



AEROSPACE INFORMATION REPORT

AIR5301™

REV. B

Issued 2000-04
Reaffirmed 2007-11
Revised 2017-11
Stabilized 2023-12

Superseding AIR5301A

Installed Outdoor Engine Testing

RATIONALE

This revision is being issued to stabilize the document. The information in the report is still valid but with a limited potential users market. The information should be retained for anyone who would like to consider utilizing these techniques for outdoor on-wing testing.

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1. SCOPE

1.1 Introduction

This SAE Aerospace Information Report (AIR) was written because of the growing interest in aircraft installed outdoor engine testing by the Federal Aviation Administration, airlines, charter/commercial operators, cargo carriers, engine manufacturers and overhaul and repair stations. This document was developed by a broad cross section of personnel from the aviation industry and government agencies and includes information obtained from a survey of a variety of operators of fixed and rotary wing aircraft and research of aircraft and engine maintenance manuals.

1.2 Purpose

This document will provide aircraft operators with an overview of current industry on-the-wing engine test practices including advantages/disadvantages derived, test criteria, capabilities of remote ground based test data acquisition/instrumentation and on-board condition monitoring systems, aircraft installation effects, and a general discussion of procedures, data, equipment and personnel required to perform safe, accurate, on-the-wing engine tests. In addition, the report also discusses the use of specific facilities that can be used in the control of noise and other environmental effects as a result of installed outdoor engine testing. This information is provided as a guide to help operators decide to initiate, improve, expand or cease performing installed engine testing and offer assistance with understanding the limitations of specialized outdoor facilities should they be necessary.

2. REFERENCES

2.1 Applicable Documents

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

2.1.1 ARP1587, Aircraft Gas Turbine Engine Health Management System Guide

2.1.2 OEM produced current Aircraft Maintenance Manuals

2.1.3 NAVAIR 17-15A-89 Technical Manual, Operating Instruction and Intermediate Maintenance with IPB

2.1.4 ISO/TAG4/WG3; June 1992, Guide to Expression of Uncertainty in Measurement

2.1.5 AIR1871, Lessons Learned from Developing, Implementing, and Operating a Health Management System for Propulsion and Drive Train Systems

2.1.6 AIR1873, Guide to Limited Engine Monitoring Systems for Aircraft Gas Turbine Engines

2.1.7 ARD50002, A Discussion of Standardization Concepts for Condition Monitoring and Performance Analysis Software

2.1.8 AIR4061, Guidelines for Integrating Typical Engine Health Management Functions Within Aircraft Systems

2.1.9 AIR1839, A Guide to Aircraft Turbine Engine Vibration Monitoring Systems

2.1.10 Naval Air Warfare Center, Aircraft Division, Lakehurst, New Jersey, Jet Engine Test Facility Correlation Report. NAS Sigonella, Italy, A/F37T-19 Turboprop Jet Engine Test Facility, T56-A-14, T56-A-16, and T56-A-425, Engines

2.1.11 Naval Air Warfare Center, Aircraft Division, Lakehurst, New Jersey, Jet Engine Test Facility Correlation Report, MCAS Futema, Japan, A/F37T-19 Turboprop Engine Test Facility, T56-A-16 Engines

2.1.12 Pratt & Whitney Aircraft Operating Instruction 200

2.1.13 General Electric Company T700 Engine Model Specification E1221 dated October 1997



3. TECHNICAL BACKGROUND

Installed engine testing has been performed since aircraft started to fly and was an accepted practice to determine engine performance after most maintenance actions except for complete engine overhaul. In most cases cockpit instruments were all that were available and used to determine performance because the engines and test requirements were less complex than today's. As the complexity of engines and test requirements increased so too did concern for safety and performance guarantees making it necessary to more accurately measure more engine performance parameters. Although cockpit instrumentation systems accuracies have improved dramatically, and remote ground test systems have been developed that are equal to test cell systems accuracies for the same engine performance parameters, the capability to measure all parameters specified by the airframe and engine manufacturers is not yet available (e.g., thrust) with sufficient accuracies to completely eliminate the need for uninstalled testing in test cells after complete engine overhaul. Recent research of current maintenance manuals and results of a survey of a cross section of operators shows that most maintenance manuals provide installed test procedures and performance criteria. In most cases test criteria are provided for the full spectrum from simple leak check tests requiring only basic operating parameters such as speed, temperature and pressures through full performance tests requiring recording most of the same parameters as those recorded during uninstalled engine tests in a test cell. The advantages and disadvantages of installed testing, engine test criteria, remote ground based and on-board-condition-monitoring systems, installation effects, procedures, data, equipment and personnel required, and engine modularity relative to on-the-wing testing, will be addressed in subsequent sections.

Figure 1 shows the generally accepted existing work flow path for processing new, overhauled and repaired engines. New engines usually go from final assembly to test cell acceptance tests. If all the engine manufacturers, appropriate regulating authority and customer uninstalled acceptance test criteria are met, the engine is delivered to the customer and installed on an aircraft. A high-power assurance test is then made to verify the engine can produce installed engine takeoff power. However, there may be occasions when a new engine is run on an operator's test cell before installation on an aircraft (e.g., when a regulating authority or engine manufacturer's service bulletin is issued, and a new spare engine has not had it incorporated and tested). The need to test an installed in-service engine is determined by analyzing whatever one of the five conditions shown is applicable. The flow shows that the type of test required is determined by the level of repair.

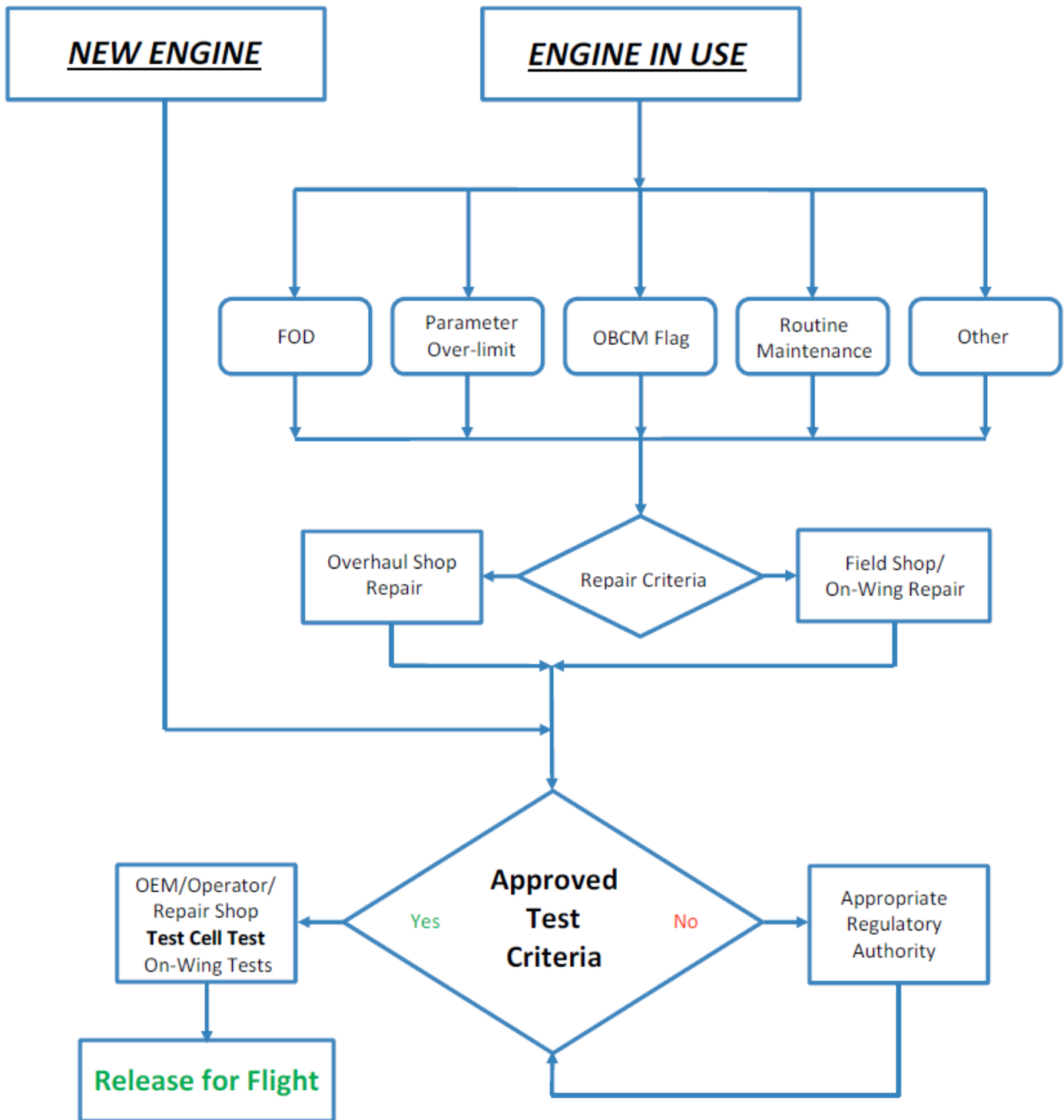


Figure 1 - Engine test requirement flow chart

ADVANTAGES

Table 1 lists advantages that may be derived from installed engine testing. The reduced need for a test cell and associated personnel, reduced fuel consumption and maintenance turnaround time are obviously economically significant. Just as important may be the advantage of reduced handling of the engine which lowers the probability of human errors. Testing quick engine change kit (QECK) configured engines and related systems and comparing the test data with on-board-condition-monitoring system data ensures the integrity of the complete propulsion system. It also allows trimming to optimum performance and enhances trend analysis which can extend in-service life of components and reduce the number of major failures; all contributing to increased flight safety (Reference 2.1.1). The advantages listed in Table 1 can be realized if the airframe and engine maintenance manuals on-the-wing-test requirements are met. However, there are also many disadvantages that can be encountered which are addressed in Section 5.

Table 1 - Advantages of on-the-wing engine testing¹

-
1. May eliminate costs of designing, building, operating and maintaining engine test cells by operators.
 2. Reduces maintenance man-hours by eliminating the engine test cell personnel which results in significant cost savings.
 3. Reduces fuel costs by eliminating some test cell tests.
 4. Eliminates the need to resolve differences between uninstalled engine test cell test and on-the-wing engine test results.
 5. Engines are tested in full QECK flight configuration which provides complete propulsion systems integrity checks/assurance.
 6. Related aircraft systems, i.e., fuel, hydraulic, electrical, APU, etc., are tested.
 7. Provides the opportunity to compare cockpit, remote ground trim, and on-board-condition-monitoring systems data and increases performance data bases for each engine tested.
 8. Enhances engine trend analysis accuracy by providing initial installed engine baseline data.
 9. Lowers the number of times an engine is handled which reduces the possibility of human error.
 10. Allows some on-the-wing repairs and test avoiding engine removal and transportation costs.
 11. Allows installed engine vibration determination.
-

¹ These advantages could be realized provided the airframe/engine manual requirements for installed on-the-wing-testing are met.

4. DISADVANTAGES

Table 2 lists the possible disadvantages of installed engine testing. The large area needed for testing because of intake and exhaust blast hazards may only be a problem with large turbofan/jet aircraft not turboprop aircraft and helicopters. The restraint system may be a significant problem if the operator is operating a variety of aircraft. In most cases the aircraft can be secured by using the aircraft brakes, chain or cable holdbacks and a variety of wheel chocks, some simple, others more complex such as "Alameda Chocks" used by the U.S. Navy (Figure 2). Noise from ground testing is usually buried in overflight noise, but nevertheless must be addressed. Fixed and movable inlet and exhaust noise suppressors can be used or alternatively acoustic facilities such as Ground Run-up Enclosures (GRE) or complete acoustic enclosure (Hush House) can be employed to alleviate this problem, examples of which are discussed in Section 6. Other techniques such as active noise control might be feasible, but are not common. Environmental conditions may occasionally preclude installed testing because of high crosswinds, ground and atmospheric icing conditions and extremely heavy precipitation. Crosswinds can be overcome by repositioning the aircraft so that the inlets are headed into the wind or using a modern design of GRE which can extend the testing envelope in such condition through the use of appropriate aerodynamic design of the facility. Some engine manufacturers use turbulence control structures (TCS) to reduce crosswind effects which allows accurate uninstalled ground testing in a much wider crosswind envelope. They do not incorporate noise abatement capabilities. Figure 3 shows a specialized TCS installed on an engine at an outdoor engine test facility. If a cost/benefit analysis is favorable a similar device might be adaptable to wing pylon mounted engines. A simple example that is primarily for the prevention of FOD, but also to help break groundborne vortex stream is shown in Figure 4, this could be adapted to reduce crosswind generated turbulence. The requirement for a taxi qualified crew may only be a problem with very large aircraft. Each operator determines the qualifications required to taxi and ground test fixed wing aircraft and many maintenance personnel meet the requirements. Helicopters always are ground tested by pilots because of the potential hazard of ground effect harmonics and the need to control and/or fly out of it.

The potential disadvantages of having to repeat engine runs for adjustments and troubleshooting purposes cannot be eliminated, but can be minimized by performing high quality maintenance, repair and test. This also applies to the potential risk of catastrophic failure/fire. However, this risk must undergo thorough analysis because of the personnel safety and financial impacts of these possible incidents. The disadvantage of less accurate data from cockpit and remote ground-based test data acquisition systems than from test cell systems may no longer be true because of the increased capabilities of these systems. Access to some aircraft systems sensor/pickup mount points or pressure taps and adjustments may be difficult, but in many cases, can be overcome by the use of remote test/trim panels incorporated in the aircraft.

Probably the most significant disadvantage of on-the-wing testing is the inability to measure thrust on a routine basis. This is especially true for engines that incorporate electronic engine controls that employ data entry plugs (DEP) that adjust the net thrust/engine pressure ratio (FN/EPR/P4.95/P2) relationship to allow a FN range to be produced at a given EPR. During engine tests in a test cell this relationship is measured and adjusted by installing the appropriate DEP, by modifier class, to align the FN/EPR relationship. This cannot be accomplished during installed engine testing.

5. ENGINE TEST CRITERIA

5.1 Acceptance Tests

Engine test criteria are developed by the engine manufacturer during engine development. The basic performance criteria are developed in sea level and altitude test cells and flight test bed aircraft. This is done in close cooperation with the manufacturer of the airframe in which the engine will be used. The airframe manufacturer provides installation specifications and sometimes inlet, exhaust and nacelle hardware for testing. Subsequent to successful completion of all testing, the engine manufacturer establishes uninstalled engine test criteria for different levels of maintenance. The engines are then shipped to the airframe manufacturer for his ground and flight testing and development of installed engine test requirements. This is done in cooperation with the engine manufacturer. The airframe manufacturer is responsible for publishing the installed engine test criteria for different levels of maintenance subject to approval by the appropriate regulating authority.

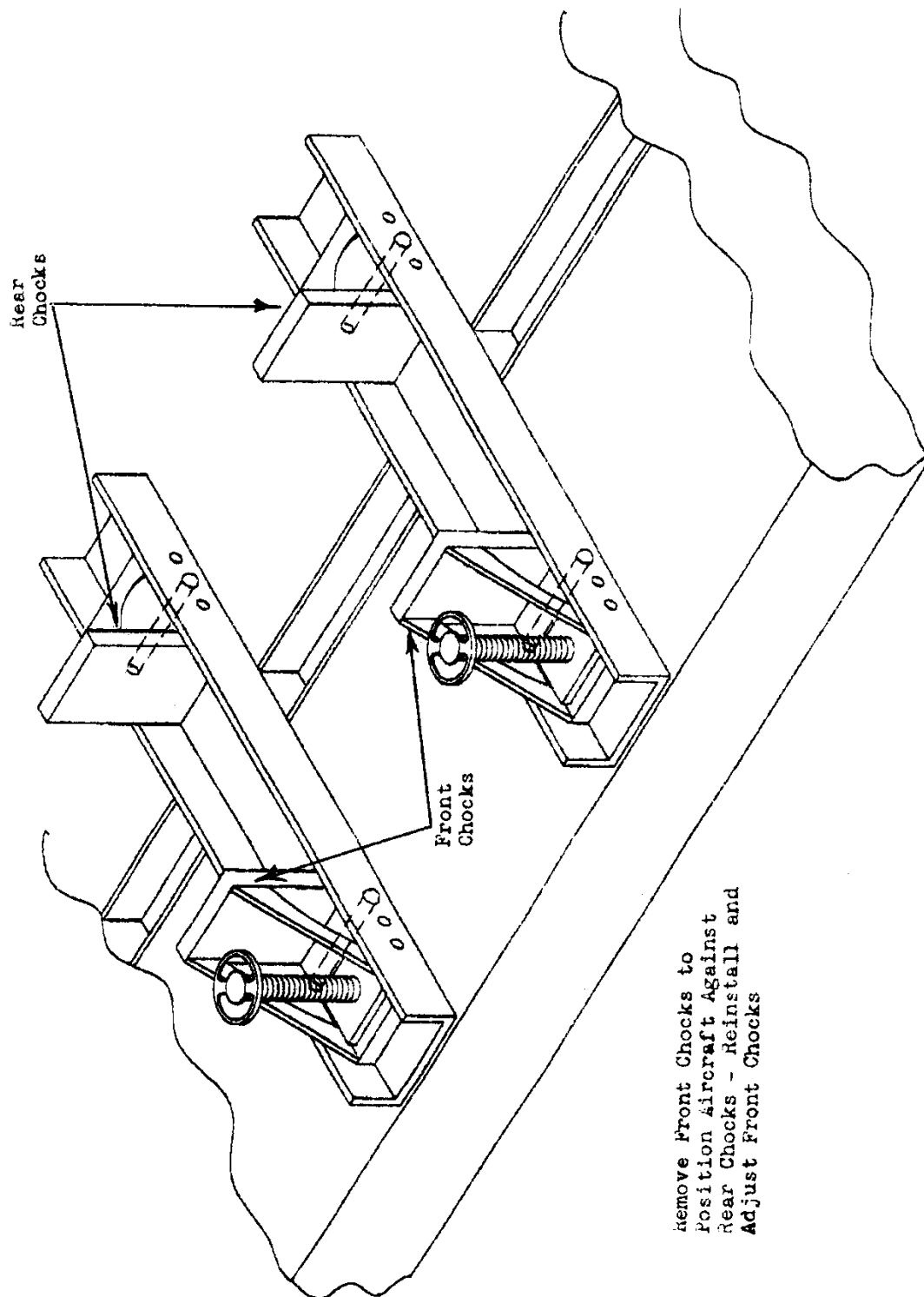


Figure 2 - Alameda chocks

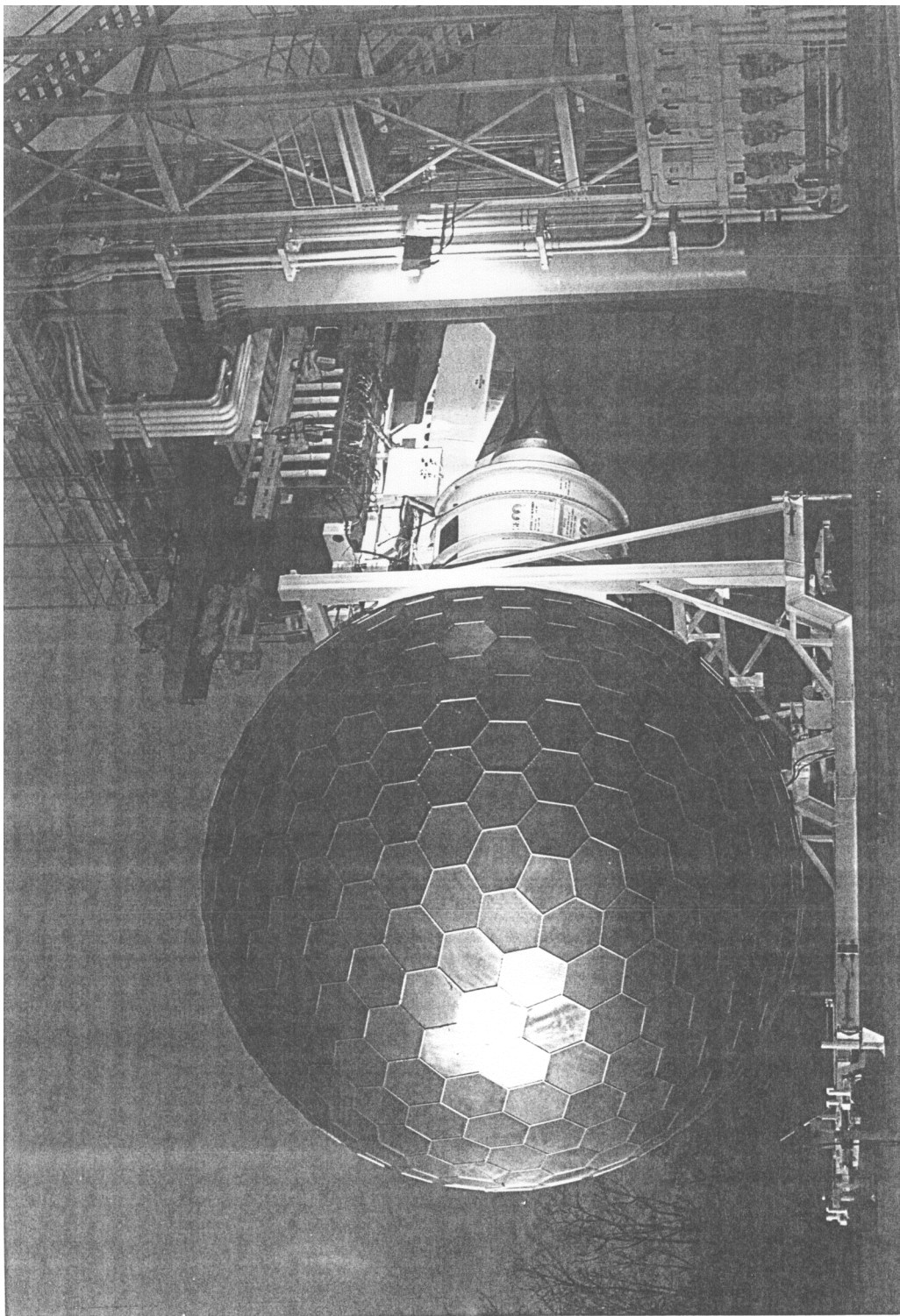


Figure 3 - Turbulence control structure



Figure 4 – Fod guard incorporating anti vortex floor mesh

Table 2 - Disadvantages of on-the-wing engine testing

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1. Requires large high-power run-up area that is secure, safe, and free from foreign object damage (FOD) hazards.
 2. Requires large, clear exhaust blast area and may also require expensive blast deflector.
 3. May require a universal high-power restraint system if many different type/model aircraft are operated.
 4. Generates very high levels of near and far field noise which may result in the need to install noise suppressors or other acoustic facilities.
 5. Crosswind effects on engines, especially fans, will sometimes delay or even preclude engine testing and/or require the use of an inlet airflow turbulence control device. Winds within limits may still affect engine performance and must be considered during data recording and analysis.
 6. Ice/sleet/snow, heavy rainfall will also sometimes cause delays, increase safety hazards and preclude engine testing.
 7. Depending on the location of the run-up area, a taxi qualified crew may be required.
 8. Difficult to perform accurate vibration analysis when different values result from cockpit gauge readouts and test cell readouts and because of the influence of the airframe configuration/condition/restraint, i.e., harmonic resonance areas, parts, components, loose or worn parts, tire and landing gear strut inflation, fuel load, etc.
 9. Takes aircraft out of service and repeat engine troubleshooting runs will increase aircraft out-of-service time.
 10. Acquiring accurate fuel flow data is very difficult. Some aircraft/engine fuel systems require adding accurate test flowmeter systems. When this is done, the integrity of the on-board fuel systems is compromised requiring an additional engine run to perform a leak check.
 11. Lack of capability to measure thrust on a routine basis.
 12. Helicopter installed engine performance tests must be performed by a rated pilot.
 13. Risk of major damage to aircraft if uncontained catastrophic engine failure occurs.
 14. Access to sensor/pickup mounting locations, pressure taps, fuel control, and throttle adjustments may be limited.
 15. Direct comparison of on-the-wing and engine test cell test results may be difficult when different data acquisition systems and techniques are used for each test.
-

Installed engine test criteria includes many of the same parameters as uninstalled testing, i.e., speed, temperatures, pressures, vibration, fuel flow, thrust, vane angles, compressor discharge characteristics, etc. Some of these may not be measured during installed testing because of difficult accessibility or in the case of thrust and vibration, the lack of a method of measurement other than a thrust bed and the complexity of vibration measurement and analysis. In the case of turboprop and turboshaft engines, propeller pitch and speed, torque, SHP and gas generator and power turbine output shaft speeds are usually measured. Reverse thrust and propeller tests may be required for some aircraft. Most helicopter installed engine ground tests are limited to part power tests because the helicopter has to be tied down or loaded to maximum gross weight to allow setting the main rotor blade pitch to the angle that applies the maximum torque load on the engine. Neither of these procedures is desirable. The tiedown procedure poses a very real possibility of ground effect vibration hazard which can destroy a helicopter and loading the aircraft requires extra man-hours and usually some flight time. Part power test data is extrapolated to full performance points based on empirical data from airframe and engine manufacturers.

Recent research of current maintenance manuals and the results of a survey of a broad cross section of operators shows that most aircraft maintenance manuals provide installed engine test procedures, engine performance criteria and limits of ambient conditions under which tests can be performed. In most cases criteria are provided for anything from a leak check to full performance/power assurance tests, depending on the type of repair/replacement done (given in OEM Aircraft Maintenance Manuals Reference 2.1.2). For instance, Boeing provides a listing of 15 different specific tests required after a PW4000 series engine on a 767 aircraft undergoes some form of maintenance. A copy of that listing is shown in Table 3. Note that table 3 is representative of a specific aircraft/engine combination for example only, additional information and requirements will form part of other aircraft/engine combinations such as engine extractions (ECS bleed, IDG load etc.) which are typically turned off. Figure 5 shows typical data sheets used to record cockpit instrument readouts during these tests. The data items recorded may vary for the different tests and aircraft/engine combinations.

Table 3 - Power plant test list

Test Number	Test title
1	Pneumatic Leak Test
2	Engine Motoring Test
3	Ground Test - Idle Power
4	Engine Power and Acceleration/Deceleration Test
5	Oil System Static Leak Test
6	Electronic Engine Control EEC
7	EEC Static Test
8	Vibration Survey
9	Performance Test
10	Replacement Engine Test (Pretested)
11	Replacement Engine Test (Untested)
12	Engine Vacuum Test
13	Main Oil Pressure Test
14	PT2 System Leak Test
15	EEC Ground Test of Engine Control System

Figure 5 shows a typical data sheet used to record cockpit instrument readouts during performance tests of turboprop engines. Similar data sheets, minus propeller data, are used for helicopter turboshaft engine tests. Figures 6, 7, 8, and 9 are examples of performance curves used to plot test data for a turbofan, turbojet, turboshaft and a turboprop engine; however, each company or operator develops its own curves which may plot different parameters. Instead of curves, some of the new aircraft maintenance manuals for aircraft with digital cockpit instrument displays provide look-up tables showing allowable engine performance parameter limits.

Installed engine testing can be severely restricted by wind conditions. Examples are shown in Figures 11 and 12 from Reference 2.1.2 which show wind direction and velocity limits for twin engine and four engine aircraft respectively. It is very obvious that direct tailwinds are the most restrictive. For example, for the twin engine aircraft the maximum allowable headwind is 25 knots and zero tailwind. For the four-engine aircraft the maximum allowable headwind is 30 knots and zero tailwind. Some aircraft manufacturers limitations are related to the power level at which the test will be performed (Reference 2.1.2). Other aircraft and engine combinations will have different crosswind restrictions/limits

Performing tests under conditions exceeding crosswind limits can result in hot starts and fan/compressor stalls that can cause serious damage to any engine. As previously noted in this document, wind restricted operations can be improved with the use of appropriately designed ground running facilities and these are briefly discussed in Section 6.