AEROSPACE RECOMMENDED PRACTICE	ARP741™	REV. D
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Turbofan and Turbojet Gas Turbine Engine Test Cell Correlation

RATIONALE

Revised to include some background into the design of a typical thrust measurement system, some background on the center line pull technique (why and how), and to discuss conditions where a center line pull may not be required.

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1. SCOPE

1.1 General

This SAE Aerospace Recommended Practice (ARP) describes a recommended practice and procedure for the correlation of test cells that are used for the performance testing of turbofan and turbojet engines. Test cell correlation is performed to determine the effect of any given test cell enclosure and equipment on the performance of an engine relative to the baseline performance of that engine. When baseline testing is performed in an indoor test cell, the baseline performance data are adjusted to open air conditions. Although no original equipment manufacturer (OEM) documents are actually referenced, the experience and knowledge of several OEM's contributed to the development of this document. Each engine Manufacturer has their own practices relating to correlation and they will be used by those OEMs for the purpose of establishing certified test facilities.

1.2 Beneficiaries

This ARP will benefit the OEM, commercial users, repair stations and military depots as well as intermediate level maintenance activities. Specific cases in which the information contained herein will be beneficial are:

a. As an aid for providing correlation of test cell data between engine and airframe companies supporting commercial and military requirements.

b. As an aid for providing military maintenance facilities and commercial repair stations a method by which to correlate test cells.

c. As an aid in establishing correlation practices for new test cells, for updating, and maintaining existing test cells.

d. As an aid to an engine manufacturer's facility in correlation of test cells used for engine development and acceptance in accordance with the applicable engine model specification.

1.3 Limitations

Known methods of determining test cell correlation factors include, but are not limited to, the following:

a. Momentum balance (analytical).

b. Back-to-back.

c. Cross-cell.

d. Airflow correlation.

e. Correlation engine.

The "correlation engine" procedure is the recommended and most common method for the correlation of an engine test cell. This ARP is limited to the discussion of this one method.

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 International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR5026 Test Cell Instrumentation

ARP4755 Turboshaft/Turboprop Gas Turbine Engine Test Cell Correlation

ARP4990 Turbine Flowmeter Fuel Flow Calculations

ARP5435 APU Gas Turbine Test Cell Correlation

ARP5758 Trend Analysis for Maintaining Correlation of Gas Turbine Engine Test Cells

ARP6028 Configuration Control for Maintaining Correlation of Gas Turbine Engine Test Cells

ARP6196 Gas Turbine Engine Test Facility Audit Process

Webb, W., "A Forward Look at Gas Turbine Testing Facilities," SAE Technical Paper 801124, 1980, https://doi.org/10.4271/801124.

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

Annual Book of ASTM Standards, Section 5: Petroleum Products, Lubricants, and Fossil Fuels. Volumes 05.01, 05.02, and 05.03.

2.1.3 AGARD Publications

Available from Advisory Group of Aerospace Research and Development (AGARD), https://www.sto.nato.int/.

AGARD-AG-269 Air-Breathing Engine Test Facilities Register

AGARD-AG-307 Measurement Uncertainty within the Uniform Engine Test Programme

AGARD-AR-248 Propulsion and Energetics Panel Working Group 15 on the Uniform Engine Test Programme

AGARD-LS-132 Operation and Performance Measurement on Engines in Sea Level Test Facilities

AGARD-LS-169 Comparative Engine Performance Measurements

2.1.4 AIAA Publications

Available from American Institute of Aeronautics and Astronautics, 1801 Alexander Bell Drive, Suite 500, Reston, VA 20191-4344, Tel: 703-264-7500, www.aiaa.org.

AIAA-88-3020 Comparability Tests in the International Turbine Engine Test Facilities

2.1.5 U.S. Air Force Publications

AEDC-TR-73-5 Handbook: Uncertainty in Gas Turbine Measurements

TO 33DA-6-261 Test Cell Correlation Set Technical Manual: Operation, Maintenance, and Parts Breakdown

2.2 Definitions

AIRFLOW CORRELATION: A method which uses cell airflow to calculate the thrust corrections required to determine a correlation factor.

BACK-TO-BACK: A test performed with the same engine before and after a modification to the facility or associated equipment.

BASELINE FACILITY: A facility designated as the standard for certification of an engine.

CALIBRATION: The comparison of a particular instrument or system with a standard of known accuracy.

CORRELATION: The comparison of engine performance parameters measured on a common engine tested in two test facilities, where one facility is the reference.

CORRELATION ENGINE: An engine of known and repeatable performance used for test cell correlation.

CORRELATION FACTOR: A multiplier or delta used where appropriate to adjust for the difference in performance between the customer facility and a reference facility, also known as a “correction factor” or a “facility modifier.”

CROSS-CELL: The comparison of engine performance parameters measured on a common engine, which is not necessarily a correlation engine, in at least two previously correlated test cells for the purpose of checking facility correlation of a third test cell.

CUSTOMER FACILITY: The test facility which is to be correlated against the reference facility.

ENGINE DRESS KIT: Typically consists of an engine mounted nacelle, aerodynamic hardware, accessories, and test instrumentation required to permit operation of the engine in the test cell. This kit may or may not include QEC items.

FREE FIELD TEST: An engine test performed on an outdoor test stand to determine the baseline performance of the engine.

INDOOR TEST CELL: A facility for the testing of gas turbine engines in a restricted environment.

MOMENTUM BALANCE: An analytical method used to compute the correlation factor using the difference in airflow momentum measured upstream and downstream of the engine.

OUTDOOR TEST STAND: An open air facility, without any enclosure, for testing engines.

QUICK ENGINE CHANGE (QEC) KIT: May include a nacelle or cowling set with engine driven and required aircraft accessories or hardware installed on the engine for faster engine removal and installation on the aircraft.

REFERENCE FACILITY: A test facility of known performance, traceable to the designated baseline facility, against which the customer’s facility is compared.

TEST FACILITY (TEST CELL): An area in which a gas turbine engine is operated to determine its performance and other information as required by a given test.

3. FACTORS AFFECTING CORRELATION

The following factors may affect the correlation of an engine test cell:

a. Configuration of the test cell, particularly the primary and secondary inlets, augmenter tube and exhaust stack configurations.

b. Engine position in the test cell.

c. Ambient conditions and surrounding buildings and their configurations, and topographic characteristics.

d. Instrumentation: calibration, location, measurement accuracy, and quantity.

e. Test cell thrust measurement system.

f. Propulsion system test configuration.

g. Testing procedures.

h. Data acquisition system.

i. Fuel properties.

j. Engine dress kit.

k. Total cell airflow.

4. PERFORMANCE MEASUREMENTS

4.1 General

The primary function of the engine test facility is to obtain proper performance evaluation of an engine. The test facility and test configuration must provide a stable test environment conducive to smooth surge-free operation of the engine.

All test facilities create an environment which influences the data obtained during testing. This is particularly true of indoor ground level test cells. In addition, the engine test configuration, including the engine dress kit, influences the data taken during testing.

Variation in test facilities and engine test configurations cause differences in measured engine performance. The test cell correlation provides the means to quantify these differences, to understand them, to reduce them whenever possible, and to establish the appropriate cell correlation factors.

4.2 Performance Parameters

A variety of engine performance parameters should be examined in the process of test cell correlation. This list may include, but is not limited to:

a. Engine fuel flow.

b. Engine thrust.

c. Engine speeds.

d. Engine airflows.

e. Engine pressures and temperatures.

f. Engine inlet conditions.

g. Test cell temperatures and pressures.

h. Test cell inlet airflow.

i. Vibrations.

4.3 Instrumentation Calibration

The engine test facility is an article of test equipment and as such requires appropriate design and calibration of measurement systems.

The importance of proper calibration of the test cell and its instruments cannot be overemphasized. This procedure firmly establishes the accuracy of the individual instrument and system measurements. Rather than accept the reading of an instrument, it is essential to make a calibration check to verify the validity of the measurements.

In most cases, an end-to-end calibration of a measurement system is better than removing an instrument from the test cell and calibrating it in an instrument shop. However, periodic calibration of individual instruments, either performed in place or in the instrumentation shop is necessary. For example, a pressure measurement may be affected by a leak or liquids in a pressure line; electrical measurements may be disturbed by noise, or by wiring flaws; liquid flowmeters are affected by turbulence in the liquid. Many such conditions can be detected during calibration, and should be corrected before the final calibration curves are established.

4.3.1 Hierarchy/Secondary Standards

In the U.S., the National Institute of Standards and Technology (NIST) has the primary responsibility for maintaining the standard units of length, mass, time, temperature, and electrical quantities. Other nations have comparable standards bodies. Instruments used as transfer standards should have calibrations traceable to a national standard.

Common practice requires a secondary or transfer standard be at least four times more accurate than the instrument being calibrated. With the development of electronic equipment, it is increasingly difficult to achieve this hierarchy of secondary standards. In any case the transfer standard should be substantially more accurate than the working instrument.

4.3.2 Traceability

Traceability establishes the calibration hierarchy for a particular measurement. It identifies all possible error contributions between the test facility measurement system and the national standard. Traceability does not reduce the uncertainty of a measurement; it simply documents the process of its determination. Documentation of the instrument and test cell calibrations and hierarchy should be established and maintained.

4.4 Thrust Calibration

Measurement of the thrust created by the engine on test is usually critical to the evaluation or declaration of performance. Thrust is a primary performance parameter for most aero engines in thrust or gas generator configurations and is also important as a secondary measurement when using other parameters such as engine pressure ratio (EPR) and spool speeds as the primary parameters.

The most common method of engine thrust measurement uses a frame fixed firmly to the test cell structure. To this is mounted a moveable or “floating” frame, to which the engine is securely mounted. Load cells transmit the thrust between the two frames and hence measure the force generated by the engine translated to the measurement plane.

The usual method of calibration of force measurement is to introduce secondary calibration load cell(s) (also referred to as proving or transfer standard cells). This method is often known as an in-frame calibration. During engine operation the transfer standard load cell is not in contact with the frame and not in use, but during a calibration/audit a system of rams applies a range of forces mimicking the engine thrust, and the outputs from the transfer standard load cell(s) used to determine the relationship and transfer the calibration to the working load cells. For more detail on the design and operation of thrust measurement systems and in-frame calibration, refer to AIR4951.

Unfortunately, even in a perfect thrust measurement system (TMS), the force measured in the measurement plane in the TMS is not an absolute measurement of engine thrust. Several factors are at play, the key ones being:

a. The moment caused by the difference in height of the engine thrust line and the load cell location.

b. The stiffness of the thrust stand suspension system and engine service connections.

c. The bending of the thrust stand, frame, and engine mountings.

The relationship between the force measured by the TMS and actual thrust generated by the engine in the cell can be assessed and calibrated using a combination of methods—e.g., correlation against a known reference cell, mathematical analysis, and center line pull (CLP).

Correlation (as described in this document) is the typical method used to determine the relationship between the force measured by the TMS and actual thrust generated by the engine.

As its name suggests, the CLP technique simulates the engine thrust by applying a force at the engine center line to mimic engine thrust. This method is typically used when correlation is not applicable, or in addition to correlation as risk mitigation. For CLP, a dummy engine of representative mass is mounted to the TMS and a string of rods and hydraulic cylinders used to apply a force. A calibrated load cell in the string measures the actual force applied, which can be used to determine the relationship between actual thrust and TMS measured force. For more detail on the CLP technique, refer to AIR4951.

In all cases, if the measurement of thrust is important, a mathematical analysis of the TMS measurement uncertainty (AIR4951) is recommended.

4.5 Factors Affecting Performance Measurement

To compare performance parameters between various facilities or various conditions within the same test facility, it is necessary to correct the parameters to common reference conditions. These reference conditions fall into three groups:

a. Ambient (humidity, temperature, and pressure).

b. Fuel properties (density, viscosity and lower heating value).

c. Aerodynamic (ram pressure ratio and cell bypass airflow interaction).

4.5.1 Humidity

It is recognized that high humidity levels will affect the performance of gas turbine engines, although no consensus exists on how to account for the effects. Water vapor contained in the air will have several influences on the engine and its performance. Although the consequences are complex, they fall into two major categories: condensation and changes in gas properties. While the relative humidity controls the extent of inlet condensation, it is the absolute or specific humidity which affects the gas properties of the engine cycle, and hence the performance elements.

Actual condensation in an engine inlet depends on a series of factors, such as relative humidity, air temperature and pressure, inlet Mach number, dwell time and air cleanliness. At a given humidity, the probability for condensation is higher in long inlet ducts and lower in bellmouth intakes. High inlet Mach numbers can result in inlet condensation at lower relative humidity.

For most performance parameters, the humidity corrections have been found to be small. However, when evaluating differences between engine or component configurations, these humidity corrections can be important. To minimize humidity effects during correlation, some test facilities and engine manufacturers choose to impose humidity limits when testing an engine model.

4.5.2 Engine Inlet Temperature and Pressure

Gas turbine engines are affected by the ambient conditions in which they operate. Engine operation and correlation can be affected by inlet temperature distortion or gradient due to exhaust gas recirculation or other sources of heat. This gradient should be minimized by modifications to the test cell and engine test configuration. An individual engine project should determine its own inlet temperature profile limits for acceptability, and if there are questions or concerns the engine OEM should be contacted for guidance.

It is usually not possible to control the engine inlet air temperature and pressure to standard day values; therefore, to compare one engine run to another, the measured engine performance parameters must be adjusted to the values which they would have with standard day inlet air. This process is called making standard day corrections.

Since the methods for making standard day corrections vary between engine types and models, the procedures to correct these parameters are contained in the specification, technical order, or engine (overhaul) manual for particular engines. Certain primary operating variables of gas turbines are normalized as functions of total temperature and total pressure at the engine inlet. The basic normalizing parameters are:

θ (theta) = (observed inlet total absolute temperature)/(absolute temperature of ISO sea level standard day reference atmosphere)

δ (delta) = (observed inlet total absolute pressure)/(absolute pressure of ISO sea level standard day reference atmosphere)

NOTE: These ratios require the use of consistent units and absolute values; i.e., temperatures in Kelvin or degrees Rankine, pressures in psia, in-HgA, or kPa, respectively.

Some gas turbine engines are referenced to conditions other than ISO standard day values. Refer to the applicable model specification, technical order, or engine manual for pertinent information.

The correction or normalizing of the major engine performance parameters requires the use of θ and δ as follows:

a. Rotor speed, N, is normalized when divided by θ^x, i.e., N/θ^x, where x is dependent on the engine type and defined by the manufacturer (commonly 0.5 is used).

b. Thrust, F, is normalized when divided by δ, i.e., F/δ.

c. Airflow rate, W_a, is normalized when multiplied by $\sqrt{\theta}/\delta$, i.e., $W_a\,(\theta/\delta)$^0.5.

d. Fuel flow rate, W_f, is normalized when divided by $\delta\theta^y$, i.e., $W_f/\delta\theta^y$, where y is dependent on the engine type and defined by the manufacturer (typical values of y range from 0.5 to 0.7).

e. Engine cycle total temperatures (e.g., T_3, T_4, T_5, T_7) are normalized when divided by θ^z, i.e., T_5/θ^z, where z is dependent upon the location within the engine and the engine type. Z is usually defined by the engine manufacturer (typical values of z range from 0.85 to 1.1).

f. Engine cycle total pressures (e.g., compressor discharge, turbine discharge, nozzle exit, etc.) are normalized when divided by δ, i.e., P_3/δ.

4.5.3 Fuel Properties

Experience has shown that fuel purchased to a particular specification from a single supply source maintains reasonably stable fuel properties. However, fuels obtained from various sources, even when purchased to the same specification, can vary by several percent.

When comparing fuel property data taken from different sources, the differences must be taken into consideration.

4.5.3.1 Fuel Density

The relative density, also referred to as specific gravity, of the fuel enters the flow calculation as a first order correction, and is, therefore, of prime importance when using volumetric flow measurement devices (such as turbine flowmeters). The establishment of relative density takes place in two steps: (1) the evaluation of the relative density at a given reference temperature, and (2) the correct assessment of the relative density at the temperature of the fuel, at the point of flow measurement. The relative density is determined at the reference temperature, usually 60 °F or 15.56 °C, and then corrected to the actual fuel temperature, using either a graph or an empirical equation. The relative density is a direct multiplier on the fuel flow, therefore any error in the former will be transferred to the latter. Refer to ARP4990 for additional guidance on the use of turbine flowmeter corrections for density.

4.5.3.2 Viscosity

Depending upon the type of fuel flow measuring device utilized, the viscosity of the fuel can play a role in the calibration of that device. A turbine flow meter that is calibrated for JP4, for instance, would have a significantly different calibration for JP5 because of its higher viscosity. Temperature also has a strong effect on viscosity and must be accounted for when using turbine flow meters to measure fuel flow. Refer to ARP4990 for additional guidance on the use of turbine flowmeter corrections for viscosity.

4.5.3.3 Fuel Lower Heating Value

Analysis of the fuel lower heating value (LHV) can usually be obtained from the supplier. In many cases, the fuel LHV can be calculated with acceptable accuracy from a measurement of the aniline point of a fuel sample, which requires a minimum of laboratory equipment. A more accurate fuel LHV may be determined by use of a precision bomb calorimeter.

The fuel flow measurements are typically corrected to a common fuel LHV base by applying the direct ratio of the LHV used to the LHV of the engine model specification, or of the baseline test fuel LHV.

4.5.4 Ram Pressure Ratio

The ram pressure ratio is defined as the engine inlet total pressure divided by the final nozzle exit static pressure. The airflow in the cell causes pressure differences between the front and the rear of the engine. The result is equivalent to “flying” the engine at some low forward velocity. This relative velocity generates a ram pressure ratio, and thus the engine cycle is altered slightly and the thrust produced is affected. Since the main objective of test cell engine runs is the determination of performance corrected to standard conditions, the effects of the ram pressure ratio must be measured and documented, either separately or in the thrust correlation factor.

4.5.5 Cell Bypass Airflow Interactions

When a gas turbine engine is operated in an indoor test cell, its performance is altered because of the aerodynamic interference between the engine and the cell. To establish the thrust of the engine, this interaction must be evaluated.

Aerodynamic thrust corrections result from flow-induced forces within the test cell and may be divided into three components:

a. Inlet momentum drag.

b. Structural drag on the engine and thrust stand.

c. Static pressure drag along the engine.

4.5.5.1 Inlet Momentum Drag

The most significant aerodynamic component of the thrust measurement is the inlet momentum, also known as the intrinsic inlet momentum, which produces a force on the engine as a result of drawing air into the test cell. For static engine testing, the magnitude of this force may be substantial; values from 1 to 10% of the measured thrust are typical. Since this force is, in effect, a drag term, it must be added to the measured thrust of the engine. The inlet momentum is a function of the engine airflow and the approach velocity in front of the engine, which is significantly affected by the amount of cell airflow and the geometry of the test cell.

4.5.5.2 Structural Drag

Structural drag is generated by the cell bypass airflow scrubbing the exposed surface area of the engine casing, and pushing against the exposed structure which supports the engine on the thrust measurement stand.

4.5.5.3 Static Pressure Drag

Local acceleration of cell bypass airflow results in static pressure gradients along projected surfaces of the engine, particularly the bellmouth and exhaust nozzle. These pressure gradients generate horizontal forces which affect the measured thrust of the engine. Static pressure drag is sometimes broken down into bellmouth drag and boat tail drag. The magnitude of the static pressure drag is very sensitive to the cell exhaust geometry and engine to exhaust system spacing.

4.5.6 Dress Kit Hardware

Engine dress kit hardware affects engine performance due to airflow and operational impact effects on the engine. Dimensional characteristics of the dress kit hardware (especially bellmouths, exhaust nozzles and fan cowling) will directly affect engine airflow and pressure ratios. In addition, dress kit hardware affects the cell bypass airflow interactions described in 4.5.5 through 4.5.5.3.

Changes in engine dress kit hardware may cause operational changes in engine performance. The same dress kit hardware used during a customer correlation test should be used for all subsequent tests of this engine model in that test cell. To ensure this, all parts of the customer's dress kit hardware should be recorded by part number and serial number along with appropriate area measurements.

If the customer owns several sets of engine dress kit hardware, it may be necessary to establish correlation factors for each engine/dress kit configuration. Once the initial customer cell correlation is complete, back-to-back tests using different dress kit hardware will establish if any change is necessary in correlation factor. Test configurations need to be documented by part number and serial number and matched to the appropriate correlation factor. If a customer purchases a new piece of engine dress kit hardware, a similar back-to-back test should be performed at that time to establish if the correlation factor needs to be changed.

4.5.7 Data Acquisition

Data acquisition techniques can affect engine performance measurements significantly, often in subtle ways. Prior to the utilization of computers, data was collected by visually reading and hand recording all measured parameters on a test log sheet. Many facilities now use high speed, computer driven data acquisition systems. Technology advancement has many advantages, but care in software design is essential if reliable and unbiased data are to be produced.

When a variation exists between data acquisition systems, special attention should be paid to cell to cell engine performance differences during the test cell correlation.

4.5.7.1 Scan Characteristics

Computer-operated data acquisition systems quickly scan hundreds of channels of data (e.g., temperatures, pressures, vibrations, resolver angles, etc.) in short, controlled bursts of repetitive signal collection within a short period of time. These bursts or frames of raw data are then averaged by the computer (see 4.5.7.2).

Whether data are manually or automatically recorded, the recording process or scanning takes a finite amount of time. With a rapid scan, the engine operating conditions change negligibly during a single scan period. With a slow scan, however, the sequence in which the parameters are recorded can influence the data quality due to time skew. This requires care in choosing the recording sequence and the parameter groupings.

The performance parameters of even a well-stabilized engine will oscillate slowly around a steady state average, due to the interaction of the engine control system and the engine hardware. One can visualize this oscillation as an approximate sine wave with a period lasting from fractions of a second to minutes.

In addition, the engine parameters drift slowly following any change in the engine's power setting, caused by temperature changes in various parts of the engine; this is sometimes referred to as thermal soak-in. Some parts of the engine change temperature more quickly than others, changing (for example) the turbine blade-to-shroud clearances. Thermal soak-in can take from a few minutes to sometimes over 15 minutes for complete thermal stabilization. Data acquisition should not be initiated before full thermal stabilization occurs.

At each power setting enough data should be taken over a long enough period so that with proper data editing the effects of engine oscillations can be averaged out. An ideal technique would be to record several points per engine cycle over an integral number of engine oscillations cycles; alternatively, one can average over a much larger number of engine cycles, so that the effect of an incomplete cycle is negligible.

Note that with some frequency measurement techniques, poor selections of scanning rates can reduce the accuracy of parameters which are measured by frequencies, such as rotor speeds.

4.5.7.2 Data Averaging and Editing

Data averaging and data editing are important functions in the correlation of a test cell. The goal of data editing is to discard erroneous data points and use only the correct (true) data measurements. So stated this goal is both prudent and desirable. On the other hand, one purpose of a correlation test is to try to find measurement problems in the test cell and to remedy them. When data editing is used, there is the risk that data showing a mis-measurement problem may be discarded as erroneous data. If this happens the opportunity to find and correct a measurement problem may be missed. Once a data acquisition scan rate methodology has been selected (see 4.5.7.1), an averaging technique must be determined. These averaged parameters are then used in the performance calculations. Several averaging techniques can be employed. A simple average of all collected data is commonly performed.

In many cases, in addition to averaging the data, a data editing procedure is used to produce the most representative data. Various editing methods include data tolerances, minimum and maximum limits, and a wild reading test (an outlier test). Editing tolerances are especially useful on multiple pressure readings (e.g., bellmouth static or total pressures) where line leaks can affect the validity of the data.

Special caution should be employed on applying editing tolerances to parameters such as torque, fuel flow, and measured gas temperatures, where editing might mask engine stability problems. In any editing method, all measurements should be displayed and deleted data should be flagged so that miss-measurements can be corrected at a convenient time.

Different averaging techniques can produce different results, especially if the engine cycles significantly or if the data were acquired before full thermal stabilization. Therefore, averaging methodology must be carefully considered when correlating a test cell utilizing different averaging techniques on engine data.

4.6 Software Verification

Computer software may be used to control test cell data acquisition and/or common reference conditions. It is necessary to examine this software to make sure that:

a. The correct software program is used.

b. The correct version or revision to the software program is used (usually the latest version).

c. The computer is performing the calculation/operations properly.

d. For a given input, the reference and customer facility produce the same output.

5. DESIGNATION OF BASELINE AND REFERENCE FACILITIES

5.1 General

Correlations relate engine performance back to a known standard. The performance level of other engines later tested in the customer facility can therefore be compared with established limits. These limits are derived from a performance baseline for a particular engine model. Such a baseline performance standard is usually the average of a number of engine tests as established by the engine manufacturer. It is defined for a specific engine test hardware configuration and test facility, becoming the baseline reference test hardware configuration and test facility for that engine model type.

5.2 Identification of a Suitable Reference Facility

In order to conduct a successful correlation program, it is first necessary to identify a suitable reference facility. This may be either an indoor or outdoor facility.

It is desirable to use the manufacturer's baseline facility as the reference for correlation tests. Where access to the baseline facility is not possible, another facility is normally designated as the reference once suitability and traceability to the baseline has been established.

A non-traceable correlation hierarchy will make substantiation of the reference facility difficult.

5.2.1 Alternative Reference Facilities

It may be necessary to use a facility other than an established reference facility for a correlation. This is acceptable providing the proposed facility has been correlated directly to a reference facility, thus ensuring traceability of performance back to the baseline facility.

Any modifications to an alternative reference facility that are likely to affect the correlation will require full re-correlation of that facility to the baseline facility before it can be reestablished as a suitable reference facility.

5.3 Uncertainty Stack-Up

If the reference facility is not used for testing in a correlation, an analysis of the stack-up of uncertainty should be performed for each correlation between the baseline and the customer facility. The customer's facility correlation will be satisfactory if the uncertainty is shown to be smaller than the required tolerance (see references for uncertainty stack-up, e.g., AEDC-TR-73-5).

5.3.1 Reducing Uncertainty

With each step away from the baseline test facility, the uncertainty about test facility accuracy tends to increase. There are measures that may be used to increase the confidence in the correlation and reduce uncertainty to the acceptable level. Such measures may include the cross-cell method (2.2), trending (9.3.1), and periodic checks (9.3.2).

5.4 Engine Test Hardware Configuration for Reference Testing

As stated in 5.1, correlation relates an engine's performance back to a known reference standard for a specific engine model type. Such a reference standard is defined not only for testing in a specific facility or facilities, but also for a specific engine test hardware configuration.

As with facilities, the engine's baseline configuration and the reference configuration may or may not be the same for a specific engine model. One or the other should be considered the prime test hardware configuration for a correlation reference unless a specific exception can be justified. The same rules apply to facilities when alternative reference configurations are being considered; that is, the proposed test hardware configuration is correlated directly to the reference or baseline configuration.

For correlation purposes, engine configuration is defined as the associated hardware necessary for performance testing an engine, primarily the engine cowling, fairing or pylon, exhaust nozzle, and bellmouth.

6. REFERENCE TEST

6.1 General

It is necessary to establish and follow a reference testing procedure to ensure consistent and standard test cell correlations. The following elements are essential to that procedure:

a. Establish appropriate dialogue between the involved parties.

b. Ensure test cell suitability for the correlation at hand.

c. Identify an acceptable engine.

d. Ensure valid calibration of all test cell instruments.

e. Make the reference facility engine performance test(s).

f. Ship the engine, with the necessary performance data for a valid analysis, to the customer facility.

6.2 Preparation and Engine Running

6.2.1 Establishing Appropriate Dialogue

Before commencing any part of the correlation exercise the interested parties need to clearly communicate the objectives of the exercise, the requirements involved and the sequence of events. The parties will normally be the reference facility and the customer facility personnel but may also include others, e.g., test cell contractor or regulatory authority personnel.

6.2.2 Ensuring Test Cell Suitability

The reference facility to be used for the exercise must be appropriate to the task at hand. If it is not a baseline facility for the type of engine to be run, it must have been correlated, directly or indirectly, with a baseline facility. Section 5 gives further information on reference facility requirements.

6.2.3 Identifying an Acceptable Correlation Engine and Dress Kit Configuration

An engine configured and instrumented for performance testing should be selected specifically for the correlation program. The engine must be capable of safely achieving minimum take-off thrust and be stable in its performance across the entire corrected thrust range (idle to takeoff). It need not be new, but must be of such condition that the performance stability is sustained during the entire correlation exercise.

The dress kit should be that belonging to and used by the reference facility. Its parts should be identified and recorded.

6.2.4 Ensuring Validity of Calibration of Test Cell Instruments

The reference test cell instrumentation is required to be calibrated on a regular basis to prove continued serviceability and suitability. Section 4.3 details these requirements.

6.2.5 Reference Facility Engine Performance Test

To ensure consistent and repeatable engine testing, the proposed reference test sequence must be recorded. The procedure must address which test cell, engine and dress kit configuration are to be used. It must refer to or include a listing of what performance parameters are to be measured, to what precision, and over what ranges of speed or thrust.

The test cell must be correlated with an engine in the same configuration as it would be for the customer's routine testing. Part numbers and serial numbers should be recorded for all engine dress hardware.

The test cell instrumentation and data system must read and record at least the following items:

a. Engine fuel flow.

b. Engine thrust.

c. Engine rotor speeds.

d. Engine airflows (optional).

e. Engine pressures and temperatures.

f. Engine inlet air conditions.

g. Test cell temperatures and pressures.

h. Test cell inlet airflow (optional).

i. Vibrations.

j. Engine control parameters (optional; e.g., variable stator vanes, bleed valves, etc.).

Sufficient data must be obtained to document the performance of the engine. Secondary parameters used in the derivation of any of the above items must also be measured and recorded. A fuel sample should be taken during the test and accurately analyzed for LHV and density (specific gravity) values. In addition, redundant instrumentation can be useful for data verification and troubleshooting purposes.

The actual data obtained during the test must be recorded on a manual or automatic log sheet at the time of the test.

Reference testing may include seven to 15 performance points distributed across the engine thrust range. The sequence in which these are to be performed and the direction of approach for each (to avoid the effects of hysteresis) should be identified in the test procedure. Care should be taken to fully stabilize the engine thermally and dynamically before data acquisition is initiated (see 4.5.7.1). Stabilization times should be recorded so that they can be duplicated during future reference testing and during the customer facility correlation runs. It is desirable to minimize the differences in air inlet temperature and humidity between the reference facility test and the customer facility test.

6.2.6 Shutdown Period

Following an initial reference test, the engine should be shut down in order to reach a cool engine state for repeatability testing. Refer to the engine manufacturer's manuals for recommended cooling periods.

6.2.7 Repeating the Reference Test

After the shutdown period, the reference test should be duplicated to demonstrate repeatability of test engine performance and measurement systems.

If the engine is routinely used for correlations, the requirement for a second run at the reference facility may be waived. This should be permitted only if the data from the first test are consistent with test data from several previous runs in the same facility.

6.2.8 Correcting and Analyzing the Correlation Data

Once all reference tests are completed, the data must be reduced (i.e., calculations performed). Section 4.5.2 describes the process of correcting or normalizing the measured data to standard day conditions. The normalized data should then be plotted and a smooth characteristic curve (by manual or automatic means) should be drawn through the data points.

A data analysis should then be performed. Analysis should include the following two steps:

a. Data validation (i.e., instrumentation uncertainty isolation).

b. Performance shift determination.

Section 7.3 gives more detail of these analysis processes.

6.3 Shipping the Engine to the Customer Facility

Once the reference engine performance test(s) are complete, the engine should be immediately preserved and shipped to the customer facility in an appropriate manner.

7. TEST CELL CORRELATION (CUSTOMER FACILITY)

7.1 General

The following steps are followed in performing customer facility correlations:

a. Establish appropriate dialogue between the involved parties.

b. Ensure test cell suitability.

c. Calibrate all test cell instruments.

d. Implement pre-correlation procedure.

e. Perform a customer facility engine correlation run.

f. Shut the engine down for a cooling period and analyze data.

g. Repeat the correlation test.

h. Implement post-correlation procedure.

i. Normalize or correct the measured data to standard day conditions. Plot the data and draw a smooth characteristic line through the plotted points.

j. Analyze data for measurement error (i.e., data validation).

k. Analyze data for performance shift.

l. Determine cell correlation factors and apply them to the normalized data. Plot the adjusted normalized data.

7.2 Preparation and Engine Running

7.2.1 Establishing Appropriate Dialogue

The interested parties need to agree on the objectives of the exercise, the requirements involved and the sequence of events. The parties will normally be the reference facility and customer facility personnel, but may also include others such as the test cell contractor or regulatory authority personnel.

7.2.2 Ensuring Test Cell Suitability

An evaluation of the customer facility and its systems should be performed to confirm that the test cell construction and configurations are appropriate for their intended purposes. This evaluation intercepts and eliminates costly errors due to test cell incompatibility prior to the correlation attempt.

7.2.3 Calibrating the Instrumentation

All test cell and engine instrumentation should be calibrated back to the national standard on a regular and sufficiently frequent basis. In addition, it is recommended that a full instrument calibration take place just prior to correlation. The calibrations should include both gauge calibration and instrumentation system end-to-end calibration (see 4.3).

7.2.4 Pre-Correlation Procedure

Prior to the correlation engine run, the customer facility including the data system and calculation procedures should be thoroughly checked for correct and consistent operation. The test cell should be cleaned of any remaining debris, especially if recent construction or cell modifications have been performed.

A full “shakedown” run of all the systems should then be performed using a suitable engine, other than the correlation engine, in order to protect the integrity of the correlation engine. If the facility is a new test cell, the shakedown engine should be similar to the largest engine (i.e., highest thrust and engine airflow) planned for the test cell; otherwise, the shakedown engine and configuration should be similar, but not necessarily identical, to the correlation engine and its correlation configuration.

7.2.5 Performing the Correlation Procedure

Once the customer facility is thoroughly tested via the pre-checks and shakedown run, the formal correlation process can begin.

Just prior to commencing correlation testing a final inspection should be made of the dressed engine mounted in the test facility. Extreme care should be taken to ensure that any variables between the reference test and the customer test are minimized or justified. Part numbers and serial numbers should be recorded for all engine external cowling (e.g., QEC) and test facility engine mounted hardware such as bellmouths and exhaust nozzles. Part numbers and serial numbers should be recorded for all engine dress kit parts along with the appropriate area measurements.

The correlation procedure should mirror the reference test procedure in all aspects: in the number of test points; in the power settings; in the sequence and the direction of approach to the test points; in the stabilization time; and in the data recorded, etc. The test cell instrumentation and data system must read and record at least the following items:

a. Engine fuel flow.

b. Engine thrust.

c. Engine speeds.

d. Engine airflows (optional).

e. Engine pressure ratios and temperatures.

f. Engine inlet air conditions.

g. Test cell temperatures and pressures.

h. Test cell inlet airflow (optional).

i. Vibrations.

j. Engine control parameters (optional; e.g., variable stator vanes, bleed valves, etc.).

Sufficient data must be obtained to correctly document the performance of the engine. Secondary parameters used in the derivation of any of the above items must also be measured and recorded. A fuel sample should be taken during the test and analyzed for LHV and density (or specific gravity) values. In addition, redundant instrumentation can be useful for data verification and troubleshooting purposes.