SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP4755 REV. A

Issued 1994-03
Revised 2003-09
Reaffirmed 2007-11

Superseding ARP4755

Turboshaft/Turboprop Gas Turbine Engine Test Cell Correlation

TABLE OF CONTENTS

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: http://www.sae.org

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

1. SCOPE:

1.1 General:

This paper describes a recommended practice and procedure for the correlation of test cells that are used for the performance testing of turboprop and turboshaft engines. This Aerospace Recommended Practice (ARP) shall apply to both dynamometer and propeller based testing. 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.

1.2 Beneficiaries:

This ARP will benefit the original equipment manufacturer (OEM), commercial users, repair stations, 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 for 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 turboprop/turboshaft test cell correlation include, but are not limited to, the following:

a. Back-to-Back
b. Cross-Cell
c. Correlation Engine

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

2. REFERENCES:

2.1 Applicable Documents:

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

ARP741 Gas Turbine Engine Test Cell Correlation

2.1.2 ASTM Publications: Available from ASTM, 100 Barr Harbor, West Conshohocken, PA 19428-2959.

Annual Book of ASTM (American Society for Testing Materials) Standards, 1990. Section 5, Petroleum Products, Lubricants and Fossil Fuels. Volumes 05.01, 05.02, and 05.03.

2.1.3 Other Publications:

Advisory Group for Aerospace Research and Development (AGARD). 1984. Operation and Performance Measurement on Engines in Sea Level Test Facilities. AGARD-LS-132.

Advisory Group for Aerospace Research & Development (AGARD). 1989. Measurement Uncertainty Within the Uniform Engine Test Programme. AGARD-AG-307.

Advisory Group for Aerospace Research & Development (AGARD). 1990. Comparative Engine Performance Measurements. AGARD-LS-169.

Advisory Group for Aerospace Research & Development (AGARD). 1990. Propulsion and Energetics Panel Working Group 15 on the Uniform Engine Test Programme. AGARD-AR-248.

Rolls Royce Ltd. 1985. Approval of Engine Test Facilities. Rolls Royce Company Quality Control Report (CQC) No. 116.

The Aerospace Industries Division of Instrument Society of America. 1980. Measurement Uncertainty Handbook. AEDC-TR-73-5.

United States Air Force. 1984. Test Cell Correlation Set Technical Manual; Operation, Maintenance and Parts Breakdown. United States Air Force Technical Order (TO) 33DA-6-261.

2.2 Definitions:

The following list defines the terms and phrases used in this document:

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 the reference facility, also known as a "Facility Modifier" or "Correction Factor".

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 facility which is to be correlated against the reference facility.

DYNAMOMETER: An apparatus other than a propeller for absorbing the power produced by the engine being tested. This device may or may not have the ability to measure the amount of power produced. This definition includes, but is not limited to: waterbrake, air, electric, hydraulic or steam dynamometers.

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

FREE FIELD TEST: An engine test performed on an outdoor test stand.

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

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

OUTPUT SHAFT: The engine shaft connected to a loading device, e.g., a dynamometer or a propeller. In general, for a turboprop engine, it is the propeller shaft. For turboshaft engines, it is the shaft connecting the engine to the airframe load, e.g., the main gearbox for helicopter rotors.

2.2 (Continued):

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. Load absorption system configuration and characteristics (test propeller, or dynamometer and dynamometer to engine shafting)

f. Propulsion system test configuration

g. Testing procedures

h. Data acquisition system

i. Fuel properties

j. Waste heat or airflow generated by the dynamometer

k. The facility fans etc. which may be used to assist airflow thru the test cell

l. Engine power measurement system

m. External engine bypass air flow

n. Engine dress kit

4. PERFORMANCE MEASUREMENTS:

4.1 General:

The primary function of the engine test facility is to obtain a 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. The propeller or dynamometer must provide adequate power absorption to control the engine in a stable operating condition.

All test facilities create an environment which may influence the data obtained during testing. In addition, the engine test configuration including the engine dress kit may influence the data taken during testing.

Variations in test facilities and engine test configurations may 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 output shaft torque
c. Engine output shaft speed
d. Other engine rotor speeds
e. Engine airflows
f. Engine pressures and temperatures
g. Engine inlet conditions
h. Test cell temperatures and pressures
i. Test cell inlet airflow
j. 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.

4.3 (Continued):

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 United States of America 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 work 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 Torque Measurement/Calibration:

4.4.1 Propeller Test Stand: Engine torque in tests with a propeller is normally measured by the engine torque sensing system if so equipped. In addition, propeller test stands often incorporate a torque measurement system where the engine is mounted on a torque or thrust reacting cradle and measured by a load cell.

Prior to correlation, laboratory calibration of the load cell and static calibration of the torque measuring system should be performed.

4.4.2 Dynamometer Test Stand: Engine torque in tests with a dynamometer is measured by provisions built into the dynamometer or by an "in-line" torque measurement device in the drive shafting between the engine and the dynamometer. Drive shafting, pedestal bearings, flywheels, etc., as well as drive shafting alignment can all affect torque measurement. These effects need to be corrected for by the torque correction factors.

Prior to correlation, laboratory calibration of the torque measurement device, and static calibration of the torque measuring system should be performed.

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: ambient (humidity, temperature, and pressure), fuel properties (density, viscosity and lower heating value), and aerodynamic (ram pressure ratio and cell bypass airflow interaction). In a dynamometer test cell without airflow augmentation or inlet depression the airflow rate is generally low enough that ram pressure ratio and bypass airflow interactions are not significant factors.

However, airflow augmentation systems such as inlet or exhaust fans may have some effect on cell airflow and apparent engine performance, due to inlet temperature stability, exhaust recirculation or radiant air heating. It is desirable that airflow augmentation is stable and reasonable, and is accounted for in the correlation factor during the test cell correlation.

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, and dwell time. At a given humidity, the probability for condensation is higher in long inlet ducts and lower in bell mouth intakes. High inlet Mach number 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 particular engine models.

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, dynamometer/engine heat rejection, airflow stagnation, or other sources of heat. This gradient should be minimized by modifications to the test cell and engine test configuration.

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.

4.5.2 (Continued):

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:

a. θ (THETA) = (observed inlet total absolute temperature)/(absolute temperature of International Standards Organization (I.S.O.) sea level standard day reference atmosphere)

b. δ (DELTA) = (observed inlet total absolute pressure)/(absolute pressure of I.S.O. sea level standard day reference atmosphere)

NOTE: These ratios require the use of consistent units and absolute values, i.e., temperatures in degrees 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 use of θ and δ as follows:

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

b. Shaft Horsepower, SHP, is normalized when divided by $\delta\theta^X$, i.e., $SHP/(\delta\theta^X)$, where X is dependent on the engine type and defined by the manufacturer (typical values of X range from 0.50 to 0.59).

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

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 on 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 flow meters). The establishment of relative density takes place in two steps: the evaluation of the relative density at a given reference temperature, and 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, ASTM D 287, 1984) 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.

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 fuel flow meter that is calibrated for JP4, for instance, would have a significantly different calibration for JP5 because of its higher viscosity. Viscosity is also a strong function of temperature and the appropriate effect can be found in ASTM Volume 5.01, D341-89, 1990.

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 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: Ram pressure ratio is normally insignificant in dynamometer turboshaft or dynamometer turboprop test cells utilizing natural pumping. Cells utilizing airflow augmentation through inlet, and/or exhaust fans, or cells utilizing a propeller need to consider ram pressure ratios. 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 velocity. This apparent velocity generates a ram pressure ratio and thus the engine cycle is altered slightly thus impacting on produced power. 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 accounted for in horsepower determination, either separately or in the horsepower 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. In the case of turboprop and turboshaft engines these losses may not be significant as the work expended in overcoming them is accounted for in the torque/speed measurement process.

4.5.5 (Continued):

There is a potential, however, for cell bypass airflow to influence the engine performance parameter measurements and these need to be considered both in terms of good quality measurements and in terms of correlation. The most likely cause of such interference is the cooling effect of cell bypass air on the engine hardware or instrumentation or test cell measurement systems. Thermocouple systems would be particularly prone to this effect. The quantity of air flow, the engine systems and the test cell system design are all potential causes.

These errors are most likely to occur where the engine bypass airflows between the Reference cell and the Customer cell differ significantly. Comparison of propeller-based test cell performance versus dynamometer-based test cell performance could show significant errors and would warrant consideration. Engine manufacturers should be consulted for information on any such known effects and how to address them.

4.5.6 Dress Kit Hardware: Engine dress kit hardware affects engine performance due to airflow effects on the engine. Dimensional characteristics of the dress kit hardware (especially bell mouths and exhaust nozzles) will directly affect engine airflow and pressure ratios. In addition, dress kit hardware affects the cell bypass airflow interactions described in 4.5.5.

Changes in engine dress kit hardware may cause 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, 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.

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 15 min 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 Editing and Averaging: 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 mismeasurement 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.

4.5.7.2 (Continued):

Several averaging techniques can be employed. A simple average of all collected data is commonly performed. Alternately, more selective techniques can be applied, requiring an automatic screening of all data, with some data being discarded. An example of a more selective technique would be "middle-third-averaging" (MA). MA assumes that the data are "normally distributed" in a bell-shaped distribution. Then the statistically significant data are grouped in the middle third of the range.

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 (outlier test). Editing tolerances are especially useful on multiple pressure readings (e.g., bell mouth 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 mismeasurements 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.

4.5.8 Dynamometer Configuration and Characteristics: When comparing and evaluating test cell configurational differences between the reference facility and the customer facility, attention should be focused on the dynamometer configuration and characteristics. In order to reduce the impact of the dynamometer on engine performance and operation, the customer's dynamometer and accompanying hardware should be chosen to match that of the reference facility. Dynamometer characteristics such as inertia and control system are of particular importance.

Dynamometer inertia is designed to simulate aircraft rotor or prop inertia. The dynamometer inertia characteristic is often managed by adding an appropriately sized flywheel to the dynamometer or through dynamometer electrical circuitry. This circuitry is separate from the dynamometer control system circuitry. Dynamometer inertia can have an effect on engine steady state stability and acceleration/deceleration rates. Additionally, the engine control system can adversely interact with the facility dynamometer control system resulting in engine instability.

4.5.9 Propeller Configuration and Characteristics: In propeller-based test cells the selection of test propeller is important. Depending on the type of engine test the propeller style, inertia, blade quantity and dimensions, etc. may have to be preserved. However, if the propeller is purely a load-absorbing device, the choice of propeller may be less critical even to the extent of cutting-down the blade length ("cropping") to reduce airflow and the radial dimension.

4.5.9 (Continued):

Testing with the correct propeller has the additional advantage of confirming satisfactory operation of the complete, integrated power-plant and its control systems.

4.6 Software Verification:

Computer software may be used to control test cell data acquisition and/or 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 calculations/operations properly.
d. For a given input, both the reference facility and the customer facility provide the same output.

5. DESIGNATION OF REFERENCE AND BASELINE 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.

The time lapse between engine test cell correlations, as well as the time lapse between tests of a given correlation engine, must be given thoughtful consideration to assure that the end result will be valid.

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 nontraceable 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.

5.2.1 (Continued):

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 uncerainty stack up.)

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 (2.1), 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 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, or a test stand at static condition; i.e., engine inlet, engine exhaust, dynamometer or propeller, etc.

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, and engine dress kit.
d. Ensure valid calibration of all test cell instruments.
e. Make the reference facility engine performance test(s).
f. Ship 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 communicate clearly 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, 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 needs to 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. The power and speed range and configuration are primary items for consideration. 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 takeoff power, or one engine inoperative power setting (if applicable) and be stable in its performance across the entire corrected power 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. Paragraph 4.3 details these requirements.

6.2.5 Reference Facility Engine Performance Tests: 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 is being 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 power.

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 output shaft torque
c. Engine 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 lower heating value (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 7 to 15 performance points distributed across the engine power 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 further 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 run 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 only be permitted if data from the first test are consistent with data from several previous runs in the reference 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). Paragraph 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

Paragraph 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 customer facility engine correlation run
f. Shut down engine 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, if appropriate, 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, 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 gage calibration and instrumentation system end-to-end calibration (see 4.3).

7.2.4 Precorrelation 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 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. 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 prechecks 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 bell mouths and exhaust nozzles. Part numbers and serial numbers should be recorded for all engine dress kit parts, along with 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.

7.2.5 (Continued):

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

a. Engine fuel flow
b. Engine output shaft torque
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 valve, 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.

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

Any preestablished climatic envelope for satisfactory testing should be observed.

7.2.6 Shutdown Period: Following an initial correlation test, the engine should be shutdown in order to reach a cool engine state for repeatability testing. Refer to the engine manufacturer's manuals for recommended cooling periods.

7.2.7 Repeating the Correlation Run: After the shutdown period, the correlation test should be duplicated to demonstrate stable engine performance, the repeatability of the data measurement, acquisition and reduction systems.

7.2.8 Postcorrelation Procedure: It is recommended that the correlation engine be carefully stored until the total correlation exercise is complete, in case, further testing is deemed necessary.

7.3 Correcting and Analyzing the Correlation Data:

Once all engine correlation tests are complete, the data must be reduced (i.e., calculations must be performed). Paragraph 4.5.2 describes the process of correcting or normalizing the measured data to common reference 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.