SAE INTERNATIONAL

# AEROSPACE RECOMMENDED PRACTICE

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## APU Gas Turbine Engine Test Cell Correlation

RATIONALE

ARP5435A was updated per the Five-Year Review requirement.

The SAE EG-1E committee is composed of a cross section of representatives from OEMs, commercial users, repair stations, and military depots. Based on the inputs from representatives of these various areas of interest, it was concluded that there was a need for a standardized procedure for correlating an APU gas turbine test cell. This paper represents the committee's best effort to satisfy the interest of all parties concerned and arrive at a valid realistic correlation procedure. It is the belief of the committee members that this document meets that objective.

ARP5435A has been reaffirmed to comply with the SAE Five-Year Review policy.



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# 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 APU (auxiliary power unit) 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. The baseline performance is generally determined at the original equipment manufacturer (OEM) designated test facility. Although no original equipment manufacturer (OEM) documents are actually referenced, the experience and knowledge of several OEMs 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 recommended practice 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. 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

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.

ARP741 Turbofan and Turbojet Gas Turbine Engine Test Cell Correlation

ARP4755 Turboshaft/Turboprop Gas Turbine Engine Test Cell Correlation

ARP4990 Turbine Flowmeter Fuel Flow Calculations

AIR5026 Test Cell Instrumentation

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, doi: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 (American Society for Testing Materials) Standards. 1992. 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). Operation and Performance Measurement on Engines in Sea Level Test Facilities. AGARD-LS-132.

Krengel, J.H. Air-Breathing Engine Test Facilities Register. AGARD-AG-269

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

United States Air Force. 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 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 aerodynamic hardware, accessories, and test instrumentation required to permit operation of the engine in the test cell.

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.

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 inlet, augmenter tube and exhaust stack configurations

b. Engine position in the test cell

c. Ambient conditions

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

e. Test cell power measurement system consisting of bleed air and/or shaft power

f. Testing procedures

g. Data acquisition system

h. Fuel properties

i. Engine dress kit

## 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 stable 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 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 power extraction consisting of bleed air and/or shaft power

c. Engine speed(s)

d. Engine pressures and temperatures

e. Engine inlet conditions

f. Test cell temperatures and pressures

g. Engine vibrations

h. Engine variable geometry system (where applicable)

### 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. A calibration procedure firmly establishes the uncertainty 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 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.

Prior common practice required a secondary or transfer standard have an uncertainty at least four times better than the instrument being calibrated. It is increasingly more difficult to achieve this hierarchy of secondary standards with the development of low uncertainty electronic equipment. The transfer standard, in this case, should have an uncertainty equal to or better 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 Power Extraction Determination

Power extraction for APUs is normally in the form of shaft and/or pneumatic power. While there are a variety of devices available to measure airflow or output shaft power, it is important that whatever device is used, it meets the accuracy requirement that may be specified in the applicable model specification, Technical Order, or engine manual.

Pneumatic power is usually in the form of bleed air extraction. Bleed airflow can be measured using a variety of devices such as a venturi, orifice, or other gas flow measurement devices. The airflow measurement device may be calibrated at the factory or standard laboratory with calibration curves provided to the user. The airflow measurement device is normally not calibrated by the user as it typically requires a large calibration facility with associated support equipment. Airflow instrumentation that measure parameters such as temperature and pressure are calibrated by conventional calibration systems.

Shaft power extraction can be determined through the use of a dynamometer, generator, or hydraulic loading device. A dynamometer applies a torque load to the engine. The shaft power extracted from the engine can then be calculated from the measured torque and output shaft speed. Generators are also commonly used to provide a load on the output shaft. In this case, the measured generator electrical load and the generator efficiency are used to calculate the shaft power extraction from the engine. A hydraulic loading device applies a load to the output shaft by driving a hydraulic pump. Output shaft power is calculated from the measured flow, pressure, and pump efficiency. Output shaft loading systems require calibration systems specific to the type of loading systems. Most are calibrated by conventional calibration equipment.



### 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 two groups:

a. Ambient (humidity, temperature, and pressure)

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

#### 4.5.1 Humidity

It is recognized that high humidity levels will affect the performance of gas turbine engines. 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 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 and, for the most part can be ignored. 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. Engine manufacturers may make humidity corrections to engine performance data when comparing the correlation data between test facilities.

#### 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 temperatures and pressures, therefore, to compare one engine run to another, the measured engine performance parameters must be normalized. Since the methods for normalizing engine performance 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. Some test facilities use conditioned inlet air to control and minimize variation in inlet temperature and pressure.

Two common methods for normalizing engine performance for ambient effects are the corrected speed method and the lapse rate method.

For the corrected speed method, the basic normalizing parameters are:

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

$\delta$ (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 $\theta$ and $\delta$ as follows:

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

b. 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)).

c. Engine cycle total temperatures (e.g., $T_3$, $T_4$, $T_5$, $T_7$) are normalized when divided by $\theta^z$, i.e., $T_5/\theta^z$, 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).

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

For the lapse rate method, the basic normalizing parameters are:

$\Delta$ = A parameter specific correction factor applied to each performance parameter, usually additive, (i.e., $\Delta T_5$, $\Delta P_3$, $\Delta W_b$, $\Delta P_b$). These adjustments are normally found in the model specification, Technical Order, or Engine Overhaul Manual for particular engines.

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

The correction or normalizing of the major engine performance parameters requires the use of $\Delta$ and $\delta$ as follows:

a. Bleed air flow, $W_b$, is normalized by $\delta$ to account for barometric differences then, adjusted with $\Delta W_b$ to account for ambient temperature differences, i.e., $W_b/\delta + \Delta W_b$.

b. Fuel flow rate, $W_f$, is normalized by $\delta$ to account for barometric differences then, adjusted with $\Delta$ to account for ambient temperature differences, i.e., $W_f/\delta + \Delta W_f$.

c. Engine cycle total temperatures (e.g., $T_3$, $T_4$, $T_5$, $T_7$) are adjusted with Δ to account for ambient temperature differences, i.e., $T_5 + \Delta T_5$.

d. Engine cycle total pressures (e.g., compressor discharge, turbine discharge, nozzle exit, etc.) are normalized by δ to account for barometric differences then, adjusted with Δ to account for ambient temperature differences, i.e., $P_b/\delta + \Delta P_b$.

4.5.3 Fuel Properties

Experience has shown that fuel purchased to a particular specification from a single supply source maintains reasonable 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: 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) and then corrected to the 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 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 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 Dress Kit Hardware

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 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.

#### 4.5.5 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.

##### 4.5.5.1 Scan Characteristics

Computer-operated data acquisition systems quickly scan dozens 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 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.

### 4.6 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.

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, for example, Measurement Uncertainty Handbook).

### 5.3.1 Reducing Uncertainty

With each step away from the baseline test facility; the uncertainty of test facility measurement 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 (2.3), trending (9.3.1), and periodic checks (9.3.2).

## 5.4 Engine Test Hardware Configuration for Reference Testing

As stated in 4.1, 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.

# 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 communicate clearly 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 4 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 power output and be stable in its performance. 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. 4.3 discusses 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 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 power extraction consisting of bleed air and/or shaft power

c. Engine speed(s)

d. Engine pressures and temperatures

e. Engine inlet conditions

f. Test cell temperatures and pressures

g. Engine vibrations

h. Engine variable geometry system (where applicable)

i. Engine exhaust conditions

j. Engine control parameters (optional, e.g., 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 should include any performance conditions as required by the model specification, Technical Order, or Engine Overhaul Manual. The test may include additional performance points distributed across the engine power extraction 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 4.5.5.1). 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 Repeating the Reference Test with Customer Dress Kit Installed

If the customers dress kit hardware is available, an additional run should be made with that dress kit installed. This test is to identify any performance changes due to the customer’s dress kit.

6.2.9 Correcting and Analyzing the Correlation Data

Once all reference tests are completed, the data must be reduced (i.e., calculations performed). 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 steps:

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

b. Performance shift determination

c. Performance evaluation of customer dress kit hardware (if applicable)

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.

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 horsepower rating, shaft speed, engine airflow, and bleed 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.

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 power extraction consisting of bleed air and/or shaft power

c. Engine speed(s)

d. Engine pressures and temperatures

e. Engine inlet conditions

f. Test cell temperatures and pressures

g. Engine vibrations

h. Engine variable geometry system (where applicable)

i. Engine exhaust conditions

j. Engine control parameters (optional, e.g., 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.

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

Any pre-established climatic envelope for satisfactory testing should be observed.

7.2.6 Shutdown Period

Following an initial correlation 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.

7.2.7 Repeating the Correlation Test

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 Post-Correlation 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). 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.

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

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

b. Performance shift determination

c. Correlation factors determination

Each of the three items listed above must be isolated independently in the order shown. If invalid data or real performance shifts are not recognized, then their respective effects on performance might be erroneously lumped into the correlation factors, resulting in inconsistent performance.

The original engine manufacturers' manuals and reports should be referenced for a more thorough analysis description.

7.3.1 Data Validation

Data validation determines the acceptability of the measured data.