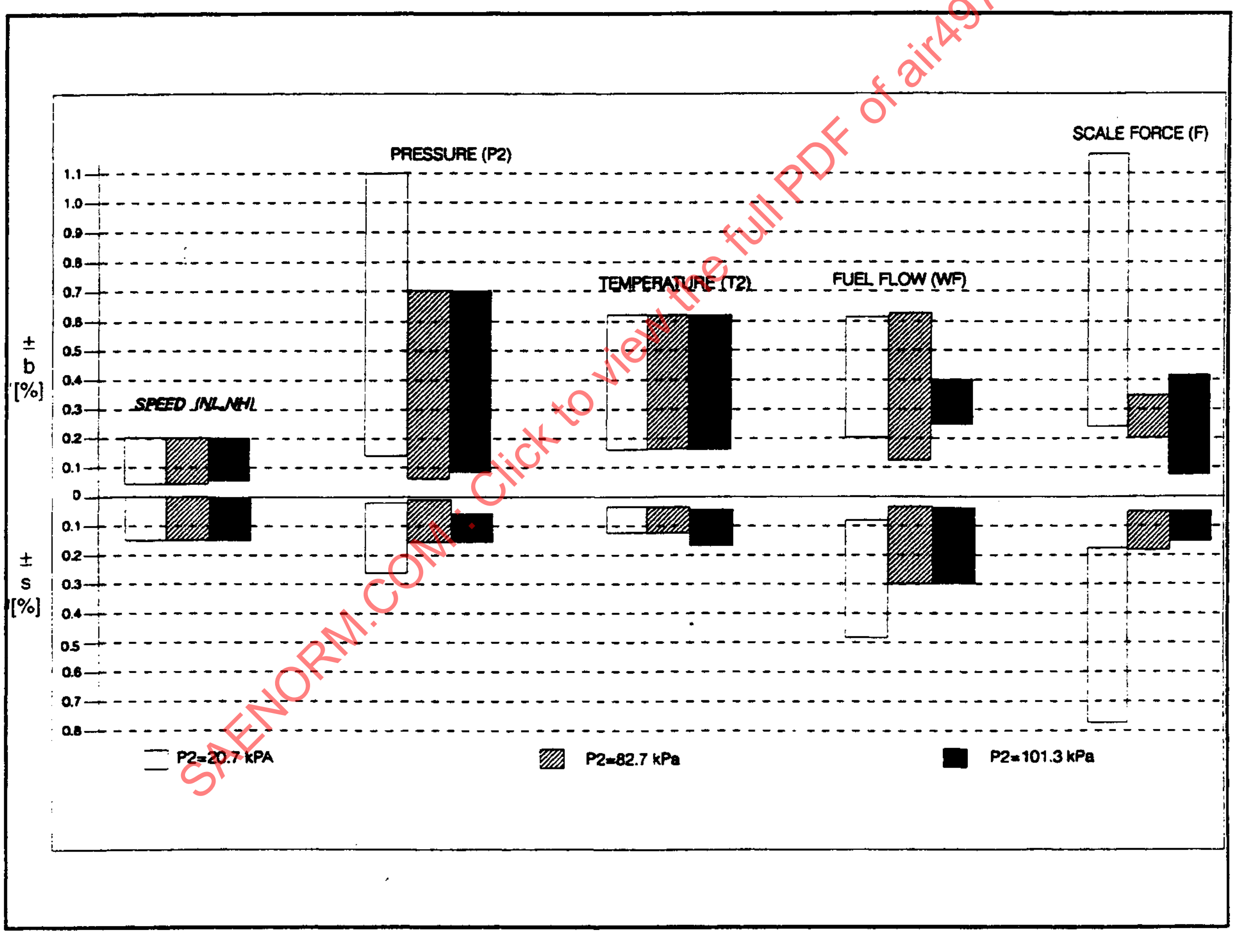


FIGURE 1 - The Range of Facility Uncertainty Components for Measurements at Three Test Conditions

5.2.4 Performance Parameter Components: Each facility derived influence coefficients for their installation and used these to propagate the measurement uncertainty components to produce the estimates for the performance parameters. The UETP General Test Plan called for the combination of measurement uncertainty components, weighted by the influence coefficients, using the root-sum-square method.

Table 5-1A, Appendix B, of AGARD-AG-307 (Reference 2.1.4.16), shows an example of a method for reporting the influence coefficients and performing the uncertainty propagation. For this discussion, Figure 2 has been prepared from AGARD-AG-307 (Reference 2.1.4.16) to show how the uncertainty components from Figure 1 are affected by the influence coefficients. Table C2, in Appendix C, contains the numerical values for Figure 2.

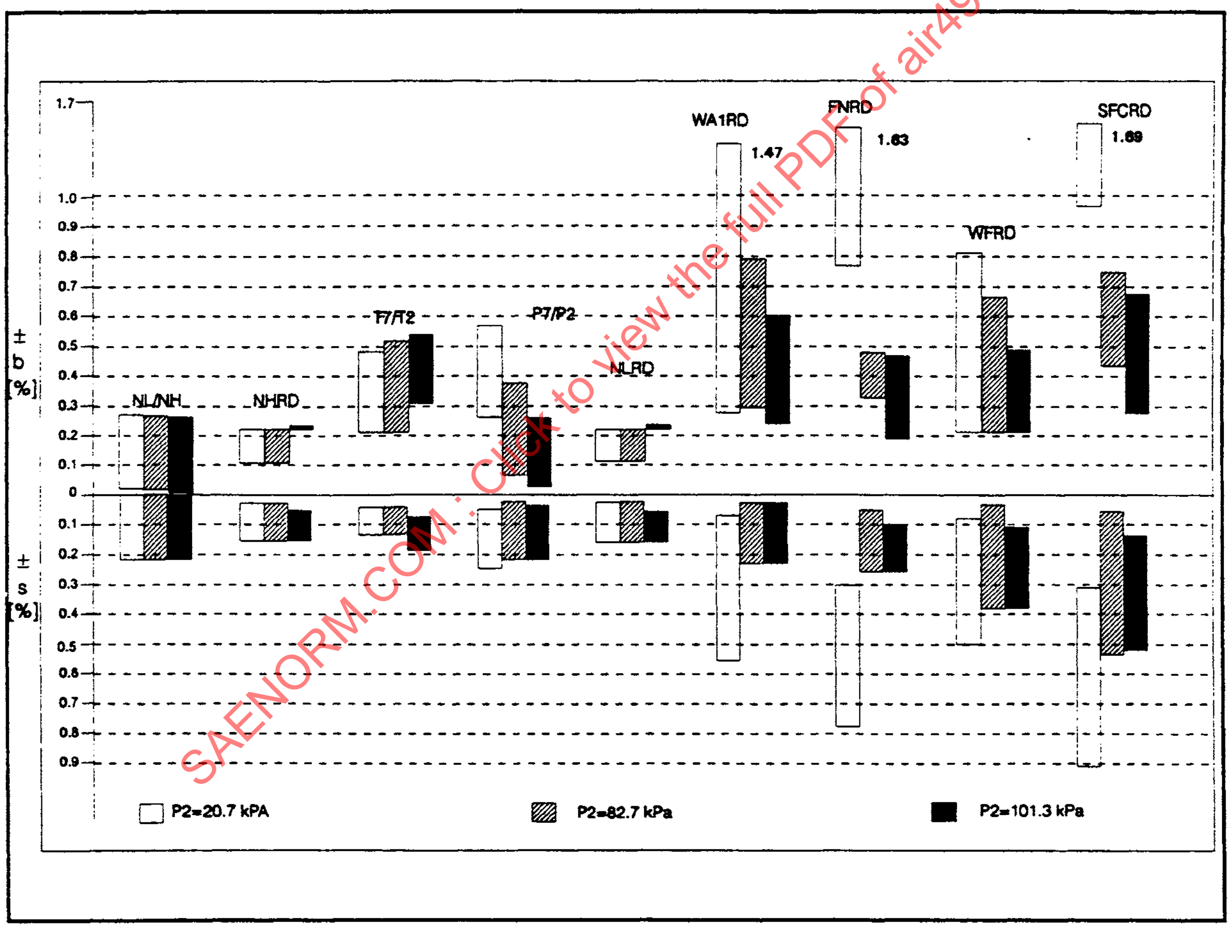


FIGURE 2 - The Range of Facility Uncertainty Components for Performance Parameters at Three Test Conditions

5.2.4 (Continued):

It was observed that there was a large variation in the parameter uncertainties. The individual influence coefficients were not reported; this would have helped determine the contribution of any differences among facilities to the errors in the performance parameters. AEDC, NASA and NRCC have reported that their influence coefficients were calculated by perturbation of the inputs to the data reduction software used for the program. Each facility indicated that influence coefficients had been useful in determining the most important contributors to key performance parameter uncertainties. For example, RAE(P) highlights the importance of engine inlet duct static pressure on SFCRD, while NASA notes that the greatest influence on FNRD was P2.

5.2.5 Uncertainty: Using the uncertainty components for the performance parameters, the uncertainty may be calculated with the additive uncertainty model specified in the UETP General Test Plan: $U_{Add} = B + t_{95}\ S_{\overline{X}}$, where in most cases, more than 30 samples were available or were assumed, so that t_{95} was set at 2.

The uncertainty components of Figure 2 (Table C2, Appendix C) can then be presented as an uncertainty in the value of the performance parameter, at the reference engine operating point, for a single facility. Figure 3 (Table C3, Appendix C) has been prepared from Section 5.3 of AGARD-AG-307 (Reference 2.1.4.16).

Figure 3 shows that variations in uncertainty values, resulting from differences in facility equipment and procedures, were less for speed and temperature and higher for parameters with thrust. The facility instrumentation differences described by Vleghert (Reference 2.1.4.16) generally agree with these observations but variations in estimation methods and DMPs may also be significant contributors to the differences.

5.2.6 Validation of the Uncertainty: The test data from the UETP tests were used by most facilities to review their estimates. First, the test data were reviewed for consistency by checking :

a. The apparent temperature or pressure profiles at stations where spatial averages were used, i.e., P2, P7, T7, PAMB;

b. Thermodynamic relationships like work balance, turbine and final nozzle flow functions (assumed constant at higher power), thrust coefficient (fixed nozzle);

c. Comparisons between facility and UETP-specific reference instruments.

For example, turbine and nozzle flow coefficient data were reviewed in AGARD-AR-248 (Reference 2.1.4.18) (Section 14.3) for the P2=82.7 kPa test condition. Pretest estimates and observed random uncertainties were in good agreement at NASA1, AEDC, RAE(P) and NASA2, being within 0.1%.

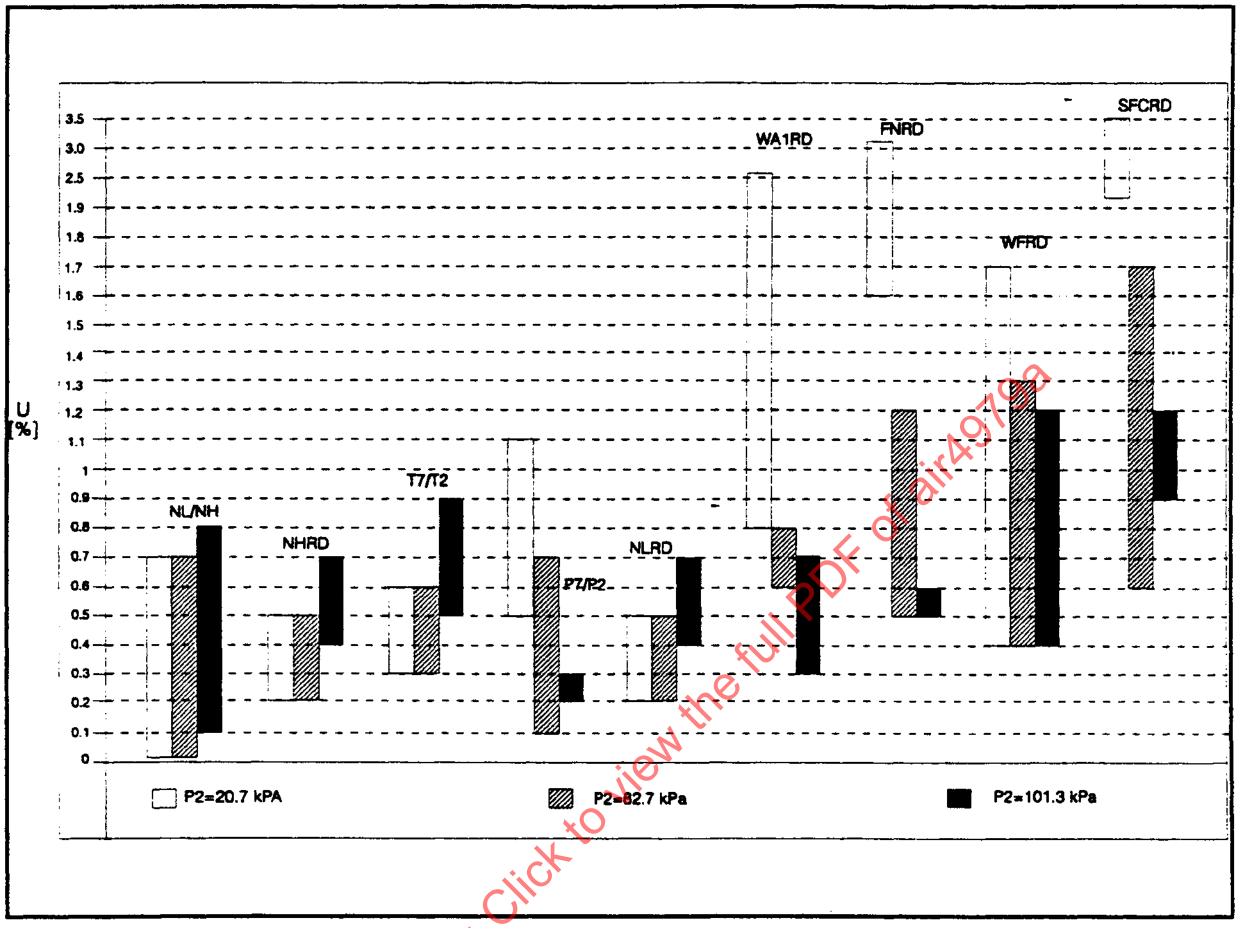


FIGURE 3 - The Range of Facility Uncertainties for Performance Parameters for Three Test Conditions

5.2.7 Interfacility Comparisons: The interfacility comparisons were carried out according to the test plan and are reported in detail in AGARD-AR-248 (Reference 2.1.4.18). However, some test procedure, facility and instrumentation differences were evident. For the purposes of these analyses, specific differences were flagged for:

5.2.7 (Continued):

a. Large data scatter and offsets in certain parameters at CEPr as a result of shorter stabilization times, e.g., -0.5% shift in thrust for test condition 6 (AGARD-AR-248 (Reference 2.1.4.18), Section 12.4). Also, CEPr recorded data outside the range of other facilities. These data, as shown in Figure 4, were eliminated from the SAE uncertainty analysis,

b. Suspect fuel flow readings at RAE(P) and at NASA for the second entry ESN 607594 tests (both fuel flow systems were considered suspect),

c Suspect T5 and fuel flow readings at CEPr (P2=20.7 kPa), and

d. Suspect P7 exhaust pressure measurement at CEPr.

The interfacility comparisons were done using functional relationships and target values for the independent parameters. Additional contributions to uncertainty for (dependent) performance parameters (Figure 2, Table C2) because of the uncertainty in the independent parameter (5.2(e)) or "curve-slope effects", also result from these functional relationships. An explanation of these effects are described in a document by Price (Reference 2.1.4.14). Results of these effects have been included (Table 2) for some of the functional relationships specified in the UETP General Test Plan.

TABLE 2 - Curve-Slope Effects on UETP Performance Parameters

Comparison (Y Versus X)	Systematic Uncertainty %	Curve-Slope Contribution %	Net Systematic Uncertainty %	Change in Systematic Uncertainty %
NL/NH versus NHR	0.09	0.000004 (NH) 0.00001 (T2)	0.09	-
WA1R versus NLR	0.60	0.004 (NL) 0.001 (T2)	0.60	-
WFR versus NHR	0.45	0.116 (T2) 0.039 (NH)	0.47	+0.02
T7/T2 versus P7/P2	0.53	0.076 (P2) 0.068 (P7)	0.54	+0.01
FNR versus P7/P2	0.43	3.19 (P2) 2.87 (P7)	4.3	+3.9
SFCR versus FNR	0.60	0.008 (FS) 0.002 (P2)	0.60	-

It can be seen that the particular choice of the functional relationship can accentuate the uncertainty and possibly jeopardize the purpose of a test. In some relationships, such as FNR versus P7/P2, the curve-slope contribution can be found to have a substantial effect as FNR is highly sensitive to a change in P7/P2.

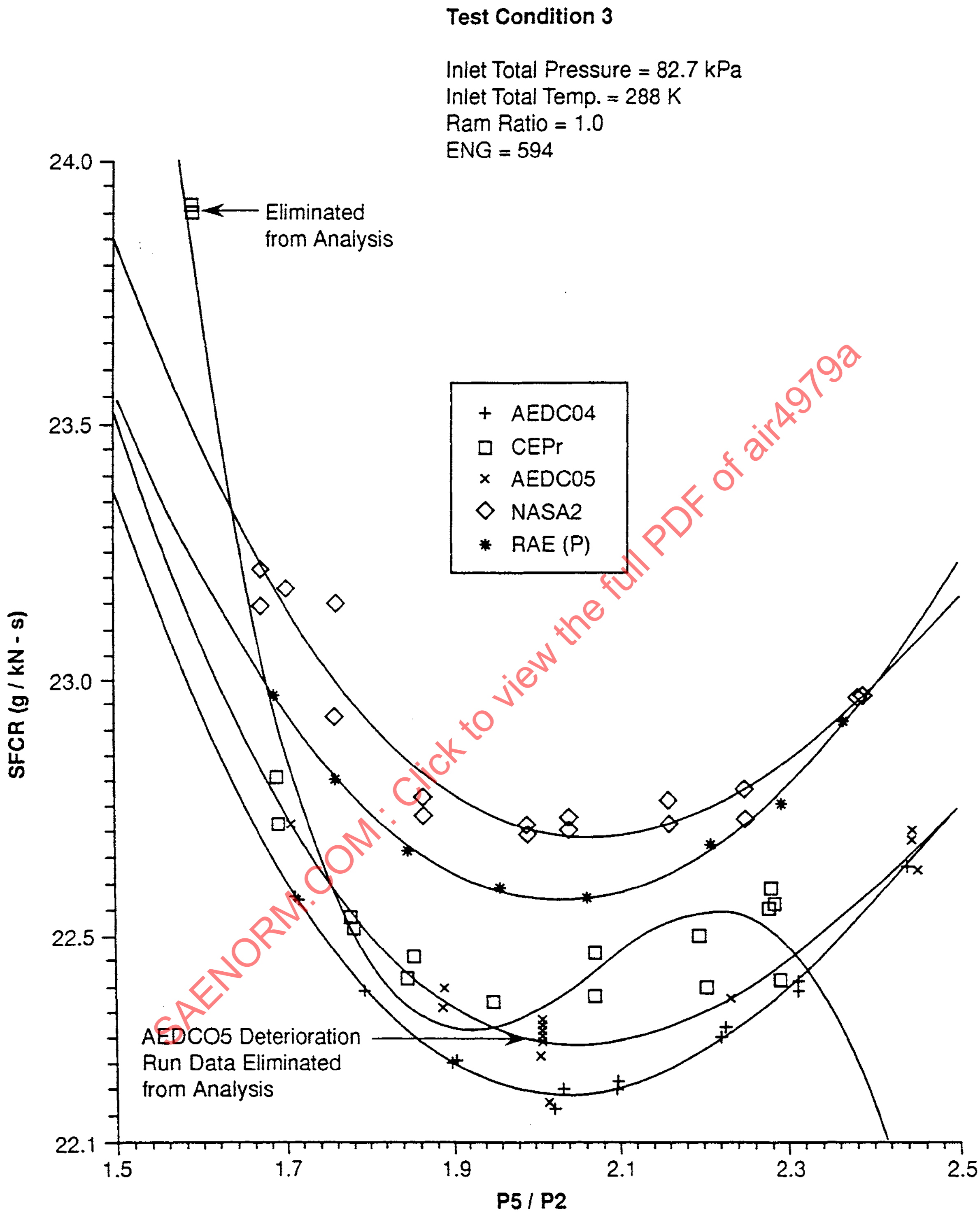


FIGURE 4 - Corrected Specific Fuel Consumption Versus Engine Pressure Ratio

5.3 Summary:

The UETP exercises demonstrated that a standard uncertainty methodology is not sufficient to allow for meaningful comparisons of facility uncertainty results. Many other factors must be coordinated, such as, the DMP and the classification of error sources into systematic and random components.

Observations have shown that the selection of engine performance parameters and power test points have a significant influence upon the magnitude of the uncertainty results.

Curve-slope effects can also be significant if the uncertainty evaluation is done for a parameter which exhibits a steep slope relationship. Repeatability of set points, from power-cal-to-power-cal or facility-to-facility can further create large uncertainties in the final results.

As a general case, low power points will have higher elemental uncertainties due to the dynamic range of the measurement devices and should be evaluated very carefully both in the estimates and during the testing process.

6. STATISTICAL ANALYSIS OF UETP RESULTS:

The test processes and analyses of the UETP were reviewed by Committee E-33 in order to arrive at a methodology for its own analysis. The following sections will describe the UETP test processes and analyses and the rationale and methodology associated with the SAE analyses.

6.1 UETP Test Processes and Analysis:

Originally there were nine candidate engines for the UETP exercise, from which one was to be chosen. The choice was the Pratt & Whitney J57, a simple, rugged engine of 50.7 kN takeoff thrust with no variable geometry. For the UETP exercise two refurbished engines were supplied by the US Air Force, code numbered P607594 and F615037 referenced in this report as engines 594 and 037.

Before the engines could be used certain modifications had to be made. To allow for a fully instrumented engine inlet, a special engine inlet bullet-nose was manufactured and used in conjunction with an instrumentation spool piece which contained an array of total pressure rakes, total temperature rakes and boundary layer probes along with both static pressure and temperature taps. The more significant modification was made to the nozzle of the engine. On a standard J57 engine the tailcone extends through the nozzle exit plane and because of this it was felt that it would be difficult to calculate the nozzle flow and thrust coefficients with an accuracy to meet the test requirements. Therefore a cylindrical tailpipe was manufactured and used in place of the standard nozzle. Although it proved not to be true, it was believed that the new nozzle would provide a more uniform nozzle inlet profile and a more suitable base for the pressure and temperature probes needed to establish nozzle inlet conditions.

6.1 (Continued):

For testing in the altitude facilities a set of 10 flight conditions were created to allow for variations in three different parameters; inlet total pressure, inlet total temperature and ram ratio, each parameter being varied in turn while the other two were kept stable. In this way the effects of each on the engine performance could be examined. At each test condition data points were taken at nine engine power settings approximately equally spaced from "bleeds just closed" speed to military power. At each power setting two data points were obtained. The requirement was to have stabilized engine performance, therefore the initial data point was taken 5 min after the conditions were set, with the second data point a further 2 min later (these time limits were confirmed by experimentation at Pyestock and at NRCC during the UETP exercise).

A set of six parameters pairs was chosen for the main interfacility comparison. These six parameter pairs were:

a. NLQNH versus NHR(D): rotor speed ratio versus corrected high pressure compressor speed

b. T7Q2 versus P7Q2: engine temperature ratio versus engine pressure ratio

c. WA1R(D) versus NLR(D): corrected engine airflow versus corrected low pressure compressor speed

d. WFR(D) versus NHR(D): corrected engine fuel flow versus corrected high pressure compressor speed

e. FNR(D) versus P7Q2: corrected net thrust versus engine pressure ratio

f. SFCR(D) versus FNR(D): corrected specific fuel consumption versus corrected net thrust

It was hoped that the above six parameter pairs would enable the checking of the important aspects of gas turbine performance.

To eliminate the small as-tested differences between the altitude facilities the data were corrected to the desired (RD) flight conditions using nondimensional pressure and temperature relationships. When the altitude facilities were compared with the sea-level test beds a different nomenclature, R, was used to signify that the data had been corrected to standard sea-level, static conditions (inlet pressure = 101.325 kPa, inlet temperature = 288 K and ram ratio = 1.0).

For the SAE exercise three test conditions were examined, Test Condition, 3, 9 and 11. Test Condition 3 (82.7 kPa/288 K/1.0) was taken as being the closest condition to sea-level, static that could be obtained by the altitude test facilities (the R nomenclature was used for the parameters). Test Condition 9 (20.7 kPa/288 K/1.3) was taken as it was considered to be the most difficult test condition (the RD nomenclature was used for the parameters). Test Condition 11 (101.3 kPa/288 K/1.0) was the sea-level, static condition tested by the sea-level test beds (the R nomenclature was used for the parameters)

6.1 (Continued):

For the performance analysis of the altitude facilities engine 594 was used as it was the only one of the pair that visited all four sites (engine 037 did not come to either the RAE(P) or CEPr). For the performance analysis of the sea-level facilities engine 037 was used as it visited 5 facilities against only 2 for 594.

The use of P7 (nozzle inlet pressure) to describe the engine pressure ratio instead of P5 (LP turbine exit) was due to the amount of instrumentation available at each station (see Table 3). At the P5 position there were only one total pressure measurement and five total temperature measurements; whereas, at the P7 position there were 36 total pressure and temperature measurements and 4 static measurements. Thus there was a better description of the flow field at the P7 position than at the P5 position.

TABLE 3 - Station 5 and 7 Instrumentation Summary

Station No.	Description	Number of Pressure Total	Number of Pressure Static	Number of Temperature Total	Number of Temperature Static
5	LP Turbine Exit	1	0	5	0
7	Exhaust Nozzle Exit	36	4	36	4

Analysis of the test results indicated to the UETP members that there was a problem with the measurement of P7 at CEPr. The likely explanations included a misaligned tailcone and instability of the engine (CEPr collected their data points much sooner than was recommended by the UETP). As a result, the SAE decided to use the P5 station for computing the engine pressure ratio, even though there was only a single total pressure probe. The effects of this choice are shown in Figures 5 and 6.

Changes to the parameter list were also made leaving a SAE final list of:

a. FNR(D) versus P5Q2 corrected net thrust versus engine pressure ratio

b. WFR(D) versus P5Q2 corrected engine fuel flow versus engine pressure ratio

c. SFCR(D) versus P5Q2 corrected specific fuel consumption versus engine pressure ratio

d. SFCR(D) versus FNR(D) corrected specific fuel consumption versus corrected net thrust

e. WA1R(D) versus NLR(D) corrected engine airflow versus corrected low pressure compressor speed

f. WA1R(D) versus P5Q2 corrected engine airflow versus engine pressure ratio

g. T7Q2 versus P5Q2 engine temperature ratio versus engine pressure ratio

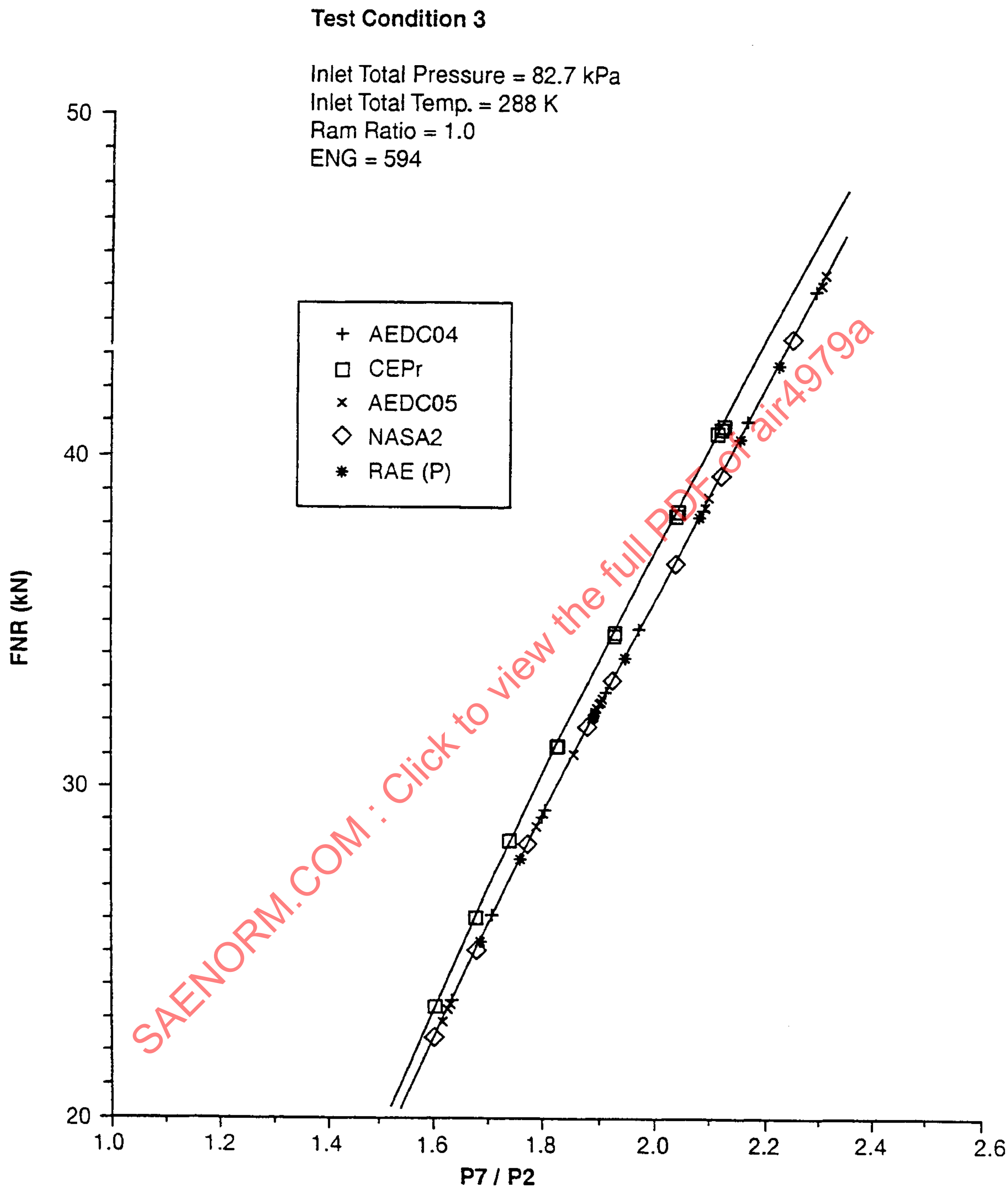


FIGURE 5 - Corrected Thrust Versus Engine Pressure Ratio

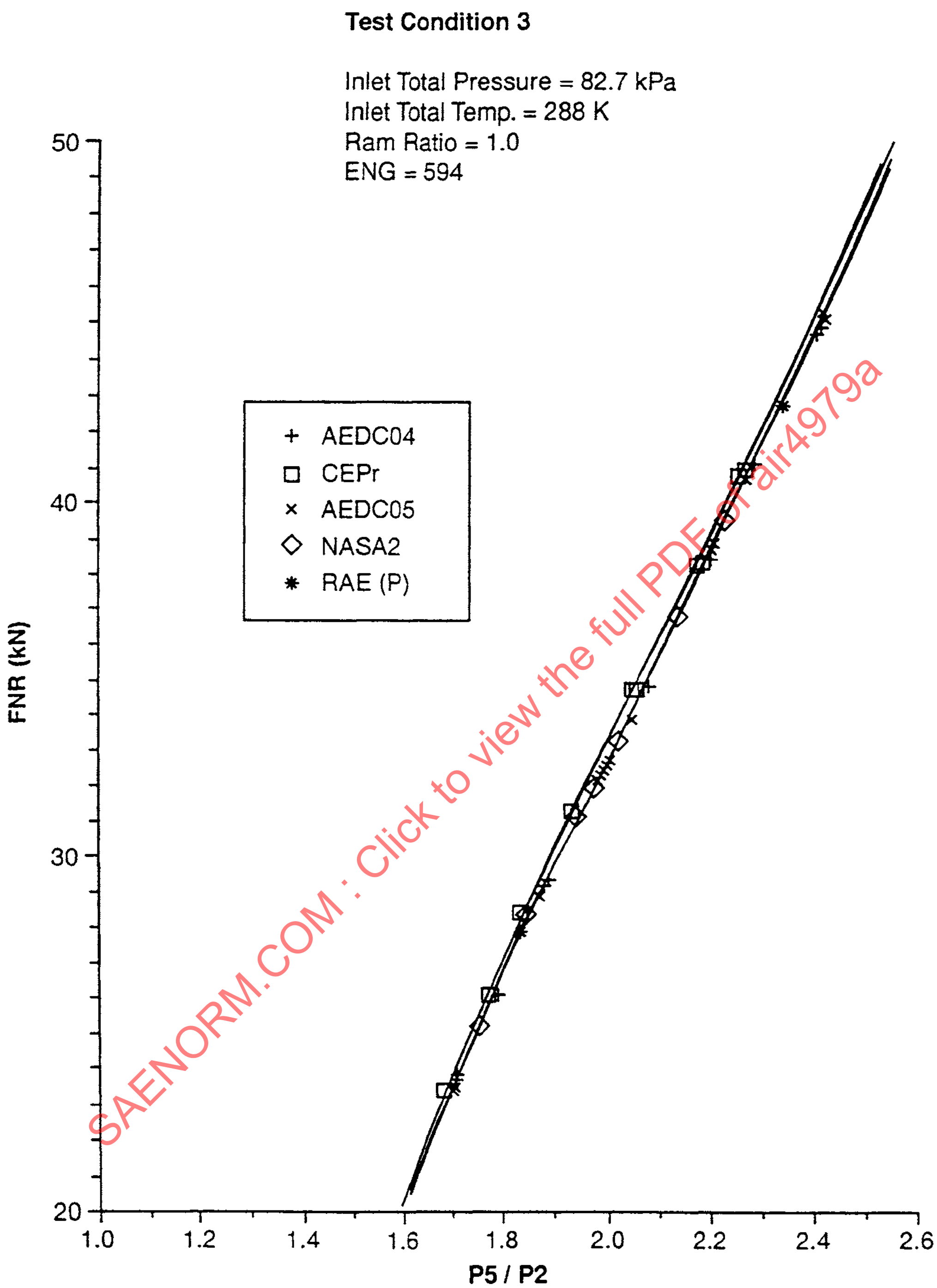


FIGURE 6 - Corrected Thrust Versus Engine Pressure Ratio

6.1 (Continued):

To allow for uniform processing of the data the UETP test plan (Reference 2.1.4.15) specified that all curve-fitting would take the form of a quadratic polynomial. This policy was justified on the grounds that the main interest for the comparisons was at the mid-thrust point.

For the SAE exercise, interest was expressed to look at other points along the power curve, a high-thrust point and a low-thrust point as well as the mid-thrust point. Thus the selection of a quadratic polynomial for the curve-fitting would not necessarily be optimal, so it was decided to allow polynomial curve-fits up to a cubic (however it was agreed that the data from each facility should use the same degree of curve-fit for each parameter pair at each of the test conditions). As an example, the effect of choosing polynomials with higher degrees is illustrated in Figures 7, 8, and 9 for the relationship of SFCR and P5Q2. (See 6.4.1 for further discussion of these figures.)

One of the most important aspects for the UETP exercise was the provision of a so-called "identical" engine to each test facility and the test plan was designed with this in mind; however, it was accepted that some variations, i.e., performance deterioration, would occur throughout the program. To reduce performance deterioration, the test matrix was designed to minimize high engine power operating time and limit engine operation to well below the temperature limits on the high pressure spool.

With the acceptance that there would be some performance deterioration, three procedures were adopted to obtain a quantitative assessment of the changes in engine performance over the life of the UETP exercise. They were:

a. Quantifying engine performance changes at each test facility

b. Conducting the first and last engine tests in the same test facility and measuring the overall change in engine performance

c. Monitoring data from the engine reference instrumentation throughout the test programme.

For item b above, the engines were returned to the facility that first tested them, NASA in the case of the altitude facilities and NRCC in the case of the sea-level test beds. The results of the second tests were only for checking performance deterioration not as part of the main exercise. Unfortunately, due to the length of the test program, the engines did not return to NASA and NRCC until after significant modifications had been made to those facilities. NASA changed both the test cell and the data acquisition system. Also a new exhaust detuner was installed at NRCC. However, the test cell aerodynamic characteristics at NRCC were retained. As a result of the changes at both facilities, changes in the measured values could not be distinguished from the engine performance changes making it impossible to quantify accurately the overall performance deterioration of the engines. Therefore, engine deterioration was assumed to be negligible. These NASA modifications allowed the SAE to treat it as a separate facility (NASA2), giving the SAE an extra set of results.

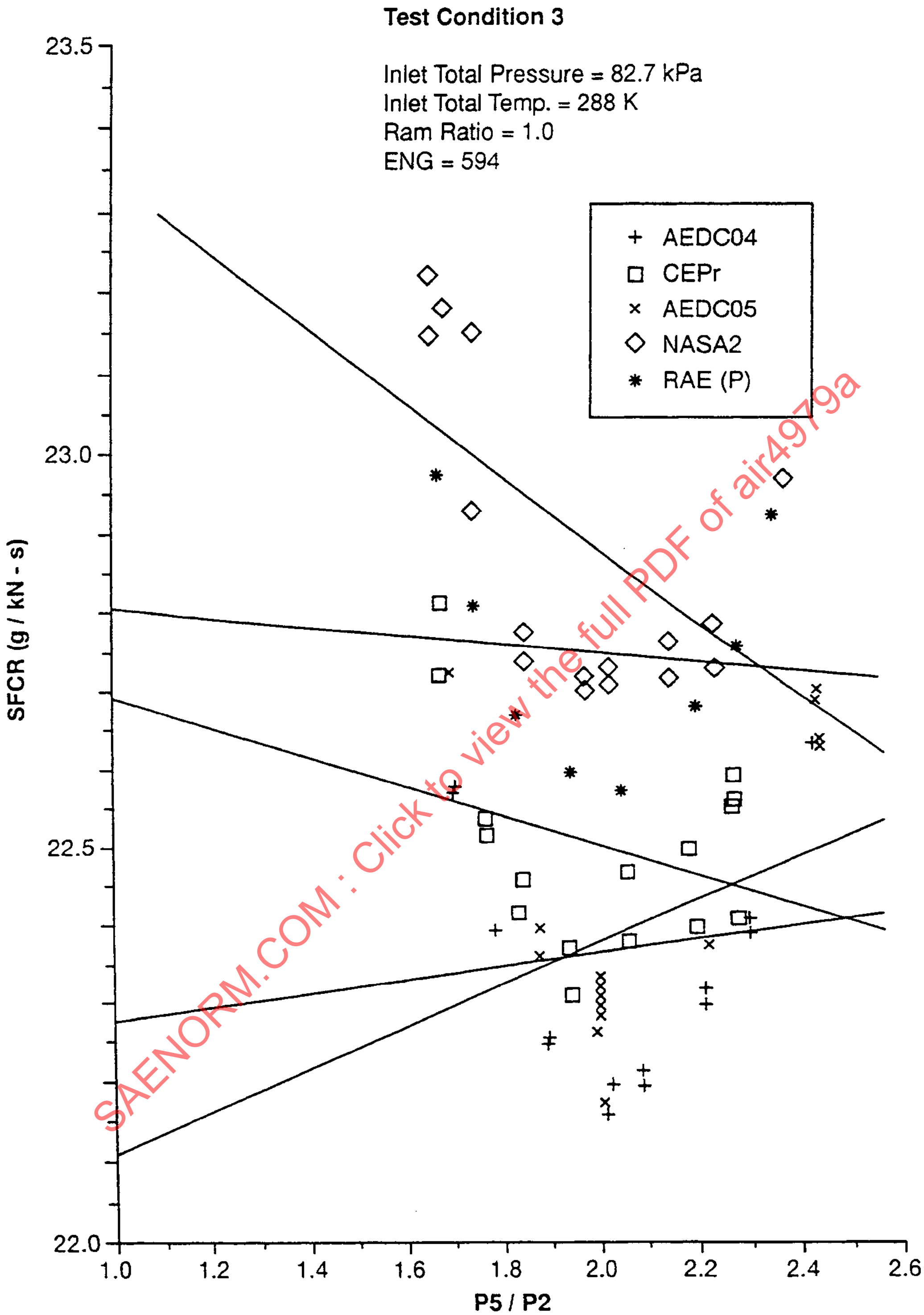


FIGURE 7 - First Degree Polynomials

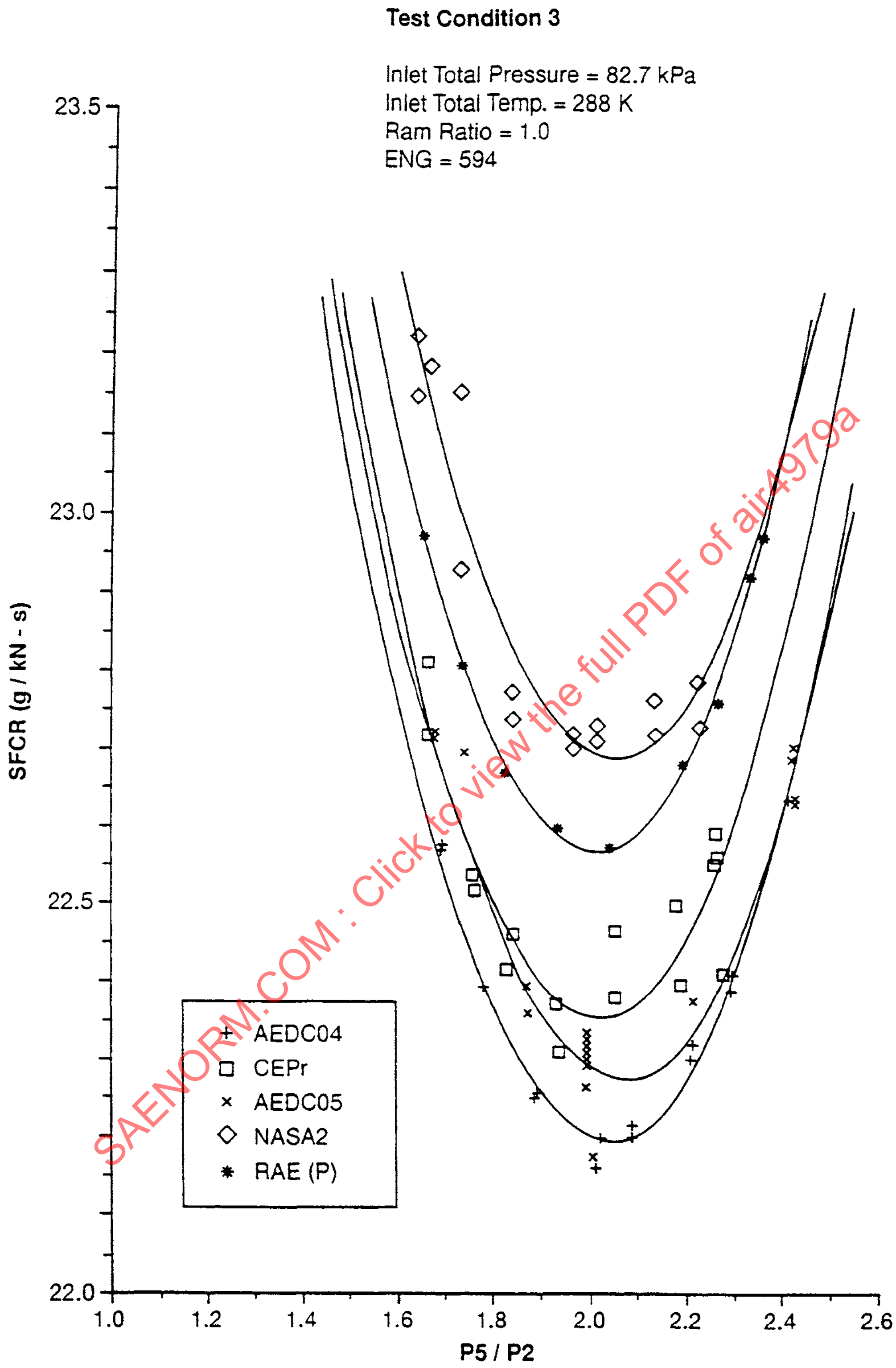


FIGURE 8 - Second Degree Polynomials

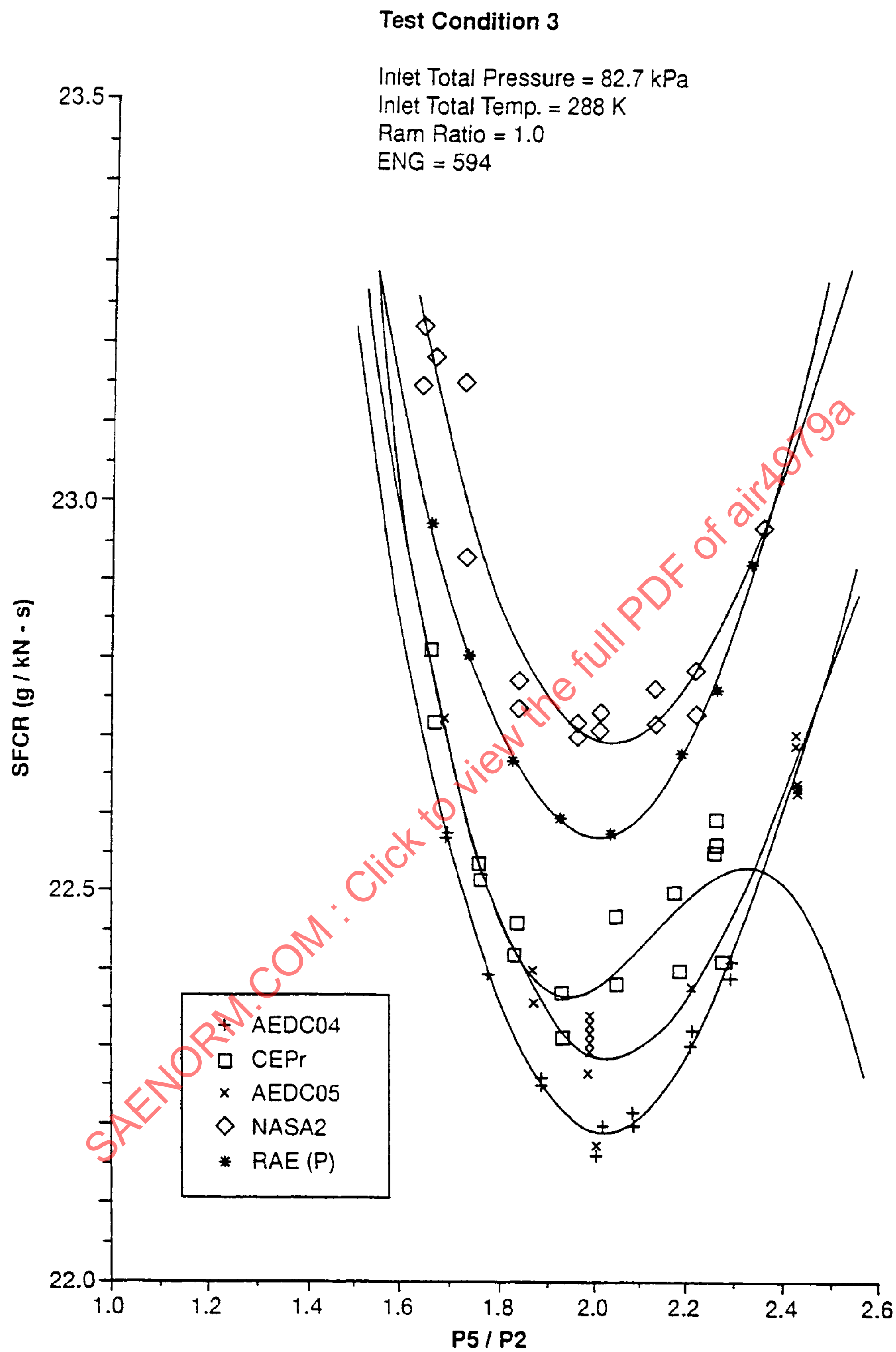


FIGURE 9 - Third Degree Polynomials

6.1 (Continued):

The summary of conditions that were run by the various facilities is given in Table 4. The AEDC05 data shown in Figure 4 which was eliminated from the analysis because this was a run made to check deterioration after the engine had been run about 100 h.

TABLE 4 - Engine and Facility Test Combination Summary

	P2=82.7 kPa (12.0 psia) Condition 3	P2=82.7 kPa (12.0 psia) Condition 3	P2=20.7 kPa (3.0 psia) Condition 9	P2=20.7 kPa (3.0 psia) Condition 9	P2=101.3 kPa (14.7 psia) Condition 11	P2=101.3 kPa (14.7 psia) Condition 11
ENGINE S/N	594	037	594	037	594	037
SITE						
NASA1	*	Y	Y	Y	N	N
AEDC	Y	Y	Y	Y	Y	Y
NRCC	N	N	N	N	Y	Y
CEPr	Y	N	Y	N	N	Y
RAE(P)	Y	N	Y	N	N	N
TUAF	N	N	N	N	N	Y
NASA2	Y	Y	Y	Y	N	N
NAPC	N	N	N	N	N	Y

In the altitude/sea-level test site comparisons, with the exception of NASA, all the altitude facility data related to an inlet temperature of 288 K. Test Condition 3 for engine 594 was omitted by NASA (the first entry) because of a restricted test window, Test Condition 4 (T1 = 308 K) corrected to 288 K was considered but not used in the analysis. This meant for the SAE analysis that, while there were five test facilities for Test Condition 9 (NASA1, AEDC, CEPr, RAE(P) and NASA2), there were only four test facilities for Test Condition 3 (AEDC, CEPr, RAE(P) and NASA2).

The UETP exercise also included uncertainty analyses of the different facilities using an uncertainty methodology based on the work by Abernethy (Reference 2.1.4.1) and Thompson (Reference 2.1.4.2). This produced a common basis for comparison of the quality of different measurement systems in use in the different facilities. The results of these analyses were published in a separate report by Vleghert (Reference 2.1.4.16).

The SAE carried out its own analysis of the interfacility and within-facility measurement uncertainty. The procedure for performing the analysis is presented in 6.4 with the results appearing in 6.5.

6.2 AGARD's Concerns:

There were several areas of concern for the UETP exercise, some of which produced scatter in the test results.

A major area of concern was that the exhaust nozzle would be damaged, thus changing the effective area, A8. However, measurements at each of the four altitude test facilities showed that there was negligible change in the geometric area (and therefore the effective area) of the exhaust nozzle exit, the extreme values being only ±0.13%.

6.2 (Continued):

Humidity was no problem for the UETP exercise, because all the altitude test facilities supplied dry air to the engine. The sea-level test beds were more vulnerable to the effects of humidity, however the humidity levels on the days that the sea-level test beds did run were sufficiently low to ensure that the effects were negligible or very small.

Another area of concern was the amount of time needed to stabilize the engine to allow the data points to be obtained at stable conditions. The UETP General Test Plan called for a settling time, once on condition, of 5 min. Investigations of this assumption were made during the UETP exercise, both at Pyestock (RAE(P)) and at NRCC.

At Pyestock, investigations centered around Test Conditions 6 and 9. Engine test conditions were set up and the throttle angle was set at military power. Successive data points were taken once every minute over a time interval of approximately 9 min. During this time no alterations were made to either the facility or the engine settings (except for Test Condition 9 when a small change was made to the engine inlet total pressure due to instability in the facility). The results indicated that the engine was stable within 3 min for Test Condition 6, and, allowing for the correction in engine inlet total pressure, within 4 min for Test Condition 9. Investigations at NRCC produced similar results. Thus there was sufficient evidence to justify the 5 min settling time recommended by the General Test Plan of the UETP (the lack of thermal equilibrium caused by not waiting 5 min after getting onto condition was given as one of the possible reasons for CEPr's problems with measurement of P7).

Some concern was expressed about the alignment of the P7 total pressure rake, the pressure profile being strongly influenced by the large upstream turbine exit struts and the attendant swirl in the flow. Initial tests at NASA showed that P7 appeared to be too low in comparison with other engine data, which suggested that the position of the rake was not allowing for an accurate description of the flow field. Thus an investigation was carried out where the tailpipe and the rake were rotated to a number of different positions, the result being that the assembly was rotated 12.5 degrees counterclockwise for the remainder of the UETP exercise.

Analysis of the UETP test results showed a significant variation in facility-to-facility airflow measurements. NASA and NRCC proved this was due to differences in the inlet ducts used by the test facilities, which affected the pressure profile of the P2 measurement in the boundary layer.

6.3 Statistical Methods:

To avoid confusion with other definitions, this section gives an overview of the statistical terms used in the SAE analysis.

6.3.1 Standard Error of Estimate (SEE), (Random Uncertainty): Random error produces the scatter between repeated measurements of the same quantity. The sample standard deviation is the best measure of random error.

6.3.1 (Continued):

For a curve-fit of two performance parameters, the standard error of estimate (SEE), also called the residual standard deviation, is the standard deviation of the points about the curve. In other words the SEE is the standard deviation of the residual variation of the points about the curve. Two SEEs is accepted as the random uncertainty of the data points about the curve-fit.

$$SEE = \sqrt{\frac{\sum_{i=1}^{N} (Y_i - Y_c)^2}{N - k}} \quad \text{(Eq.8)}$$

Where the Y_i's are the dependent data points, Y_c 's are the values of the curve at the same value of x_i (the independent variable), N is the number of data points, and k is the number of constants required to fit the polynomial.

The process and uncertainties are described in ANSI/ASME PTC 19.1 (Reference 2.1.2.3), Section 3.7, Regression Uncertainty. For a single facility the curve and the scatter around it are the objective of the measurement process. For the UETP, the SEE includes statistical variation in the engine and facility, uncertainties in the correction parameters for nonstandard inlet pressure and temperature, and the random variation in the independent parameter, X. The approximate random uncertainty of the curve is two times SEE divided by the square root of the number of data points (N).

6.3.2 Pooled Standard Error of Estimate: In order to determine a representative value of SEE for any facility, the individual SEE values were "pooled". The representative value is called the "pooled" standard error of estimate, (S_P) and is calculated as described in ANSI/ASME PTC 19.1 (Reference 2.1.2.3).

$$S_p = \sqrt{\frac{\sum_{i=1}^{K} (SEE_i^2 \, df_i)}{\sum_{i=1}^{K} df_i}} \quad \text{(Eq.9)}$$

where:

K = the number of facilities
df_i = $N_i - k_i$

6.3.2 (Continued):

The S_P, is the recommended value for the standard deviation of the functional relationship for each pair of performance parameters.

6.3.3 Sample Size: The number of points recorded by the facilities and employed in the curve-fits is a variable. When using the curve, the standard error of the mean is equal to the S_P divided by $\sqrt{\bar{N}}$. This is analogous to standard deviation divided by the $\sqrt{N}$ for a single mean dataset. $\bar{N}$ was calculated as described in Dixon and Massey (Reference 2.1.4.19) and is shown in Section 6.3.4.

6.3.4 Systematic Uncertainty: In repeated measurements, the difference between the true value and the average of a very large sample is referred to as the systematic error. An estimate of this error, the systematic uncertainty, is traditionally obtained from judgement and experience. However, if data are available, statistical methods may be used to estimate this quantity. The UETP data provides interfacility comparisons for all of the standard gas turbine performance parameters. The range and the standard deviation are two different methods used to estimate the systematic uncertainty.

The range is the difference between the smallest and largest values in a sample of data. Although not in common usage, it can be used as an estimate of variability for small samples (Duncan (Reference 2.1.4.20)) and should not be used for sample sizes greater than ten. In this case, as only four or five facilities were considered, the range was used to provide an estimate of the systematic uncertainty. The expected ratio of the standard deviation to the range for a sample size of four is $1/d_2$ where d_2 is 2.059. Values for $1/d_2$ can be found in Table 5 (Duncan (Reference 2.1.4.20)).

For example, the systematic uncertainty $\left(\frac{2*\text{Range}}{d_2}\right)$, and the corrected standard deviation ($2S_{CORR}$) were found to be 0.54 and 0.50 respectively, at one condition. The facility-to-facility variation ($2S_{CORR}$), is preferred to approximate the systematic uncertainty for the combination of performance parameters. The standard deviation (S), of the curve-fit values from each facility includes the facility-to-facility variation (S_{CORR}) and some part of the "pooled" within run variation (S_P).

The corrected standard deviation or facility-to-facility differences may be obtained from the following relationship:

$$S_{CORR} = \sqrt{S^2 - \left(\frac{S_P^2}{\bar{N}}\right)} \quad \text{(Eq.10)}$$

6.3.4 (Continued):

where:

$$S = \sqrt{\frac{\sum_{i=1}^{K} \left(Y_{c_i} - \overline{Y}\right)^2}{(K-1)}} \qquad \text{(Eq.11)}$$

$$\overline{Y} = \sum_{i=1}^{K} \left(\frac{Y_{c_i}}{K}\right)$$

$$\overline{N} = \frac{\sum_{i=1}^{K} N_i - \left(\frac{\sum_{i=1}^{K} N_i^2}{\sum_{i=1}^{K} N_i}\right)}{(K-1)}$$

and Y_{c_i} = dependent variable calculated from the equation of the line for a single facility.

6.4 Analysis Procedure:

For this document, the following criteria were chosen from the available choices for selecting a suitable curve-fit. In order to use polynomial curve-fits for fitting the data the following were assumed:

a. At a given value of the independent variable, the average of the dependent variable values will fall on the fitted polynomial.

b. At all values of the independent variable, the scatter of the dependent variable data is identical.

c. The errors (deltas of the data about the fitted polynomial) are independent and normally distributed with an average of zero. The distribution of the data about that average is assumed normal.

TABLE 5 - Population Standard Deviation Factors($1/d_2$)

Number of Observations in Sample, N	d_2	$1/d_2$
2	1.128	0.8865
3	1.693	0.5907
4	2.059	0.4857
5	2.326	0.4299
6	2.534	0.3946
7	2.704	0.3698
8	2.847	0.3512
9	2.970	0.3367
10	3.078	0.3249
11	3.173	0.3152
12	3.258	0.3069
13	3.336	0.2998
14	3.407	0.2935
15	3.472	0.2880
16	3.532	0.2831
17	3.588	0.2787
18	3.640	0.2747
19	3.689	0.2711
20	3.735	0.2677
21	3.778	0.2647
22	3.819	0.2618
23	3.858	0.2592
24	3.895	0.2567
25	3.931	0.2544

6.4.1 Selection of Curve-Fit Polynomial: For each X-Y relationship generated by each facility, first, second, and third degree polynomials were fit to the data. The degree of fit used in the analysis was chosen using two criteria:

a. The amount of decrease in the standard error of estimate as the degree of the polynomial increased

b. Visual examination of the curve to verify the fit

A ground rule that was set at the beginning of the analysis was that the data for all facilities for a particular X-Y relationship were to be fit with the same degree polynomial.

The relationship of SFCR as a function of P5Q2 shown in Figures 7, 8, and 9 with first, second, and third degree polynomials, respectively, will be used to illustrate the suitability of the curve fit.

6.4.1 (Continued):

The SEEs for the first, second, and third degree polynomial fits for the AEDC04 data were 0.1641, 0.0213, and 0.0137, respectively. By appearance alone, the first degree curve-fit should not be used. The standard error of estimates between the second and third degree polynomials decrease by about 50% for the AEDC04 data. However, the second degree fit was chosen in this case because of the inconsistent appearance of the third degree fit through one data set.

Complete tables of results and plots of the data are shown in Appendix D for engines 037 and 594.

6.4.2 Explanation of Table and Plot Terms: The following items describe the terms used in the table and plot shown in Figure 10. This example can be applied to the tables and plots in Appendix D.

1. DEGREES OF FREEDOM: This is the number of points (N) for each facility minus the number of polynomial coefficients. (polynomial coefficients = degree of polynomial + 1).

2. NUMBER OF FACILITIES: In this case, four facilities -- AEDC04, RAE(P), CEPr, and NASA2.

3. DEGREE OF POLYNOMIAL: In this case, two.

4. $\overline{N}$:

$$\overline{N} = \frac{\sum_{i=1}^{K} N_i - \left(\frac{\sum_{i=1}^{K} N_i^2}{\sum_{i=1}^{K} N_i} \right)}{(K-1)} \qquad \text{(Eq.11)}$$

5. LEVELS OF INDEPENDENT VARIABLE: Three levels of the independent variable were chosen which bracketed the available data at min, mid and max points.

6. DEPENDENT VARIABLE AVERAGE AT EACH LEVEL CALCULATED FROM EQUATION OF THE LINE THROUGH EACH FACILITY: As an example, at a minimum level of P5Q2 of 1.7 the average of the values at points A, B, C and D, (Y_{c_i}) calculated from the curve-fits through each facility, equals 22.85 ($\overline{Y}_c$).

7. MAX OF DEPENDENT VARIABLE AT EACH LEVEL: For level 1.7, this would be the maximum value (D)

8. MIN OF DEPENDENT VARIABLE AT EACH LEVEL: For level 1.7, this would be the minimum value (A)

6.4.2 (Continued):

9. RANGE - (MAX-MIN) FOR EXAMPLE, RANGE = 0.56

10. RANGE AS PERCENTAGE OF AVERAGED DEPENDENT VARIABLE AT EACH LEVEL

    Range - (MAX-MIN) / ((A+B+C+D)/4) 100% = 2.46

11. DEPENDENT VARIABLE STANDARD DEVIATION AT EACH LEVEL -- S: This is the standard deviation calculated at points A, B, C, and D.

12. POOLED STD. ERROR OF ESTIMATE (FOR EQUATIONS THROUGH EACH FACILITY -- S_P: See 6.3.2 for example $S_P = 0.0511$

13. $S_P/\sqrt{\overline{N}}$: Described above under sample size and is equal to 0.0137.

14. CORRECTED S -- S_{CORR}: The facility-to-facility variation corrected for the within facility variation.

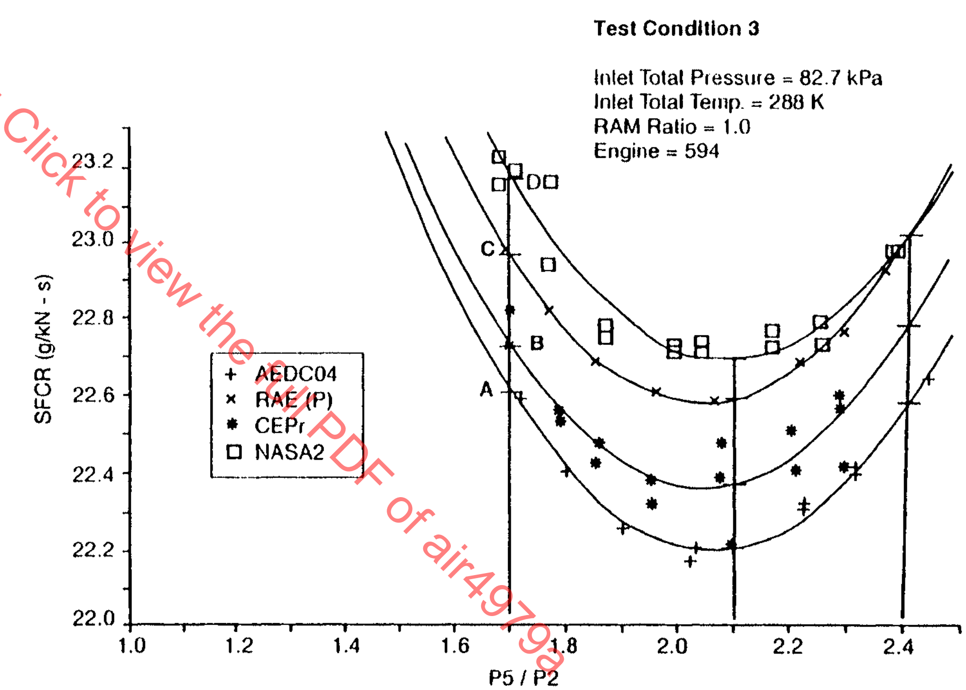
$$S_{CORR} = \sqrt{S^2 - \left(\frac{S_P^2}{\overline{N}}\right)} \qquad \text{(Eq.12)}$$

15. $2S_{CORR}$ AS A PERCENTAGE OF THE AVERAGED DEPENDENT VARIABLE:

    2 (0.2481)/22.85 (100%) = 2.17

Dependent Variable (SFCR)												
Independent Variable (FNR)												
Facility	AEDC04 (N = 16)			RAE (P) (N = 8)			CEPr (N = 18)			NASA2 (N = 18)		
P5/P2	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4
SFCR	22.59	22.20	22.56	22.94	22.58	22.99	22.71	22.37	22.76	23.15	22.69	23.0
SEE	0.02133			0.01495			0.0672			0.0603		
Degrees of Freedom (1)	13			5			13			15		

Number of Facilities (2)	4		
Degree of Polynomial (3)	2		
$\overline{N}$ (4)	14		
Levels of Independent Variable (5)	1.7	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility (6)	22.85	22.46	22.83
MAX of Dependent Variable at each level (7)	23.15	22.69	23.00
MIN of Dependent Variable at each level (8)	22.59	22.20	22.56
Range (MAX - MIN) (9)	0.56	0.49	0.44
Range as a % of Dependent Variable at each level (10)	2.46	2.18	1.92
Dependent Variable Standard Deviation at each level (S) (11)	0.2485	0.2183	0.2100
Pooled Std. Error of est. (for equations through each facility) (S_p) (12)	0.0511		
$S_p / \sqrt{N}$ (13)	0.0137		
Corrected S (S_{Corr}) (14)	0.2481	0.2179	0.2095
2 [S_{Corr}] as a % of the Dependent Variable (15)	2.17	1.94	1.84



7. COMPARISON OF PRETEST ESTIMATES WITH POSTTEST UNCERTAINTY ANALYSIS RESULTS:

The application of the uncertainty methodology employed by each facility differed. However, an attempt was made to arrive at values that identified to some degree the random, systematic and total uncertainty for each parameter. An intra and interfacility comparison of the pretest estimates with the posttest random (S) and systematic (B) uncertainties, calculated by the preceeding methods, has been made.

7.1 Random Uncertainty:

The bars shown in the lower portion of Figure 11 indicate the range of the individual posttest random uncertainties of the performance parameters computed, according to the SAE analysis, for each facility. These uncertainties were computed at a particular target condition. For the analysis, the random component of uncertainty, SEE was based on values along a performance curve for each particular parameter.

7.2 Systematic Uncertainty:

In most cases pretest facility values were based on estimates tempered by engineering judgements. If confidence checks are "built in" to the test design (e.g., dead weight reference on a pressure scanning system), the results of these checks may be used during the posttest analysis to modify the pretest systematic uncertainty estimates. However, for the UETP these data were not available and the pretest estimates were used in the posttest analysis. The range of the systematic uncertainties computed by each facility presented in Figure 2, and are shown in the upper portion of Figure 11.

7.3 Total Uncertainty:

The range of the posttest uncertainties for each facility, computed as U_{Add}, with pretest systematic uncertainty and posttest SEE, is shown in Figure 12. A curve-slope relationship, as demonstrated in 5.2.7, exists in parameter plots and therefore should be considered in a pretest analysis. However, this was not done in the UETP analysis. For comparison purposes, the range of the pretest uncertainties (Table C3) and posttest uncertainties are shown in Table 6.

7.4 Discussion:

The UETP employed a method, documented by Abernethy and Thompson (Reference 2.1.4.4), to estimate the measurement uncertainty of gas turbine performance parameters. Pretest estimates, based on the local practices of each facility, were computed by each participant covering three different subsonic test conditions for inlet pressures of 82.7, 20.7, and 101.3 kPa. The pretest estimates are summarized in Tables C1, C2 and C3 of Appendix C. The estimates provide an indication of the magnitude of the measurement uncertainty commensurate with the measurement system practices and approaches employed by the UETP participants.

The UETP provided an unique opportunity for comparing measurement systems from various facilities. For this document an analysis was completed which now provides the method for computing posttest interfacility comparisons.

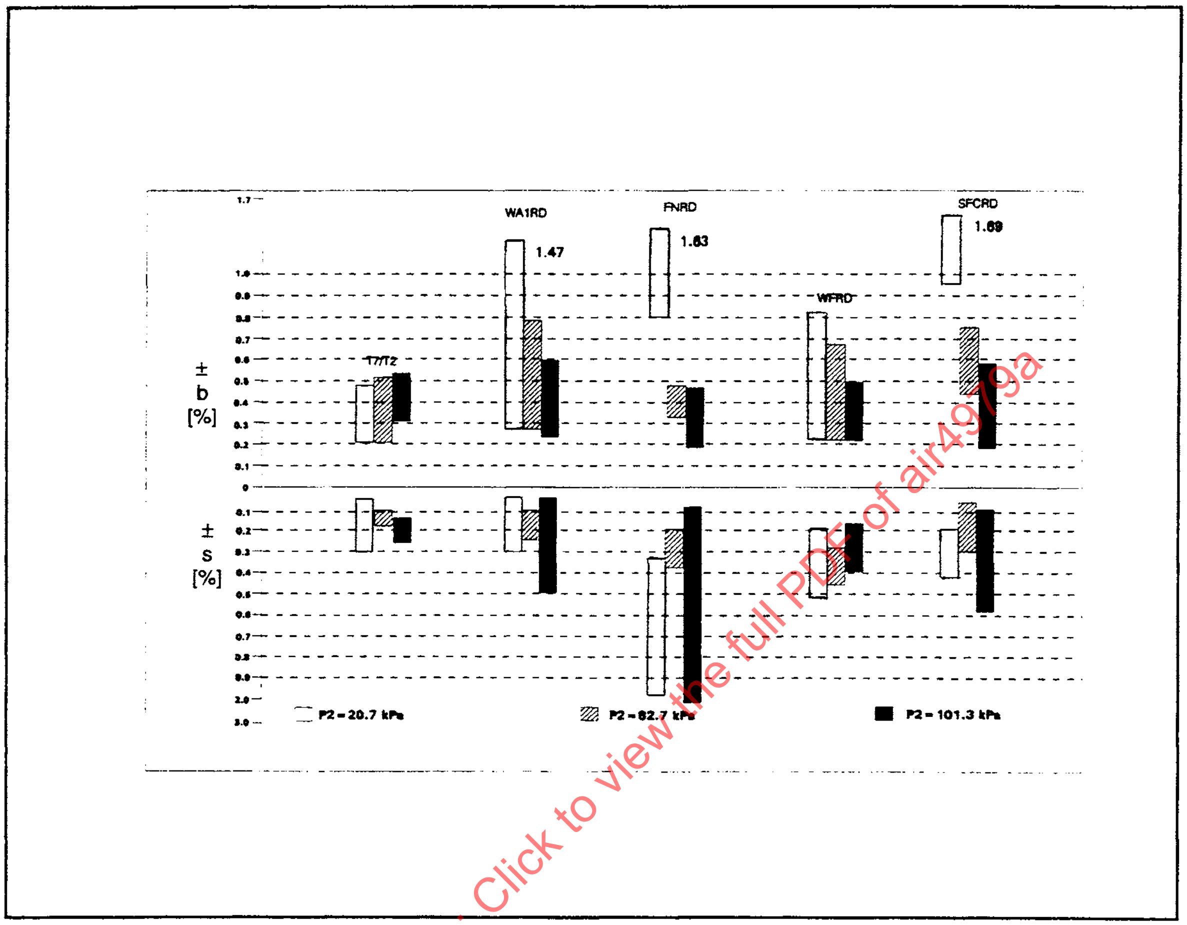


FIGURE 11 - Range of Facility Uncertainty Components for Performance Parameters at Three Test Conditions (P5/P2=2.1)

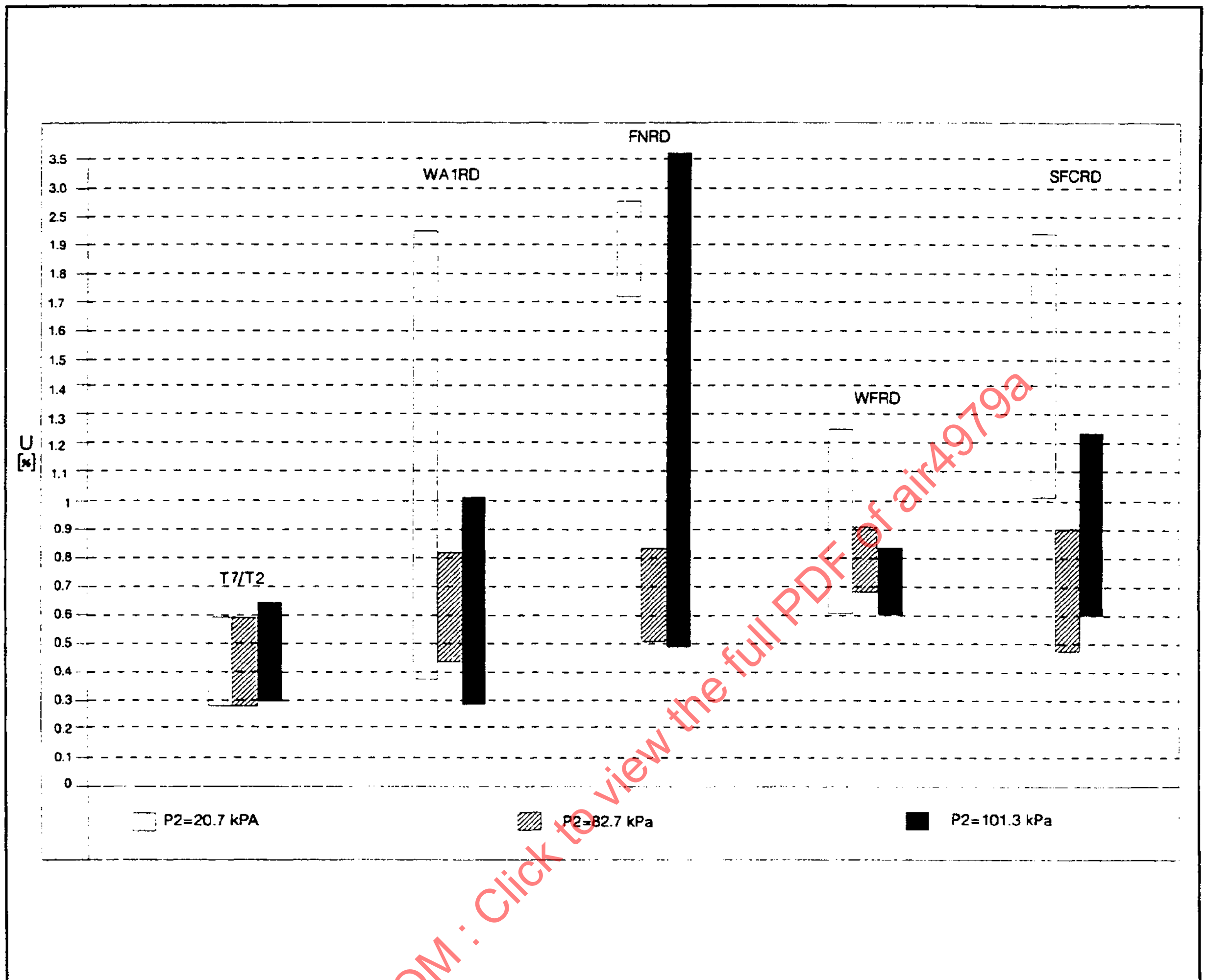


FIGURE 12 - Range of the Posttest Uncertainties for Performance Parameters at Three Test Conditions (P5/P2=2.1)

TABLE 6 - Range of Pre and Posttest Uncertainties for Performance Parameters at Three Test Conditions (P5Q2=2.1)

Performance Parameter	Range for Estimated Uncertainty (percent)	Range for Estimated Uncertainty (percent) P2=20.7 kPa	Range for Estimated Uncertainty (percent) P2=82.7 kPa	Range for Estimated Uncertainty (percent) P2=101.3 kPa
T7/T2	Pre	0.3 to 0.6	0.3 to 0.6	0.5 to 0.9
T7/T2	Post	0.3 to 0.6	0.3 to 0.6	0.3 to 0.7
WA1RD	Pre	0.8 to 2.6	0.6 to 0.8	0.3 to 0.7
WA1RD	Post	0.3 to 1.1	0.4 to 0.8	0.1 to 0.6
FNRD	Pre	1.6 to 3.2	0.5 to 1.2	0.5 to 0.6
FNRD	Post	1.7 to 2.7	0.5 to 0.8	0.5 to 4.4
WFRD	Pre	0.4 to 1.7	0.40 to 1.3	0.4 to 1.1
WFRD	Post	0.6 to 1.3	0.7 to 0.9	0.6 to 0.8
SFCRD	Pre	2.1 to 3.5	0.6 to 1.7	0.9 to 1.2
SFCRD	Post	1.1 to 2.1	0.5 to 0.9	0.6 to 1.2

7.4 (Continued):

The method consists of computing a corrected standard deviation (S_{corr}) as described in Section 6. Figure 13 shows an example of applying this method to the SFCR and P5Q2 parameter pairs. Similar plots for all other selected parameter pairs are included in Appendix E. Assuming that the grand mean ($\overline{Y}_c$) is the best representation of the true value, it would be reasonable to expect that individual facility estimates should encompass the grand mean. This desirable overlay occurred in 68% of the test condition 3 opportunities, 89% at condition 9, and 67% at condition 11.

It would be expected that other facilities using similar methods and comparable instrumentation produce results like those shown in the Figure 13, if no validation process was pursued.

The interfacility $2S_{corr}$ results for the various measured parameters are shown in Table 7. The $2S_{corr}$ parameter can be interpreted as the systematic uncertainty for testing in "world class" facilities using the process employed for the UETP test program. This process made use of local facility measurement practices for thrust, fuel flow, and airflow and did not provide for any "feedback" or validation process to check the results. No communication or cross-facility comparisons were allowed until the engine had run at all the facilities and the measurements completed.

The resulting $2S_{corr}$ systematic uncertainties are large (i.e., Thrust at a P5/P2 of 2.1 is 1.5 to 3.0%). The large inferred systematic uncertainty $2S_{corr}$ are a result of errors in the measurement process at any and all of the facilities. Typical program requirements for thrust and TSFC accuracy may be as low as ±1%. In order to reduce the systematic uncertainty to achieve required levels, the measurement process must be improved by finding and eliminating individual systematic sources and generally improving the state of the art of measurement and facility design.

7.4 (Continued):

The measurement process can be improved by introducing validation techniques whereby cross facility test results are compared with each other and systematic sources located and eliminated to reduce discrepancies (Roberts et al (Reference 2.1.4.21)). Results can be compared with independent wind tunnel measurements from sub-scale models (Roberts et al (Reference 2.1.1.5)) and even with airplane in-flight results. The validation techniques are documented in AIR1703 (Reference 2.1.1.2).

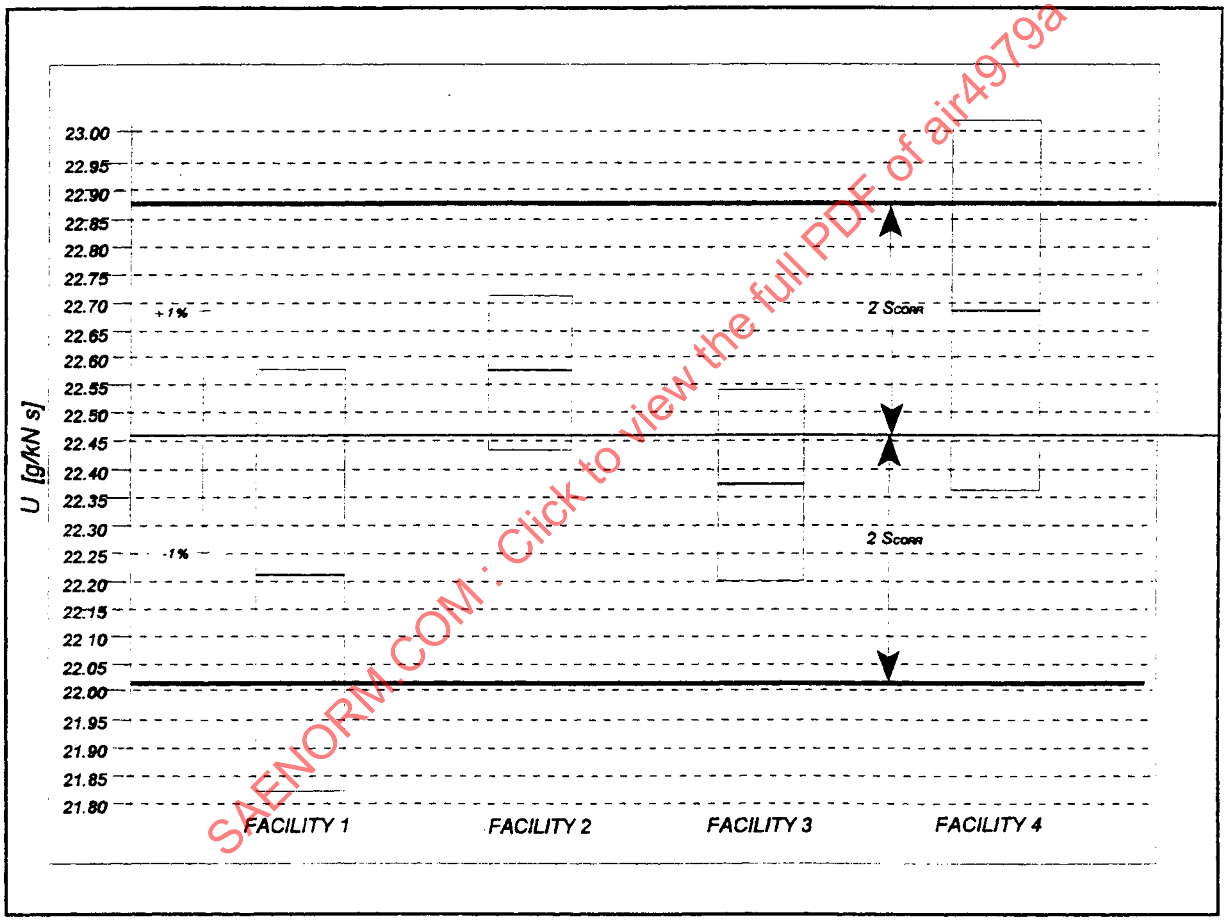


FIGURE 13 - Posttest Interfacility Uncertainty Comparison for Performance Parameter SFCR as a Function of P5Q2

TABLE 7 - $2S_{corr}$ Presented as a Percentage of $\overline{Y}_c$

	FNR Versus P5Q2	WFR Versus P5Q2	SFCR Versus P5Q2	SFCR Versus FNR	WA1R Versus NLR	WA1R Versus P5Q2	T7Q2 Versus P5Q2
Condition 3 Engine 594							
$\overline{Y}_c$	35.1	789.05	22.46	22.46	62.25	65.89	2.67
$2S_{corr}$	0.5088	18.4652	0.4358	0.4280	0.6518	1.0846	0.019
% of $\overline{Y}_c$	1.45	2.34	1.94	1.91	1.05	1.65	0.71
Condition 9 Engine 594							
$\overline{Y}_c$	5.09	170.51	33.53	33.41	12.14	12.31	2.84
$2S_{corr}$	0.1524	3.4524	0.6798	0.512	0.214	0.217	0.0256
% of $\overline{Y}_c$	2.99	2.02	2.03	1.53	1.76	1.76	1.04
Condition 11 Engine 037							
$\overline{Y}_c$	35.47	784.35	22.09	22.06	65.37	66.82	2.62
$2S_{corr}$	0.3692	10.6192	0.2458	0.243	1.2758	1.388	0.0386
% of $\overline{Y}_c$	1.95	1.35	1.11	1.10	1.95	2.08	1.47

8. CONCLUSIONS:

a. Comparisons of the UETP data illustrate the potentially large magnitude of systematic error between facilities.

b. The UETP exercise demonstrated that for interfacility comparisons, careful coordination and application of the uncertainty methodolgy is required. This includes the classification of error sources for a defined measurement process.

c. The systematic uncertainties are indicators of areas which may need improvement to meet specific test objectives.

d. The procedures outlined in this document can be used as a guide for estimating facility-to facility systematic uncertainties for checking the validity of pretest uncertainty estimates.

8. (Continued):

e. Most facility estimates encompassed the grand mean, indicating that the estimates were sufficiently large. However, the fact that the interfacility dispersions were larger than most of the facility uncertainty estimates, indicates that the pretest estimates were reasonable and not excessively large. (Cases where the facility estimates did not encompass the grand mean indicate the existence of unaccounted systematic errors.)

f. UETP data indicates that interfacility comparisons are required to validate the magnitude of uncertainty estimates. These comparisons must be used to eliminate biases that exceed customer requirements.

APPENDIX A
UNCERTAINTY/ERROR PROPAGATION

A.1 The term "error propagation" is widely used to represent an analysis to estimate the uncertainty in a calculated parameter caused by the uncertainty in the individual variables within the defining function. If the error in a measured variable is known, either correct for known error or simply calculate the effect of the various variable errors on the parameter through the defining function. This process propagates uncertainties not errors. The effect of propagation of variable uncertainties can be approximated by a first order Taylor series. The three variable general form is:

$$\sigma_Z^2 = \left(\frac{\partial Z}{\partial X}\right)^2 \sigma_X^2 + \left(\frac{\partial Z}{\partial Y}\right)^2 \sigma_Y^2 + \left(\frac{\partial Z}{\partial W}\right)^2 \sigma_W^2 + 2\left(\frac{\partial Z}{\partial X}\right)\left(\frac{\partial Z}{\partial Y}\right)\rho_{XY}\,\sigma_X\,\sigma_Y + 2\left(\frac{\partial Z}{\partial X}\right)\left(\frac{\partial Z}{\partial W}\right)\rho_{XW}\,\sigma_X\,\sigma_W + 2\left(\frac{\partial Z}{\partial Y}\right)\left(\frac{\partial Z}{\partial W}\right)\rho_{YW}\,\sigma_y\,\sigma_W \qquad \text{(Eq.A1)}$$

where:

ρ_{ij} = the correlation coefficient between uncertainties of variable i and j, where i and j represent combinations of x, y, and w.

The first step in performing any propagation estimate is to do an elemental uncertainty estimate for each variable. The recommended form of the elemental uncertainty table is:

TABLE A1 - Elemental Uncertainty Table for Variable - X

Source	Systematic	Random (s)	N	$s/\sqrt{N}$	df

A.1 (Continued):

where:

Source = an elemental error contributor to the variable x
Systematic = the systematic uncertainty component
Random (s) = the standard deviation of the data sample
N = the number of observations to be taken
$s/\sqrt{N}$ = the standard deviation of the sample mean
df = the degrees of freedom for the sample standard deviation (s), calculated as (n-1)
n = the number of observations in the sample standard deviation (s).

NOTE:

a. For a posttest uncertainty estimate N will equal n.

b. For a pretest uncertainty estimate N may not equal n. This is because in a pretest estimate the sample standard deviation must come from a population estimate prior to obtaining actual test data. The standard deviation might be from a previous data set or even the pooled variances of several previous data sets. Therefore, while n for the estimated population standard deviation may be 50, the number of planned observations to be taken during the test might only be 5. The observations could be multiple independent data points or possibly multiple sensors taking data in a single data point.

As an example, the effect of measured parameter uncertainties on calculated compressor efficiency will be computed. The problem will be solved three ways. First it will be assumed the variable uncertainties are independent; that is, all the correlation coefficients are equal to zero, the next solution will be for nonindependent variable uncertainties where the correlation coefficient must first be calculated, and finally the problem will be solved using a method that is applicable when using digital computers for estimating propagation uncertainties.

The equation for calculating compressor efficiency is:

$$\eta = \frac{\left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}{\left(\frac{T_2}{T_1}\right) - 1} \qquad \text{(Eq.A2)}$$

where:

TABLE A2

Parameters	Description	Nominal Value
P_1	inlet total pressure	14.7 psia
P_2	exit total pressure	95.5 psia
T_1	inlet total temperature	530.0 °R
T_2	exit total temperature	960.0 °R
γ	ratio of specific heats	a dimensionless constant set to 1.4

As an example, an Elemental Uncertainty Table for Compressor Exit Pressure (P_2), is given below.

TABLE A3

Source	Systematic	Random(s)	N	$s/\sqrt{N}$	df
source 1	1.05	2.19	5	0.98	21
source 2	1.34	3.16	9	1.05	30
source 3	1.24	2.93	10	0.93	12
source 4	0.52	1.23	3	0.71	40
source 5	0.50	1.63	20	0.36	20
source 6	0.32	0.76	2	0.53	25
source 7	0.84	4.17	15	1.08	60
RSS Totals:	2.40			2.23	>30

For P_2 the total elemental Systematic Uncertainty equals 2.4, the Standard Deviation of the Mean $S_{\bar{X}}$ equals 2.23 and using the Welch-Satterthwaite formula for combining degrees of freedom (df), the degrees of freedom for $S_{\bar{X}}$ is, in this example, greater than 30, t_{95}=2.0. For the Systematic component of Uncertainty, for simplicity, assume 30 degrees of freedom. See ISO Guide for greater analysis detail.

A similar Elemental Uncertainty Table will need to be completed for each variable: T_1, T_2, and P_1. This leads to ->

TABLE A4

Variable	Systematic	Standard Deviation of Mean, $S_{\bar{X}}$	Degrees of Freedom
P_1	2.0 psia	1.89 psia	>30
P_2	2.4 psia	2.23 psia	>30
T_1	1.6 °F	0.40 °F	>30
T_2	1.6 °F	0.70 °F	>30

So far none of the correlations between variables has been identified. This will be discussed further in the second example where the correlation coefficient is not considered equal to zero.

A.1 (Continued):

The partial derivatives for the compressor efficiency function are:

(Eq.A3)

$$\frac{\partial \eta}{\partial P_1} = \frac{-\left(\frac{\gamma - 1}{\gamma}\right)\left[\left(\frac{P_2}{P_1}\right)^{-\frac{1}{\gamma}}\left(\frac{P_2}{P_1^2}\right)\right]}{\left(\frac{T_2}{T_1}\right)-1}$$

$$= -0.04089$$

$$\frac{\partial \eta}{\partial P_2} = \frac{\left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{1}{P_1}\right)\left[\left(\frac{P_2}{P_1}\right)^{-\frac{1}{\gamma}}\right]}{\left(\frac{T_2}{T_1}\right)-1}$$

$$= 0.00629$$

$$\frac{\partial \eta}{\partial T_1} = \frac{T_2\left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}{(T_2 - T_1)^2}$$

$$= 0.00367$$

$$\frac{\partial \eta}{\partial T_2} = \frac{-T_1\left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}{(T_2 - T_1)^2}$$

$$= -0.00203$$

γ = assumed constant and known.

Substituting these values into Equation A1,

Systematic Uncertainty Component

$$B_\eta = [(2.0 \times (-0.04089))^2 + (2.4 \times 0.00629)^2 + (1.6 \times 0.00367)^2 + (1.6 \times (-0.00203))^2]^{0.5}$$
$$= 0.08343$$

A.1 (Continued):

Random Uncertainty Component

$$S_{\bar{x}_\eta} = [(1.89 \times (-0.04089))^2 + (2.23 \times 0.00629)^2 + (0.4 \times 0.00367)^2 + (0.7 \times (-0.00203))^2]^{0.5}$$
$$= 0.07857$$

Total Uncertainty

$$U_{95} = 2\sqrt{\left(\frac{B_\eta}{2}\right)^2 + (S_{\bar{x}_\eta})^2} \quad \text{(Eq.A4)}$$
$$= 2\sqrt{\left(\frac{0.08343}{2}\right)^2 + 0.07857^2}$$
$$= 0.17791$$

Next consider the case where, while the elemental systematic uncertainty sources (error sources) are independent, there are elemental systematic uncertainties that are common between variables. In this case, there are nonzero correlation coefficients. The correlation coefficient is defined as:

$$\rho_{X1,X2} = \frac{S_{X1,X2}}{(S_{X1})\,(S_{X2})} \quad \text{(Eq.A5)}$$

where:

S_{X1}, and S_{X2} = the Standard Deviations of variables X1 and X2.
$S_{(X1,X2)}$ = the covariance.

When the variables have common units and the error sources are 100% positively correlated then:

$$S_{X1,X2} = \sum_{i=1}^{L} (S_{X1})_i (S_{X2})_i \quad \text{(Eq.A6)}$$

where:

$(S_{X1})_i$ and $(S_{X2})_i$ = the elemental systematic uncertainties common to both variable X_1 and X_2.
L = number of correlated elemental error sources.

A.1 (Continued):

Now, from the previous problem, assume that the inlet pressure and exit pressure have common elemental systematic uncertainty sources 1 and 2, see the P_2 elemental table. From Equation A5,

$$\rho_{P_1,P_2} = \frac{((1.05)^2 + (1.34)^2)}{2.0 \times 2.4} = 0.6038 \quad \text{(Eq.A7)}$$

While highly unlikely that each temperature and pressure variable would have common elemental systematic uncertainty sources, for this example lets assume that they are correlated in some manner. Following the same methodology in calculating the covariance between variables P_1 and P_2.

TABLE A5

Covariance	Value	Note
$S_{P1,P2}$	2.898	$S_{P1,P2}=S_{P2,P1}$
$S_{P1,T1}$	0.49	$S_{P1,T1}=S_{T1,P1}$
$S_{P1,T2}$	0.16	$S_{P1,T2}=S_{T2,P1}$
$S_{P2,T1}$	0.36	$S_{P2,T1}=S_{T1,P2}$
$S_{P2,T2}$	0.25	$S_{P2,T2}=S_{T2,P2}$
$S_{T1,T2}$	0.64	$S_{T1,T2}=S_{T2,T1}$

Calculate the correlation coefficients,

$$\rho_{P_1,P_2} = \frac{2.898}{2.0 \times 2.4} = 0.6038 \quad \text{(Eq.A8)}$$

$$\rho_{P_1,T_1} = \frac{0.49}{2.0 \times 1.6} = 0.1531$$

$$\rho_{P_1,T_2} = \frac{0.16}{2.0 \times 1.6} = 0.0500$$

$$\rho_{P_2,T_1} = \frac{0.36}{2.4 \times 1.6} = 0.0938$$

A.1 (Continued):

$$\rho_{P_2,T_2} = \frac{0.25}{2.4 \times 1.6} = 0.6051$$

$$\rho_{T_1,T_2} = \frac{0.64}{1.6 \times 1.6} = 0.2500$$

Recalculate the Systematic Uncertainty Components,

B_η = $[(2.0 \times (-0.04089))^2 + (2.4 \times 0.00629)^2 + (1.6 \times 0.00367)^2 + (1.6 \times (-0.00203))^2 + 2(0.00367)$
$(-0.00203) \times 0.25 \times 1.6 \times 1.6 + 2(0.00629)(-0.00203) \times 0.0651 \times 2.4 \times 1.6$
$+ 2(0.00629)(0.00367) \times 0.0.0938 \times 2.4 \times 1.6$
$+ 2(-0.04089)(-0.00203) \times 0.05 \times 2.0 \times 1.6$
$+ 2(-0.04089)(0.00367) \times 0.1531 \times 2.0 \times 1.6$
$+ 2(-0.04089)(0.00629) \times 0.6038 \times 2.0 \times 2.4]^{0.5}$
= 0.074788

Total Uncertainty

(Eq.A9)

$$U_{95} = 2\sqrt{\left(\frac{B_{\eta S}}{2}\right)^2 + \left(S_{\bar{X}_\eta}\right)^2}$$

$$= 2\sqrt{\left(\frac{0.074788}{2}\right)^2 + 0.07857^2}$$

$$= 0.08701$$

Some uncertainty problems can not be handled analytically but instead must utilize a computer to propagate the variable uncertainties through the functional equation. Many computer programs are written to propagate the simple case where the variable uncertainties are independent as in the first example worked. However, there are methods to utilize these programs when the propagation problem includes correlated uncertainties. The approach is to substitute for the variables in the function variables that include the various correlated elemental systematic uncertainties.

A.1 (Continued):

If ($P_1 + b_1 + b_2 + \ldots b_i$) is substituted for P_1 into Equation A2 and likewise for the other variables, and $\left(S_{\bar{x}_\eta}\right)^2$ was calculated in accordance with Equation A1, taking the partial derivatives with respect to each variable and each elemental systematic uncertainty variable, the resulting Taylor Series will have correlation coefficients equal to zero, as in the first problem worked. This allows the use of simplified computer programs, designed for uncorrelated uncertainties, by making the above variable substitutions.

The numerical values of the variables P_1, P_2, T_1, T_2 will be equal to their nominal values and their propagated uncertainties are equal to the uncorrelated portion of the variable uncertainty, B. The elemental systematic uncertainty terms (b_i) have nominal value zero and propagated values equal to the individual elemental uncertainties.

APPENDIX B
SUMMARIES OF ELEMENTAL MEASUREMENT PROCESS COMPONENTS AND PRACTICES

B.1 This Appendix contains a summary of the components and practices that were utilized by each of the UETP participants. Components and practices are listed for pressure, temperature, speed, force and fuel flow measurements. In addition, systematic and random uncertainty values for each elemental measurement are also included. The uncertainty values listed in Tables B1 to B5 are based on the following representative parameter values:

a. P_2 - 99.2 kPa
b. P_7 - 186 kPa
c. T_2 - 289 K
d. T_3 - 572 K
e. T_5 - 718 K
f. T_7 - 718 K
g. NLR - 5280 rpm
h. NHR - 8900 rpm

TABLE B1 - Pressure Measurement Process Components and Practices

	Pressure Measurement Systems													
Components/Practices	NASA1		NASA2		AEDC			RAE(P)		CEPr			NAPC	NRCC
<u>Sensors</u>														
• Transducer Per Channel			X					X						
• Pneumatically Multiplexed	-		-		X					X			X	X
<u>Data Acquisition</u>														
• Absolute Transducer					X					X				
• Differential Transducer Plus Barometer	X		X					X		X				X
<u>Calibration</u>														
• In-place Dead Weights	X													
• In-place Pressure Generators			X		X			X		X				X
Test Conditions	3	9	3	9	3	9	11	3	9	3	9	11	11	11
Systematic Uncertainty [% rdg] Inlet Total Pressure (P2) Turbine Exit Pressure (P7)	0.07 0.05	0.27 0.20	0.07 0.34	0.26 1.36	0.7	1.1	0.7	0.14	0.36	0.20	0.14	0.02	0.03	0.09
Random Uncertainty[% rdg] Inlet Total Pressure (P2) Turbine Exit Pressure (P7)	0.01 0.01	0.05 0.04	0.01 0.02	0.05 0.08	0.15	0.26	0.15	0.0	0.01	0.12	0.09	0.10	0.12	0.05

TABLE B2 - Temperature Measurement Process Components and Practices

Components/Practices	NASA1		NASA2		AEDC			RAE(P)		CEPr			NAPC	NRCC
	Temperature Measurement Systems													
Sensors														
• Type K (chromel-alumel)	X		X					X		X			X	X
• Type T (inlet only)					X			X					X*	X
• Platinum Resistance Therm.										X				
Reference Junction														
• Ice Bath														X
• Electronic Ice Point								X		X				
• 338.7 K Heated Block	X		X		X									
• Uniform Temp. Reference					X								X	X
Data Acquisition														
• Multiplexer	X		X		X			X		X			X	X
• Preamplifier					X								X	X
• Analog/Digital Converter	X		X		X			X		X			X	X
• Digital computer	X		X		X			X		X			X	X
Data Reduction														
• NBS Polynomial	X		X		X									
• BS 1827:1952 Polynomial								X						
• Numerical Averaging	X		X		X			X						
• Number of Inlet Probes														
Calibration														
• Wire manufacturers spec.	X		X		X									X
• H_2O bath with glass thermometer								X						
• Millivolt insertion					X									X
Test Conditions	3	9	3	9	3	9	11	3	9	3	9	11	11	11
Systematic Uncertainty [% of RD]														
• Inlet air temperature	0.42	0.42	0.42	0.41	0.17	0.17	0.17	0.35	0.35		0.03	0.03		0.42
• Compressor inlet temperature	0.42	0 42	0.42	0.41	0.17	0.17	0.17	0.35	0.35		0.21		0.29	0.29
• T5 (Turbine exit temperature)					2.0•	2.0•								0.32
• T7 (Exhaust gas temperature)	0.30	0.30	0.30	0.27	2.0•	2.0•								0.32
• Fuel temperature								0.35	0.35		0.24	0.63		0.25
Random Uncertainty [% of RD]														
• Inlet air temperature	0.03	0.03	0.03	0.03	0.12	0.12	0.12	0	0.02		0	0		0.17
• Compressor inlet temperature	0.03	0.03	0.03	0.03	0.12	0.12	0.12	0	0.04		0.03		0.05	0.09
• T5 (Turbine exit temperature)					0.34•	0.34•								0.08
• T7 (Exhaust gas temperature)	0.01	0.01	0.01	0.01	0.34•	0.34•								0.08
• Fuel temperature								0	0		0.03	0.09		0.17

TABLE B3 - Speed Measurement Process Components and Practices

	Speed Measurement Systems													
	NASA1		NASA2		AEDC			RAE(P)		CEPr			NAPC	NRCC
<u>Sensors</u> • 60 Tooth Gear	X		X		X			X		X				X
<u>Signal Conditioning</u> • Pulse Shaper • Frequency/Analog	X		X		X			X						
<u>Data Acquisition</u> • Counter-Frequency/Digital • Analog/Digital Converter	X		X		X			X		X				X
Test Conditions	3	9	3	9	3	9	11	3	9	3	9	11	11	11
Systematic Uncertainty [% rdg]	0.015	0.015	0.015	0.015	0.2	0.2	0.2	0.02	0.02	0.06	0.06	0.06	0.07	0.07
Random Uncertainty [% rdg]	0	0	0	0	0.15	0.15	0.15	0.02	0.02				0.07	0

TABLE B4 - Force Measurement Process Components and Practices

Components/Practices	NASA1	NASA2	AEDC	RAE(P)	CEPr	NAPC	NRCC
	Force Measurement Systems						
Sensors							
• load cells	2	2	2	1	1	1	1
• Tension/Compression/Shear	-	-	T	Shear	T	-	C
• bed alignment	N	N	-	-	N	-	*
• no. bridge circuits	2	2	2	1	1	1	2
Data Acquisition							
• data sampling rate	1 Hz	2/3 Hz	50 Hz	-	24 samples	100 Hz	100 Hz
• time averaging period	20 s	30 s	-	-	-	-	1 TO 10 S
• real time calibration	-	-	-	-	-		-
Data Reduction							
• electronic cal. freq.	Per run	Per run	-	Per run	-	-	2
• calibration type							
- centreline	-	-	*				*
- in-frame	*	*	-	*		*	-
• record pre-post tare	-	-	-	-		-	Both
• calibration corrections							
- linearity, hysteresis, repeatability	*	*	*		*	-	*
- thermal effects	*	*	*		-	-	*
Calibrations							
• data system	-	-	Shunt	-	Special	-	*
• no. centreline	-	-	2	-	-	-	2
• no. in frame	B/F	B/F	-	Per test	Per test	-	-
• no. readouts/load cell	-	-	-		100	1	1000
• no. load cells	-	-	3	-	1	1	1
Test Conditions	3 / 9	3 / 9	3 / 9 / 11	3 / 9	3 / 9 / 11	11	11
Systematic Uncertainty [% rdg]	0.35 / 1.55	0.32 / 1.44	0.20 / 0.24 / 0.20	0.19 / 0.86	0.26 / 1.15 / 0.22	0.08	0.41
Random Uncertainty [% rdg]	0.18 / 0.78	0.19 / 0.75	0.15 / 0.18 / 0.15	0.06 / 0.25	0.06 / 0.27 / 0.12	0.05	0.06

"N" = Negligible "B/F" = Before and After "T" = Tension "C" = Compression
"*" = Considered in analysis.

TABLE B5 - Fuel Flow Measurement Process Components and Practices

Components/Practices	Fuel Flow Measurement Systems: NASA1	NASA2	AEDC	RAE(P)	CEPr	NAPC	NRCC
Sensors							
• Turbine Meters	X	X	X		X	X	X
• Positive Displacement				X			
• Dual Range	X	X	X		X		
Data Acquisition							
• Frequency/Analog/Digital			X				
• Frequency/Digital	X	X		X	X	X	X
Data Reduction Corrections							
• Specific Gravity	X	X	X	X	X	X	X
• Viscosity	X	X	X				X
• Temp. Effect on FM	X	X	X	X			X
• Lower Heating Value	X	X	X	X	X	X	X
Calibration							
• Standard-Volumetric			X			X	X
• Standard-Mass	X	X		X			
• Fluid-Water	X	X					
• Fluid-Fuel			X	X			X
Test Conditions	3 / 9	3 / 9	3 / 9 / 11	3 / 9	3 / 9 / 11	11	11
Systematic Uncertainty [% rdg]	0.61 / 0.62	0.56 / 0.61	0.4 / 0.4 / 0.4	0.12 / 0.28	0.2 / 0.2 / 0.2	0.25	0.38
Random Uncertainty [% rdg]	0.29 / 0.49	0.29 / 0.49	0.3 / 0.3 / 0.3	0.03 / 0.09	0.1 / 0.1 / 0.1	0.03	0.08

APPENDIX C
TABULAR PRESENTATION OF UETP PRETEST UNCERTAINTY RESULTS

C.1 This appendix gives a summary of the error components for each elemental measurement, the uncertainty components for performance parameters and the total uncertainty for performance parameters at three test conditions. The values have been compiled from the individual UETP participant facility reports and are based on the following representative measurements:

a. P_2 - 99.2 kPa
b. P_7 - 186 kPa
c. T_2 - 289 K
d. T_3 - 572 K
e. T_5 - 718 K
f. T_7 - 718 K
g. NLR - 5280 rpm
h. NHR - 8900 rpm
i. WAIR - 62.1 kg/s
j. SFCR - 22.3 g/kN·s
k. FN - 29.8 kN
l. WFR - 680 g/s
m. NLQNH - 0.59
n. P_7/P_2 - 1.85
o. T_7/T_2 - 2.49

TABLE C1 - The Range of Facility Error Components for Elemental Measurements for Three Test Conditions

Measurement	Range of Uncertainty (bias, percent) (precision, percent) P2=20.7 kPa	Range of Uncertainty (bias, percent) (precision, percent) P2=82.7 kPa	Range of Uncertainty (bias, percent) (precision, percent) P2=101.3 kPa
Speed	0.014 to 0.2	0.014 to 0.2	0.056 to 0.20
Speed	0 to 0.15	0 to 0.15	0 to 0.15
Pressure (P2)	0.14 to 1.1	0.066 to 0.70	0.09 to 0.70
Pressure (P2)	0.015 to 0.26	0.004 to 0.15	0.05 to 0.15
Temperature (T2)	0.17 to 0.42	0.17 to 0.42	0.17 to 0.42
Temperature (T2)	0.031 to 0.12	0.031 to 0.12	0.048 to 0.09
Fuel Flow	0.20 to 0.61	0.12 to 0.62	0.25 to 0.40
Fuel Flow	0.092 to 0.49	0.027 to 0.30	0.033 to 0.30
Scale Force	0.24 to 1.55	0.2 to 0.35	0.08 to 0.41
Scale Force	0.18 to 0.78	0.056 to 0.19	0.05 to 0.15

TABLE C2 - The Range of Facility Uncertainty Components for Performance Parameters for Three Test Conditions

Performance Parameter	Range for Uncertainty Components (bias, percent) (precision, percent) P2=20.7 kPa	Range for Uncertainty Components (bias, percent) (precision, percent) P2=82.7 kPa	Range for Uncertainty Components (bias, percent) (precision, percent) P2=101.3 kPa
NL/NH	0.02 to 0.28	0.02 to 0.28	0.01 to 0.28
NL/NH	0 to 0.21	0 to 0.21	0 to 0.21
NHRD	0.11 to 0.22	0.11 to 0.22	0.22 to 0.23
NHRD	0.02 to 0.16	0.02 to 0.16	0.05 to 0.16
T7/T2	0.21 to 0.49	0.21 to 0.51	0.31 to 0.53
T7/T2	0.03 to 0.13	0.03 to 0.13	0.08 to 0.19
P7/P2	0.28 to 0.57	0.08 to 0.38	0.02 to 0.28
P7/P2	0.06 to 0.24	0.02 to 0.21	0.03 to 0.21
NLRD	0.11 to 0.22	0.11 to 0.22	0.22 to 0.23
NLRD	0.02 to 0.16	0.02 to 0.16	0.05 to 0.16
WA1RD	0.28 to 1.47	0.28 to 0.79	0.24 to 0.60
WA1RD	0.07 to 0.55	0.03 to 0.23	0.03 to 0.23
FNRD	0.80 to 1.63	0.33 to 0.48	0.19 to 0.47
FNRD	0.30 to 0.78	0.05 to 0.35	0.10 to 0.35
WFRD	0.21 to 0.81	0.21 to 0.67	0.21 to 0.49
WFRD	0.08 to 0.50	0.03 to 0.38	0.11 to 0.38
SFCRD	0.96 to 1.69	0.43 to 0.75	0.28 to 0.68
SFCRD	0.31 to 0.91	0.06 to 0.53	0.14 to 0.52

TABLE C3 - The Range of Facility Uncertainties for Performance Parameters for Three Test Conditions

Performance Parameter	Uncertainty Range (percent) P2=20.7 kPa	Uncertainty Range (percent) P2=82.7 kPa	Uncertainty Range (percent) P2=101.3 kPa
NL/NH	0.02 to 0.7	0.02 to 0.7	0.1 to 0.8
NHRD	0.2 to 0.5	0.2 to 0.5	0.4 to 0.7
T7/T2	0.3 to 0.6	0.3 to 0.6	0.5 to 0.9
P7/P2	0.5 to 1.1	0.1 to 0.7	0.2 to 0.3
NLRD	0.2 to 0.5	0.2 to 0.5	0.4 to 0.7
WA1RD	0.8 to 2.6	0.6 to 0.8	0.3 to 0.7
FNRD	1.6 to 3.2	0.5 to 1.2	0.5 to 0.6
WFRD	0.4 to 1.7	0.4 to 1.3	0.4 to 1.1
SFCRD	2.1 to 3.5	0.6 to 1.7	0.9 to 1.2

APPENDIX D
PLOTS OF UETP TEST DATA AND STATISTICAL ANALYSIS RESULTS

Dependent Variable (WA1R)												
Independent Variable (P5/P2)												
Facility	AEDC04 (N = 16)			RAE (P) (N = 8)			CEPr (N = 16)			NASA2 (N = 18)		
P5/P2	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4
FNR	23.22	34.91	43.57	23.37	35.04	43.57	23.58	35.48	43.78	23.29	34.99	43.8
SEE	0.0781			0.0674			0.1315			0.0699		
Degrees of Freedom	13			5			13			15		

Number of Facilities	4		
Degree of Polynomial	2		
$\overline{N}$	14		
Levels of Independent Variable	1.7	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	23.36	35.10	43.69
MAX of Dependent Variable at each level	23.58	35.48	43.85
MIN of Dependent Variable at each level	23.22	34.91	43.57
Range (MAX - MIN)	0.36	0.57	0.28
Range as a % of Dependent Variable at each level	1.54	1.62	0.64
Dependent Variable Standard Deviation at each level (S)	0.1559	0.2557	0.1443
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0933		
$S_p / \sqrt{\overline{N}}$	0.0249		
Corrected S (S_{Corr})	0.1539	0.2544	0.1421
2 [S_{Corr}] as a % of the Dependent Variable	1.32	1.45	0.65

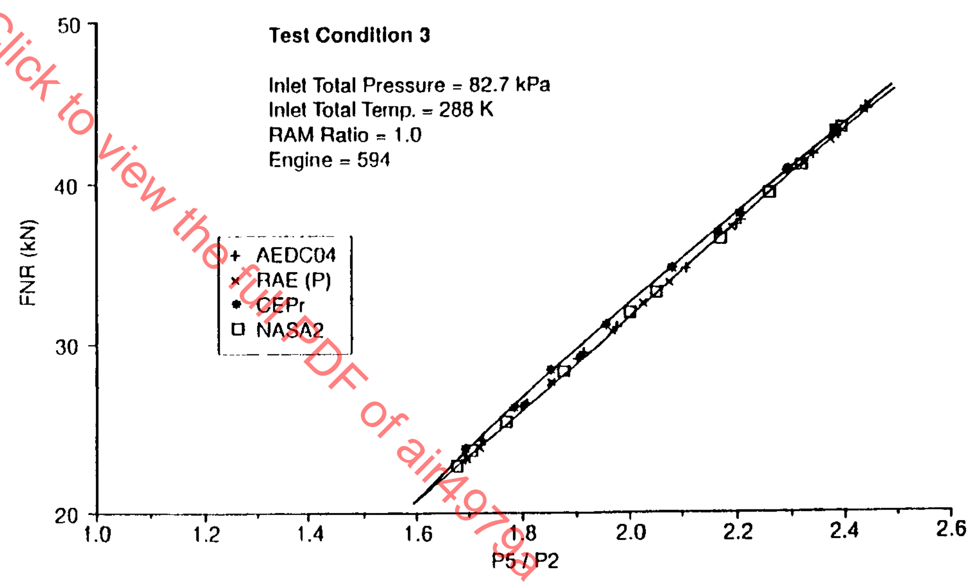


FIGURE D1 - Corrected Net Thrust Versus Engine Pressure Ratio

Dependent Variable (SFCR)												
Independent Variable (FNR)												
Facility	AEDC04 (N = 16)			RAE (P) (N = 8)			CEPr (N = 16)			NASA2 (N = 18)		
FNR	23.0	35.0	45.0	23.0	35.0	45.0	23.0	35.0	45.0	23.0	35.0	45.0
SFCR	22.61	22.21	22.67	22.97	22.58	23.11	22.76	22.37	22.83	23.17	22.69	23.0
SEE	.0203			0.0133			0.0643			0.0602		
Degrees of Freedom	13			5			13			15		

Number of Facilities	4		
Degree of Polynomial	2		
$\overline{N}$	14		
Levels of Independent Variable	23.0	35.0	45.0
Dependent Variable avg. at each level calculated from equation of line through each facility	22.88	22.46	22.92
MAX of Dependent Variable at each level	23.17	22.69	23.11
MIN of Dependent Variable at each level	22.61	22.21	22.67
Range (MAX - MIN)	0.56	0.48	0.44
Range as a % of Dependent Variable at each level	2.44	2.14	1.92
Dependent Variable Standard Deviation at each level (S)	0.2446	0.2144	0.2100
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0499		
$S_p / \sqrt{N}$	0.0133		
Corrected S (S_{Corr})	0.2442	0.2140	0.2096
2 [S_{Corr}] as a % of the Dependent Variable	2.14	1.91	1.83

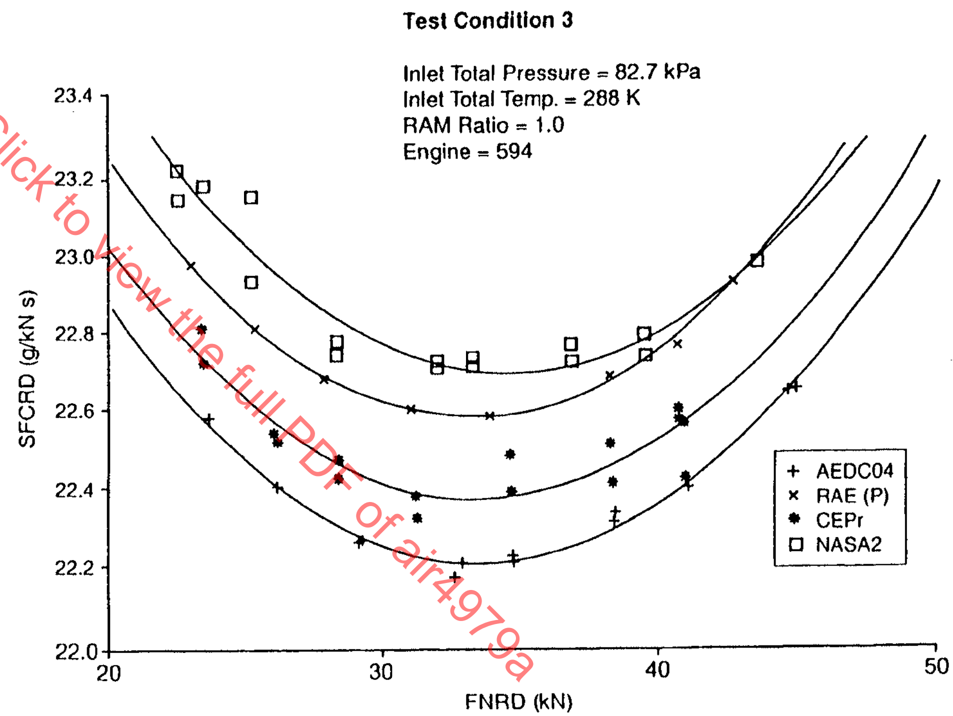


FIGURE D2 - Corrected Specific Fuel Consumption Versus Corrected Net Thrust

Dependent Variable (WA1R)												
Independent Variable (NLR)												
Facility	AEDC04 (N = 16)			RAE (P) (N = 8)			CEPr (N = 16)			NASA2 (N = 18)		
NLR	4900	5300	5800	4900	5300	5800	4900	5300	5800	4900	5300	5800
WA1R	54.39	62.60	72.47	53.77	61.82	72.05	54.66	62.37	72.52	54.09	62.21	72.4
SEE	0.0988			0.1624			0.1476			0.1773		
Degrees of Freedom	13			5			13			15		

Number of Facilities	4		
Degree of Polynomial	2		
$\overline{N}$	14		
Levels of Independent Variable	4900	5300	5800
Dependent Variable avg. at each level calculated from equation of line through each facility	54.23	62.25	72.37
MAX of Dependent Variable at each level	54.66	62.60	72.52
MIN of Dependent Variable at each level	53.77	61.82	72.05
Range (MAX - MIN)	0.89	0.78	0.47
Range as a % of Dependent Variable at each level	1.64	1.26	0.64
Dependent Variable Standard Deviation at each level (S)	0.3837	0.3283	0.2148
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1484		
$S_p / \sqrt{N}$	0.0397		
Corrected S (S_{Corr})	0.3816	0.3259	0.2111
2 [S_{Corr}] as a % of the Dependent Variable	1.41	1.05	0.58

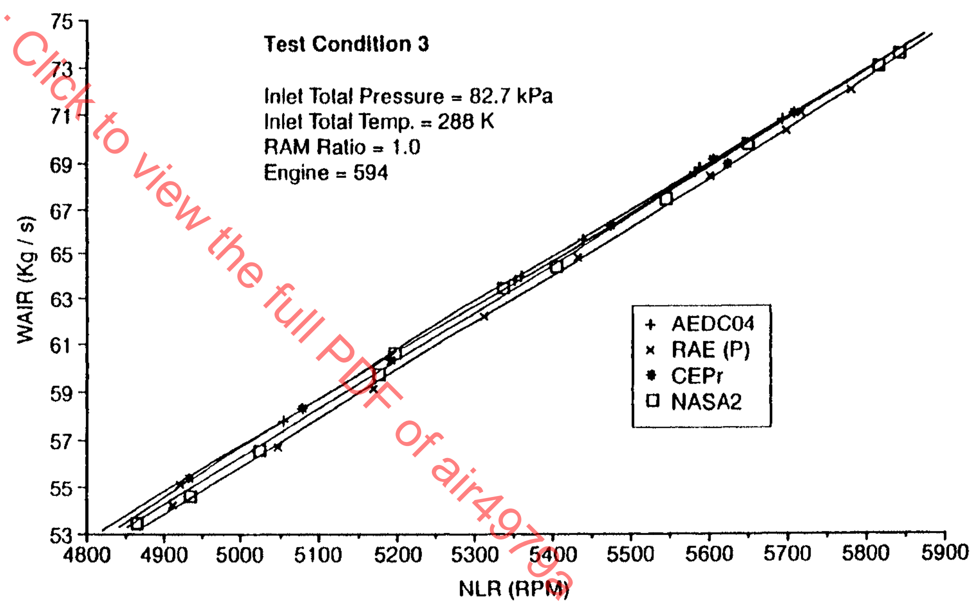


FIGURE D3 - Corrected Engine Airflow Versus Corrected Low Pressure Compressor Speed

Dependent Variable (WA1R)												
Independent Variable (P5/P2)												
Facility	AEDC04 (N = 16)			RAE (P) (N = 8)			CEPr (N = 16)			NASA2 (N = 18)		
P5/P2	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4
WA1R	54.54	65.53	72.32	54.59	65.57	72.20	55.50	66.69	72.69	54.58	65.77	72.8
SEE	0.1075			0.0638			0.1634			0.1627		
Degrees of Freedom	13			5			13			15		

Number of Facilities	4		
Degree of Polynomial	2		
$\overline{N}$	14		
Levels of Independent Variable	1.7	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	54.80	65.89	72.52
MAX of Dependent Variable at each level	55.50	66.69	72.89
MIN of Dependent Variable at each level	54.54	65.53	72.20
Range (MAX - MIN)	0.96	1.16	0.69
Range as a % of Dependent Variable at each level	1.76	1.76	0.96
Dependent Variable Standard Deviation at each level (S)	0.4655	0.5436	0.3205
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1410		
$S_p / \sqrt{\overline{N}}$	0.0377		
Corrected S (S_{Corr})	0.4640	0.5423	0.3182
2 [S_{Corr}] as a % of the Dependent Variable	1.69	1.65	0.88

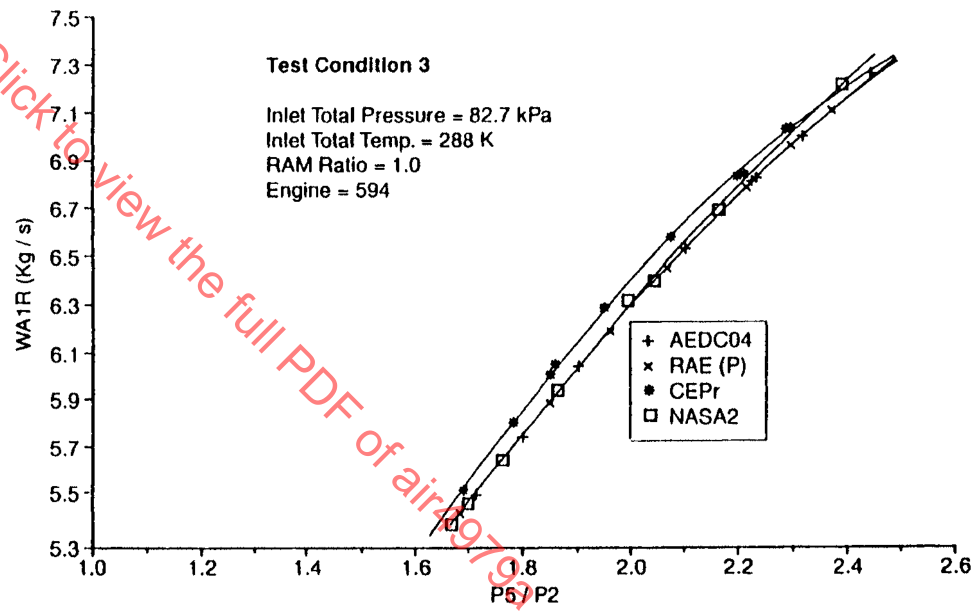


FIGURE D4 - Corrected Engine Airflow Versus Engine Pressure Ratio

Dependent Variable (T7/T2)												
Independent Variable (P5/P2)												
Facility	AEDC04 (N = 16)			RAE (P) (N = 8)			CEPr (N = 16)			NASA2 (N = 18)		
P5/P2	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4
T7/T2	2.37	2.66	2.87	2.39	2.68	2.90	2.39	2.68	2.89	2.38	2.67	2.89
SEE	0.00303			0.00268			0.0050			0.0040		
Degrees of Freedom	14			6			14			16		

Number of Facilities	4		
Degree of Polynomial	1		
$\overline{N}$	14		
Levels of Independent Variable	1.7	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	2.38	2.67	2.89
MAX of Dependent Variable at each level	2.39	2.68	2.90
MIN of Dependent Variable at each level	2.37	2.66	2.87
Range (MAX - MIN)	0.02	0.02	0.03
Range as a % of Dependent Variable at each level	0.84	0.74	1.04
Dependent Variable Standard Deviation at each level (S)	0.0096	0.0096	0.0126
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0039		
$S_p / \sqrt{N}$	0.0011		
Corrected S (S_{Corr})	0.0095	0.0095	0.0125
2 [S_{Corr}] as a % of the Dependent Variable	0.80	0.71	0.87

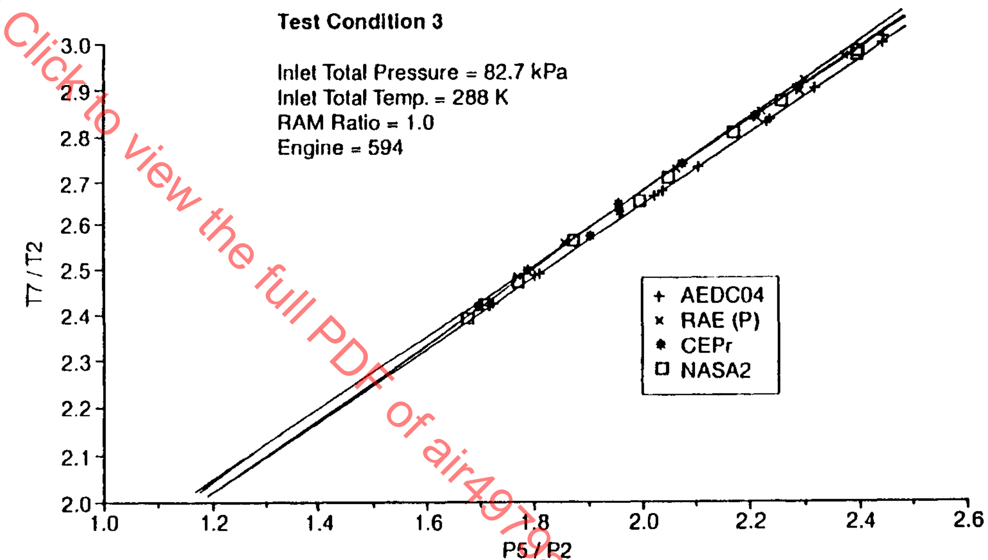


FIGURE D5 - Engine Temperature Ratio Versus Engine Pressure Ratio

Dependent Variable (SFCR)												
Independent Variable (P5/P2)												
Facility	AEDC04 (N = 16)			RAE (P) (N = 8)			CEPr (N = 16)			NASA2 (N = 18)		
P5/P2	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4
SFCR	22.59	22.20	22.56	22.94	22.58	22.99	22.71	22.37	22.76	23.15	22.69	23.0
SEE	0.02133			0.01495			0.0672			0.0603		
Degrees of Freedom	13			5			13			15		

Number of Facilities	4		
Degree of Polynomial	2		
$\overline{N}$	14		
Levels of Independent Variable	1.7	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	22.85	22.46	22.83
MAX of Dependent Variable at each level	23.15	22.69	23.00
MIN of Dependent Variable at each level	22.59	22.20	22.56
Range (MAX - MIN)	0.56	0.49	0.44
Range as a % of Dependent Variable at each level	2.46	2.18	1.92
Dependent Variable Standard Deviation at each level (S)	0.2485	0.2183	0.2100
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0511		
$S_p / \sqrt{\overline{N}}$	0.0137		
Corrected S (S_{Corr})	0.2481	0.2179	0.2095
2 [S_{Corr}] as a % of the Dependent Variable	2.17	1.94	1.84

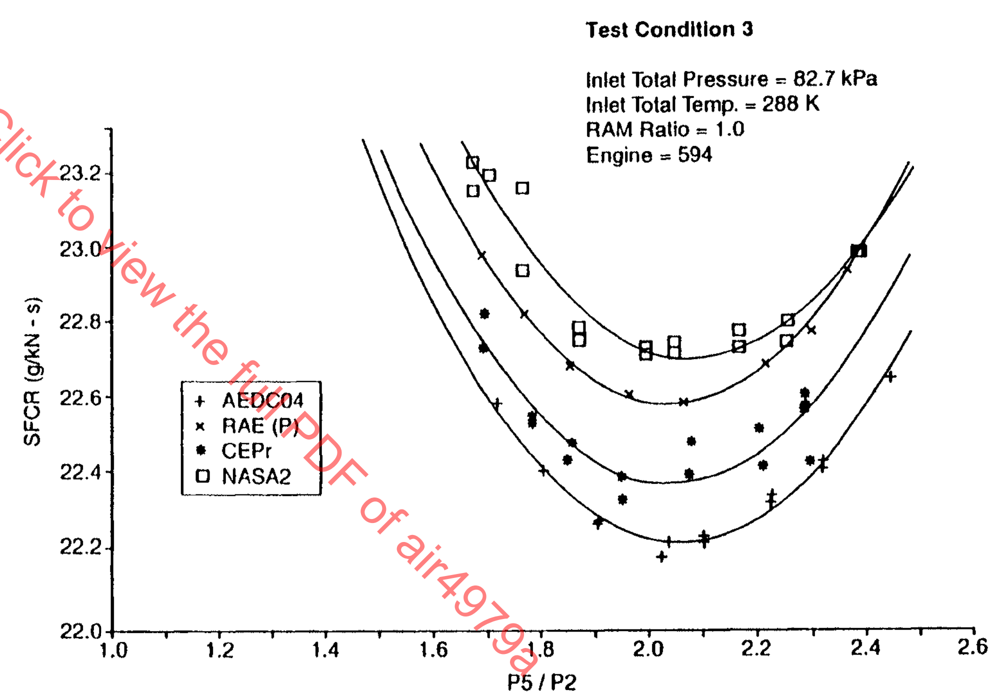


FIGURE D6 - Corrected Specific Fuel Consumption Versus Engine Pressure Ratio

Dependent Variable (WFR)												
Independent Variable (P5/P2)												
Facility	AEDC04 (N = 16)			RAE (P) (N = 8)			CEPr (N = 16)			NASA2 (N = 18)		
P5/P2	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4	1.7	2.1	2.4
WFR	525.84	775.29	982.73	536.79	791.83	999.87	535.74	794.46	992.60	539.30	794.61	1007.2
SEE	2.0774			2.2930			3.4830			2.4154		
Degrees of Freedom	13			5			13			15		

Number of Facilities	4		
Degree of Polynomial	2		
$\overline{N}$	14		
Levels of Independent Variable	1.7	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	534.42	789.05	995.61
MAX of Dependent Variable at each level	539.30	794.61	1007.24
MIN of Dependent Variable at each level	525.84	775.29	982.73
Range (MAX - MIN)	13.46	19.32	24.51
Range as a % of Dependent Variable at each level	2.52	2.44	2.46
Dependent Variable Standard Deviation at each level (S)	5.9101	9.2601	10.4620
Pooled Std. Error of est. (for equations through each facility) (S_p)	2.6687		
$S_p / \sqrt{\overline{N}}$	0.7132		
Corrected S (S_{Corr})	5.8669	9.2326	10.4376
2 [S_{Corr}] as a % of the Dependent Variable	2.20	2.34	2.10

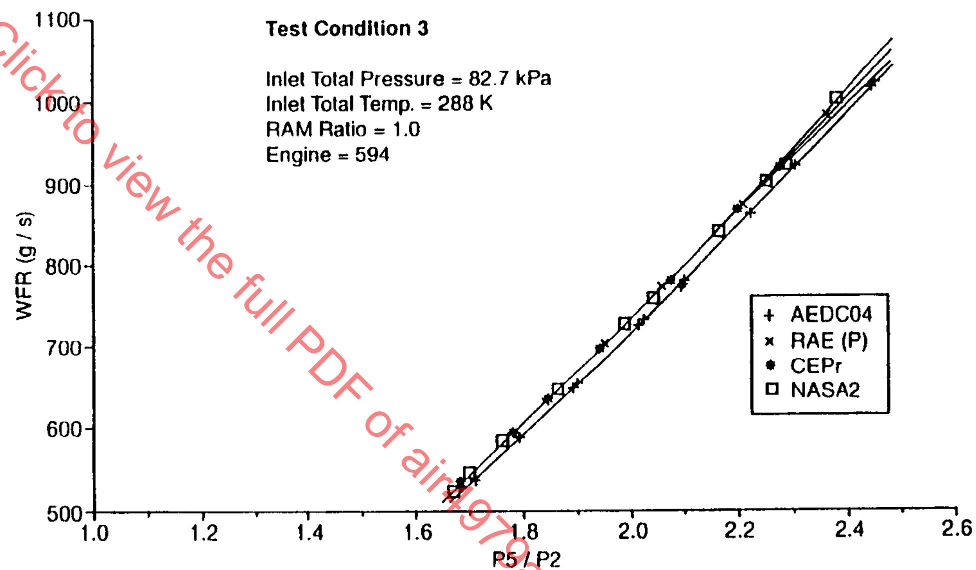


FIGURE D7 - Corrected Engine Fuel Flow Versus Engine Pressure Ratio

Dependent Variable (WA1R)															
Independent Variable (P5/P2)															
Facility	AEDC05 (N = 19)			RAE (P) (N = 17)			CEPr (N = 18)			NASA1 (N = 18)			NASA2 (N = 17)		
P5/P2	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3
FNRD	3.08	5.02	6.48	3.15	5.05	6.48	3.18	5.10	6.55	3.14	5.08	6.54	3.29	5.22	6.67
SEE	0.0635			0.0198			0.0346			0.0161			0.0192		
Degrees of Freedom	17			15			16			16			15		

Number of Facilities	5		
Degree of Polynomial	1		
$\overline{N}$	18		
Levels of Independent Variable	1.6	2.0	2.3
Dependent Variable avg. at each level calculated from equation of line through each facility	3.17	5.09	6.54
MAX of Dependent Variable at each level	3.29	5.22	6.67
MIN of Dependent Variable at each level	3.08	5.02	6.48
Range (MAX - MIN)	0.21	0.20	0.19
Range as a % of Dependent Variable at each level	6.62	3.92	2.90
Dependent Variable Standard Deviation at each level (S)	0.0773	0.0767	0.0777
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0362		
$S_p / \sqrt{N}$	0.0085		
Corrected S (S_{Corr})	0.0768	0.0762	0.0772
2 [S_{Corr}] as a % of the Dependent Variable	4.85	2.99	2.36

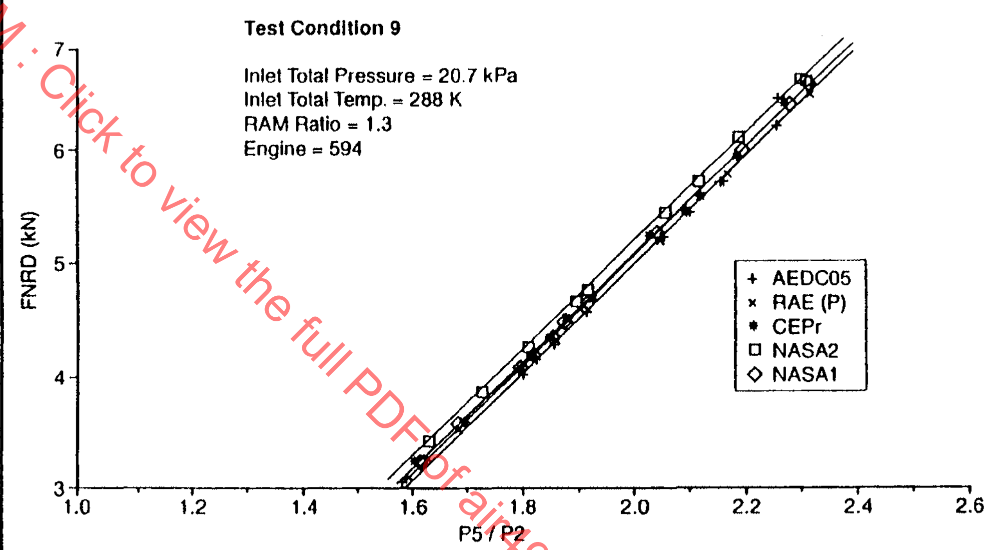


FIGURE D8 - Corrected Net Thrust Versus Engine Pressure Ratio

Dependent Variable (SFCRD)															
Independent Variable (FNRD)															
Facility	AEDC05 (N = 18)			RAE (P) (N = 17)			CEPr (N = 18)			NASA1 (N = 18)			NASA2 (N = 17)		
FNRD	3.1	5.2	6.5	3.1	5.2	6.5	3.1	5.2	6.5	3.1	5.2	6.5	3.1	5.2	6.5
SFCRD	38.50	33.83	32.66	37.35	33.23	32.46	37.16	33.32	32.47	38.60	33.48	32.63	37.73	33.20	32.51
SEE	0.06985			0.0794			0.21519			0.05787			0.14764		
Degrees of Freedom	14			13			14			14			13		

Number of Facilities	5		
Degree of Polynomial	3		
$\overline{N}$	18		
Levels of Independent Variable	3.1	5.2	6.5
Dependent Variable avg. at each level calculated from equation of line through each facility	37.87	33.41	32.55
MAX of Dependent Variable at each level	38.60	33.83	32.66
MIN of Dependent Variable at each level	37.16	33.20	32.46
Range (MAX - MIN)	1.44	0.63	0.20
Range as a % of Dependent Variable at each level	3.80	1.88	0.62
Dependent Variable Standard Deviation at each level (S)	0.6565	0.2578	0.0929
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1288		
$S_p / \sqrt{\overline{N}}$	0.0304		
Corrected S (S_{Corr})	0.6558	0.2560	0.0878
2 [S_{Corr}] as a % of the Dependent Variable	3.46	1.53	0.54

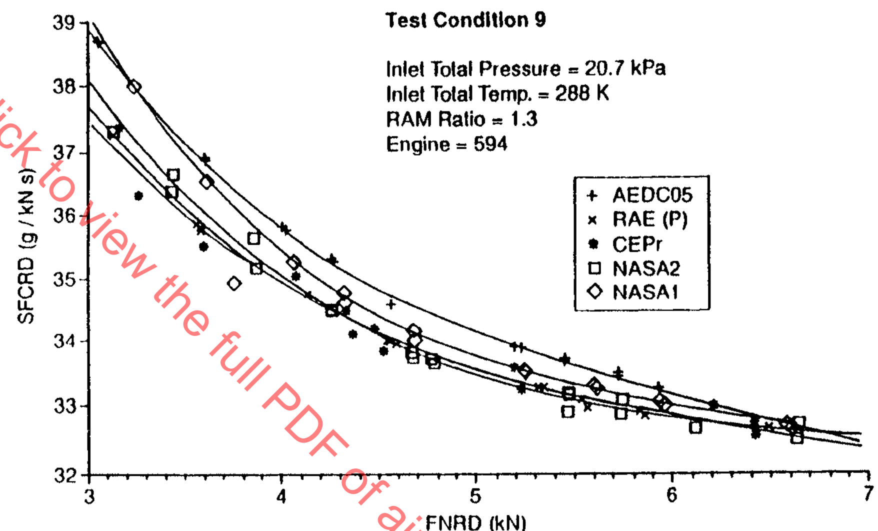


FIGURE D9 - Corrected Specific Fuel Consumption Versus Corrected Net Thrust

Dependent Variable (WA1RD)															
Independent Variable (NLRD)															
Facility	AEDC05 (N = 19)			RAE (P) (N = 17)			CEPr (N = 18)			NASA1 (N = 18)			NASA2 (N = 17)		
NLRD	5000	5400	5700	5000	5400	5700	5000	5400	5700	5000	5400	5700	5000	5400	5700
WA1RD	10.24	12.06	13.42	10.29	12.07	13.40	10.30	12.08	13.42	10.49	12.31	13.68	10.35	12.19	13.5
SEE	0.0169			0.0260			0.0586			0.0284			0.0719		
Degrees of Freedom	17			15			16			16			15		

Number of Facilities	5		
Degree of Polynomial	1		
$\overline{N}$	18		
Levels of Independent Variable	5000	5400	5700
Dependent Variable avg. at each level calculated from equation of line through each facility	10.33	12.14	13.50
MAX of Dependent Variable at each level	10.49	12.31	13.68
MIN of Dependent Variable at each level	10.24	12.06	13.40
Range (MAX - MIN)	0.25	0.25	0.28
Range as a % of Dependent Variable at each level	2.42	2.06	2.08
Dependent Variable Standard Deviation at each level (S)	0.0956	0.1076	0.1226
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0451		
$S_p / \sqrt{\overline{N}}$	0.0106		
Corrected S (S_{Corr})	0.0950	0.1070	0.1221
2 [S_{Corr}] as a % of the Dependent Variable	1.84	1.76	1.81

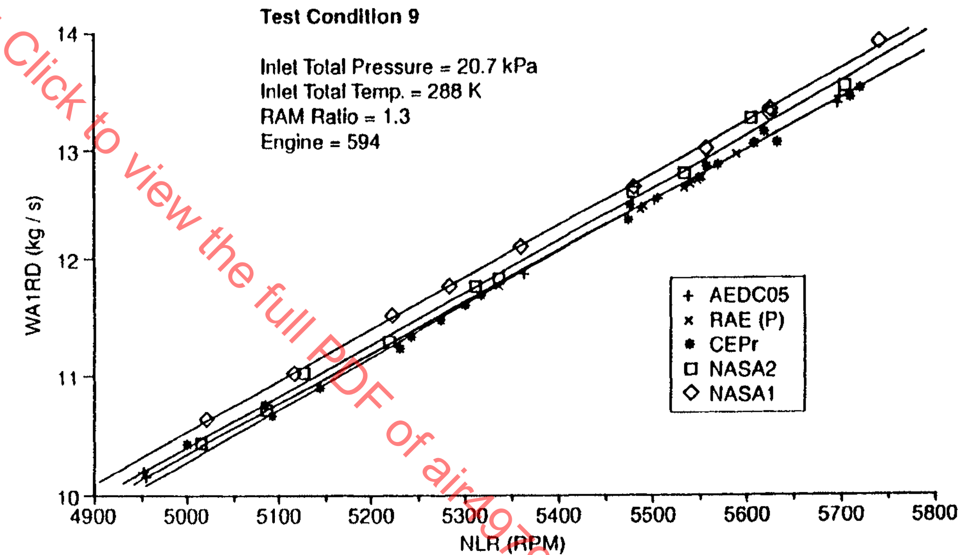


FIGURE D10 - Corrected Engine Airflow Versus Corrected Low Pressure Compressor Speed

Dependent Variable (WA1RD)					
Independent Variable (P5/P2)					
Facility	AEDC05 (N = 19)	RAE (P) (N = 17)	CEPr (N = 18)	NASA1 (N = 18)	NASA2 (N = 17)
P5/P2	1.6 2.0 2.3	1.6 2.0 2.3	1.6 2.0 2.3	1.6 2.0 2.3	1.6 2.0 2.3
WA1RD	10.34 12.30 13.63	10.22 12.18 13.49	10.30 12.27 13.62	10.55 12.48 13.85	10.27 12.31 13.5
SEE	0.0171	0.0171	0.0482	0.0196	0.0780
Degrees of Freedom	16	14	15	15	14

Number of Facilities	5		
Degree of Polynomial	2		
$\overline{N}$	18		
Levels of Independent Variable	1.6	2.0	2.3
Dependent Variable avg. at each level calculated from equation of line through each facility	10.34	12.31	13.64
MAX of Dependent Variable at each level	10.55	12.48	13.85
MIN of Dependent Variable at each level	10.22	12.18	13.49
Range (MAX - MIN)	0.33	0.30	0.36
Range as a % of Dependent Variable at each level	3.20	2.44	2.64
Dependent Variable Standard Deviation at each level (S)	0.1274	0.1089	0.1318
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0426		
$S_p / \sqrt{N}$	0.0101		
Corrected S (S_{Corr})	0.1270	0.1085	0.1314
2 [S_{Corr}] as a % of the Dependent Variable	2.46	1.76	1.93

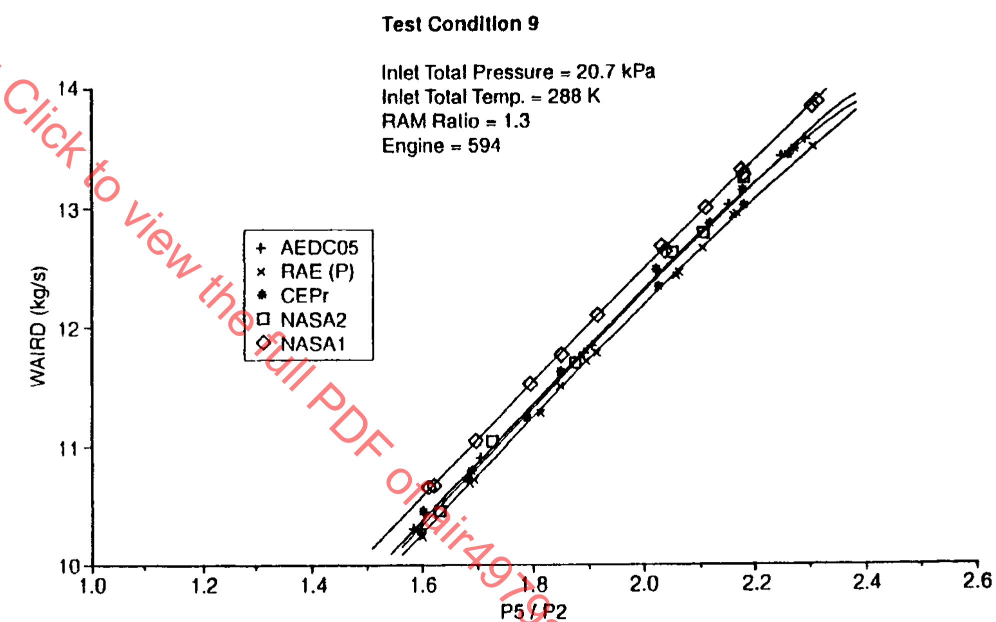


FIGURE D11 - Corrected Engine Airflow Versus Engine Pressure Ratio

Dependent Variable (T7/T2)

Independent Variable (P5/P2)

Facility	AEDC05 (N = 18)			RAE (P) (N = 17)			CEPr (N = 18)			NASA1 (N = 18)			NASA2 (N = 17)		
P5/P2	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3
T7/T2	2.56	2.86	3.07	2.53	2.85	3.06	2.51	2.82	3.03	2.54	2.84	3.06	2.53	2.84	3.05
SEE	0.00205			0.0027			0.0085			0.0085			0.0013		
Degrees of Freedom	15			14			15			15			14		

Number of Facilities	5		
Degree of Polynomial	2		
$\overline{N}$	18		
Levels of Independent Variable	1.6	2.0	2.3
Dependent Variable avg. at each level calculated from equation of line through each facility	2.53	2.84	3.05
MAX of Dependent Variable at each level	2.56	2.86	3.07
MIN of Dependent Variable at each level	2.51	2.82	3.03
Range (MAX - MIN)	0.05	0.04	0.04
Range as a % of Dependent Variable at each level	1.98	1.40	1.30
Dependent Variable Standard Deviation at each level (S)	0.0182	0.0148	0.0152
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0044		
$S_p / \sqrt{\overline{N}}$	0.0010		
Corrected S (S_{Corr})	0.0181	0.0148	0.0151
2 [S_{Corr}] as a % of the Dependent Variable	1.43	1.04	0.99

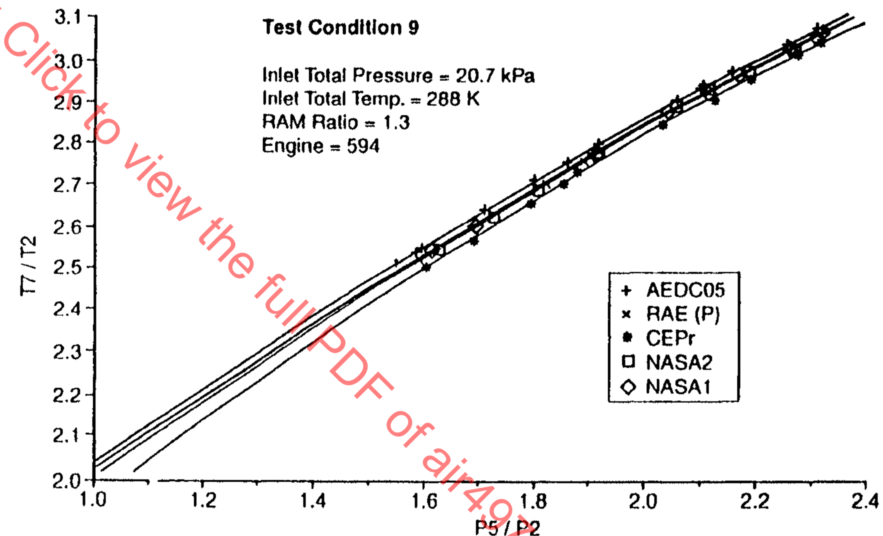


FIGURE D12 - Engine Temperature Ratio Versus Engine Pressure Ratio

Dependent Variable (SFCRD)															
Independent Variable (P7/P2)															
Facility	AEDC05 (N = 18)			RAE (P) (N = 17)			CEPr (N = 18)			NASA1 (N = 18)			NASA2 (N = 17)		
P5/P2	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3
SFCRD	38.41	34.08	32.71	37.16	33.37	32.47	36.83	33.42	32.45	38.31	33.60	32.59	36.98	33.18	32.4
SEE	0.0825			0.1076			0.2737			0.06935			0.15124		
Degrees of Freedom	14			13			14			14			13		

Number of Facilities	5		
Degree of Polynomial	3		
$\overline{N}$	18		
Levels of Independent Variable	1.6	2.0	2.3
Dependent Variable avg. at each level calculated from equation of line through each facility	37.54	33.53	32.54
MAX of Dependent Variable at each level	38.41	34.08	32.71
MIN of Dependent Variable at each level	36.83	33.18	32.45
Range (MAX - MIN)	1.58	0.90	0.26
Range as a % of Dependent Variable at each level	4.20	2.68	0.80
Dependent Variable Standard Deviation at each level (S)	0.7602	0.3419	0.1126
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1562		
$S_p / \sqrt{N}$	0.0368		
Corrected S (S_{Corr})	0.7594	0.3399	0.1064
2 [S_{Corr}] as a % of the Dependent Variable	4.05	2.03	0.65

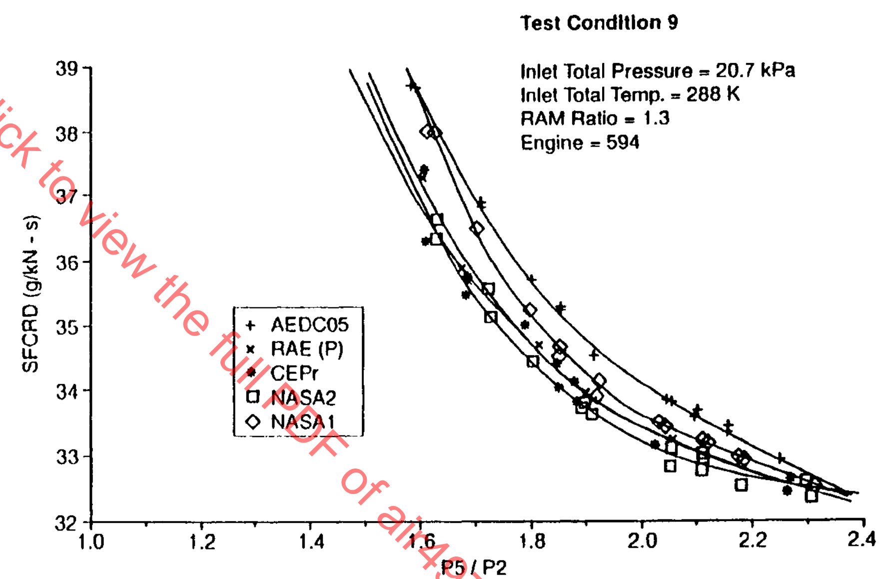


FIGURE D13 - Corrected Specific Fuel Consumption Versus Engine Pressure Ratio

Dependent Variable (WFRD)															
Independent Variable (P5/P2)															
Facility	AEDC05 (N = 19)			RAE (P) (N = 17)			CEPr (N = 18)			NASA1 (N = 18)			NASA2 (N = 17)		
P5/P2	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3	1.6	2.0	2.3
WA1RD	119.92	170.00	211.65	117.21	168.53	210.60	117.91	170.22	213.35	120.86	170.50	213.97	122.00	173.29	216.6
SEE	0.3359			0.4666			0.6256			0.4503			0.8894		
Degrees of Freedom	16			14			15			15			14		

Number of Facilities	5		
Degree of Polynomial	2		
$\overline{N}$	18		
Levels of Independent Variable	1.6	2.0	2.3
Dependent Variable avg. at each level calculated from equation of line through each facility	19.58	170.51	213.24
MAX of Dependent Variable at each level	122.00	173.29	216.64
MIN of Dependent Variable at each level	117.21	168.53	210.60
Range (MAX - MIN)	4.79	4.76	6.04
Range as a % of Dependent Variable at each level	4.00	2.80	2.84
Dependent Variable Standard Deviation at each level (S)	2.0010	1.7315	2.3239
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.5794		
$S_p / \sqrt{\overline{N}}$	0.1366		
Corrected S (S_{Corr})	1.9963	1.7262	2.3199
2 [S_{Corr}] as a % of the Dependent Variable	3.34	2.02	2.18

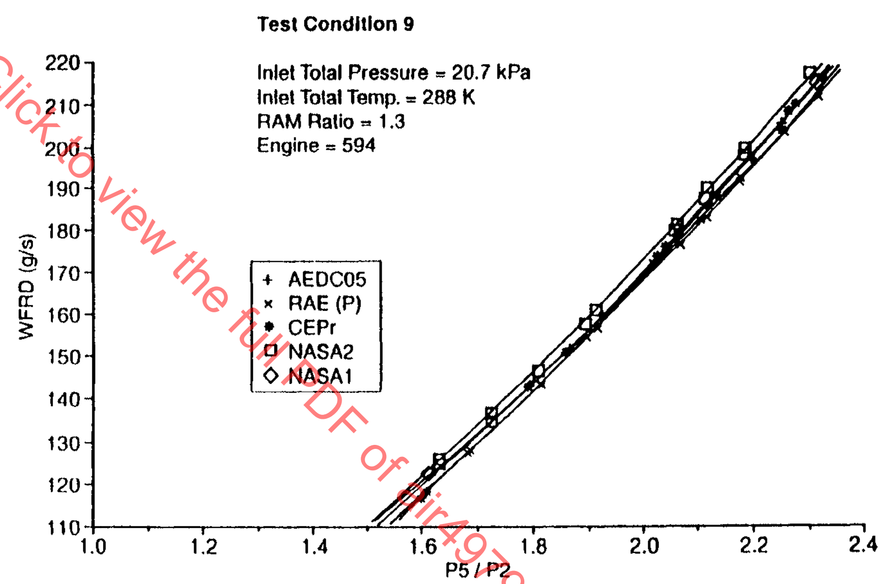


FIGURE D14 - Corrected Engine Fuel Flow Versus Engine Pressure Ratio

Dependent Variable (WA1RD)									
Independent Variable (P5/P2)									
Facility	AEDC01 (N = 17)			NASA2 (N = 18)			NASA1 (N = 18)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
FNR	26.31	35.26	44.15	26.34	35.24	44.07	26.27	35.15	43.77
SEE	0.0916			0.0657			0.0864		
Degrees of Freedom	14			15			15		
Number of Facilities	3								
Degree of Polynomial	2								
$\overline{N}$	18								
Levels of Independent Variable	1.8	2.1	2.4						
Dependent Variable avg. at each level calculated from equation of line through each facility	26.31	35.22	44.00						
MAX of Dependent Variable at each level	26.34	35.26	44.15						
MIN of Dependent Variable at each level	26.27	35.15	43.77						
Range (MAX - MIN)	0.07	0.11	0.38						
Range as a % of Dependent Variable at each level	0.27	0.31	0.86						
Dependent Variable Standard Deviation at each level (S)	0.0351	0.0586	0.2003						
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0818								
$S_p / \sqrt{N}$	0.0195								
Corrected S (S_{Corr})	0.0292	0.0553	0.1994						
2 [S_{Corr}] as a % of the Dependent Variable	0.22	0.31	0.91						

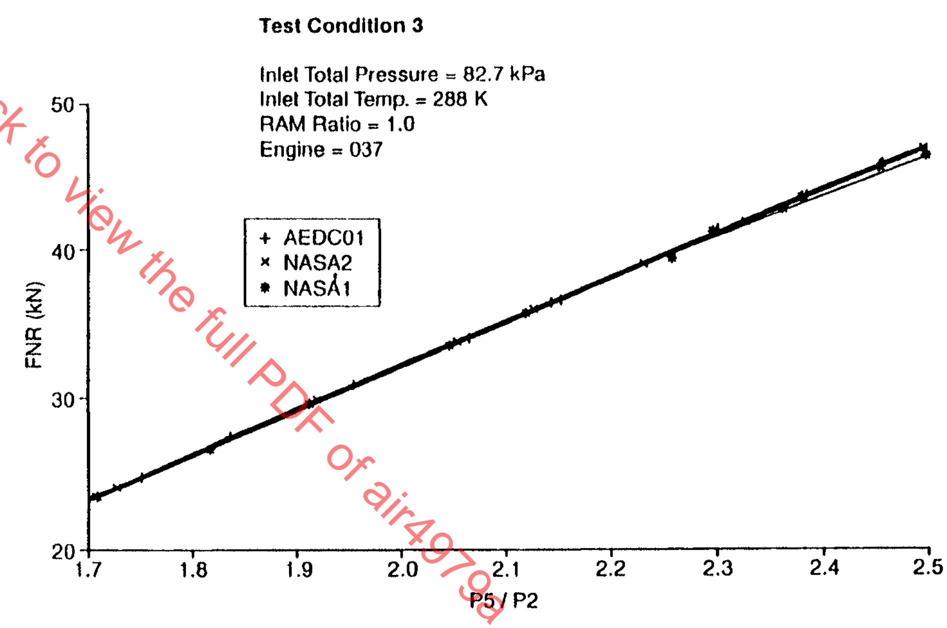


FIGURE D15 - Corrected Net Thrust Versus Engine Pressure Ratio

Dependent Variable (SFCR)									
Independent Variable (FNR)									
Facility	AEDC01 (N = 17)			NASA2 (N = 18)			NASA1 (N = 18)		
FNR	23.0	34.0	45.0	23.0	34.0	45.0	23.0	34.0	45.0
SFCR	22.43	22.00	22.50	23.05	22.54	23.04	22.85	22.43	22.98
SEE	0.0283			0.0481			0.0347		
Degrees of Freedom	13			14			14		
Number of Facilities	3								
Degree of Polynomial	3								
$\overline{N}$	18								
Levels of Independent Variable	23.0	34.0	45.0						
Dependent Variable avg. at each level calculated from equation of line through each facility	22.78	22.32	22.84						
MAX of Dependent Variable at each level	23.05	22.54	23 04						
MIN of Dependent Variable at each level	22.43	22.00	22.50						
Range (MAX - MIN)	0.62	0.54	0.54						
Range as a % of Dependent Variable at each level	2.72	2.42	2.36						
Dependent Variable Standard Deviation at each level (S)	0.3164	0.2854	0.2960						
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0381								
$S_p / \sqrt{N}$	0.0091								
Corrected S (S_{Corr})	0.3163	0.2852	0.2958						
2 [S_{Corr}] as a % of the Dependent Variable	2.78	2.56	2.59						

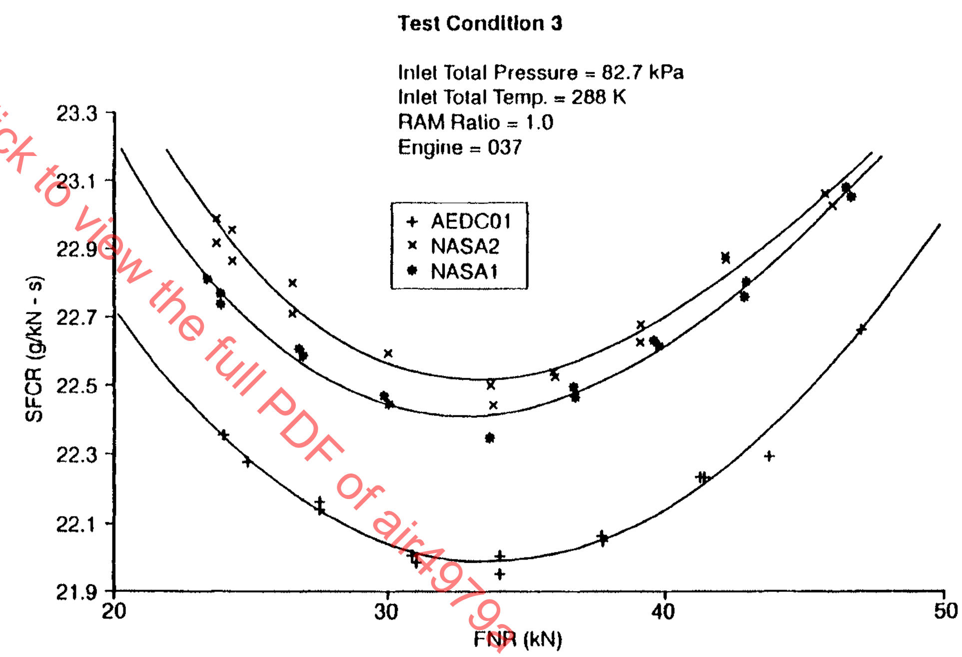


FIGURE D16 - Corrected Specific Fuel Consumption Versus Corrected Net Thrust

Dependent Variable (WA1R)									
Independent Variable (NLR)									
Facility	AEDC01 (N = 17)			NASA2 (N = 18)			NASA1 (N = 18)		
NLR	4950	5400	5900	4950	5400	5900	4950	5400	5900
WA1R	55.87	65.05	74.43	55.73	65.12	74.69	56.43	65.58	74.99
SEE	0.0450			0.1406			0.2270		
Degrees of Freedom	13			14			14		
Number of Facilities	3								
Degree of Polynomial	3								
$\overline{N}$	18								
Levels of Independent Variable	4950	5400	5900						
Dependent Variable avg. at each level calculated from equation of line through each facility	56.01	65.25	74.70						
MAX of Dependent Variable at each level	56.43	65.58	74.99						
MIN of Dependent Variable at each level	55.73	65.05	74.43						
Range (MAX - MIN)	0.70	0.53	0.56						
Range as a % of Dependent Variable at each level	1.25	0.81	0.75						
Dependent Variable Standard Deviation at each level (S)	0.3704	0.2879	0.2802						
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1581								
$S_p / \sqrt{\overline{N}}$	0.0376								
Corrected S (S_{Corr})	0.3685	0.2855	0.2777						
2 [S_{Corr}] as a % of the Dependent Variable	1.32	0.87	0.74						

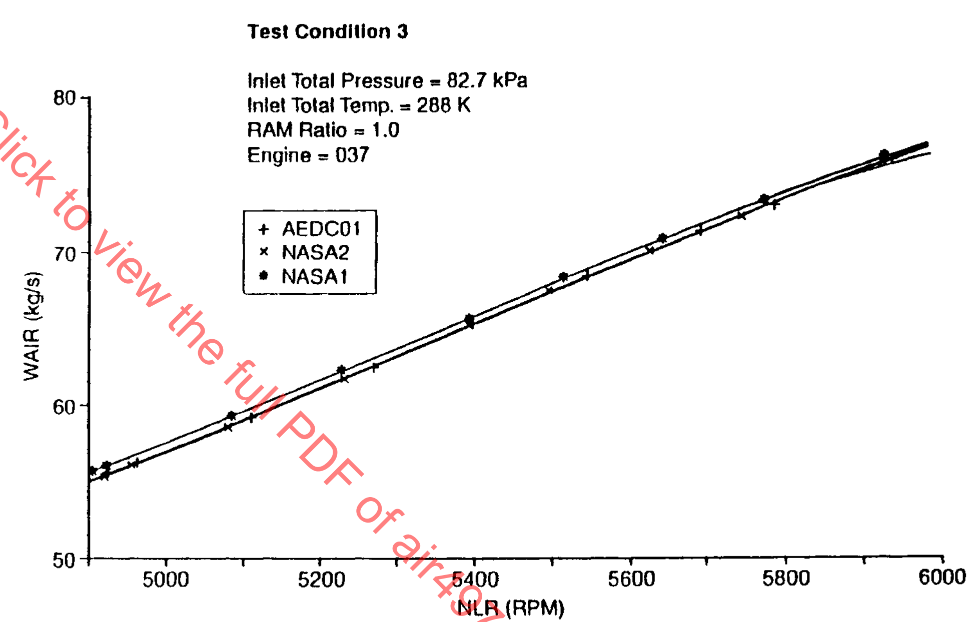


FIGURE D17 - Corrected Engine Airflow Versus Corrected Low Pressure Compressor Speed

Dependent Variable (WA1R)									
Independent Variable (P5/P2)									
Facility	AEDC01 (N = 17)			NASA2 (N = 18)			NASA1 (N = 18)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
WA1R	57.95	66.17	73.08	58.22	66.61	73.54	58.58	66.85	73.67
SEE	0.0830			0.1225			0.2200		
Degrees of Freedom	14			15			15		

Number of Facilities	3		
Degree of Polynomial	2		
$\overline{N}$	18		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	58.25	66.54	73.43
MAX of Dependent Variable at each level	58.58	66.85	73.67
MIN of Dependent Variable at each level	57.95	66.17	73.08
Range (MAX - MIN)	0.63	0.68	0.59
Range as a % of Dependent Variable at each level	1.08	1.02	0.80
Dependent Variable Standard Deviation at each level (S)	0.3161	0.3449	0.3100
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1543		
$S_p / \sqrt{\overline{N}}$	0.0367		
Corrected S (S_{Corr})	0.3139	0.3429	0.3078
2 [S_{Corr}] as a % of the Dependent Variable	1.08	1.03	0.84

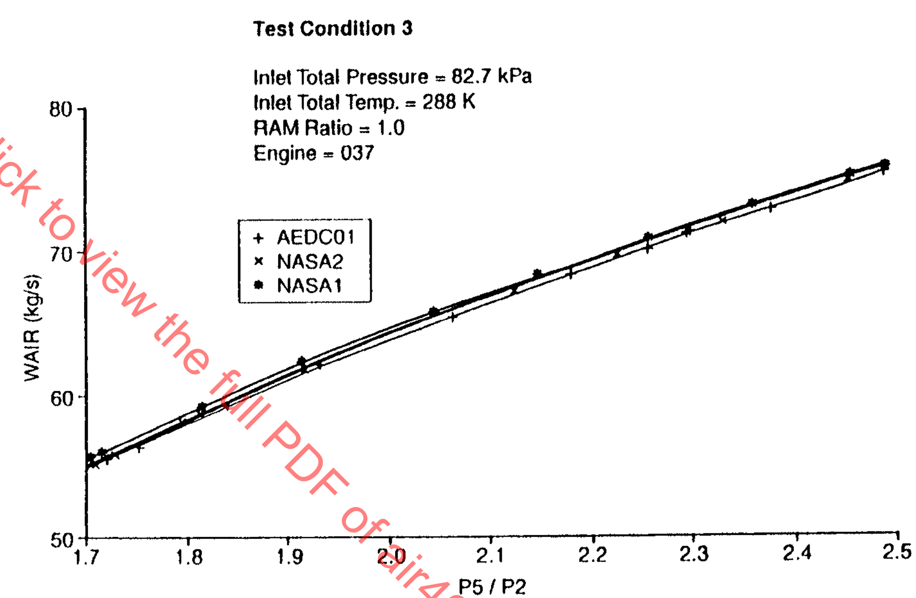


FIGURE D18 - Corrected Engine Airflow Versus Engine Pressure Ratio

Dependent Variable (T7/T2)									
Independent Variable (P5/P2)									
Facility	AEDC01 (N = 17)			NASA2 (N = 18)			NASA1 (N = 18)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
T7/T2	2.427	2.641	2.883	2.431	2.643	2.888	2.406	2.629	2.871
SEE	0.0055			0.0061			0.0043		
Degrees of Freedom	14			15			15		

Number of Facilities	3		
Degree of Polynomial	2		
$\overline{N}$	18		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	2.42	2.64	2.88
MAX of Dependent Variable at each level	2.43	2.64	2.89
MIN of Dependent Variable at each level	2.41	2.63	2.87
Range (MAX - MIN)	0.02	0.01	0.02
Range as a % of Dependent Variable at each level	1.03	0.53	0.59
Dependent Variable Standard Deviation at each level (S)	0.0134	0.0076	0.0087
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0053		
$S_p / \sqrt{\overline{N}}$	0.0013		
Corrected S (S_{Corr})	0.0134	0.0075	0.0086
2 [S_{Corr}] as a % of the Dependent Variable	1.10	0.57	0.60

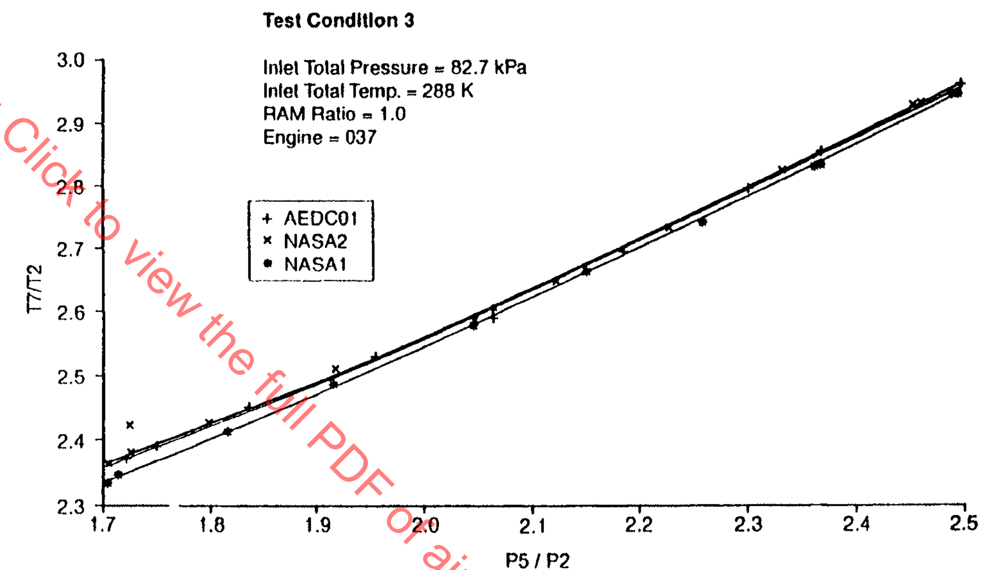


FIGURE D19 - Engine Temperature Ratio Versus Engine Pressure Ratio

Dependent Variable (SFCR)									
Independent Variable (P5/P2)									
Facility	AEDC01 (N = 17)			NASA2 (N = 18)			NASA1 (N = 18)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
SFCR	22.20	22.01	22.43	22.74	22.55	22.98	22.60	22.45	22.89
SEE	0.0273			0.0460			0.0329		
Degrees of Freedom	13			14			14		
Number of Facilities	3								
Degree of Polynomial	3								
$\overline{N}$	18								
Levels of Independent Variable	1.8	2.1	2.4						
Dependent Variable avg. at each level calculated from equation of line through each facility	22.51	22.34	22.77						
MAX of Dependent Variable at each level	22.74	22.55	22.98						
MIN of Dependent Variable at each level	22.20	22.01	22.43						
Range (MAX - MIN)	0.54	0.54	0.55						
Range as a % of Dependent Variable at each level	2.40	2.42	2.42						
Dependent Variable Standard Deviation at each level (S)	0.2802	0.2873	0.2950						
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0364								
$S_p / \sqrt{\overline{N}}$	0.0087								
Corrected S (S_{Corr})	0.2801	0.2872	0.2949						
2 [S_{Corr}] as a % of the Dependent Variable	2.49	2.57	2.59						

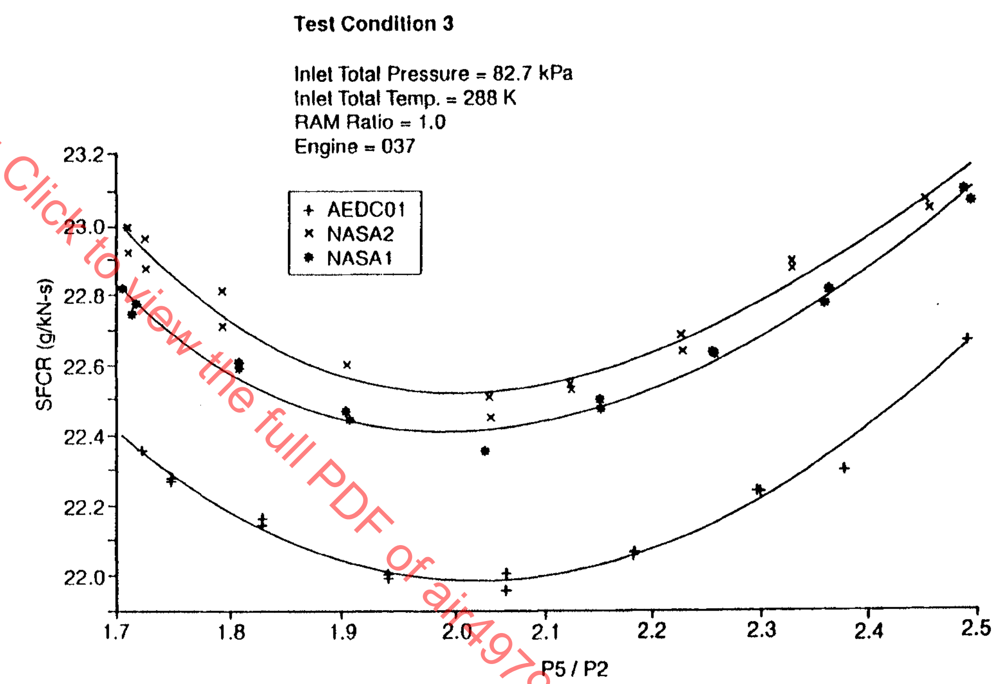


FIGURE D20 - Corrected Specific Fuel Consumption Versus Engine Pressure Ratio

Dependent Variable (WFR)									
Independent Variable (P5/P2)									
Facility	AEDC01 (N = 17)			NASA2 (N = 18)			NASA1 (N = 18)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
WFR	583.4	776.0	990.9	598.8	794.9	1012.4	593.1	789.0	1001.8
SEE	2.3448			2.5179			2.2100		
Degrees of Freedom	14			15			15		
Number of Facilities	3								
Degree of Polynomial	2								
$\overline{N}$	18								
Levels of Independent Variable	1.8	2.1	2.4						
Dependent Variable avg. at each level calculated from equation of line through each facility	591.77	786.63	1001.70						
MAX of Dependent Variable at each level	598.80	794.90	1012.40						
MIN of Dependent Variable at each level	583.40	776.00	990.90						
Range (MAX - MIN)	15.40	18.90	21.50						
Range as a % of Dependent Variable at each level	2.60	2.40	2.15						
Dependent Variable Standard Deviation at each level (S)	7.7862	9.6697	10.7503						
Pooled Std. Error of est. (for equations through each facility) (S_p)	2.3613								
$S_p / \sqrt{\overline{N}}$	0.5619								
Corrected S (S_{Corr})	7.7659	9.6533	10.7357						
2 [S_{Corr}] as a % of the Dependent Variable	2.62	2.45	2.14						

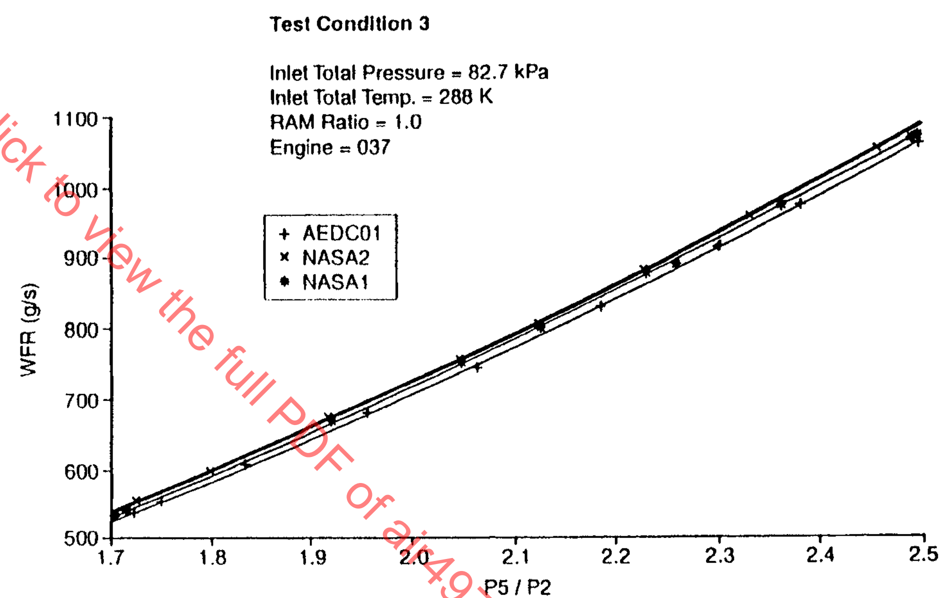


FIGURE D21 - Corrected Fuel Flow Versus Engine Pressure Ratio

Dependent Variable (FNR)															
Independent Variable (P5/P2)															
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)			TUAF (N = 16)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
FNR	26.46	35.45	44.47	26.09	35.20	44.17	26.56	35.70	44.71	26.73	35.54	44.19	25.31	34.38	43.50
SEE	0.0293			0.1091			0.7868			0.1591			0.1433		
Degrees of Freedom	15			13			13			13			13		

Number of Facilities	5		
Degree of Polynomial	2		
$\overline{N}$	16		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	26.23	35.25	44.21
MAX of Dependent Variable at each level	26.73	35.70	44.71
MIN of Dependent Variable at each level	25.31	34.38	43.50
Range (MAX - MIN)	1.42	1.32	1.21
Range as a % of Dependent Variable at each level	5.41	3.74	2.74
Dependent Variable Standard Deviation at each level (S)	0.5652	0.5210	0.4538
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.3626		
$S_p / \sqrt{N}$	0.0896		
Corrected S (S_{Corr})	0.5581	0.5133	0.4449
2 [S_{Corr}] as a % of the Dependent Variable	4.26	2.91	2.01

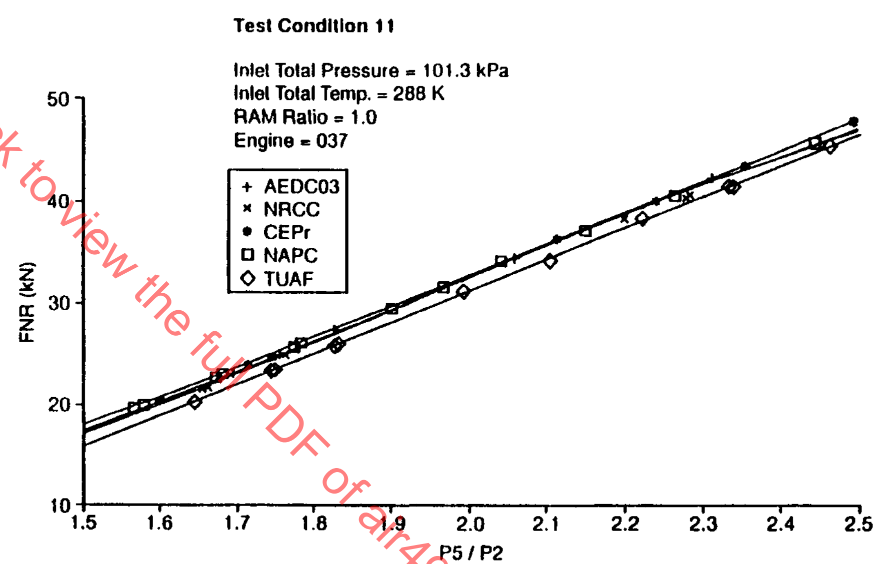


FIGURE D22 - Corrected Net Thrust Versus Engine Pressure Ratio

Dependent Variable (SFCR)															
Independent Variable (FNR)															
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)			TUAF (N = 16)		
FNR	23.0	34.0	45.0	23.0	34.0	45.0	23.0	34.0	45.0	23.0	34.0	45.0	23.0	34.0	45.0
SFCR	22.26	21.90	22.51	22.71	22.20	22.73	22.44	22.06	22.74	22.40	22.06	22.74	23.22	22.58	22.51
SEE	0.0245			0.0210			0.0542			0.1334			0.0793		
Degrees of Freedom	14			12			12			12			12		

Number of Facilities	5		
Degree of Polynomial	3		
$\overline{N}$	16		
Levels of Independent Variable	23.0	34.0	45.0
Dependent Variable avg. at each level calculated from equation of line through each facility	22.61	22.16	22.67
MAX of Dependent Variable at each level	23.22	22.58	22.85
MIN of Dependent Variable at each level	22.26	21.90	22.51
Range (MAX - MIN)	0.96	0.68	0.34
Range as a % of Dependent Variable at each level	4.25	3.07	1.50
Dependent Variable Standard Deviation at each level (S)	0.3800	0.2568	0.1517
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0738		
$S_p / \sqrt{\overline{N}}$	0.0182		
Corrected S (S_{Corr})	0.3795	0.2561	0.1506
2 [S_{Corr}] as a % of the Dependent Variable	3.36	2.31	1.33

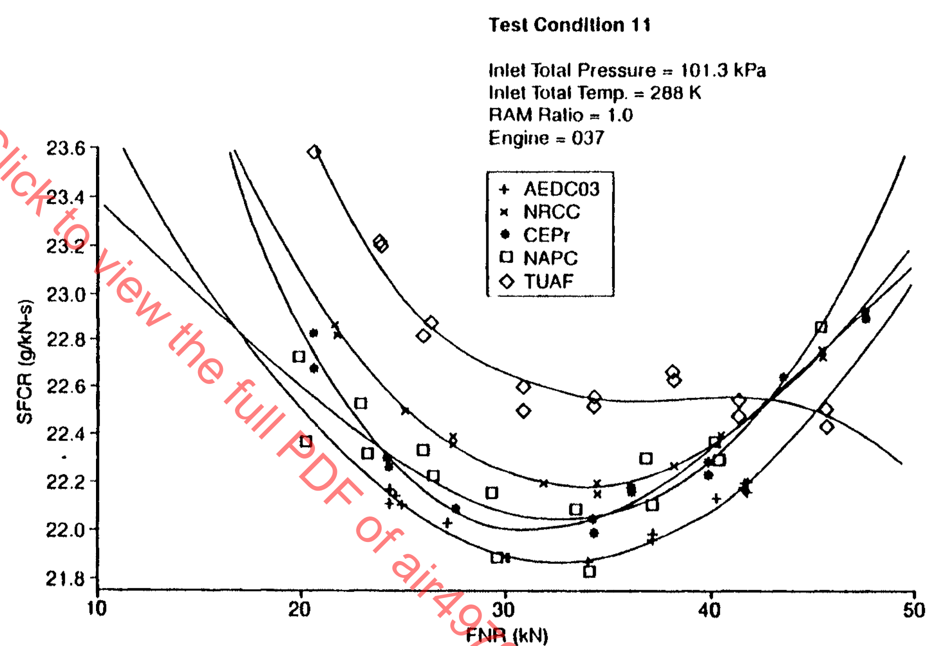


FIGURE D23 - Corrected Specific Fuel Consumption Versus Corrected Net Thrust

Dependent Variable (WA1R)															
Independent Variable (NLR)															
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)			TUAF (N = 16)		
NLR	4950	5400	5900	4950	5400	5900	4950	5400	5900	4950	5400	5900	4950	5400	5900
WA1R	56.22	65.38	74.23	55.43	64.49	73.64	56.55	65.63	74.91	56.50	65.99	75.58	57.88	67.25	76.35
SEE	0.0325			0.0666			0.2168			0.2846			0.0644		
Degrees of Freedom	14			12			12			12			12		

Number of Facilities	5		
Degree of Polynomial	3		
$\overline{N}$	16		
Levels of Independent Variable	4950	5400	5900
Dependent Variable avg. at each level calculated from equation of line through each facility	56.52	65.75	74.94
MAX of Dependent Variable at each level	57.88	67.25	76.35
MIN of Dependent Variable at each level	55.43	64.49	73.64
Range (MAX - MIN)	2.45	2.76	2.71
Range as a % of Dependent Variable at each level	4.34	4.20	3.62
Dependent Variable Standard Deviation at each level (S)	0.8844	1.0058	1.0715
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1633		
$S_p / \sqrt{\overline{N}}$	0.0403		
Corrected S (S_{Corr})	0.8835	1.0050	1.0708
2 [S_{Corr}] as a % of the Dependent Variable	3.13	3.06	2.86

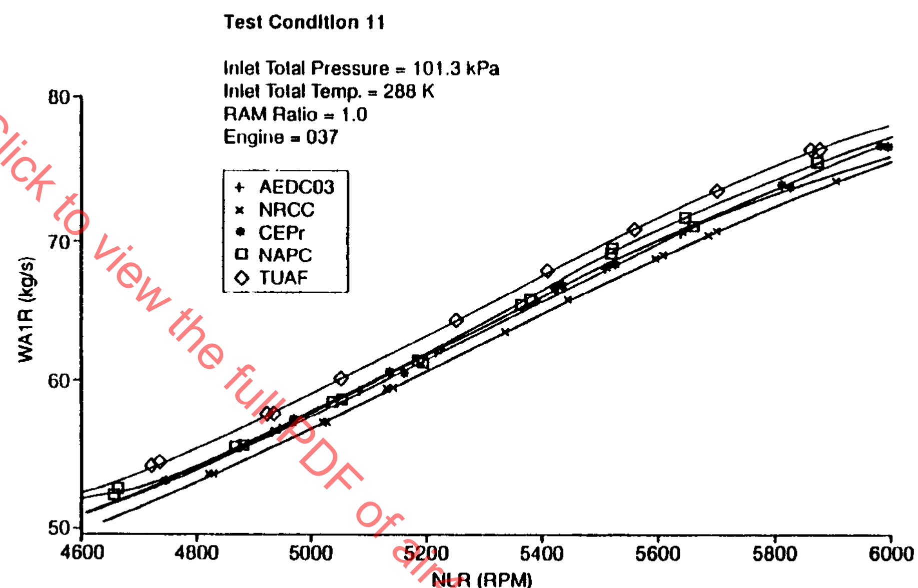


FIGURE D24 - Corrected Engine Airflow Versus Corrected Low Pressure Compressor Speed

Dependent Variable (WA1R)															
Independent Variable (P5/P2)															
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)			TUAF (N = 16)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
WA1R	58.18	66.40	73.26	57.83	66.12	72.93	59.24	67.65	74.48	58.85	67.13	74.44	58.98	67.50	74.62
SEE	0.0298			0.0765			0.1393			0.3505			0.0802		
Degrees of Freedom	15			13			13			13			13		

Number of Facilities	5		
Degree of Polynomial	2		
$\overline{N}$	16		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	58.62	66.96	73.95
MAX of Dependent Variable at each level	59.24	67.65	74.62
MIN of Dependent Variable at each level	57.83	66.12	72.93
Range (MAX - MIN)	1.41	1.53	1.69
Range as a % of Dependent Variable at each level	2.41	2.28	2.29
Dependent Variable Standard Deviation at each level (S)	0.5883	0.6738	0.7884
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1737		
$S_p / \sqrt{N}$	0.0429		
Corrected S (S_{Corr})	0.5868	0.6724	0.7872
2 [S_{Corr}] as a % of the Dependent Variable	2.00	2.01	2.13

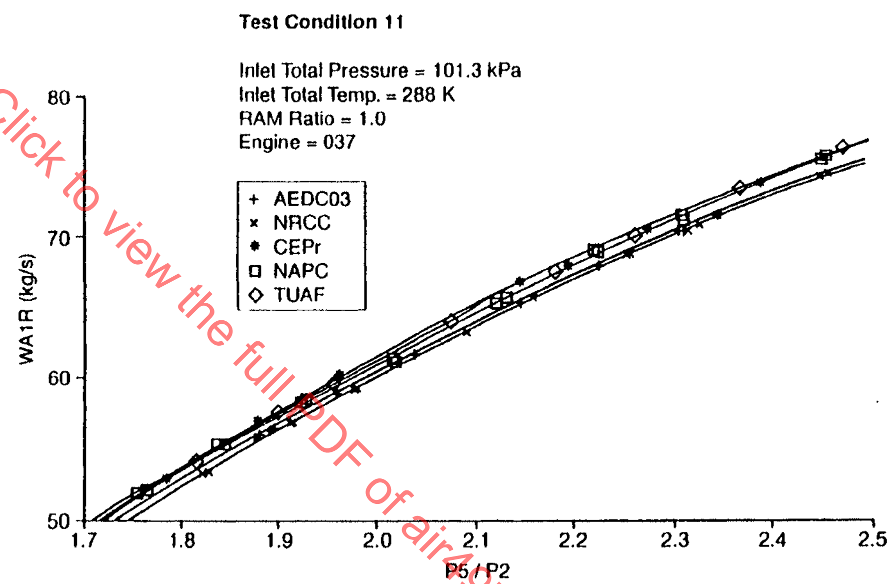


FIGURE D25 - Corrected Engine Airflow Versus Engine Pressure Ratio

Dependent Variable (T7/T2)															
Independent Variable (P5/P2)															
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)			TUAF (N = 16)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
T7/T2	2.409	2.631	2.882	2.388	2.602	2.837	2.409	2.639	2.893	2.388	2.602	2.828	2.342	2.562	2.805
SEE	0.0036			0.0037			0.0040			0.0063			0.0052		
Degrees of Freedom	15			13			13			13			13		

Number of Facilities	5		
Degree of Polynomial	2		
$\overline{N}$	16		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	2.39	2.61	2.85
MAX of Dependent Variable at each level	2.4 1	2.64	2.89
MIN of Dependent Variable at each level	2.34	2.56	2.81
Range (MAX - MIN)	0.07	0.08	0.09
Range as a % of Dependent Variable at each level	2.81	2.95	3.09
Dependent Variable Standard Deviation at each level (S)	0.0274	0.0303	0.0372
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0046 ...		
$S_p / \sqrt{\overline{N}}$	0.0011		
Corrected S (S_{Corr})	0.0273	0.0303	0.0372
2 [S_{Corr}] as a % of the Dependent Variable	2.29	2.32	2.61

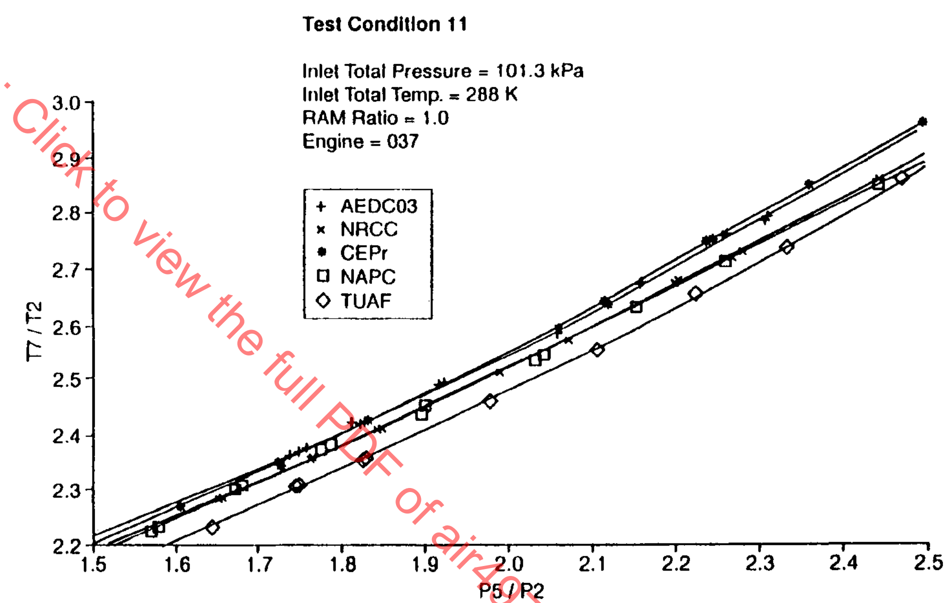


FIGURE D26 - Engine Temperature Ratio Versus Engine Pressure Ratio

Dependent Variable (SFCR)															
Independent Variable (P5/P2)															
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)			TUAF (N = 16)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
SFCR	22.05	21.92	22.45	22.45	22.22	22.66	22.14	22.11	22.72	22.20	22.10	22.74	22.95	22.58	22.55
SEE	0.0244			0.0211			0.0534			0.1337			0.0772		
Degrees of Freedom	14			12			12			12			12		

Number of Facilities	5		
Degree of Polynomial	3		
$\overline{N}$	16		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	22.36	22.19	22.62
MAX of Dependent Variable at each level	22.95	22.58	22.74
MIN of Dependent Variable at each level	22.05	21.92	22.45
Range (MAX - MIN)	0.90	0.66	0.29
Range as a % of Dependent Variable at each level	4.03	2.97	1.28
Dependent Variable Standard Deviation at each level (S)	0.3627	0.2451	0.1222
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0734		
$S_p / \sqrt{N}$	0.0181		
Corrected S (S_{Corr})	0.3623	0.2444	0.1208
2 [S_{Corr}] as a % of the Dependent Variable	3.24	2.20	1.07

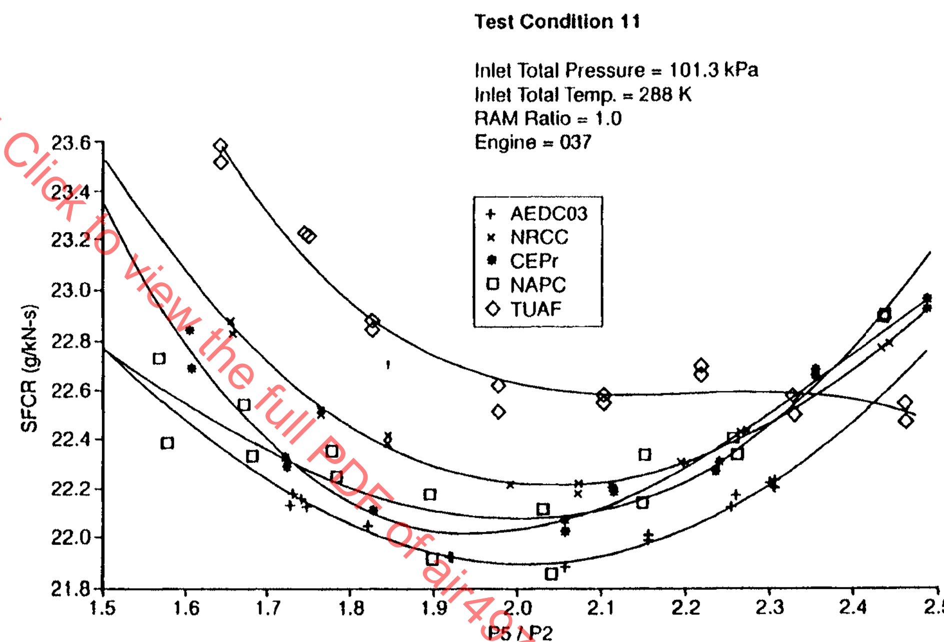


FIGURE D27 - Corrected Specific Fuel Consumption Versus Engine Pressure Ratio

Dependent Variable (WFR)															
Independent Variable (P5/P2)															
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)			TUAF (N = 16)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
WFR	583.0	777.8	994.9	584.4	782.4	1000.6	587.6	789.8	1015.4	590.2	787.4	1004.5	582.2	776.4	979.8
SEE	1.3416			2.4177			2.7882			3.1869			4.5917		
Degrees of Freedom	15			13			13			13			13		

Number of Facilities	5		
Degree of Polynomial	2		
$\overline{N}$	16		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	585.48	782.76	999.04
MAX of Dependent Variable at each level	590.20	789.80	1015.40
MIN of Dependent Variable at each level	582.20	776.40	979.80
Range (MAX - MIN)	8.00	13.40	35.60
Range as a % of Dependent Variable at each level	1.37	1.71	3.56
Dependent Variable Standard Deviation at each level (S)	3.3485	5.8368	13.1073
Pooled Std. Error of est. (for equations through each facility) (S_p)	3.0178		
$S_p / \sqrt{\overline{N}}$	0.7454		
Corrected S (S_{Corr})	3.2644	5.7890	13.0861
2 [S_{Corr}] as a % of the Dependent Variable	1.12	1.48	2.62

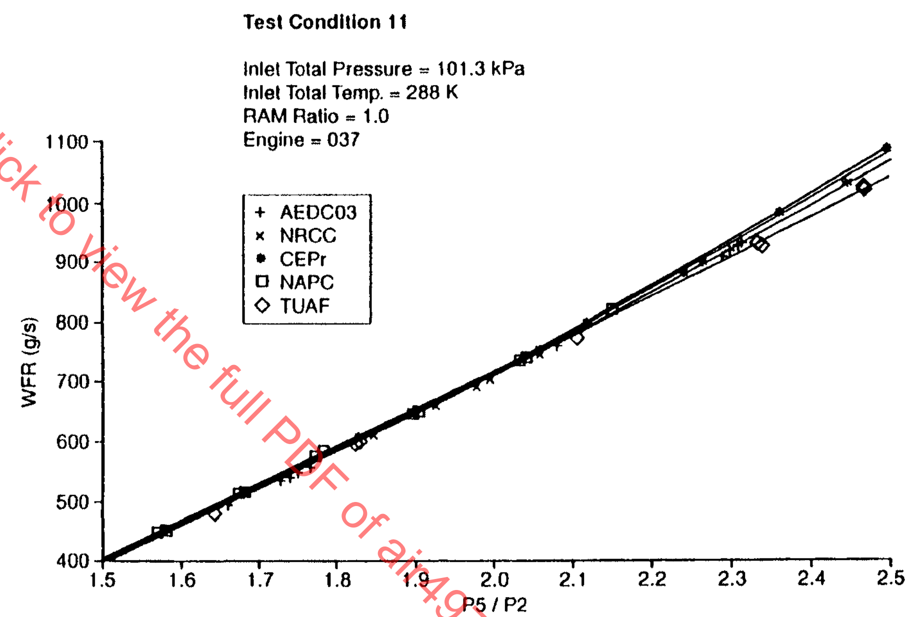


FIGURE D28 - Corrected Engine Fuel Flow Versus Engine Pressure Ratio

Dependent Variable (FNR)												
Independent Variable (P5/P2)												
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
FNR	26.46	35.45	44.47	26.09	35.20	44.17	26.56	35.70	44.71	26.73	35.54	44.19
SEE	0.0293			0.1091			0.7868			0.1591		
Degrees of Freedom	15			13			13			13		

Number of Facilities	4		
Degree of Polynomial	2		
$\overline{N}$	16		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	26.46	35.47	44.38
MAX of Dependent Variable at each level	26.73	35.70	44.71
MIN of Dependent Variable at each level	26.09	35.20	44.17
Range (MAX - MIN)	0.64	0.50	0.54
Range as a % of Dependent Variable at each level	2.42	1.41	1.22
Dependent Variable Standard Deviation at each level (S)	0.2707	0.2090	0.2563
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.3978		
$S_p / \sqrt{N}$	0.0980		
Corrected S (S_{Corr})	0.2523	0.1846	0.2369
2 [S_{Corr}] as a % of the Dependent Variable	1.91	1.04	1.07

Test Condition 11

Inlet Total Pressure = 101.3 kPa
Inlet Total Temp. = 288 K
RAM Ratio = 1.0
Engine = 037

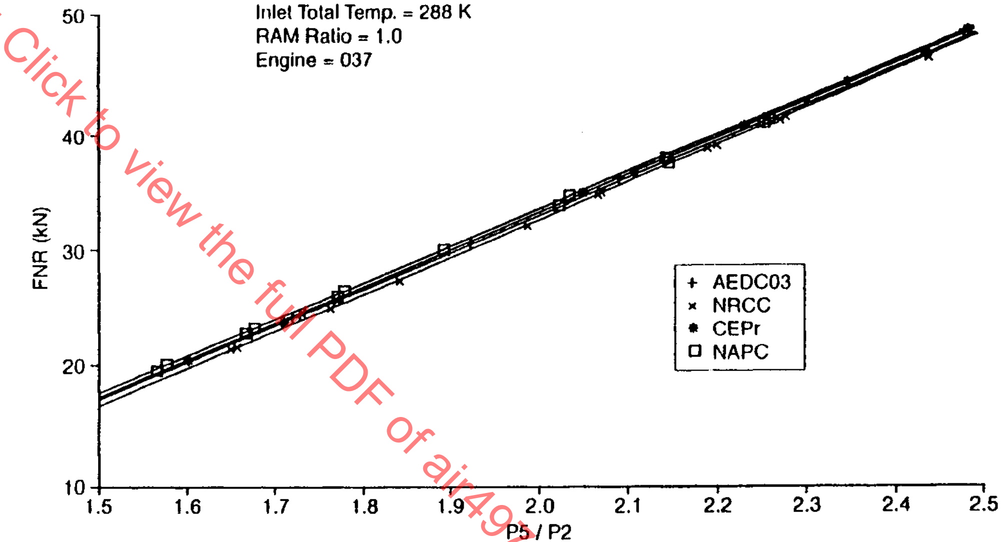


FIGURE D29 - Corrected Net Thrust Versus Engine Pressure Ratio

Dependent Variable (SFCR)												
Independent Variable (FNR)												
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)		
FNR	23.0	34.0	45.0	23.0	34.0	45.0	23.0	34.0	45.0	23.0	34.0	45.0
SFCR	22.26	21.90	22.51	22.71	22.20	22.73	22.44	22.06	22.74	22.40	22.07	22.85
SEE	0.0245			0.0210			0.0542			0.1334		
Degrees of Freedom	14			12			12			12		

Number of Facilities	4		
Degree of Polynomial	3		
$\overline{N}$	16		
Levels of Independent Variable	23.0	34.0	45.0
Dependent Variable avg. at each level calculated from equation of line through each facility	22.45	22.06	22.71
MAX of Dependent Variable at each level	22.71	22.20	22.85
MIN of Dependent Variable at each level	22.26	21.90	22.51
Range (MAX - MIN)	0.45	0.30	0.34
Range as a % of Dependent Variable at each level	2.00	1.36	1.50
Dependent Variable Standard Deviation at each level (S)	0.1882	0.1228	0.1425
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0725		
$S_p / \sqrt{N}$	0.0178		
Corrected S (S_{Corr})	0.1874	0.1215	0.1413
2 [S_{Corr}] as a % of the Dependent Variable	1.67	1.10	1.24

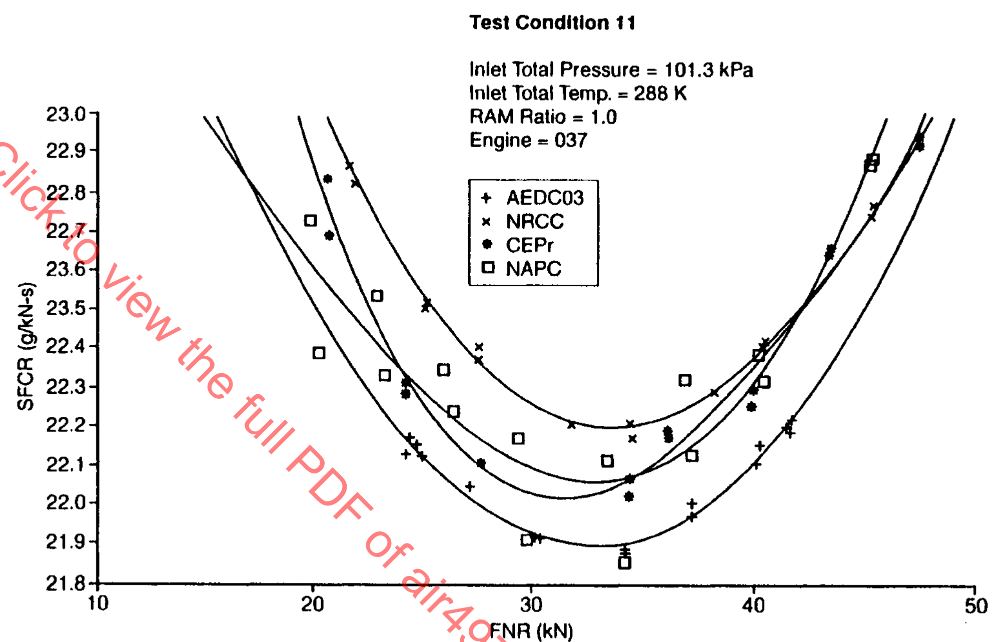


FIGURE D30 - Corrected Specific Fuel Consumption Versus Corrected Net Thrust

Dependent Variable (WA1R)												
Independent Variable (NLR)												
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)		
NLR	4950	5400	5900	4950	5400	5900	4950	5400	5900	4950	5400	5900
WA1R	56.22	65.38	74.23	55.43	64.49	73.64	56.55	65.63	74.91	56.50	65.99	75.58
SEE	0.0325			0.0666			0.2168			0.2846		
Degrees of Freedom	14			12			12			12		

Number of Facilities	4		
Degree of Polynomial	3		
$\overline{N}$	16		
Levels of Independent Variable	4950	5400	5900
Dependent Variable avg. at each level calculated from equation of line through each facility	56.17	65.37	74.59
MAX of Dependent Variable at each level	56.55	65.99	75.58
MIN of Dependent Variable at each level	55.43	64.49	73.64
Range (MAX - MIN)	1.12	1.50	1.94
Range as a % of Dependent Variable at each level	1.99	2.29	2.60
Dependent Variable Standard Deviation at each level (S)	0.5175	0.6394	0.8396
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1791		
$S_p / \sqrt{\overline{N}}$	0.0441		
Corrected S (S_{Corr})	0.5156	0.6379	0.8384
2 [S_{Corr}] as a % of the Dependent Variable	1.84	1.95	2.25

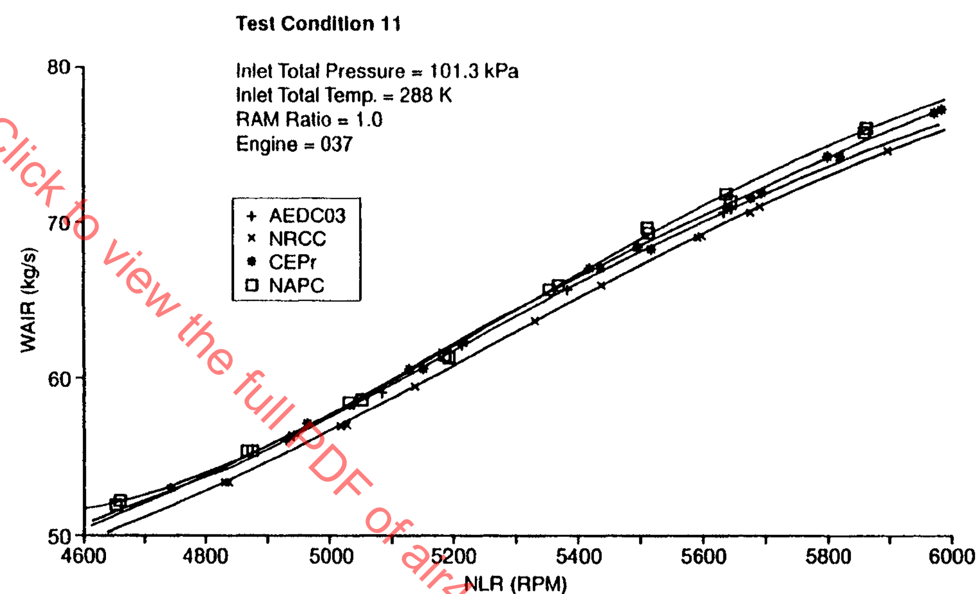


FIGURE D31 - Corrected Engine Airflow Versus Corrected Low Pressure Compressor Speed

Dependent Variable (WA1R)												
Independent Variable (P5/P2)												
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
WA1R	58.18	66.40	73.26	57.83	66.12	72.93	59.24	67.65	74.48	58.85	67.13	74.44
SEE	0.0298			0.0765			0.1393			0.3505		
Degrees of Freedom	15			13			13			13		

Number of Facilities	4		
Degree of Polynomial	2		
$\bar{N}$	16		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	58.52	66.82	73.78
MAX of Dependent Variable at each level	59.24	67.65	74.48
MIN of Dependent Variable at each level	57.83	66.12	72.93
Range (MAX - MIN)	1.41	1.53	1.55
Range as a % of Dependent Variable at each level	2.41	2.29	2.10
Dependent Variable Standard Deviation at each level (S)	0.6374	0.6955	0.7997
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1895		
$S_p / \sqrt{\bar{N}}$	0.0467		
Corrected S (S_{Corr})	0.6357	0.6940	0.7983
2 [S_{Corr}] as a % of the Dependent Variable	2.17	2.08	2.16

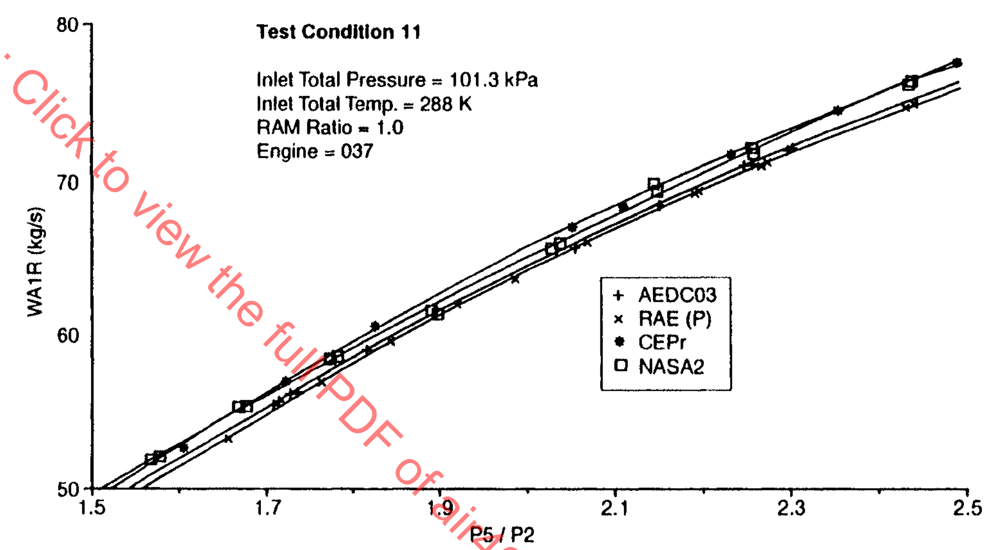


FIGURE D32 - Corrected Engine Airflow Versus Engine Pressure Ratio

Dependent Variable (T7/T2)												
Independent Variable (P5/P2)												
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
T7/T2	2.409	2.631	2.882	2.388	2.602	2.837	2.409	2.639	2.893	2.388	2.602	2.828
SEE	0.0036			0.0037			0.0040			0.0063		
Degrees of Freedom	15			13			13			13		

Number of Facilities	4		
Degree of Polynomial	2		
$\overline{N}$	16		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	2.40	2.62	2.86
MAX of Dependent Variable at each level	2.41	2.64	2.89
MIN of Dependent Variable at each level	2.39	2.60	2.83
Range (MAX - MIN)	0.02	0.04	0.06
Range as a % of Dependent Variable at each level	0.88	1.41	2.27
Dependent Variable Standard Deviation at each level (S)	0.0121	0.0193	0.0323
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0045		
$S_p / \sqrt{N}$	0.0011		
Corrected S (S_{Corr})	0.0121	0.0193	0.0323
2 [S_{Corr}] as a % of the Dependent Variable	1.01	1.47	2.26

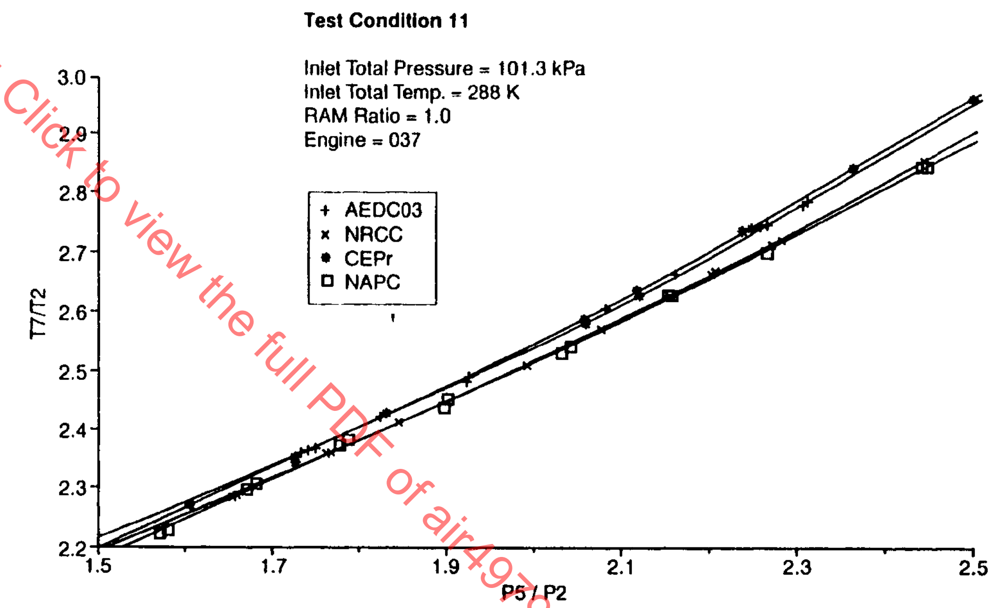


FIGURE D33 - Engine Temperature Ratio Versus Engine Pressure Ratio

Dependent Variable (SFCR)												
Independent Variable (P5/P2)												
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
SFCR	22.05	21.92	22.45	22.45	22.22	22.66	22.14	22.11	22.72	22.20	22.10	22.74
SEE	0.0244			0.0211			0.0534			0.1337		
Degrees of Freedom	14			12			12			12		

Number of Facilities	4		
Degree of Polynomial	3		
$\overline{N}$	16		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	22.21	22.09	22.64
MAX of Dependent Variable at each level	22.45	22.22	22.74
MIN of Dependent Variable at each level	22.05	21.92	22.45
Range (MAX - MIN)	0.40	0.30	0.29
Range as a % of Dependent Variable at each level	1.80	1.36	1.28
Dependent Variable Standard Deviation at each level (S)	0.1715	0.1242	0.1328
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0724		
$S_p / \sqrt{N}$	0.0178		
Corrected S (S_{Corr})	0.1705	0.1229	01316
2 [S_{Corr}] as a % of the Dependent Variable	1.54	1.11	1.16

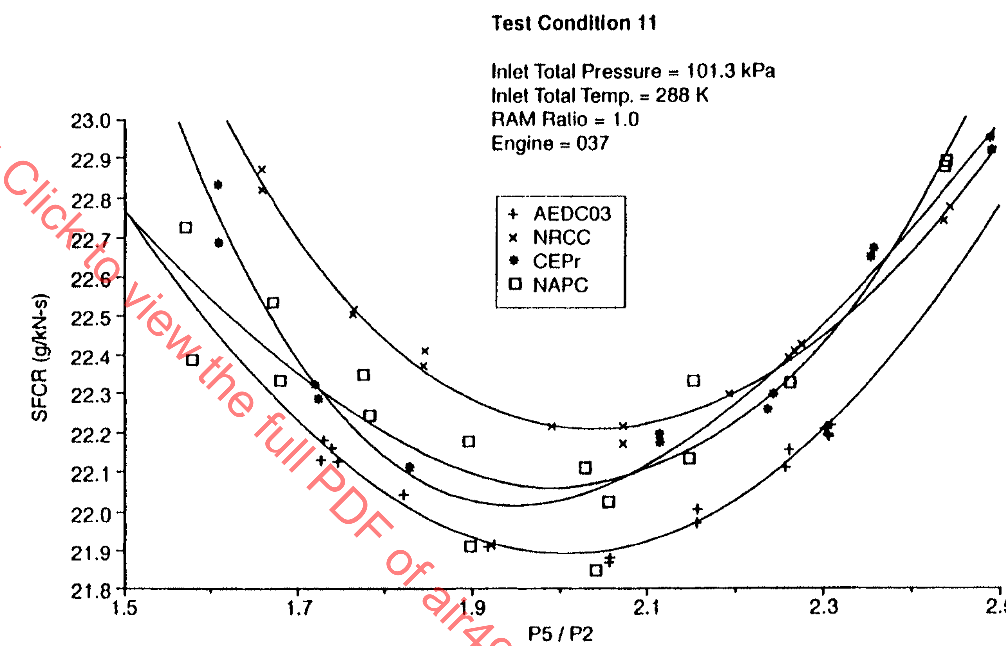


FIGURE D34 - Corrected Specific Fuel Consumption Versus Engine Pressure Ratio

Dependent Variable (WFR)												
Independent Variable (P5/P2)												
Facility	AEDC03 (N = 18)			NRCC (N = 16)			CEPr (N = 16)			NAPC (N = 16)		
P5/P2	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4	1.8	2.1	2.4
WFR	583.0	777.8	994.9	584.4	782.4	1000.6	587.6	789.8	1015.4	590.2	787.4	1004.5
SEE	1.3416			2.4177			2.7882			3.1869		
Degrees of Freedom	15			13			13			13		

Number of Facilities	4		
Degree of Polynomial	2		
$\overline{N}$	16		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	586.30	784.35	1003.85
MAX of Dependent Variable at each level	590.20	789.80	1015.40
MIN of Dependent Variable at each level	583.00	777.80	994.90
Range (MAX - MIN)	7.20	12.00	20.50
Range as a % of Dependent Variable at each level	1.23	1.53	2.04
Dependent Variable Standard Deviation at each level (S)	3.2352	5.3451	8.6504
Pooled Std. Error of est. (for equations through each facility) (S_p)	2.4947		
$S_p / \sqrt{N}$	0.6144		
Corrected S (S_{Corr})	3.1763	5.3096	8.6286
2 [S_{Corr}] as a % of the Dependent Variable	1.08	1.35	1.72

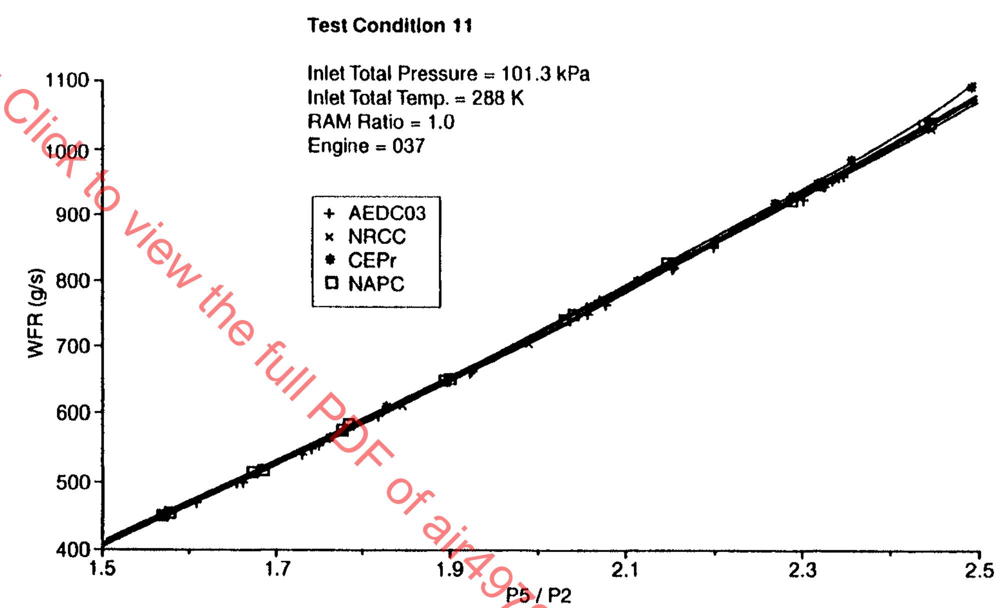


FIGURE D35 - Corrected Engine Fuel Flow Versus Engine Pressure Ratio

Dependent Variable (FNR)			
Independent Variable (P5/P2)			
Number of Facilities	7		
Degree of Polynomial	2		
$\overline{N}$	17		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	26.39	35.36	44.22
MAX of Dependent Variable at each level	26.73	35.70	44.71
MIN of Dependent Variable at each level	26.09	35.15	43.77
Range (MAX - MIN)	0.64	0.55	0.94
Range as a % of Dependent Variable at each level	2.42	1.56	2.13
Dependent Variable Standard Deviation at each level (S)	0.2092	0.2042	0.2989
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.3003		
$S_p / \sqrt{\overline{N}}$	0.0729		
Corrected S (S_{Corr})	0.1961	0.1907	0.2898
2 [S_{Corr}] as a % of the Dependent Variable	1.49	1.08	1.31

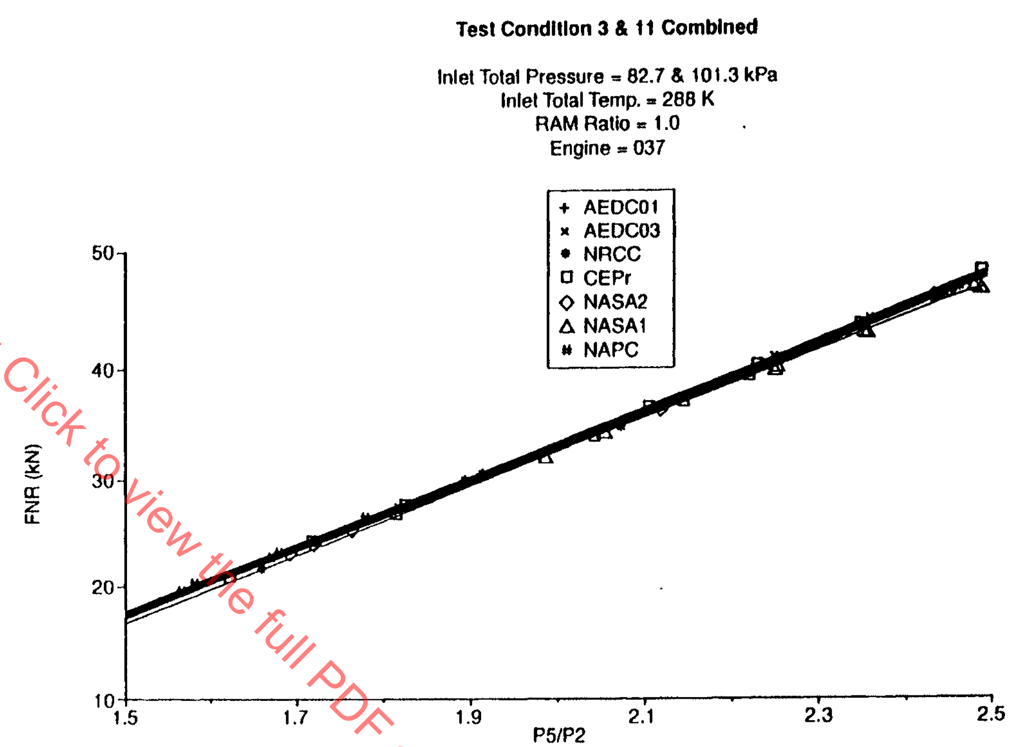


FIGURE D36 - Corrected Net Thrust Versus Engine Pressure Ratio

Dependent Variable (SFCR)			
Independent Variable (FNR)			
Number of Facilities	7		
Degree of Polynomial	3		
$\overline{N}$	17		
Levels of Independent Variable	23.0	34.0	45.0
Dependent Variable avg. at each level calculated from equation of line through each facility	22.59	22.17	22.76
MAX of Dependent Variable at each level	23.05	22.54	23.04
MIN of Dependent Variable at each level	22.26	21.90	22.50
Range (MAX - MIN)	0.79	0.64	0.54
Range as a % of Dependent Variable at each level	3.50	2.89	2.37
Dependent Variable Standard Deviation at each level (S)	0.2848	0.2343	0.2106
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0595		
$S_p / \sqrt{N}$	0.0144		
Corrected S (S_{Corr})	0.2844	0.2338	0.2101
2 [S_{Corr}] as a % of the Dependent Variable	2.52	2.11	1.85

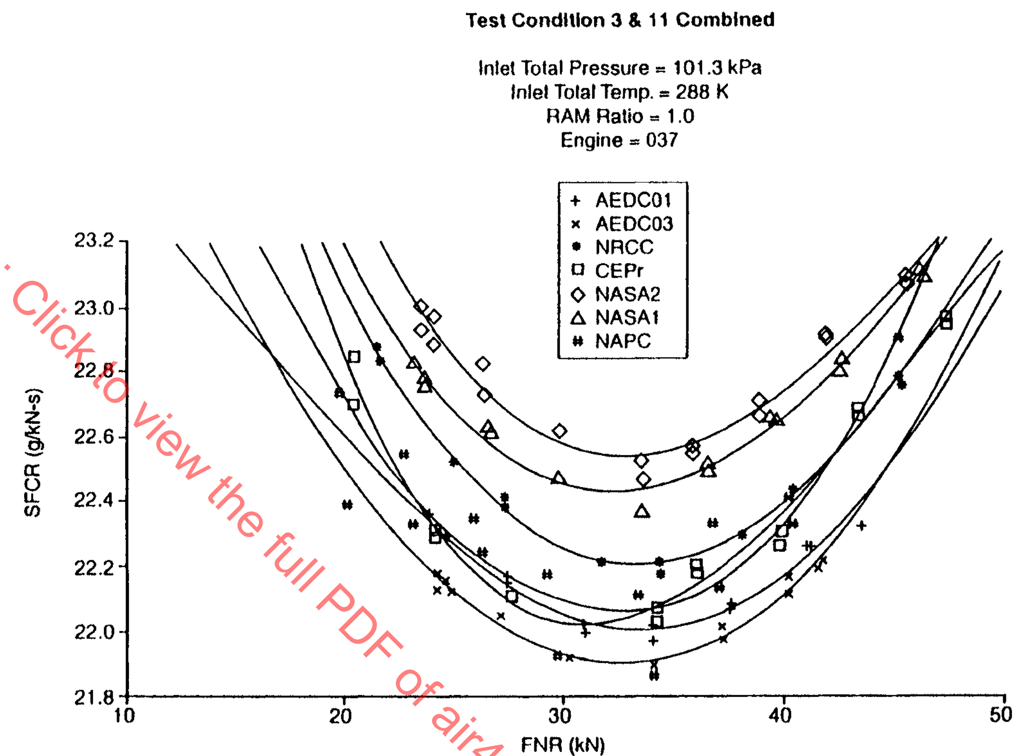


FIGURE D37 - Corrected Specific Fuel Consumption Versus Corrected Net Thrust

Dependent Variable (WA1R)			
Independent Variable (NLR)			
Number of Facilities	7		
Degree of Polynomial	3		
$\overline{N}$	17		
Levels of Independent Variable	4950	5400	5900
Dependent Variable avg. at each level calculated from equation of line through each facility	56.10	65.32	74.64
MAX of Dependent Variable at each level	56.55	65.99	75.58
MIN of Dependent Variable at each level	55.43	64.49	73.64
Range (MAX - MIN)	1.12	1.50	1.94
Range as a % of Dependent Variable at each level	2.00	2.30	2.60
Dependent Variable Standard Deviation at each level (S)	0.4329	0.4861	0.6183
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1700		
$S_p / \sqrt{N}$	0.0412		
Corrected S (S_{Corr})	0.4309	0.4844	0.6169
2 [S_{Corr}] as a % of the Dependent Variable	1.54	1.48	1.65

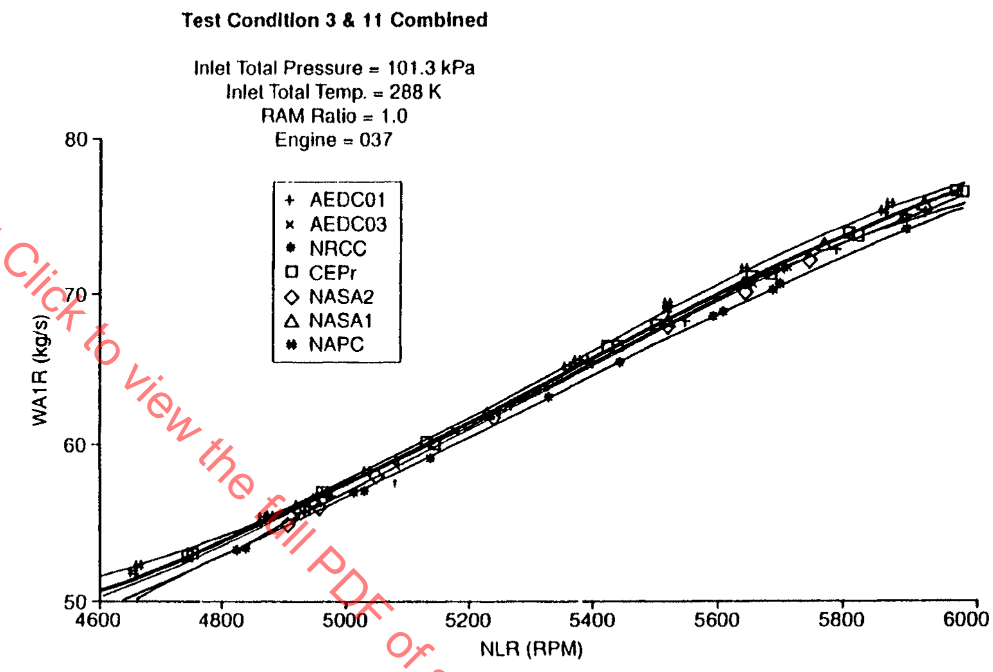


FIGURE D38 - Corrected Engine Airflow Versus Corrected Low Pressure Compressor Speed

Dependent Variable (WA1R)			
Independent Variable (P5/P2)			
Number of Facilities	7		
Degree of Polynomial	2		
$\overline{N}$	17		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	58.41	66.70	73.63
MAX of Dependent Variable at each level	59.24	67.65	74.48
MIN of Dependent Variable at each level	57.83	66.12	72.93
Range (MAX - MIN)	1.41	1.53	1.55
Range as a % of Dependent Variable at each level	2.41	2.29	2.11
Dependent Variable Standard Deviation at each level (S)	0.5080	0.5515	0.6215
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.1746		
$S_p / \sqrt{\overline{N}}$	0.0423		
Corrected S (S_{Corr})	0.5062	0.5499	0.6201
2 [S_{Corr}] as a % of the Dependent Variable	1.73	1.65	1.68

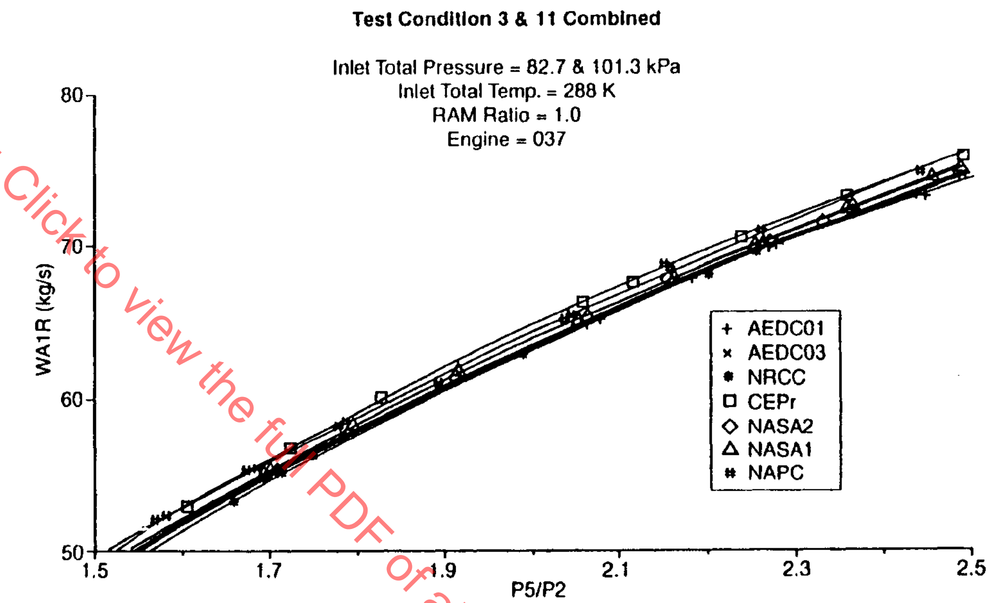


FIGURE D39 - Corrected Engine Airflow Versus Engine Pressure Ratio

Dependent Variable (T7/T2)			
Independent Variable (P5/P2)			
Number of Facilities	7		
Degree of Polynomial	2		
$\overline{N}$	17		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	2.41	2.63	2.87
MAX of Dependent Variable at each level	2.43	2.64	2.89
MIN of Dependent Variable at each level	2.39	2.60	2.83
Range (MAX - MIN)	0.04	0.04	0.06
Range as a % of Dependent Variable at each level	1.79	1.56	2.27
Dependent Variable Standard Deviation at each level (S)	0.0168	0.0176	0.0259
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0049		
$S_p / \sqrt{\overline{N}}$	0.0012		
Corrected S (S_{Corr})	0.0168	0.0176	0.0258
2 [S_{Corr}] as a % of the Dependent Variable	1.39	1.34	1.80

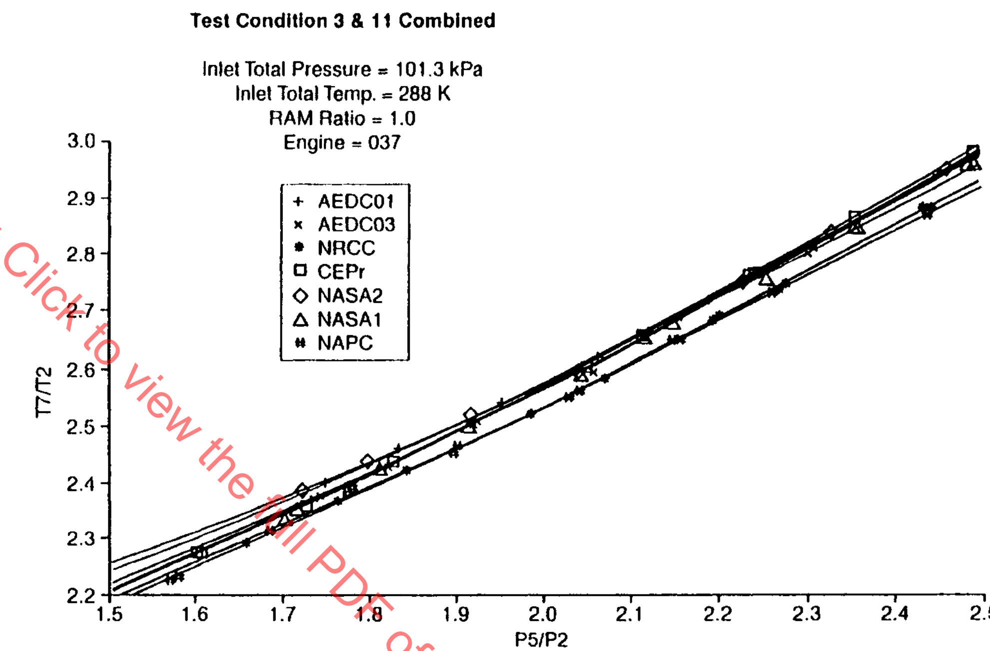


FIGURE D40 - Engine Temperature Ratio Versus Engine Temperature Ratio

Dependent Variable (SFCR)			
Independent Variable (P5/P2)			
Number of Facilities	7		
Degree of Polynomial	3		
$\overline{N}$	17		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	22.34	22.19	22.70
MAX of Dependent Variable at each level	22.74	22.55	22.98
MIN of Dependent Variable at each level	22.05	21.92	22.43
Range (MAX - MIN)	0.69	0.63	0.55
Range as a % of Dependent Variable at each level	3.09	2.84	2.42
Dependent Variable Standard Deviation at each level (S)	0.2592	0.2301	0.2055
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.0590		
$S_p / \sqrt{N}$	0.0143		
Corrected S (S_{Corr})	0.2588	0.2297	0.2050
2 [S_{Corr}] as a % of the Dependent Variable	2.32	2.07	1.81

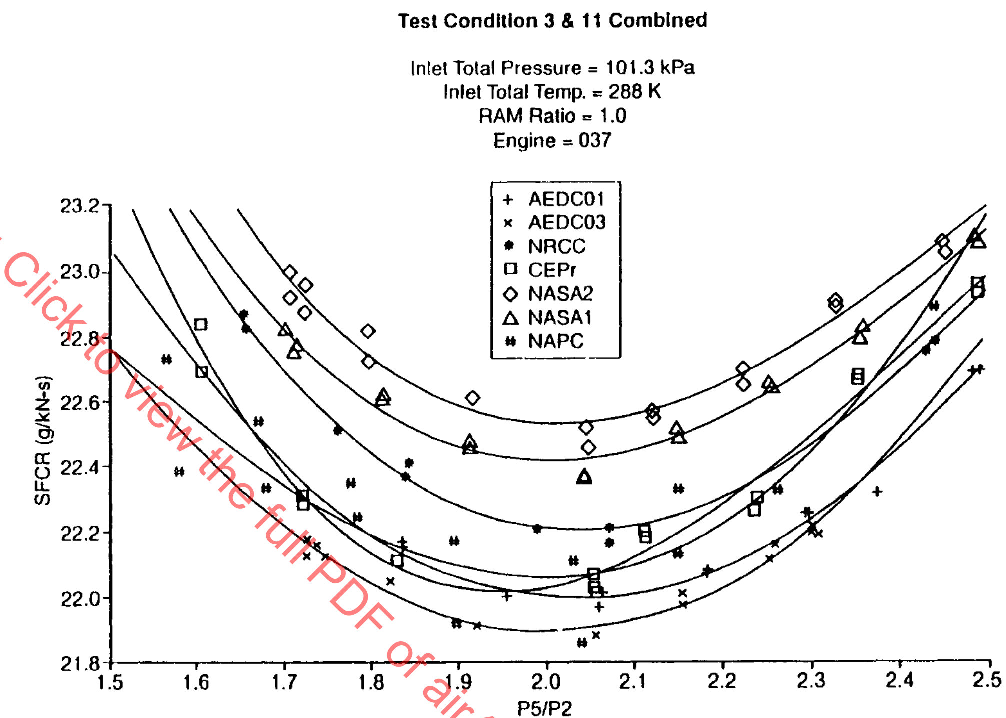


FIGURE D41 - Corrected Specific Fuel Consumption Versus Engine Pressure Ratio

Dependent Variable (WFR)			
Independent Variable (P5/P2)			
Number of Facilities	7		
Degree of Polynomial	2		
$\overline{N}$	17		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	588.64	785.33	1002.93
MAX of Dependent Variable at each level	598.80	794.90	1015.40
MIN of Dependent Variable at each level	583.00	776.00	990.90
Range (MAX - MIN)	15.80	18.90	24.50
Range as a % of Dependent Variable at each level	2.68	2.41	2.44
Dependent Variable Standard Deviation at each level (S)	5.8292	6.8514	8.7897
Pooled Std. Error of est. (for equations through each facility) (S_p)	2.4357		
$S_p / \sqrt{\overline{N}}$	0.5909		
Corrected S (S_{Corr})	5.7992	6.8259	8.7698
2 [S_{Corr}] as a % of the Dependent Variable	1.97	1.74	1.75

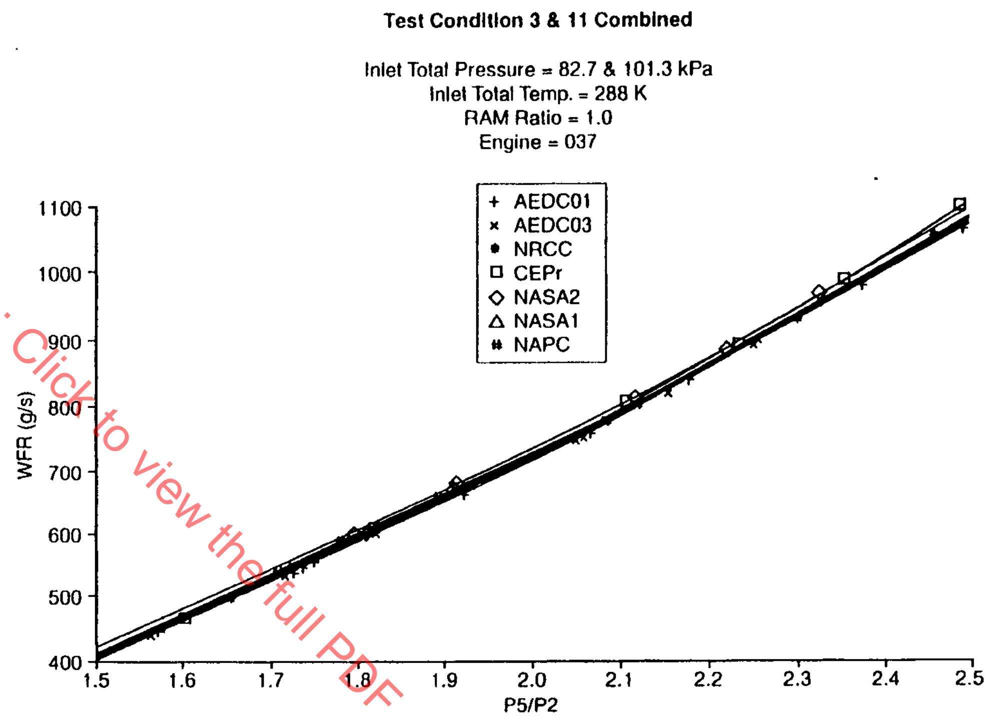


FIGURE D42 - Corrected Engine Fuel Flow Versus Engine Pressure Ratio

Dependent Variable (FNR)			
Independent Variable (P5/P2)			
Number of Facilities	8		
Degree of Polynomial	2		
$\overline{N}$	17		
Levels of Independent Variable	1.8	2.1	2.4
Dependent Variable avg. at each level calculated from equation of line through each facility	26.26	35.24	44.13
MAX of Dependent Variable at each level	26.73	35.70	44.71
MIN of Dependent Variable at each level	25.31	34.38	43.50
Range (MAX - MIN)	1.42	1.32	1.21
Range as a % of Dependent Variable at each level	5.41	3.75	2.74
Dependent Variable Standard Deviation at each level (S)	0.4295	0.3956	0.3756
Pooled Std. Error of est. (for equations through each facility) (S_p)	0.2864		
$S_p / \sqrt{\overline{N}}$	0.0697		
Corrected S (S_{Corr})	0.4238	0.3894	0.3691
2 [S_{Corr}] as a % of the Dependent Variable	3.23	2.21	1.67

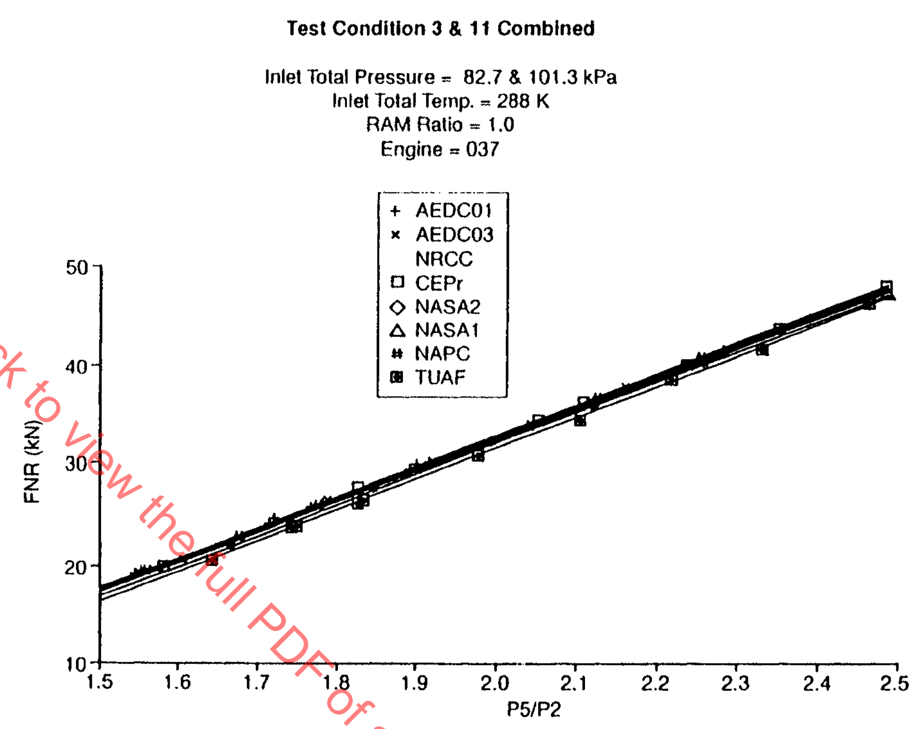


FIGURE D43 - Corrected Net Thrust Versus Engine Pressure Ratio