U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: CORRELATION, OPERATION, DESIGN, AND MODIFICATION OF TURBOFAN/JET ENGINE TEST CELLS

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1. PURPOSE. This advisory circular (AC) provides guidance regarding test cell correlation procedures for test cells used for in-service acceptance testing of turbofan and turbojet engines. This AC discusses the effects of the design, operation, and modification of a test cell and engine test hardware on engine performance. The AC also provides guidance on conducting, evaluating, and maintaining test cell correlation. Like all advisory material, this AC is not in itself mandatory and does not constitute a regulation. The Federal Aviation Administration (FAA) issues it to describe an acceptable means, but not the only means, for correlating and maintaining a satisfactory correlation status of a test cell.

2. RELATED REGULATIONS IN TITLE 14 OF THE CODE OF FEDERAL REGULATIONS (14 CFR).

a. Part 1, Definitions and Abbreviations.

b. Part 21, Certification Procedures for Products and Parts.

c. Part 33, Airworthiness Standards: Aircraft Engines.

d. Part 43, Maintenance, Preventive Maintenance, Rebuilding, and Alteration.

e. Part 121, Operating Requirements: Domestic, Flag, and Supplemental Operations.

f. Part 135, Operating Requirements: Commuter and On Demand Operations and Rules Governing Persons On Board Such Aircraft.

g. Part 145, Repair Stations.

3. RELATED READING MATERIAL. References to additional documents relating to this subject may be found in Appendix 1.

/s/ James J. Ballough
Director, Flight Standards Service

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CHAPTER 1. INTRODUCTION

100. GENERAL. This AC describes an enclosed test cell or facility, with fixed instrumentation, that is used for in-service acceptance testing of turbofan and turbojet engines. The AC prescribes:

- General test cell design guidelines
- Initial correlation procedures for these test cells
- Procedures that may be necessary following repairs and/or modifications to the test cell and/or engine test hardware
- General procedures for maintaining a satisfactory correlation status

101. BACKGROUND. Turbine original engine manufacturers (OEM) require that their turbine engines be evaluated for performance and operational characteristics by engine testing following overhaul and certain other maintenance. The OEM's overhaul manual specifies engine acceptance test procedures, parameters to be measured, and "operational" limits. The FAA requires engine maintenance and testing in accordance with 14 CFR part 43, section 43.2(a)(2).

a. The design and construction of turbofan/jet engine test facilities will influence engine operation and performance. Hardware installed on engines, such as bellmouths, thrust reversers, exhaust nozzles, noise suppressers, cowling, and quick engine change (QEC) components, can alter engine performance and influence test results. Therefore, accurate turbofan/jet engine performance evaluation requires that the influences of both the test facility and the engine, including its installed equipment, be known. Test cell correlation testing is performed to determine the effect of these items on the performance of an engine relative to the baseline performance of that engine. The Federal Aviation Administration (FAA) intends for the incorporation of the information described in this AC to provide a controlled, accurate, consistent, and repeatable engine acceptance test of turbofan and turbojet engines.

b. Test cell correlation is the recommended and most common method used to demonstrate that a test cell is operating correctly and producing engine performance data that matches the reference or baseline test cell data within an acceptable small tolerance. Therefore, the correlated test cell provides a means to ensure that accepted engines meet minimum rated requirements. Test cell correlation factors, which may be determined to be necessary based on the results of correlation testing, would then be applied in all subsequent engine acceptance testing. When a test cell is correlated for a specific engine model, the correlation may also be valid for derivative models of engines having lower thrust but using the same design installed hardware. Test cell correlation procedures, pertinent to specific engine models, may be provided in a document published by the OEM. These correlation procedures should be specific enough to ensure that future in-service acceptance testing will consistently result in obtaining the required engine performance parameters within the manufacturer's prescribed accuracy. When an OEM's correlation documents are nonexistent or nonspecific, this AC provides information for satisfactory test cell correlation test procedures.

c. Unless an acceptable alternative method is performed, test cell correlation or recorrelation should be accomplished under the following circumstances:

(1) Following construction of a new test cell;

(2) When either a new engine model or derivative model of higher (or sometimes lower) thrust is introduced;

(3) When repairs or structural modifications have been made to an existing test cell that significantly affect engine performance;

(4) When repairs or modifications that significantly affect engine performance are made to the engine test hardware, as well as to the entire engine configuration (e.g., QEC, thrust reverser, bare engine);

(5) When modifications have been made to existing data acquisition or data reduction systems, and these modifications are introduced in the test cell in a manner that could affect engine performance evaluation;

(6) If and when recommended by the OEM; and

(7) Where the FAA has determined that there is valid reason to perform a test cell correlation.

d. Reference engine testing, which is the first stage of a correlation, is usually performed at the OEM's baseline test facility. This baseline test cell is correlated or referenced to an open-air condition through testing using an outdoor test facility or through analysis. For various reasons, the baseline test facility is sometimes not available for reference testing. In this case, another facility may be used for reference testing. This facility must be FAA-approved and traceable to the OEM's baseline facility. The use of the OEM's test cell, which is FAA-approved for production acceptance testing of engines of the same type and model, is permissible for correlation reference testing.

102. CALIBRATION AND CORRELATION STANDARDS AND METHODS. Test cell correlation is a separate requirement beyond the calibration requirements for the test cell instrumentation. During the performance of instrument calibration, each instrument must be tested for conformity to an accepted known standard (e.g., National Institute of Standards and Technology (NIST)). In addition, a check of each instrument system should be performed by comparing a particular readout device and its associated components from the engine interface point with either a primary or secondary standard or a known input source.

a. Test cell correlation testing should be accomplished by operating a designated correlation engine that exhibits stable performance and produces at least minimum thrust. Also, it should be of the same type and model that is to be tested in the test cell. In some cases, correlation testing may also be accomplished by using an engine model of a higher thrust rating to substantiate test cell utilization for derivative models of lower thrust.

b. The performance of the designated correlation engine should be established by conducting performance tests at an open-air test site or in the OEM's baseline test cell. However, an alternative accepted practice is to determine the performance of the correlation engine at another FAA-approved facility, provided the facility is traceable to the OEM's baseline cell. This FAA-approved facility is designated a "Reference Facility."

103. ALTERNATIVE CORRELATION METHODS. There may be test cell correlation methods alternative to those methods described in paragraph 102. When a facility proposes to correlate its test cell by procedures that deviate from the OEM's recommendations or this AC, the facility should refer the proposed correlation process to its respective FAA Flight Standards District Office (FSDO). Although the Regulations permit an alternative means of compliance, an FAA aviation safety inspector (ASI) should not make this determination alone because the proper correlation of a test cell is generally an engineering function. Facilities correlating test cells by alternative means may receive assistance from one or more of the following: the OEM, respective FSDO, FAA regional engineering organization, and

FAA Designated Engineering Representatives (DER) with knowledge and experience in engine test cell correlation.

104. DEFINITIONS OF TERMS. The following are clarifications of the terms used within this AC. They reflect the definitions generally accepted in the industry.

a. Facility. The facility under evaluation, which is to be correlated against the reference facility. Also termed Applicant's Facility.

b. Back-to-Back Test. A test comparing performance parameters measured on the same engine in the same facility, typically before and after a repair or modification to a test facility and/or engine test hardware.

c. Baseline Facility. A facility designated by the OEM as the standard for certification of an engine model.

d. Cell Depression (Pcd). The difference between ambient barometric pressure and the static pressure in the test cell chamber referenced to the engine inlet.

e. Correlation. The comparison of performance parameters measured on the same engine (i.e., correlation engine) tested in two individual test facilities, where one facility is the reference/baseline.

f. Correlation Engine. An engine of known and repeatable performance, possibly equipped with extra instrumentation, designated to be used for test cell correlation.

g. Correlation Factor. A multiplier or an algebraic difference that is normally used to adjust corrected performance parameters measured at the facility to be correlated. This adjustment accounts for the difference in engine performance between the facility to be correlated and the reference, or baseline, facility. Correlation factors are also known as correction factors or facility modifiers.

h. Engine Dress Kit. Hardware, consisting of external engine cowling, bellmouth, exhaust nozzle, accessories, and test instrumentation, to facilitate engine operation in a test cell. The terms engine dress kit and engine test hardware are used interchangeably throughout this AC. They are intended to have the same meaning and may include QEC package hardware.

i. Engine Test Hardware. See Engine Dress Kit.

j. Instruments. Measurement and readout devices (e.g., gauges and sensors such as probes and pickups) used for obtaining test cell and engine operation or performance measurements.

k. Instrument Calibration. The comparison of a particular instrument with either a primary or secondary (transfer) standard. The standard should be traceable to a standard maintained by NIST or another national standards organization.

l. Instrument System. A system comprising a readout device and its associated components (e.g., sensors, interconnecting cables, tubing, fiber optics) from the engine interface point to the respective readout device.

m. One-away Facility. An FAA-approved facility that is used for reference testing and has been correlated directly to the OEM's baseline facility.

n. Outdoor Test Facility. An open-air facility without any enclosure for testing engines in an environment not influenced by man-made surroundings (e.g., walls, silencers). Not considered a test cell within this AC.

o. Quick Engine Change (QEC) Kit. Engine accessory packages that permit QECs.

p. Reference Facility. A designated test facility of known performance that is traceable to the OEM's baseline facility. The reference facility is the test facility against which the facility to be correlated is compared. The reference facility may be the OEM's baseline facility.

q. Test Cell. An enclosed facility that provides a controlled environment of fixed instrumentation designed to evaluate turbine engine performance following overhaul or other maintenance (when specified by the OEM). Test cells, as defined in this AC, do not include open-air facilities, outdoor test facilities, or on-wing test devices.

CHAPTER 2. CONFIGURATION AND CONSTRUCTION

200. GENERAL DESIGN CONSIDERATIONS. The primary function of the engine test cell (facility) is to provide a controlled environment for engine testing that is compatible with the engine under test and, thus, will not hinder engine operation. It is therefore necessary to conduct tests in a facility that can accurately and consistently provide a measurement of engine performance relative to the performance that would have been obtained if the engine had been tested at the OEM's baseline facility. All test facilities affect the testing environment and influence the data obtained during testing. This is particularly true of indoor test cells. An OEM's document, such as a test cell facility planning manual, may be used as a design guide. If a document is not available or if the facility elects not to use it, the information contained in this AC may be used as a general guideline in planning and operating a test cell facility. This AC can be useful in evaluating the design of a test cell, troubleshooting correlation results, and in maintaining a satisfactory correlation status of the facility.

a. Generally, the cell construction is of reinforced concrete for primary support structures with control room construction that consists of either reinforced concrete or concrete block. Secondary cell support areas, such as preparation rooms, may be of any industrial construction. Additional information on design can be found in reference 1-2(a)(2) of Appendix 1.

b. The following system elements are common to most cell configurations. The design of these components may affect engine performance and data accuracy and, thus, the correlation results.

- Intake section
- Engine test and mount system section
- Augmentor/diffuser section
- Exhaust section
- Data acquisition and reduction system
- Instrumentation system and control room
- Engine fuel supply system
- Auxiliary system (may be required by a particular powerplant being evaluated)

201. TEST CELL CONFIGURATIONS. The presence of vortices, turbulence, and non-uniform temperatures and pressures in the area surrounding the engine under test can drastically affect engine performance and test repeatability. Therefore, all test cell configurations should be designed to provide stable testing conditions and minimize turbulent flow by minimizing pressure loss and temperature and pressure variations. Under most environmental conditions, a test cell configuration should not allow recirculation of engine exhaust gases from the cell exhaust stack into the cell inlet. It should also prevent reingestion of engine exhaust gases at the rear of the engine back into the engine inlet. Test cell designs are typically of the following three general configurations:

a. "L" Type. This design has a horizontal intake and a vertical exhaust. Airflow treatment may include at least one turning vane to turn the intake air uniformly. A grid may be installed on the horizontal inlet to assist with airflow straightening and provide increased noise reduction. The type "L" is the simplest design and the least costly to construct. A horizontal inlet will generally have good flow distribution and a reduced Pcd when the external wind is directly entering the inlet. This configuration is sensitive to prevailing wind conditions and loses efficiency and repeatability when the wind changes direction. This configuration requires a relatively large, unobstructed test area at the engine inlet station for maximum performance (see Figure 2-1 for details).

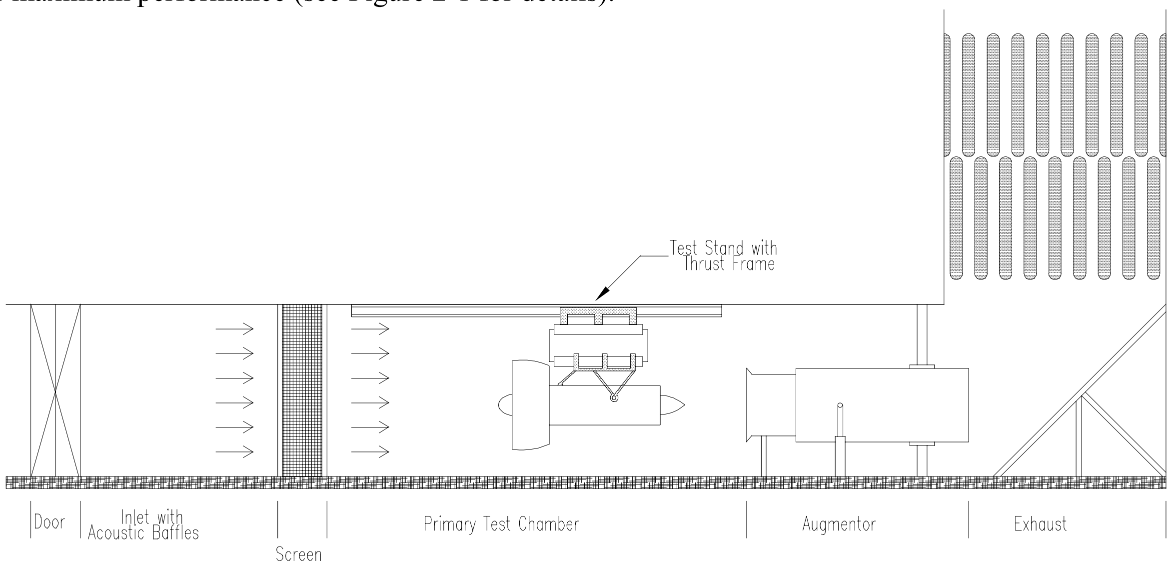


FIGURE 2-1. TEST CELL CONFIGURATION: "L" TYPE

b. "U" Type. This design incorporates a vertical stack for both inlet and exhaust. The vertical intake tends to have a more uniform inlet air velocity. This design is less subject to wind disturbances. Airflow treatment may include at least one turning vane to turn the intake air uniformly. The inlet may be designed to produce a uniform airflow within the test area at the engine inlet station, as well as a uniform engine inlet temperature. A grid may be installed on the vertical inlet to assist with airflow straightening and provide increased noise reduction (see Figure 2-2 for details).

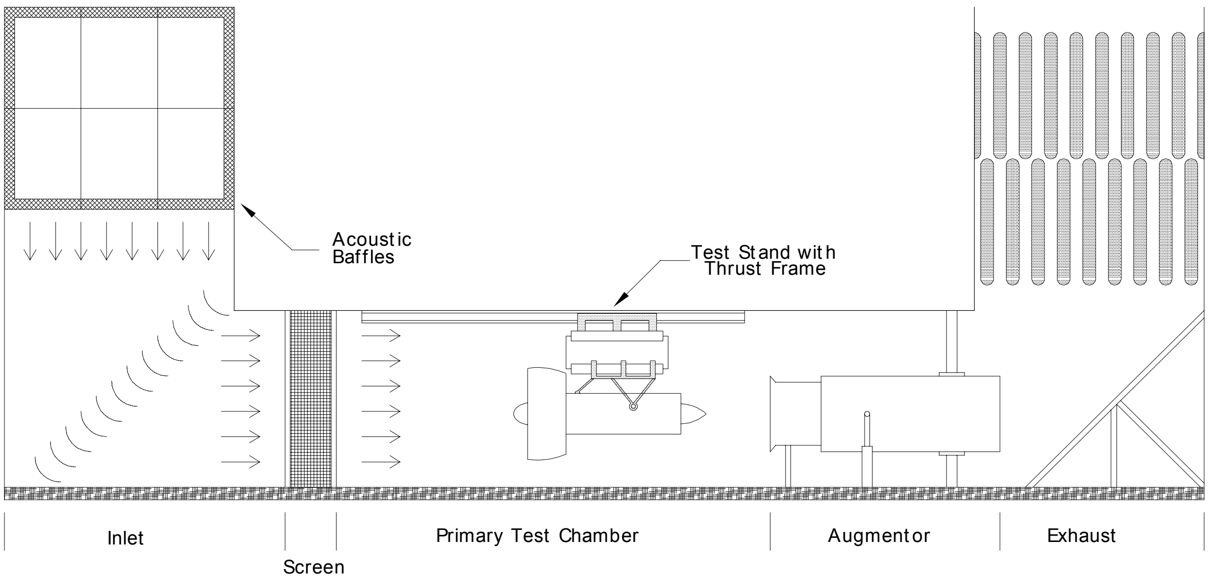


FIGURE 2-2. TEST CELL CONFIGURATION: "U" TYPE

c. Folded Inlet Type. This design usually incorporates vertical inlets on the building sides, resulting in a more accessible test section because the engine entry door can be located directly in front of the thrust stand. Another variant of this design includes a horizontal inlet on the building top. In both cases, the exhaust is configured vertically. Using a series of turning vanes, the inlet air is uniformly drawn through a winding flow path to a large plenum, which then supplies air to the test section. This configuration is also not significantly affected by wind direction (see Figure 2-3 for details).

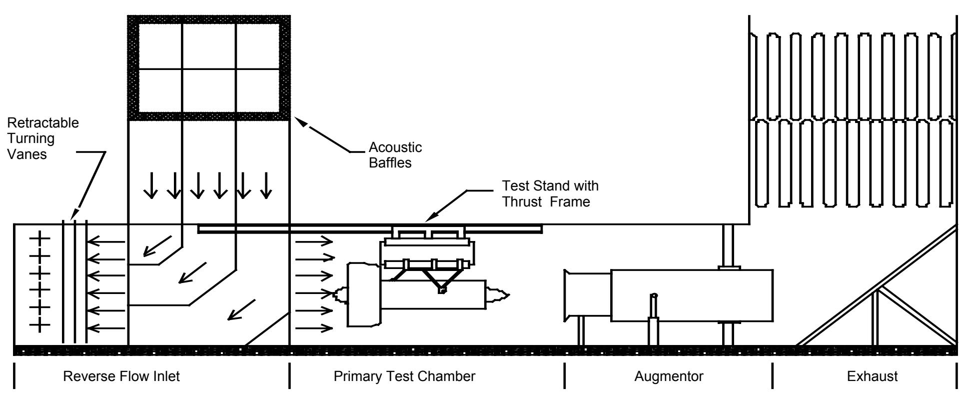


FIGURE 2-3. TEST CELL CONFIGURATION: FOLDED INLET TYPE

202. ENGINE TEST CELL MAJOR COMPONENTS/SYSTEMS.

a. Engine Test Section. The engine test section is the area immediately approaching the engine under test. Generally, this area will be of a sufficient cross section so that the air velocity approaching the engine inlet will not exceed approximately 50 feet per second (fps). In this section of a well-designed test cell, the airflow tends to have uniform pressure distribution. Test section design and construction may incorporate tapered or concave corners at the rear section where the air flows into the augmentor.

b. Interior Treatment.

(1) Steep floor grades should be avoided

(2) All drains, fittings, and other floor access areas should be flush with the floor

(3) Floor surfaces should be clean, dry, and sealed to prevent foreign object ingestion into the engine and degradation of the test cell surfaces due to leakage of engine oils, jet fuel, and other engine-related substances.

(4) Interior walls and ceilings should be smooth and free of protrusions.

(5) Moveable mechanical equipment should be removed from the engine test area during testing.

c. Engine Mounts. The engine mounts support the engine during testing and permit engine thrust to be accurately measured. Thrust of the engine is usually produced at the engine centerline and transmitted through the mounts to a thrust frame. The thrust frame then pushes against or pulls on a load cell. Thus, it enables the reaction to be measured.

NOTE: The most common method of engine mounting is overhead suspension. However, at some engine test facilities, the engine is mounted on a pedestal supported by the test cell floor. The overhead mount more closely simulates the mounting in many aircraft, and more easily accommodates the cleaning of the engine test section and the accessibility of bottom-mounted engine accessories. The engine mount should be designed to prevent transverse motion, fishtailing, or any type of lateral instability. With turbofans, poor lateral stability due to mount flexibility can result in severe engine oscillations during testing. Thrust mount designs should also ensure that engine axial alignment is maintained during testing. See Figure 2-4 for a schematic representation of a typical overhead mount installation.

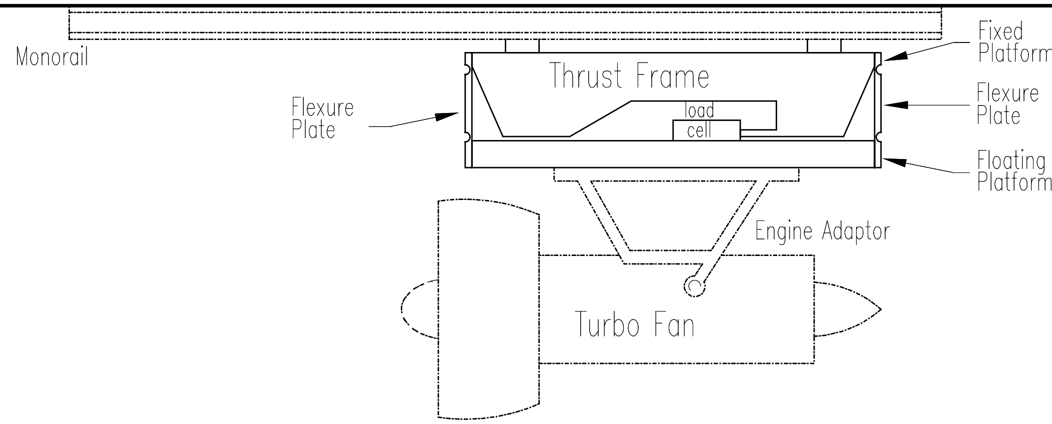


FIGURE 2-4. TYPICAL THRUST MOUNT DESIGN

d. Test Cell Inlet System. The test cell inlet system conditions incoming air to reduce the effects of wind speed, direction, and extreme temperatures. This system consists of flow straighteners, heaters, screens, and noise suppressers. These components tend to create a pressure loss or Pcd. The following test cell inlet design features may have an influence on engine performance:

- Area
- Blockage
- Turning angle
- Axial distance between engine inlet and exit of the cell inlet
- The angle of inlet turning vanes

e. Test Cell Exhaust System. The test cell exhaust system augmentor removes engine exhaust gases from the engine test section, induces the flow of secondary air for cooling, and provides some noise abatement. The mix of exhaust gases and the cooling secondary airflow that goes through the augmentor is then directed through an exhaust stack prior to exiting the facility. The following test cell exhaust design features may have an influence on engine performance:

- Augmentor configuration (i.e., convergent or divergent)
- Augmentor tube length and diameter
- Exhaust inlet tube diameter
- Axial distance between engine exhaust and augmentor inlet
- Area ratio of the engine exhaust to the augmentor area

CHAPTER 3. MEASUREMENT SYSTEMS, CALIBRATION, AND CORRELATION

300. MEASUREMENT SYSTEMS. The following paragraphs provide a general description of typical measurement systems. Instrumentation quantity, position, range, and accuracy are usually specified in an OEM's document, such as a facility planning manual or overhaul manual.

> **NOTE: End-to-end checks of each of the systems addressed in this section are extremely important to assure the validity and accuracy of the data being collected. These checks involve the comparison of data from a particular readout with its associated primary or secondary standard or with a known source. During these system checks, many physical, electrical, or flow discrepancies can be detected and corrected before correlation testing begins.**

a. Pressure Measurement Systems. Pressure measurement systems usually use simple pressure gauges, individual dedicated pressure transducers, or a scanning-valve system. Scanning-valve systems are typically a single pressure transducer that alternately measures many pressure lines of similar pressure range.

> **NOTE: High humidity or rain drawn into the test cell can result in water getting into the pressure lines and producing erroneous pressure measurements for both types of pressure management systems. (See section 305a(2) of this AC.)**

b. Temperature Measurement Systems. Temperature measurement systems should be capable of independently evaluating "low and medium" and "high" temperatures. Commonly, low and medium temperature measurement systems utilize E- or J-type thermocouples to measure engine cold section and facility temperatures. High temperature systems typically use K-type thermocouples to measure exhaust gas temperatures. The parameters to be measured will depend on the OEM's requirements for testing. Thermocouple junction locations should be minimized within the test cell environment to reduce system noise and error.

c. Engine Speed Measurement System. The engine speed measurement system must be capable of measuring all engine speeds. A typical system may consist of a digital electronic frequency counter device and a readout device, or an analog type with a graduated display dial readout. Both systems provide engine speeds in revolutions per minute or percentages.

d. Fuel Flow Measurement Systems. A typical fuel flow measurement system may consist of one or more turbine flow meters (or comparable flow measuring device(s)), each connected to a digital frequency counter and display gauge. This total measurement system, from the flow meter through the frequency counter to the display gauge, must be checked end-to-end for the entire operating range of the system. For example, a defective frequency counter could provide an acceptable error in the low flow range, while generating a divergently increasing unacceptable error in the high range.

> **NOTE: Fuel flow measurement becomes increasingly important when it is used in turbine gas temperature calculations. This calculation is sometimes required by OEMs for acceptance testing.**

e. Vibration Measurement System. Vibration is not typically evaluated during test cell correlation testing because it does not normally affect engine performance. However, turbine engines cannot be properly evaluated during in-service acceptance testing, as required by the overhaul manual, without employing a system to provide vibration measurement. System components can include vibration pickups, amplifiers, tracking filters, spectrum analyzers, band pass filters, and audio oscillators. Engine pickup locations can include the fan case, intermediate case, diffuser case, and turbine exhaust case. Hot section vibration pickups may require insulation to prevent high-temperature damage.

f. Trim Balance System. Although trim balancing of the low speed compressor is not required for test cell correlation, performing such balancing before correlation testing is acceptable. In addition, the OEM may specify a trim balance during in-service engine acceptance testing to determine imbalance moment values and, thus, the location and weights of balance counterweights. Generally, trim balancing is accomplished with the aid of a trim balance analyzer. However, procedures are also available for trim balancing with trial balance weights.

g. Thrust Measurement Systems. Thrust measurement is typically accomplished by either an electronic strain gauge or a hydraulic measurement system. The required system accuracy should be specified by the OEM.

301. INSTRUMENT CALIBRATION.

a. Engine Test Facility. The test cell can be considered a component of an engine's test equipment. As such, it requires instrumentation calibration and an end-to-end check of the measurement systems. Instrument calibration plus system checks ensure acceptable measurement accuracy within engine acceptance testing limits specified in the OEM's overhaul manual. The OEM's overhaul manual and other documents, such as a facility planning manual, reflect the procedures and test equipment that are required to test engines and the parameters to be measured. Test cell instrumentation must be calibrated and traceable to an accepted, known national standard.

b. Standards. In the United States, the NIST represents the United States at the International Conference on Weights and Measurements and has the primary responsibility for maintaining the national and international standard units of length, mass, time, temperature, and electrical quantities. Other nations have comparable standards bodies. An acceptable secondary or transfer standard has been generally regarded as any standard that is at least four times more accurate than the accuracy requirement for the instrument being calibrated and is traceable to a national standard, such as those maintained by NIST.

c. Calibration of Instruments and a Check of Associated Systems. Calibration is used to check an instrument's measurements against an accepted known standard and to eliminate unacceptable measurement errors. Instruments should be calibrated over the expected range of operation. Periodic calibration of individual instruments is necessary and can be performed in place or in the instrumentation shop.

d. Traceability. Traceability of each instrument calibration is important to show where all possible error contributions occur between the instrument and the standard. Traceability should be well documented. The calibration hierarchy, with inherent accuracies at each point, must be documented. Traceability back to a specific standard does not reduce the uncertainty of a measurement; instead, it provides clear documentation of the process of its determination.

302. THRUST CALIBRATION. To calibrate the load cell, a common procedure is to apply known centerline forces using a centerline pull rig. This calibration procedure results in the development of a calibration curve of the known force and the measured load cell reaction. This curve is used during the correlation to obtain a true force from the load cell measurement. Another method is the use of a calibration device built into the thrust stand.

303. FACTORS INFLUENCING CORRELATION. The following factors may influence the correlation of an engine test cell:

- Configuration of the test cell (particularly the test cell inlet, engine test section, and augmentor tube and exhaust stack configurations)
- Engine position in the test cell
- Ambient conditions and surrounding area configurations
- Instrumentation (including the calibration, location, measurement accuracy, and quantity)
- Test cell thrust measurement system
- Test procedures
- Data acquisition system
- Fuel properties
- Cell airflow

NOTE: In addition, engine test hardware, such as cowling inlets, bellmouths, QEC packages, cowling thrust reversers and noise suppressers, and exhaust nozzles installed on the engine during testing may greatly influence the data. These components should be serialized for tracking control.

304. PERFORMANCE MEASUREMENT.

a. The primary function of the engine test facility is to obtain a proper performance evaluation of an engine. The test facility must provide a stable test environment conducive to a smooth, surge free operation of the specific engine model. The environment of test facilities always has an influence on the test data. This is particularly true of indoor test cells. In addition, the engine test hardware configuration influences the test data. The combined effects of the test facility and engine test configuration on performance parameters are generally the reason for differences in an engine's performance between test cells. The test cell correlation provides a means to:

- Quantify these differences with respect to a standard
- Understand these differences
- Eliminate or reduce these differences, whenever possible
- Establish appropriate cell correlation factors

b. Performance Parameters. During a test cell correlation, a variety of engine performance parameters should be examined, including those parameters specified in the overhaul manual for engine acceptance testing and any values or factors used to correct primary parameters. Parameters may include, but are not limited to, the following:

- Engine fuel flow
- Engine thrust
- Engine rotor speeds
- Engine airflows
- Engine pressures and temperatures
- Engine inlet conditions
- Test cell temperatures and pressures
- Test cell inlet airflow
- Engine control systems and variable geometry
- Barometric pressure
- Ambient humidity

NOTE: Sufficient data must be obtained to establish the performance of the engine. Secondary parameters used in the derivation of any of the above items must also be measured and recorded. As an example, a fuel sample should be taken during the test and accurately analyzed for a lower heating value (LHV) and specific gravity value. In addition, redundant instrumentation can be useful for data verification and troubleshooting purposes.

305. FACTORS AFFECTING PERFORMANCE. To compare performance parameters between various test facilities or conditions within the same test facility, correcting or normalizing the performance parameters to common reference conditions is necessary. These reference conditions fall into three groups: Ambient (humidity, temperature, and pressure); fuel properties (relative density, viscosity, and LHV); and aerodynamic (ram pressure ratio, cell depression, and cell bypass airflow interaction).

a. Humidity. While it has been recognized for a long time that high humidity levels will affect the performance of gas turbine engines, no consensus exists on how to handle the associated effects or problems. Water vapor contained in the air may have several influences on the engine and its performance. Although the consequences are complex, they fall into two major categories: engine inlet condensation and changes in engine gas properties. While the relative humidity is related to the extent of engine inlet condensation, the absolute or specific humidity affects the gas properties of the engine cycle and, hence, the performance elements.

(1) Actual condensation in an engine inlet depends on a series of factors, such as relative humidity, air temperature, air pressure, inlet Mach number, and dwell time. For given humidity conditions, the probability for condensation is higher in long inlet ducts and lower in bellmouth intakes. Bellmouths should be sized per the OEM's specifications. For example, an undersized bellmouth could result in a high local inlet Mach number that might cause inlet condensation at lower relative humidities.

(2) Humidity corrections for most performance parameters have been found to be small. However, humidity can have an impact on performance and should be considered when accurate performance measurements are required. To minimize this effect, some test facilities and OEMs choose to impose limits on test cell humidity during correlation testing for particular engine models. A relative humidity restriction of 75 percent is not uncommon for correlation testing.

b. Engine Inlet Temperature and Pressure. All gas turbine engines are affected by the ambient conditions in which they operate (primarily air temperatures and pressures). Also, engine operation and correlation can be affected by an engine inlet temperature distortion or gradient due to exhaust gas recirculation or other sources of heat. This gradient should be minimized. Unstable and low pressures in the test chamber or engine inlet also affect engine operation and correlation. Distorted/non-uniform cell airflow can cause vortices and asymmetric pressure distribution in the engine inlet. These conditions can also be caused by exhaust gas recirculation, poorly designed test cell inlet and test chamber sections, too many items protruding into the inlet airflow stream, and marginal chamber secondary airflow. In most cases, unacceptable temperature or pressure conditions are obvious because of their effect on engine performance. Their cause should be corrected to the extent possible before correlation testing.

(1) It is usually not possible to control the engine inlet air temperature and pressure to sea level, static, standard day values. Therefore, to compare one engine run to another, the measured engine performance parameters must be adjusted to the values they would have with standard day inlet air. This process is called normalizing or making standard day corrections to the measured data.

(2) The method for correcting performance parameter data often varies between different engine types and models. The procedures to correct parameters for a particular engine model can be found in a specification, Technical Standard Order, or the OEM's engine overhaul manual.

(3) Certain primary operating variables of a gas turbine engine are normalized or corrected as functions of total temperature and total pressure at the engine inlet. The basic normalizing parameters are as follows:

(a) θ (theta) = (observed inlet total absolute temperature) divided by (absolute temperature of International Standards Organization [ISO] sea level, static, standard day reference atmosphere).

(b) δ (delta) = (observed inlet total absolute pressure) divided by (absolute pressure of ISO sea level, static, standard day reference atmosphere).

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

NOTE: In some cases, measured data from certain gas turbine engines are corrected to conditions other than ISO standard day values. In these cases, refer to the applicable engine model specification, Technical Standard Order, or engine overhaul manual.

(4) 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 $\sqrt{(\theta^x/\delta)}$ (i.e., $W_a\sqrt{(\theta^x/\delta)}$).

(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 absolute temperatures (such as T_3, T_4, T_5, and 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 OEM (typical values of Z range from 0.85 to 1.1).

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

NOTE: The subscripts "3, 4, 5, 7" are designators of specific axial stations in the engine. They are peculiar to each manufacturer. Those shown in this AC are for illustrative purposes only.

c. Fuel Properties. Experience has shown that fuel selected to a particular specification from a single supply source maintains reasonably stable properties. However, fuel taken from various sources, even when selected to the same specification, can vary in properties by several percent. When comparing fuel property data taken from different sources, the factors in the following paragraphs should be taken into consideration.

(1) Fuel Relative Density. The fuel relative density, also referred to as specific gravity, may be utilized in the fuel flow calculation as a first order correction. Therefore, accuracy of the specific gravity measurement is of prime importance when using volumetric flow measurement devices, such as turbine flowmeters. Relative density calculations are made in two steps: the relative density at a given reference temperature, then the relative density at the temperature of the fuel measured at the flowmeter. Relative density determined at the reference temperature (usually 60.0 degrees Fahrenheit [F] or 15.6 degrees Celsius [C], as provided within references of section 1-2 of Appendix 1 of this AC) is then corrected to the actual fuel temperature, using either a graph or an empirical equation. Since the relative density is a direct multiplier on the fuel flow, any error in the former will be transferred to the latter.

(2) Fuel Viscosity. Depending on the type of fuel flow measuring device utilized, the viscosity of the fuel can play a role in the calibration of that device. For example, fuel flow device calibration factors for Jet A/A1 and Jet B fuels are significantly different due to their differences in viscosity. Also, viscosity is a significant function of temperature. The specific effect can be found in the SAE ARP Report No. 4990, Turbine Flowmeter Fuel Flow Calculations.

(3) Fuel Lower Heating Value.

(a) Fuel flow measurements are corrected to a common fuel LHV base. This base is obtained by applying the direct ratio of the fuel's LHV to the LHV of the engine model specification or to the LHV of the baseline test fuel (i.e., industry standard).

(b) Analysis of the LHV for a given batch of fuel can usually be obtained from the fuel supplier. An acceptable accuracy for LHV can be obtained using the aniline point gravity product method of a fuel sample. The determination of the aniline point and the fuel density requires a minimum of laboratory equipment. A more accurate fuel LHV can be determined in a laboratory by a precision bomb calorimeter.

d. Ram Pressure Ratio. Defined as the engine inlet total pressure divided by the engine exhaust nozzle exit static pressure, it is the result of airflow through the test cell causing pressure differences between the front and rear of the engine. Positive ram pressure ratio values are equivalent to flying the engine at a low forward velocity that affects the engine thrust. Negative ram can be deleterious to the operation of the engine. Since the main objective of engine test cell tests is to determine static engine performance corrected to sea level, static, standard day conditions, the effects of ram pressure ratio must be measured, documented, and accounted for in thrust determination either separately or in a correlation factor.

e. Cell Depression. The difference between ambient barometric pressure and the static pressure in the test cell test chamber referenced to the engine inlet is known as cell depression. The difference is caused by pressure loss due to the velocity of air through the cell. It is usually measured in inches of water and denoted by Pcd. High levels of cell depression are usually a result of cell inlet or exhaust pressure losses. Most test cell designs result in cell depression of 2-4 inches of water, but higher or lower pressures may be acceptable. However, very low cell depression may result in vortices in the test chamber or engine exhaust gas re-ingestion into the engine inlet, causing unacceptable performance. A very high cell depression requires a large correlation factor, may indicate inadequate airflow to the engine, and can cause excessive loads on the test cell walls.

f. 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 order to establish the thrust of the engine, the interaction of the engine with the test cell environment must be evaluated. Aerodynamic thrust corrections result from flow-induced forces within the test cell, which can be divided into three components:

(1) Inlet momentum drag;

(2) Structural drag on the engine and thrust stand; and

(3) Static pressure drag along the engine.

g. Inlet Momentum Drag. The most significant aerodynamic component of the thrust measurement is the inlet momentum, also known as the intrinsic inlet momentum. As a result of drawing air into the test cell, a force is produced on the engine. For static engine testing (i.e., non-ram facility), the magnitude of this force may be substantial; values from 1 to 10 percent 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 inlet airflow and the approach airflow velocity in front of the engine. The approach velocity is significantly affected by the amount of cell airflow and the geometry of the test cell.

h. 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 that supports the engine on the thrust measurement stand.

i. 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 that act in a direction opposite to the measured thrust of the engine. Static pressure drag is sometimes broken down into the bellmouth drag and boat-tail drag. The magnitude of the static pressure drag is very sensitive to the cell exhaust geometry and the spacing between the engine exhaust and the cell exhaust system.

j. Dress Kit Hardware.

(1) Engine performance is influenced by the airflow in the engine test section. Airflow characteristics and pressure losses in the test section are affected by protrusions in close proximity to the engine. Dress kit hardware, such as external engine cowling, bellmouth, exhaust nozzle, accessories, and test instrumentations, are examples of typical protrusions. Therefore, dress kit hardware may influence engine performance and the resulting correlation factor(s).

(2) For accuracy and consistency, the part number and serial number of each dress kit hardware item, where appropriate, and the bellmouth, fan exhaust nozzle, and primary exhaust nozzle area measurements should be documented during the correlation. Engine testing at the reference and the applicant's facilities are generally performed using each of their respective dress kit hardware. The dress kit hardware that was used during the applicant's correlation test should be used for all subsequent tests of the engine model in the applicant's test cell, unless the following applies;

(a) If the applicant owns several sets of engine dress kit hardware, it may be necessary to establish correlation factors for each dress kit configuration. In this case, immediately following correlation of the applicant's test cell, back-to-back testing using different dress kit hardware should be performed to determine if any change to the correlation factor is necessary. Test configurations need to be documented by dress kit part number, serial number, and area measurements and matched to the appropriate correlation factor.

(b) If an applicant 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.

NOTE: Paragraph 403 describes back-to-back testing.

306. DATA ACQUISITION.

a. A primary consideration of engine performance measurements should be data acquisition. When computers are not utilized in a test facility, data must be collected by visually reading and hand recording all measured parameters on a log sheet. The use of an automatic computer-operated digital data acquisition system improves the accuracy of measurements and recordkeeping.

NOTE: Technology advancement in automated data acquisition systems has given rise to potential problem areas. Close attention should be paid to potential problems in the planning stages of developing this type of system. Special attention should also be paid to cell-to-cell engine performance differences during correlation when a difference exists between data acquisition systems.

b. The following paragraphs contain items that may have a significant effect on test cell correlation.

(1) Data Scan Characteristics. Computer-operated digital data acquisition systems scan, within a short period of time, hundreds of channels of data (e.g., temperatures, pressures, vibrations, resolver angles) in short, controlled bursts of repetitive signal collection. These bursts of measured data collection may be averaged by a computer. The following additional information is offered to provide a better understanding of scan characteristics.

(a) Recommended scan characteristics may be prescribed by the OEM.

(b) Taking multiple scans or measurements of the same parameter will obtain a better average value. Due to the total interaction of the engine control system and hardware, the performance parameters of even a well stabilized engine slowly oscillate around a steady state average. This parameter oscillation may resemble a sine wave characteristic with a period possibly lasting up to several minutes.

(c) Whether data is manually or automatically recorded, this recording process or scan takes a finite amount of time. With a rapid scan, the engine operating conditions change negligibly during a single scan period. However, with a slow scan, the sequence in which the parameters are recorded can influence the data quality due to time skew. Therefore, thought should be given to the recording sequence and parameter groupings.

(d) The period (i.e., engine cycle) of each measured parameter should be determined either analytically or empirically. This information should be used in designing a scan rate for each parameter. Data scan techniques, including the rates, may be different for digital versus analog data acquisition systems. An ideal technique would be to record several points per engine cycle over a large number of engine cycles, so that a true average value will be calculated from the data recorded.

(e) The oscillating engine performance discussed in paragraph 306b(1)(b) is further complicated by engine thermal soak-in. Soak-in is a result of the turbine mass (particularly the disks) slowly heating up and causing reduced turbine blade-to-shroud clearances. Thermal soak-in initiates immediately upon reaching a given power point and results in a real and measurable shift in engine performance during thermal stabilization. Soak-in can take from a few minutes to as much as 15 minutes for complete thermal stabilization to occur. Data acquisition should not be initiated before full thermal stabilization. If data acquisition is initiated before full thermal stabilization, some parameters will incur a real migration in the average value (i.e., a performance shift). This can be accommodated by selectively organizing the data scan. However, as previously stated, waiting for the engine to fully soak in is more desirable.

NOTE: A selectively organized data scan should read the stable parameters that are unaffected by thermal soak-in (i.e., most pressures and cell temperature) toward the beginning of the scan after a minimal soak period, but before full thermal stabilization occurs. Soak-affected parameters (e.g., turbine temperature, core speed, fuel flow, variable vane angles) should be read toward the end of the scan.

(f) Parameters such as fuel flow, which are measured as frequency, could have significant errors in the calculated average value that are solely attributable to scan rate and sequencing. Therefore, special attention should be given to cell-to-cell engine performance differences during a correlation when a mismatch exists between the data acquisition systems. This could become particularly difficult when trying to correlate a computer-driven acquisition system against a manual or hand-logged system.

(2) Data Averaging and Editing. Once a data acquisition methodology has been selected, an averaging technique should be determined. Also, a procedure pertinent to editing the data should be considered. These parameters are then used in the performance calculations.

(a) Several averaging techniques can be employed. A straight average of all measured data is commonly performed. Alternatively, more selective techniques requiring an automatic screening of all data can be applied, with some data being classified as possibly erroneous.

(b) Averaging techniques can have a significant effect on the calculated parameter average and, thus, the resulting performance, particularly if the engine oscillates significantly or the data were acquired before full thermal stabilization. Therefore, any differences between averaging methodologies should be carefully considered when correlating a test cell in which different averaging techniques have been used between the test cells.

(c) Along with the averaging techniques employed, an appropriate editing procedure should be considered. Different types of editing methods can be used in conjunction with the averaging technique chosen to produce the most representative data. Editing methods include data tolerances, minimum and maximum limits, and an outlier test. Editing is especially useful on multiple pressure readings (e.g., bellmouth static or total pressures), where line leaks can affect the validity of the data. Caution should be used when applying editing to parameters, such as fuel flow and engine exhaust gas temperatures, where editing might mask engine stability problems. When using any editing method, all measured data should be displayed and the edited data flagged so mismeasurements can be corrected.

(d) The goal of data editing is to discard the erroneous data points and use only the correct (i.e., true) data measurements. One goal of correlation testing is to find and remedy problems in the test cell measurement systems. When data editing is used, there is risk that data showing a real mismeasurement problem may be discarded as erroneous data. If this happens, the opportunity to find and correct a measurement problem may be missed.

(3) Software Verification. Computer software may be used in data acquisition and reduction. The FAA recommends that steps be taken to ensure that:

(a) The appropriate software program, including version (i.e., revision), is used.

(b) The software reflects the test requirements and performance calculations of the engine manual.

(c) For a given input, the reference and applicant's facilities produce the same output.

(d) Data known to be valid can be used to verify the software functionality.

CHAPTER 4. TEST CELL CORRELATION

400. CORRELATION ACCURACY ASSURANCE. Correlation relates an engine's performance to a known standard so that the performance level of the engine can be compared with established limits. These limits are derived from a performance baseline for a particular engine model. This baseline performance standard is usually the average of a number of engine tests, as established by the OEM, and is defined for a specific engine test hardware configuration and test facility combination. This combination is thereafter considered the baseline test hardware configuration and test facility for that particular engine model. To conduct a successful correlation program, identifying a suitable reference facility is necessary. It is desirable to use the OEM's baseline test facility as the reference test facility. However, access to the baseline facility is not always possible. In this event, another facility may be designated as the reference facility. This is discussed in paragraphs 101 and 102 of this AC.

a. Uncertainty Stackup. Additional information on determining correlation factors for the applicant's facility is provided in paragraph 401e(3)(d).

(1) If a facility not designated as the OEM's baseline facility is used for reference testing, an analysis of the stackup of uncertainty of the acquired data should be performed for all correlation steps between the baseline facility and the applicant's facility. The applicant's facility correlation should be deemed satisfactory if this uncertainty is shown to be smaller than the OEM's recommended acceptance tolerances.

(2) As the correlation of the applicant's facility is further removed from the baseline facility, the uncertainty of the applicant's test facility accuracy tends to increase. There are measures that may be used to increase confidence in the correlation and reduce uncertainty to the acceptable level. The following examples may reduce uncertainty:

(a) Requiring in-service acceptance limits of engines tested in the applicant's facility to be less than those tolerances specified by the OEM.

(b) Applying correlation factors to replicate the characteristics of the OEM's baseline facility.

(c) Performing multiple cross-cell tests, which is also called round-robin testing. This involves running one or more engines in more than one previously correlated test cell. Confidence grows when more engines are used and more test cells compared.

(d) Performing multiple correlation tests between the reference and the applicant's facilities to develop sufficient confidence in the correlation. This could include conducting multiple consecutive runs at each facility or retesting at the reference facility following testing at the applicant's facility (which is referred to as A-B-A testing).

NOTE: All of these techniques assume that an unbroken sequence of correlation tests exists between the baseline and the applicant's facilities. If this sequence does not exist, then the correlation method described in this AC is not possible. In this event, efforts to substantiate that a test cell is relating engine performance back to the known standard will have to be found acceptable by the FAA. This is discussed in paragraph 103.

b. Engine Test Hardware Configuration For Reference Testing. As previously stated, correlation relates an engine's performance to a known standard for a specific engine model. This standard is defined not only for testing an engine in a specific facility (i.e., the OEM's baseline test facility), but also for testing a specific engine test hardware configuration (i.e., the OEM's baseline test hardware configuration).

(1) For testing at the reference facility, the FAA recommends that the engine test hardware configuration be the same as:

(a) The hardware to be used during correlation testing at the applicant's facility;

(b) The hardware to be used for future in-service acceptance testing at the applicant's facility; and

(c) The OEM's baseline test hardware configuration.

(2) However, the configurations that were used during testing at the baseline, reference, and applicant's facilities may be different. These differences should be evaluated for their impact on correlation.

401. CORRELATION PROCEDURES.

a. Procedure Overview. The following activities are a general overview of the step-by-step correlation process. Following this overview, details of these activities are discussed in paragraphs 401b through 401d.

(1) Identify a correlation engine. The engine must:

(a) Develop minimum rated thrust.

(b) Exhibit stable performance.

(2) Calibrate the applicant's test cell instruments and perform an end-to-end check of systems.

(3) Notify the respective FSDO and verify FAA-approval and the correlation status of the reference facility with respect to the baseline facility.

(4) Perform a shakedown engine run at applicant's test cell. The run will:

(a) Verify instrumentation accuracy.

(b) Check out all other systems.

(5) Perform an engine test at the reference facility using the correlation engine.

(6) Notify the respective FSDO.

NOTE: The FAA recommends that reference testing be performed before testing at the applicant's facility. However, this process may be performed in reverse, if necessary.

(7) Perform the applicant's facility test cell correlation.

(a) Notify the respective FSDO.

(b) Perform an 8- to 15-data point engine run.

(c) Perform engine run in the same sequence and direction of approach to the test points (i.e., acceleration versus deceleration) as that performed at the reference facility.

(d) Shut down the engine in preparation for an engine and facility repeatability check.

(e) Repeat the engine test using the same procedure.

(8) Perform a retest at the reference facility (recommended, but optional).

(9) Perform data analysis.

(a) Apply corrections to measured data for common reference (e.g., standard day). Graphically plot the data and draw a smooth characteristic line through the data for each plot. Regression analysis of the data is also an acceptable means of determining the characteristic line.

(b) Analyze the data for measurement error (e.g., perform data validation).

(c) Analyze the data for performance shift.

(d) Determine the cell correlation factor(s) and apply to (usually) corrected common reference data. Plot the adjusted, corrected data.

(e) Perform an acceptance test in accordance with the OEM's overhaul manual to ensure the applicant's test cell is capable of being utilized for satisfactory in-service acceptance testing.

(10) Develop documentation.

(a) Write the Correlation Report, as described in paragraph 402, to document details for the entire correlation exercise.

(b) Develop and document procedures for operating and maintaining the test cell and ensuring satisfactory maintenance of the test cell correlation status (i.e., develop a facility operations manual).

b. Pre-correlation Procedure. The following activities should be performed before correlation testing:

(1) Determine correlation test procedures in accordance with the OEM's correlation test requirements or recommendations.

(2) Instrument the engine in accordance with the OEM's recommendations.

(3) Obtain fuel samples at both facilities, before or during correlation testing, and determine specific gravity and LHV.

(4) Identify and record appropriate engine test hardware configuration(s) to be utilized at the reference and applicant's facilities (see paragraphs 305j and 400b). Obtain measurements of the bellmouth, fan exhaust nozzle, and primary exhaust nozzle areas to be used for reference and applicant facility testing. These measurements should be compared and may be useful when evaluating the correlation. Additionally, when specified by the OEM, bellmouth area measurement may be required for calculating airflow.

(5) Identify an acceptable correlation engine. A new, used, or rebuilt engine can be used as long as it demonstrates at least minimum takeoff thrust and maintains stable performance across the corrected thrust range from idle to takeoff. The engine's ability to reach rated takeoff thrust without overtemperaturing or overspeeding is important. It allows engine testing to be performed without safety or performance deterioration concerns. The use of an engine experiencing a gradual run-to-run variation in performance, such as a gradual performance deterioration, could result in a nonstandard and needlessly complex correlation evaluation.

(6) Immediately before the correlation run, calibrate the applicant's test cell instrumentation and engine instrumentation to the selected standard. Also, perform an end-to-end check of the applicant's facility measurement systems (see paragraph 301).

(7) Notify the respective FSDO:

(a) Early in the planning process so that all requirements are identified, and

(b) Prior to testing at both the reference and the applicant's facility, should the FAA elect to witness the test.

NOTE: If applicable, obtain proof that the reference facility is FAA-approved and traceable to the OEM's baseline facility.

(8) Perform a full power shakedown run prior to the correlation run at the applicant's facility. The entire facility, including the test cell, data system, and calculation procedures, should be thoroughly tested. This may be performed with an engine other than the correlation engine. This is also another opportunity to investigate and eliminate facility measurement system problems, since a check of the entire system operating together may not have been previously performed.

c. Correlation Procedure. The test procedure used at the applicant's facility should be the same in all aspects as the procedure conducted at the reference facility. This includes:

- The number of data points acquired
- Thrust levels
- Stabilization time
- Sequence
- Direction of approach to the test points
- The parameters recorded

(1) Once the facility to be correlated (i.e., applicant's facility) is thoroughly tested via the shakedown run, the formal correlation process can begin. In most cases, the correlation engine is first tested in the reference test facility. A correlation engine test usually includes 8 to 15 data points distributed across the thrust range.

NOTE: Under certain conditions, fewer data points could be acceptable.

(2) Care should be taken to fully stabilize the engine thermally and dynamically before data acquisition is initiated. The stabilization time should be recorded so that it can be duplicated during testing at the applicant's facility.

(3) Weather conditions should be recorded at both facilities at the time of test, as well as any weather changes occurring during the test. It is desirable to minimize the ambient temperature and humidity differences between the two facilities. Any preestablished climatic envelopes are to be observed for satisfactory testing.

(4) To ensure consistent and repeatable engine testing, the proposed test procedure should include a listing of parameters to be measured and the measurement precision and range. The following parameters should be recorded:

- Engine fuel flow
- Engine thrust
- Engine rotor speeds
- Engine airflows
- Engine pressures and temperatures
- Engine inlet conditions
- Test cell temperatures and pressures
- Test cell inlet airflow
- Engine control systems and variable geometry
- Barometric pressure
- Ambient humidity

NOTE: Sufficient data must be obtained to meet acceptance test procedures specified by the OEM. Secondary parameters used in the derivation of any of the above items must also be measured and recorded. In addition, redundant instrumentation can be useful for data verification and troubleshooting purposes.

(5) During the engine test at the reference test facility, the sequence and direction of approach to the test points performed (i.e., acceleration or deceleration) should be recorded. The data points taken at the facility to be correlated should also be collected in the same sequence and approach to eliminate performance variability due to control system hysteresis.

(6) Once the engine test at the reference facility is complete, the correlation engine should be immediately preserved and shipped to the applicant's facility for correlation testing. This will minimize engine performance deterioration due to additional operation.

(7) Following the initial correlation engine run at the applicant's facility, the engine should be shut down for a minimum of several hours to reach a cool engine state. Time periods for cooling can vary; refer to the OEM's instructions. After the shutdown period, the engine test should be repeated for an engine and facility repeatability check. The repeatability check is intended to demonstrate stable engine performance and engine run-to-run repeatability of the data measurement, acquisition, and reduction systems.

(8) Ideally, the test cell correlation should include engine runs at the reference facility, at the applicant's facility, and again at the reference facility (i.e., A-B-A). If the engine is routinely used for correlation testing, a retest at the reference facility may not be necessary if correlation engine data from several previous runs are consistent.

(9) Following the performance correlation runs, the correlation engine or another suitable engine should be tested at the applicant's facility using the overhaul manual in-service acceptance procedures. This will ensure that the applicant's facility is capable of being utilized for satisfactory engine acceptance testing. This should not be performed until after all correlation testing is complete and the correlation data has been reduced, analyzed, and accepted.

(10) Data obtained during testing at the reference and applicant's facilities must be recorded in a manual or automatic log sheet at the time of test. The FAA recommends that copies of these records be provided to the FAA representative witnessing the testing (if applicable) immediately upon conclusion of testing.

d. Post-correlation Procedure. The following paragraphs identify the post-correlation steps. The FAA recommends that the correlation engine be carefully stored until the correlation analysis is complete, in case further testing is necessary.

(1) Following completion of correlation testing, the data must be reduced (i.e., calculations must be performed). Paragraph 305b describes the process of correcting or normalizing the measured data to sea level, static, standard day conditions. The corrected data is typically graphically displayed, and a smooth characteristic curve is drawn through the data.

(2) Paragraph 401e below gives a detailed description of the post-test correlation data analysis of the plotted data. The OEM's manuals and reports should also be referenced for a more thorough analysis description relative to a specific engine model.

e. Correlation Data Analysis. Once engine tests at both facilities are complete (all data has been edited, averaged, corrected, and plotted graphically) and a smooth characteristic line has been drawn through the data for each performance plot, the data must be analyzed. Data analysis is an engineering function and requires specialized knowledge. It is typically performed by the applicant, OEM, or other qualified personnel. It should include the following three steps: data validation with instrumentation error isolation, performance shift determination, and correlation factor determination. Each of these three elements should be isolated independently in the order given. If data errors or real performance shifts are not recognized, their respective effects on performance might be erroneously lumped into the third item, the correlation factor. This could result in possible inconsistencies during future in-service acceptance testing of engines at the applicant's facility.

(1) Data Validation. Data validation analysis is the process of determining the acceptability of the measured, corrected data. The process of data validation requires specialized knowledge of standardized methods (e.g., cross-plotting of various parameters, error and cycle derivatives, influence coefficients) and general knowledge (preferably engine model specific) of aerodynamic/thermodynamic cycle effects. The following paragraphs provide some general methods of determining data validity by analyzing the characteristic plots.

(a) Plots should be constructed with the reference and applicant's facility data plotted together for comparative analysis. Sample correlation plots are given in Appendix 3. Generally, each corrected parameter is plotted separately on the y-axis, while either the corrected thrust, engine pressure ratio (EPR), or corrected rotor speed is plotted on the x-axis of each plot. Utilizing a practice of plotting the same ordinate (y-axis) values against another parameter, such as corrected rotor speed, is a useful way of independently judging data validity.

(b) Plotting each pressure ratio against corrected rotor speed can be useful in determining possible pressure mismeasurements, though care should be taken to verify that there is not a real performance shift.

(c) Once a parameter is determined to have an unacceptable error, every effort should be made to eliminate that error. Extensive troubleshooting of the measurement system should be performed. Not only should all gauges, signal conditioners, instrumentation lines, pressure probes, thermocouples, and rakes be carefully examined in an end-to-end check, but the data acquisition system and correction methodology should also be checked. Once the measurement or calculation error has been found and corrective action taken, a determination must be made as to whether another correlation run is necessary. Some errors, such as a calculation error or gauge scalar error, may be corrected without having to conduct another engine run.

(2) Performance Shift Determination.

(a) Once unacceptable measurement errors have been eliminated or compensated for, an assessment must be made as to whether the engine's performance remained unchanged between the reference and applicant's facilities. This can be done by cross-plotting the corrected data. If a shift in performance is not recognized, an incorrect correlation factor could be developed and applied to all future engine test data, resulting in repeated errors in assessing subsequent engine test data.

(b) If there is an apparent performance difference between the two test runs (i.e., reference facility and applicant's facility) that cannot be accounted for by expected facility and/or engine test configuration influences, further testing may be necessary. Follow-on actions will be determined from the results obtained. Paragraph 303 describes factors that influence correlation.

NOTE: Facility configuration and engine or facility instrumentation differences can be difficult to uncover and quantify.

(3) Correlation Factor Determination.

(a) Correlation factor determination should be done only after the first two parts of the correlation analysis (data validation and performance shift determination) have been satisfactorily completed.

NOTE: Some OEMs specify run-to-run parameter tolerances for engine correlation testing. If the OEM's baseline facility was used for reference testing and the data obtained at the two facilities was within the specified tolerances, then the applicant's facility should be deemed correlated and would not require a correlation factor. See paragraphs 400a and 401e(3)(d) for facilities other than the baseline facility that are used for reference testing.

(b) Turbofan and turbojet engines with a choked core exhaust nozzle generally require that a correlation factor be applied only to thrust. However, engines with unchoked core exhaust nozzles may require additional correlation factors (e.g., exhaust gas temperature (EGT), fuel flow, rotor speeds).

(c) OEM's manuals should be referenced for correlation factor determination and application methodology. Generally, correlation factors are applied as a curve input (algebraic difference) or a scalar (multiplier, usually greater than unity). They also usually represent the differences in corrected data obtained during testing at the reference and applicant's facilities. Correlation factors are usually applied to corrected, not raw, data. For example, when a correlation factor is developed for a choked engine, the x-axis may represent corrected thrust, corrected rotor speed, or EPR, and the y-axis would be used for plotting the appropriate correlation factor.

(d) When using a one-away facility for reference testing, caution should be used in determining correlation factors for the applicant's facility. The one-away facility may not have exactly repeated the OEM's baseline facility performance curve characteristics. As long as the one-away's characteristics were within the manufacturer's acceptable run-to-run tolerance, then a correlation factor applied to the one-away facility would not have been necessary. When a third facility's (or applicant's) characteristics are compared to the one-away's performance characteristics and found to be within the same manufacturer's acceptable run-to-run tolerance, there exists a potential for compounding the acceptable tolerance. This results in an error greater than the allowed tolerance relative to the baseline facility. The potential compounded tolerance error can be averted by taking into account the characteristic differences between the one-away and baseline facilities when evaluating the correlation factor for the applicant's facility. The possibility of compounding tolerance errors becomes greater the further the reference facility is from the baseline facility, with respect to correlation. Paragraph 400a provides additional information on this.

NOTE: As previously discussed, every effort must be made to completely eliminate or compensate for all measurement errors during data analysis. Once this is accomplished, attributing the remaining known minor, but elusive, differences to the correlation factor is generally acceptable. For example, there might be a 5-degree measured and corrected EGT difference between the applicant's facility and the reference facility. The applicant's facility would then apply the 5 degree difference to all future measured and corrected EGT data. This methodology should be applied only when the parameter has a constant error over the entire engine operating range and is constant from test to test.

NOTE: If the characteristic curve shapes for a particular parameter measured at the two facilities are divergent (not parallel), then this error should not be applied as a correlation factor. The error would result in the cell producing erroneously variable data during future acceptance testing of engines at the applicant's facility. In this case, a continued effort should be made to determine the cause and eliminate the error.

402. CORRELATION REPORT. After completion of the cell correlation program, a final report should be developed to document information necessary for subsequent engine performance and acceptance testing (e.g., test cell and engine configuration, correlation factors, performance calculations used). The final report is also useful to document a comparison of the applicant's data to the reference data and to document any recommendations. The following should be included in the final Correlation Report.

a. A statement regarding the purpose of the correlation, including any relevant background and historical information.

b. A description of:

- The test cell geometry, preferably including sketches and engineering drawings
- Correlation engine configuration, including its serial number and the bellmouth, fan exhaust nozzle, and primary exhaust nozzle areas
- A listing of dress kit part numbers and serial numbers where possible
- Results of the fuel sample analyses
- Significant changes made to the test cell, dress kit, and engine since the last correlation
- Significant changes made during the current correlation testing and the reasons for making such changes

NOTE: Detailed photographs are also useful for evaluating whether or not changes have occurred to the facility.

c. The test and performance calculation procedures used, including, where applicable, complete identification of any software programs used.

d. The analysis of the applicant's performance data compared with the reference facility data, including the measured and corrected data and the curves for both facilities. This should also include a comparison of data between the reference and baseline facilities if the applicant used a reference facility that was not the OEM's baseline facility.

e. The derived cell correlation factors and how they should be applied.

f. Recommendations for adopting any improvements in engine performance testing (e.g., in-service acceptance testing) that do not affect the validity of the current correlation results. This may include changes that would significantly improve the quality and dependability of future performance data, such as specific operator training, addressing deficiencies in instrument calibration procedures, instrumentation, and data documentation.

g. Conclusions, including any pertinent documentation (i.e., correspondence from the OEM, qualified consultants, DERs), that the applicant's test cell is acceptable for specific engine model in-service acceptance testing based on the correlation analysis.

h. If applicable, the final report should include a statement indicating that it supersedes the previous report. The report should be made part of the facility operations manual or other similar documents, as discussed in paragraph 404 below.

403. MAINTAINING CORRELATION. Once a test cell correlation has been established, it must be satisfactorily maintained. Maintaining correlation relies on recognizing elements that could adversely affect the correlation. Care must be taken to control repairs and/or modifications to the test cell and/or engine test hardware (e.g., test cell inlet and exhaust airflow, thrust stand, measurement systems, data reduction software and procedures, configuration of the engines to be tested). Changes in any of these areas may affect correlation validity. This section provides information on the quality control aspects of test cell testing; how correlation can be satisfactorily maintained; items that may affect satisfactory correlation status; and good facility maintenance practices.

a. Configuration Control. Routine acceptance testing of engines following correlation should be accomplished utilizing an engine test hardware configuration that is consistent with that used for the correlation run, unless otherwise checked out as described in paragraph 305j.

(1) It is extremely important that any items affecting airflow in or around the engine or in the test cell be of the same configuration as that used for correlation testing (e.g., the bellmouth, nacelle, substitute fan reverser, bifurcated ducts, core cowl doors, applicable exhaust nozzle(s), and plugs). Engine components projecting into the airflow, such as generators or hydraulic pumps, should also be of the same configuration. Each piece of critical test hardware must be serialized or otherwise identified. In the event that multiple sets of test hardware are used, back-to-back testing with each specific hardware configuration should be performed. Depending on the results, a separate correlation for each configuration may be required. Paragraph 403c(3) below describes back-to-back testing.

(2) Engine models using ancillary equipment projecting into the cell airflow should be identified at the time of correlation. If it is intended (or just possible) to run the engine with or without such equipment, correlation runs of the engine with and without the equipment should be performed.

b. Correlation Monitoring and Maintenance. The following paragraphs give several ways to maintain correlation. If an operator does not utilize any of the following recommended trending, periodic checks, and recorrelation testing, then it is recommended that the facility institute a process of recorrelation every seven years. This recommendation is based on reference 1-2a(1) of Appendix 1.

NOTE: If the correlation of the applicant's facility was conducted using a reference facility other than the OEM's baseline facility (e.g., a one-away facility), using one or more of the following methods to ensure that the correlation is maintained is important.

(1) Trending is the practice of recording and plotting engine performance parameters of satisfactory acceptance engine tests. The key parameters are plotted against results obtained from similar engine tests. These results are examined for signs of performance data shifts above and beyond normal data scatter. Trending can increase confidence in the correlation validity or can alert facilities' organizations to a possible test anomaly or an unacceptable drift of recorded performance data over an extended period of time. To be interpreted correctly, analysis of trend data must be done with knowledge of any engine internal hardware modifications that result in a change in engine performance. In these cases, evidence of a significant performance data trend would not necessarily indicate a loss of correlation.

(2) Re-calibration of instrumentation in a test cell must be accomplished on a regular schedule to maintain the required measurement accuracy. A system of recording and forecasting instrumentation calibration requirements should be established. As with the case of initial correlation, all instrumentation calibrations should be performed using primary or secondary standards traceable to an accepted known standard. Paragraph 301 provides additional information on instrument calibration.

(3) Continued periodic checks provide additional confidence in the current validity of the test cell correlation. Periodic check opportunities could include running an engine in another correlated test cell and checking it against run data from the test cell under evaluation or running an engine dedicated for periodic checks in the test cell under evaluation. Data error stackup should be considered in the interpretation of test results. Maximum time intervals for recorrelation may be recommended by the OEM. Additional correlations may be made on an "as needed" basis. For instance, where a test cell has undergone significant changes, recorrelation will be required. This is further discussed in paragraph 403(c).

c. Maintenance of Test Cell Correlation Following Repairs or Modifications. To monitor changes to the test cell and its systems, adequate recordkeeping of events is necessary. Records may take the form of written logs, photographs, video, and other accurate documentation media.

(1) The following are examples of items where modifications can have significant facility effects:

- Engine test hardware (e.g., dress kit)
- Facility inlet and exhaust
- Data acquisition: manual to automated acquisition, manual to automated reduction (calculation), and scanning, averaging, and editing
- Instrumentation: type, quantity, and location
- Thrust stand
- Sizable equipment changes within the cell

(2) Repairs to test cell equipment should be evaluated for possible impact on engine performance or performance measurement.

(3) Back-to-back testing is the method most frequently used to determine the effects on engine performance of a repair or modification made to either the test cell or engine test hardware. This test is accomplished by using an engine with known stable performance that is capable of operating over the engine's entire thrust range. Before any repair or modification in the cell or to the engine test hardware is made that may affect correlation, the engine must be run through the first stage of a back-to-back test. The test procedure may be defined by the OEM or developed by the applicant. The schedule should include all power points that would be recorded during routine acceptance testing and may include other data points. It is good practice to perform this initial test twice, at a minimum, before any repair or modification. The data from these runs should be carefully examined to determine if engine performance is stable. When stable engine performance has been established, the engine should be stored for later testing. After the repair and/or modification has been accomplished and documented, the same engine should be tested in the cell to the same schedule as initially tested. Data from these runs should be analyzed to determine the effect, if any, the repair and/or modification had on engine performance and, thus, any cell correlation factor(s).

(4) Total cell airflow monitoring is a useful technique for determining whether test cell changes have affected engine performance. The measurement of the airflow, pressure, and temperature distribution in front of and around the engine under test may be determined by using a hot wire anemometer, pitot-static array, or a similar system. The data obtained during the test should be compared with that obtained during the last correlation.

(5) If any of the measured parameters that have been corrected and plotted on the characteristic performance curves have changed relative to the initial test, it should be determined whether the change(s) makes sense relative to the repair and/or modification. The parameters that have changed, the magnitude of change in their values, and the direction of their change should be considered during this evaluation. If a change to any of the parameters cannot be reconciled, an analysis of the data should be performed to determine if there is an error in the data measurement (i.e., data validation). If data validation analysis is unsuccessful in reconciling parameter differences, a recorrelation should be performed. Further, if it is determined that a new correlation factor and/or a significant change to an existing correlation factor is necessary following reconciliation of all measured parameter differences, the FAA recommends that a recorrelation be performed.

d. Test Cell Equipment and Facility Maintenance. Regular inspection and maintenance of all parts of the test cell and engine dress kit are highly recommended. A maintenance schedule should be established and followed. Maintenance should include:

- Instrument calibration
- Inspection or checks of measurement systems
- Inspection and repair of intake and exhaust systems (e.g., splitter panels, augmentor tube)
- Lubrication of moving parts
- Activation of valves and limit switches
- Inspection and repair of cell structural surfaces
- Intake screen debris removal
- Exhaust cleaning
- Engine intake and exhaust nozzle inspections
- Oil system flushing
- Emergency system testing
- Personnel training

NOTE: These practices can be characterized as good housekeeping and preventive maintenance.

404. FACILITY OPERATIONS MANUAL. An FAA-approved facility performing in-service engine acceptance testing should have in place a facility operations manual, or other document(s) acceptable to the FAA, that defines a specific set of requirements for maintaining and operating the test cell and for maintaining a satisfactory correlation status. These requirements should include, but are not limited to, the following:

a. Recordkeeping. As a minimum, facility records must conform to the requirements of part 145. The current edition of FAA AC 145-3, Guide for Developing and Evaluating Repair Station Inspection Procedures Manuals, prescribes recommended practices for recordkeeping.

b. Test Cell Operations. The engine make, model, and configuration for each operation in the test cell should be documented. Provisions should be made for recording the dress kit hardware and serial numbers, as applicable. This dress kit should be the same configuration as the one used for correlation, unless the dress kit has otherwise been checked out as described in paragraph 305j. Facility operating procedures should be developed. The procedures should include operations under normal and emergency conditions (such as fire, engine failure, compressor stalls, etc). In addition, procedures should be developed in the event of engine operational warnings, as indicated on the test cell console, including the disposition of these warnings.

c. Facility Maintenance Procedures. A procedure must be established to record all repairs and modifications to the facility, especially those that may affect test cell operation and correlation status. This procedure should specify that the respective FSDO be notified of any facility modifications that may affect the correlation status. Also, a procedure should be developed to ensure that facility maintenance and instrument calibration is regularly scheduled and performed and that pertinent information is recorded.

d. Quality Control Procedures. The facility must have provisions in place to maintain a satisfactory correlation status. Various options for correlation monitoring and maintenance are discussed in paragraph 403. In addition, the facility should have a system to maintain, in a current status, the following:

(1) OEM's documents, such as a facility planning manual, if published;

(2) Service engine acceptance test procedures taken from the OEM's Instructions for Continued Airworthiness, and pertinent specifications and Technical Orders for each model being tested;

(3) Correlation reports; and

(4) Other pertinent documents.

NOTE: The provisions and systems discussed above should be defined in a facility operations manual or other documents(s) acceptable to the FAA.

APPENDIX 1. RELATED TEST CELL PUBLICATIONS AND MATERIALS

1-1. FAA Advisory Circulars (AC), current edition.

a. The following free ACs may be obtained from the U.S. Department of Transportation Subsequent Distribution Center, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785.

(1) AC 20-77, Use of Manufacturers' Maintenance Manuals.

(2) AC 20-88, Guidelines on the Marking of Aircraft Powerplant Instruments (Displays).

(3) AC 20-124, Water Ingestion Testing for Turbine Powered Airplanes.

(4) AC 20-125, Water in Aviation Fuels.

(5) AC 25.939-1, Evaluating Turbine Engine Operating Characteristics.

(6) AC 33-2, Aircraft Engine Type Certification Handbook.

(7) AC 33-5, Turbine Engine Rotor Blade Containment/Durability.

(8) AC 33.65-1, Surge and Stall Characteristics of Aircraft Turbine Engines.

(9) AC 39-6, Summary of Airworthiness Directives, Announcement of Availability.

(10) AC 43-9, Maintenance Records.

(11) AC 45-3, Installation, Removal, or Change of Identification Data and Identification Plates on Aircraft Engines.

(12) AC 145-3, Guide For Developing and Evaluating Repair Station Inspection Procedures Manuals. (Note: AC 145-3 may be superceded in the near future. Use the most current edition).

b. AC 43-4, Corrosion Control for Aircraft, is for sale and is obtainable from the Superintendent of Documents, U.S. Government Printing Office, 710 North Capitol Street, NW., Washington, D.C. 20402.

1-2. Industry Documents.

a. Society of Automotive Engineers (SAE) publications may be obtained from SAE Aerospace International, 400 Commonwealth Drive, Warrendale, PA 15096.

(1) SAE Aerospace Recommended Practice (ARP) 741B, Turbofan and Turbojet Gas Turbine Engine Test Cell Correlation, Revision B. Revised 2000-12-07 (or latest revision).

(2) SAE Aerospace Information Report (AIR) No. 4869, Design Considerations for Enclosed Turbofan/Turbojet Engine Test Cells. Issued October, 1995.

(3) SAE AIR Report No. 5026, Test Cell Instrumentation. Issued November, 1996.

(4) SAE ARP Report No. 4990, Turbine Flowmeter Fuel Flow Calculations. Issued September, 1997.

b. American Society for Testing and Materials (ASTM) publications may be obtained from ASTM, 100 Barr Harbour Road, Conshohocken, PA 19428.

(1) ASTM D341-89, Volume 5.01. 1990.

(2) ASTM D287, Fuel Specification, Gravity API. Latest revision.

c. DM-009, NCR No. 30165, A Derivation of Gross Thrust for a Sea Level Jet Engine Test Cell. MacLeod, James; National Research Council of Canada. May be obtained from: National Research Council of Canada, Montreal Road, Ottawa, Ontario, Canada K1A OR6.

d. Advisory Group for Aerospace Research & Development (AGARD) publications may be obtained from 7 Rule Ancelle, 92200 Nevilly Sur Seine, France.

(1) AGARD Lecture Series No. 169, Comparative Engine Performance Measurements.

(2) AGARD Advisory Report No. 248, Propulsion and Energetics Panel Working Group 15 on the Uniform Test Programme.

APPENDIX 2. ENGINE TEST CELL APPROVAL SCHEDULE FLOW CHART

Applicant Submits Letter To Local Flight Standards District Office (FSDO) Requesting Test Cell Approval

↓

Applicant Submits Correlation Plan to FSDO

↓

FSDO Requests Aircraft Certification Office Review of Correlation Plan and Follow-On Support for Correlation

↓

FSDO/ACO Provide Relevant Information to Applicant on Cell Correlation Approval Procedures

↓

FSDO Performs Initial Checks

- Gets Verification of Baseline/Reference Facility FAA-Approval and Traceability Data, as Applicable
- Requests and Reviews Applicant's Instrumentation Calibration Data

↓

Applicant Notifies FSDO of Test Schedule

↓

Perform Testing at Baseline/Reference Facility. If Witnessed by FSDO*, FSDO* Acquires Copy of Raw Data Before Leaving

↓

Perform Testing at Applicant's Facility. If Witnessed by FSDO*, FSDO* Acquires Copy of Raw Data Before Leaving

↓

Applicant Provides Correlation Report and Facilities Operations Manual (or Other Document(s)) to FSDO for Acceptance

↓

FSDO Forwards Correlation Report to ACO for Review

↓

ACO Reviews Report and Provides Findings to FSDO

↓

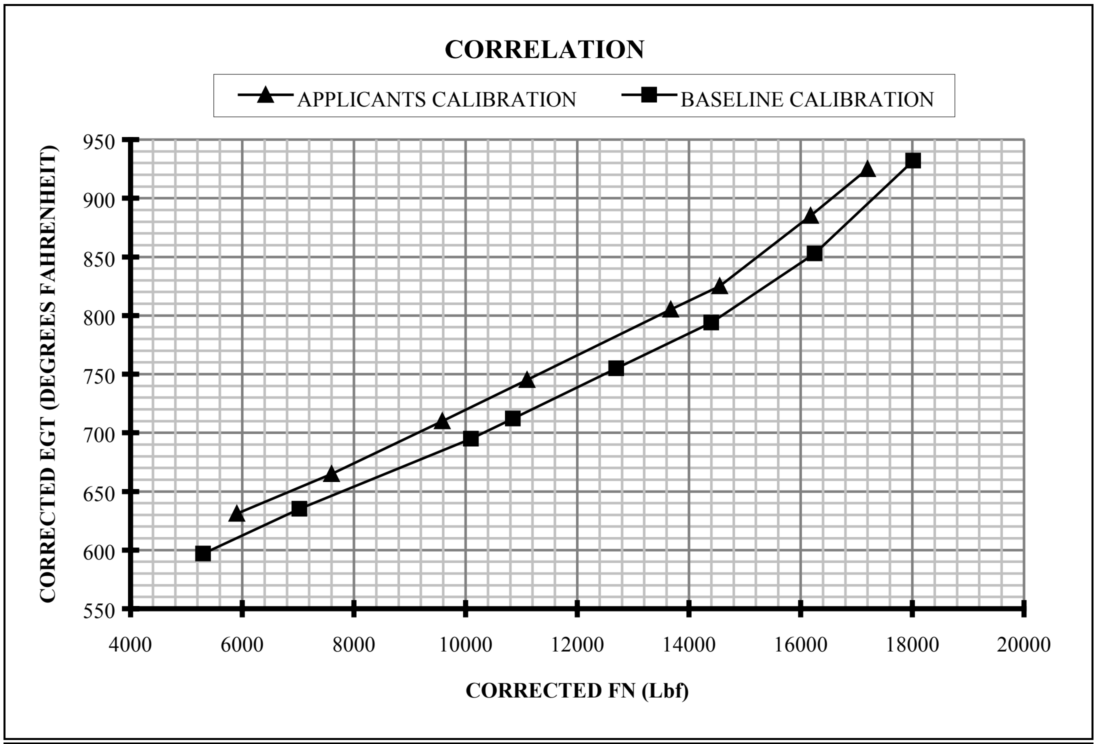
FSDO Reviews Facility Operations Manual (or Other Document(s))

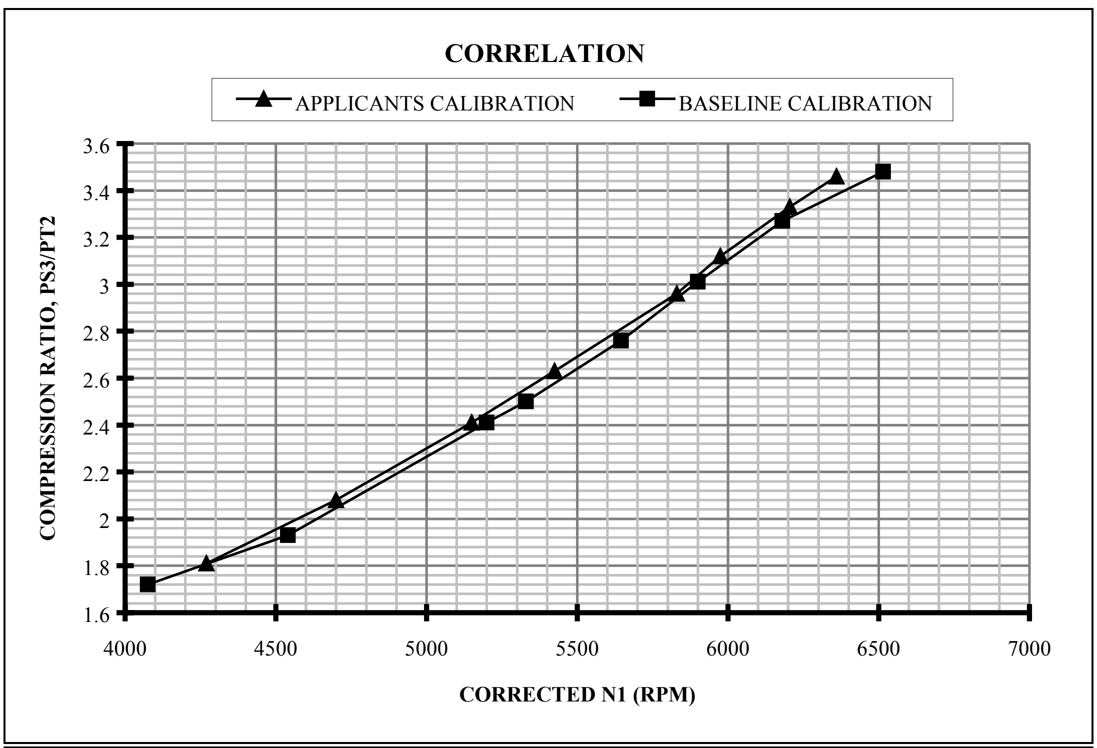
↓

FSDO Approves Facility and Specifies any ACO or FSDO Recommendations/Requirements

*FSDO or Representative of the FAA

APPENDIX 3. SAMPLE CORRELATION PLOTS





APPENDIX 4. GLOSSARY OF ACRONYMS AND ABBREVIATIONS

AC	advisory circular
ACO	Aircraft Certification Office
ARP	Aerospace Recommended Practice
ASTM	American Society for Testing and Materials
DER	Designated Engineering Representative
EGT	Exhaust Gas Temperature
EPR	Engine Pressure Ratio
°F	Temperature in degrees Fahrenheit
FAA	Federal Aviation Administration
fps	feet per second
FSDO	Flight Standards District Office
in-HgA	Inches of Mercury Absolute
ISO	International Standards Organization
°K	Temperature in degrees Kelvin
kPa	kilopascal absolute
LHV	Lower Heating Value
NIST	National Institute of Standards and Technology
OEM	Original Engine Manufacturer
Pcd	Cell Depression
psi	Pounds Per Square Inch
psia	Pounds Per Square Inch Absolute
QEC	Quick Engine Change
°R	Temperature in degrees Rankine
SAE	Society of Automotive Engineers