SAE Aerospace
An SAE International Group

AEROSPACE INFORMATION REPORT

SAE AIR5301

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Installed Outdoor Engine 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. This information is provided as a guide to help operators decide to initiate, improve, expand or cease performing installed engine testing.

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. Nothing in this document supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE ARP1587, Revision A, Gas Turbine Engine Monitoring System Guide, 1993-04-06

2.1.2 Boeing 767 AMM 71-00-00, PW 4000 Series Engines, November 10, 1992

2.1.3 Airbus Industries A320 AMM, CFM, 71-00-00, February 1988

2.1.4 Airbus Industries A310 AMM 71-00-00, CF6-80C2A Engines

2.1.5 McDonnell Douglas DC10-30 AMM 71-00-00, CF6-50C2B Engines

2.1.6 Boeing 737-200 AMM 71-00-00, JT8D-9/9a/17a Engines

2.1.7 Boeing 747-400 AMM 71-00-00, CF6-80C2B Engines, February 10, 1995

2.1.8 Airbus Industries A300-600 AMM 71-00-00, CF6-80C Engines, December 1, 1989

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

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

2.1.11 SAE AIR1871, Lessons Learned from Developmental and Operational Turbine Engine Monitoring Systems, Issued June 1984, Revised January 1988

2.1.12 SAE AIR1873, Guide to Limited Engine Monitoring Systems for Aircraft Gas Turbine Engines, Issued May 5, 1988, Reaffirmed and under revisions May 1994

2.1.13 SAE ARD50002, A Discussion of Standardized Concepts for Condition Monitoring and Performance Analysis Software, Issued November 5, 1992

2.1.14 SAE AIR4061, Guidelines for Integration of Engine Monitoring Functions with On Board Aircraft Systems, Issued August 1, 1990

2.1.15 SAE AIR1839, A Guide to Aircraft Turbine Engine Vibration Monitoring Systems, Issued October 1986, Revised March 10, 1992

2.1.16 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

2.1.17 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

2.1.18 Pratt & Whitney Aircraft Operating Instruction 200

2.1.19 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.

4. 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 turn around time are obviously economically significant. Just as important may be the technical 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.

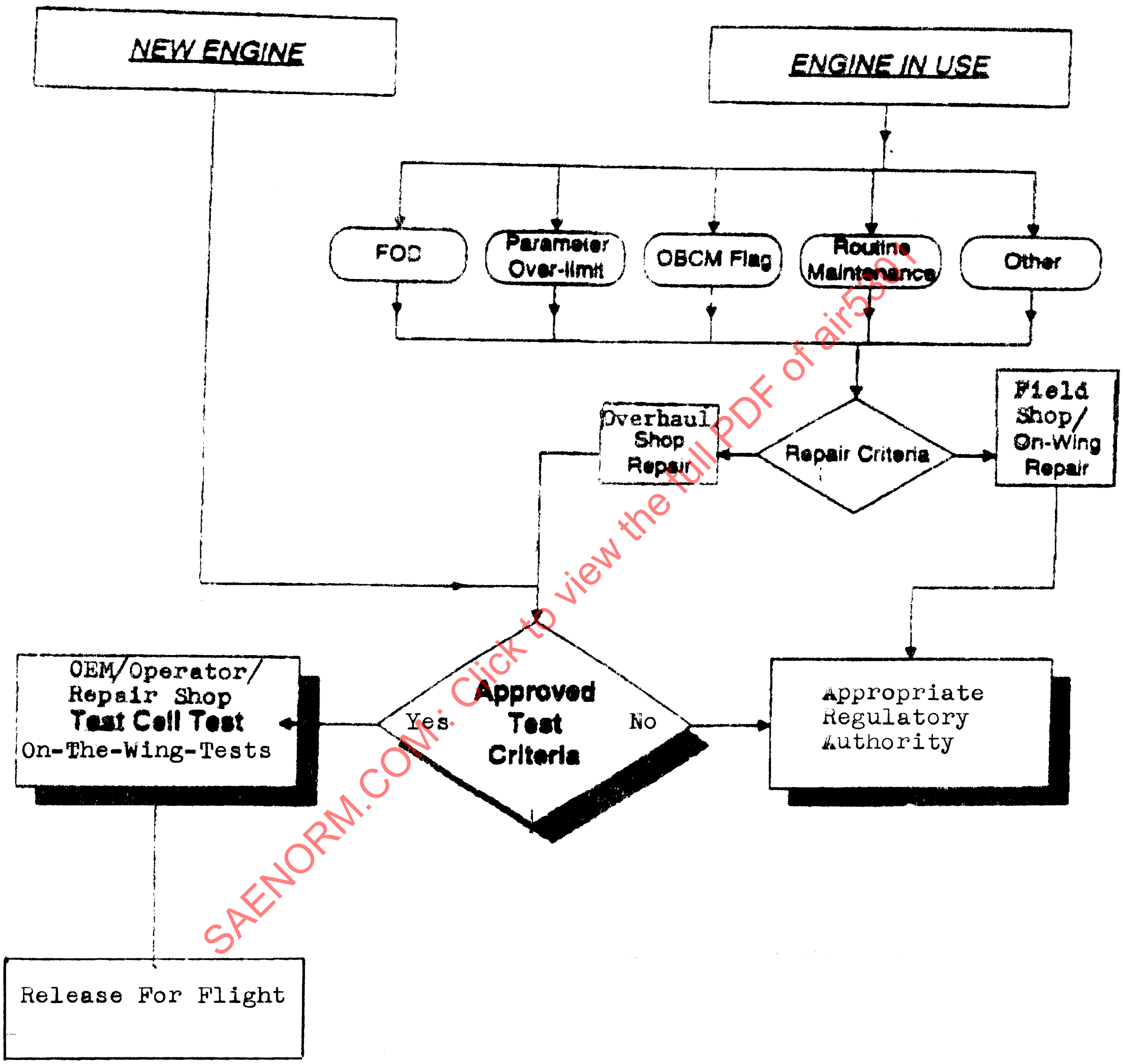


FIGURE 1 - Engine Test Requirement Flow Chart

TABLE 1 - Advantages of On-The-Wing Engine Testing[1]

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.

5. 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 or complete acoustic enclosure (Hush House) can be employed to alleviate this problem. Other techniques such as active noise control might be feasible. With today’s quieter engines and noise abatement technology external intake and exhaust noise control is not a major technical problem but more a cost concern. 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 an intake shelter, possibly a combination noise-suppressor-airflow-control shelter. Intake devices/shelters have been used successfully by operators and airframe and engine manufacturers for a number of years. 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 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. 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 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.

TABLE 2 - Disadvantages of On-The-Wing Engine Testing

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. Requires 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.

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 shelter. Winds within limits may still effect 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 gage 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.

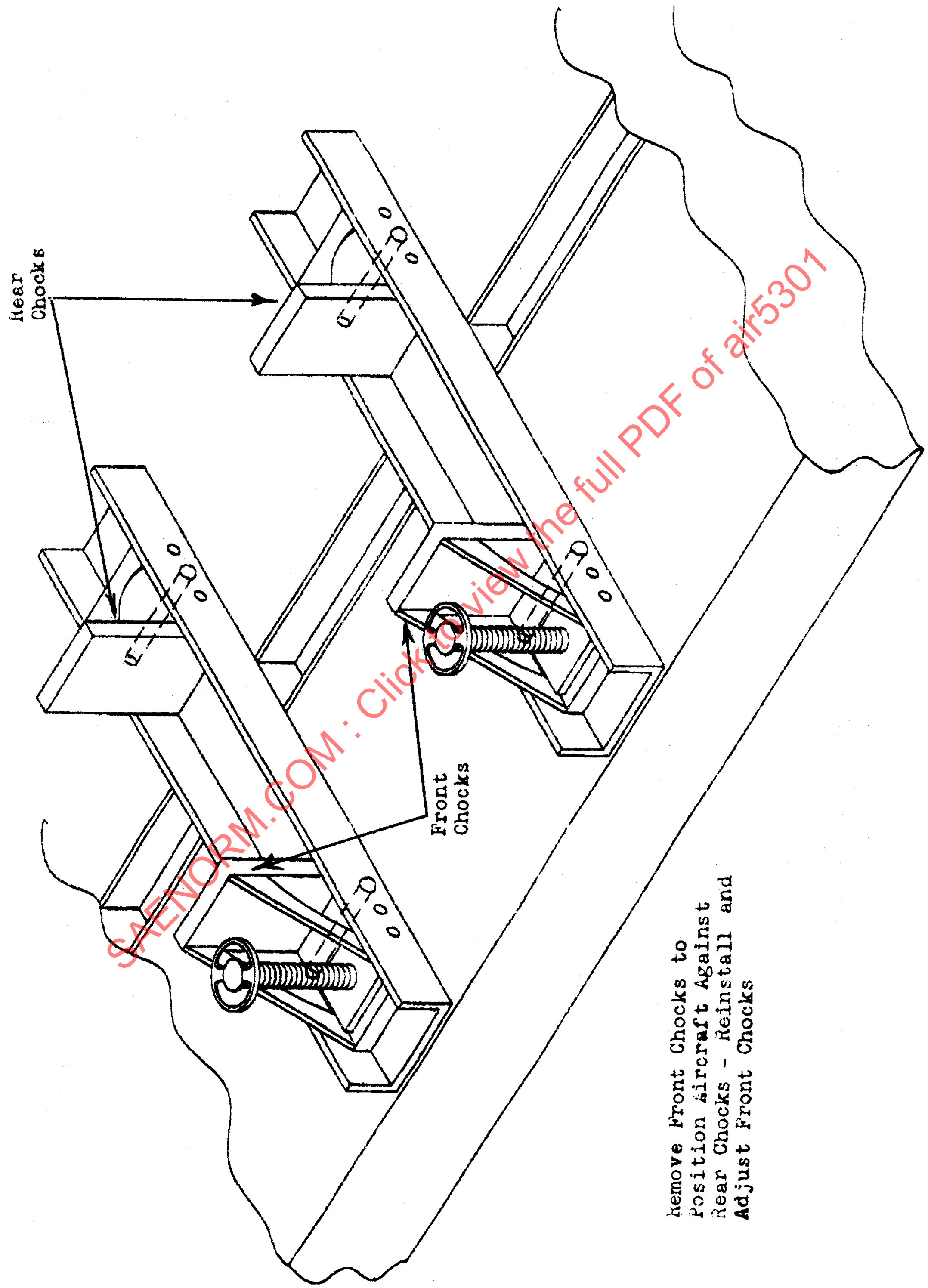


FIGURE 2 - Alameda Chocks

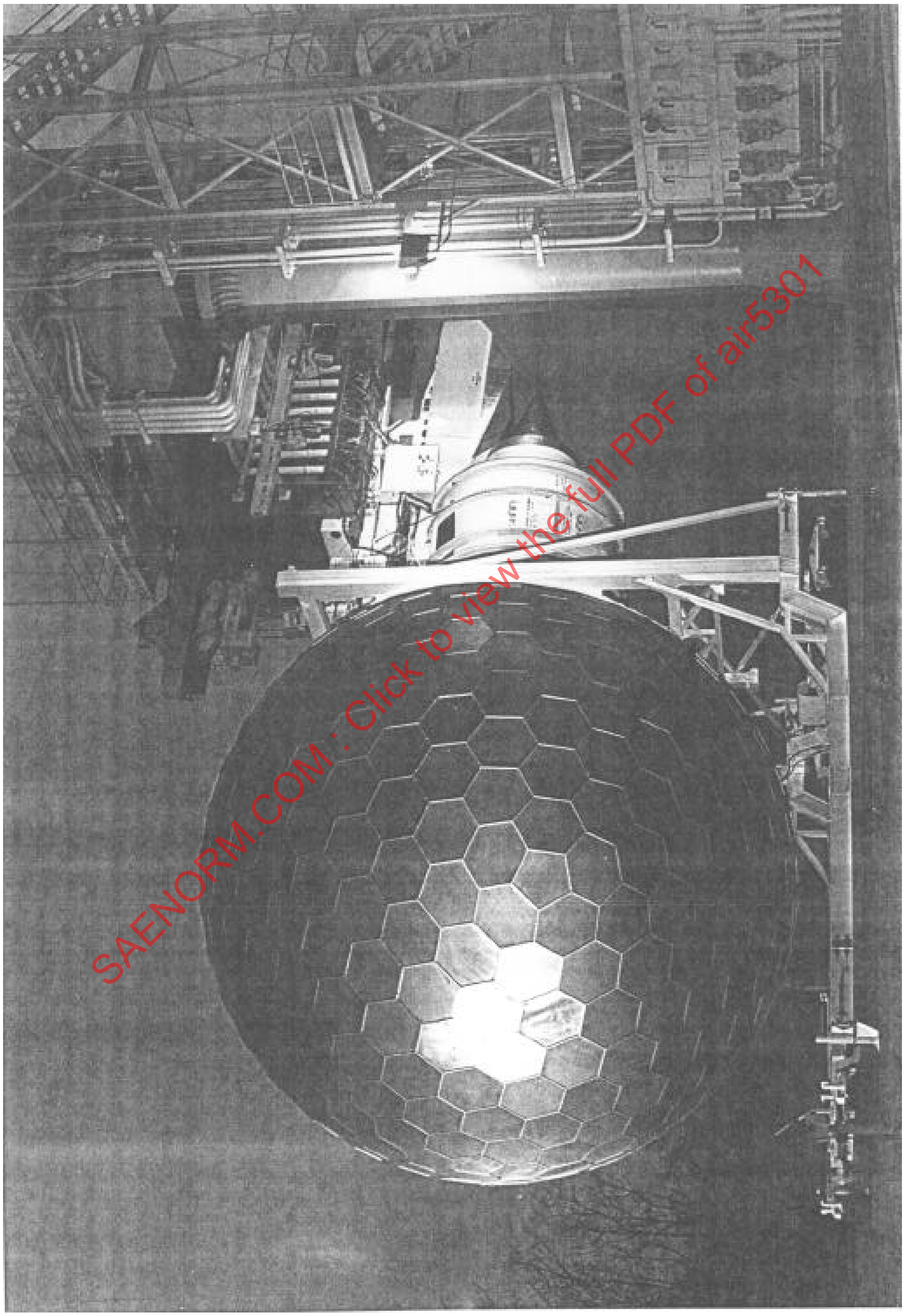


FIGURE 3 - Turbulence Control Structure

5. (Continued):

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 such as the PW4000 series engines 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.

6. ENGINE TEST CRITERIA:

6.1 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.

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.

6.1 (Continued):

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 (References 2.1.2 through 2.1.8). For instance, Boeing provides a listing of 15 different specific tests required after a PWA4000 series engine on a 767 aircraft undergoes some form of maintenance (Reference 2.1.2). A copy of that listing is shown in Table 3. Figure 4 shows typical data sheets used to record cockpit instrument readouts during these tests. The data items recorded may vary for the different tests.

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.

MAINTENANCE MANUAL

DATE ____________ AIRPLANE NUMBER ____________

ENGINE POSITION ____________ ENGINE NUMBER ____________

OAT ____________ BAROMETRIC PRESSURE ____________

MINIMUM IDLE (%N2):

TARGET	TOLERANCE	MINIMUM	MAXIMUM	ACTUAL

MINIMUM IDLE BURNER PRESSURE (PB) (PSIA):

TARGET	TOLERANCE	MINIMUM	MAXIMUM	ACTUAL

APPROACH IDLE (%N2):

TARGET	TOLERANCE	MINIMUM	MAXIMUM	ACTUAL

IDLE BVA (%) ____________

BVA STARTS TO CLOSE (%N1)

MINIMUM	MAXIMUM	ACTUAL

%N1 (NORM) ____________ %N1 (ALTN) ____________

%N1 (INC)

MINIMUM	MAXIMUM	ACTUAL

BVA FULLY CLOSED (%N1)

MINIMUM	MAXIMUM	ACTUAL

BVA CLOSED (%) ____________

OPERATOR SIGNATURE ____________

Trim Worksheet for Performance Test

FIGURE 4 (Sheet 1) - Example Data Sheet for Turbofan Engine Tests

MAINTENANCE MANUAL

PROGRAMMING PLUG P/N ____________

STATOR VANE SCHEDULE ____________

CORRECTED N2 AT 1.40 EPR (%N2C) ____________

SVA STROKE AT 1.40 EPR (%) ________ MINIMUM ________ MAXIMUM ________ ACTUAL

N1 AT 1.40 EPR (%N1):

________ TARGET ________ TOLERANCE ________ MINIMUM ________ MAXIMUM ________ ACTUAL

ENGINE DATA AT MINIMUM IDLE:

EPR ________ EGT ________ VIB ________ FUEL FLOW ________

%N1 ________ %N2 ________ OIL TEMP ________ OIL PRESS ________

ENGINE DATA AT 1.40 EPR:

EPR ________ EGT ________ VIB ________ FUEL FLOW ________

%N1 ________ %N2 ________ OIL TEMP ________ OIL PRESS ________

ENGINE DATA AT APPROACH IDLE:

EPR ________ EGT ________ VIB ________ FUEL FLOW ________

%N1 ________ %N2 ________ OIL TEMP ________ OIL PRESS ________

ACCELERATION TO 1.40 EPR (SEC) ________

DECELERATION TO 1.05 EPR (SEC) ________

OPERATOR SIGNATURE ____________

Trim Worksheet for Performance Test

FIGURE 4 (Sheet 2) - Example Data Sheet for Turbofan Engine Tests - Continued

MAINTENANCE MANUAL

DATE ________________________ AIRPLANE NUMBER ________________________

ENGINE POSITION ________________ ENGINE NUMBER ________________________

BAROMETRIC PRESSURE (PAMB) ________________________

SPECIFIC HUMIDITY ____________________

ENGINE DATA AT 1.40 EPR:

PT2.5 (PSI) __________ PS3 (PSI) ____________ PS4I (PSI) __________

TCA PRESSURE RATIO ____________________

EPR ________________ EGT ________________ PT2 ________________

%N1 ________________ %N2 ________________ TT2 ________________

N1 RPM ______________________ N2 PRM ___________________________

θT2 __________________________ RθT2 ___________________________

LPC PRESSURE RATIO ____________________

HPC PRESSURE RATIO ____________________

KHN1 ______________________ CN1 ___________________________

KHN2 ______________________ CN2 ___________________________

CEGT ___________________________

OPERATOR SIGNATURE ________________________

Performance Check Worksheet

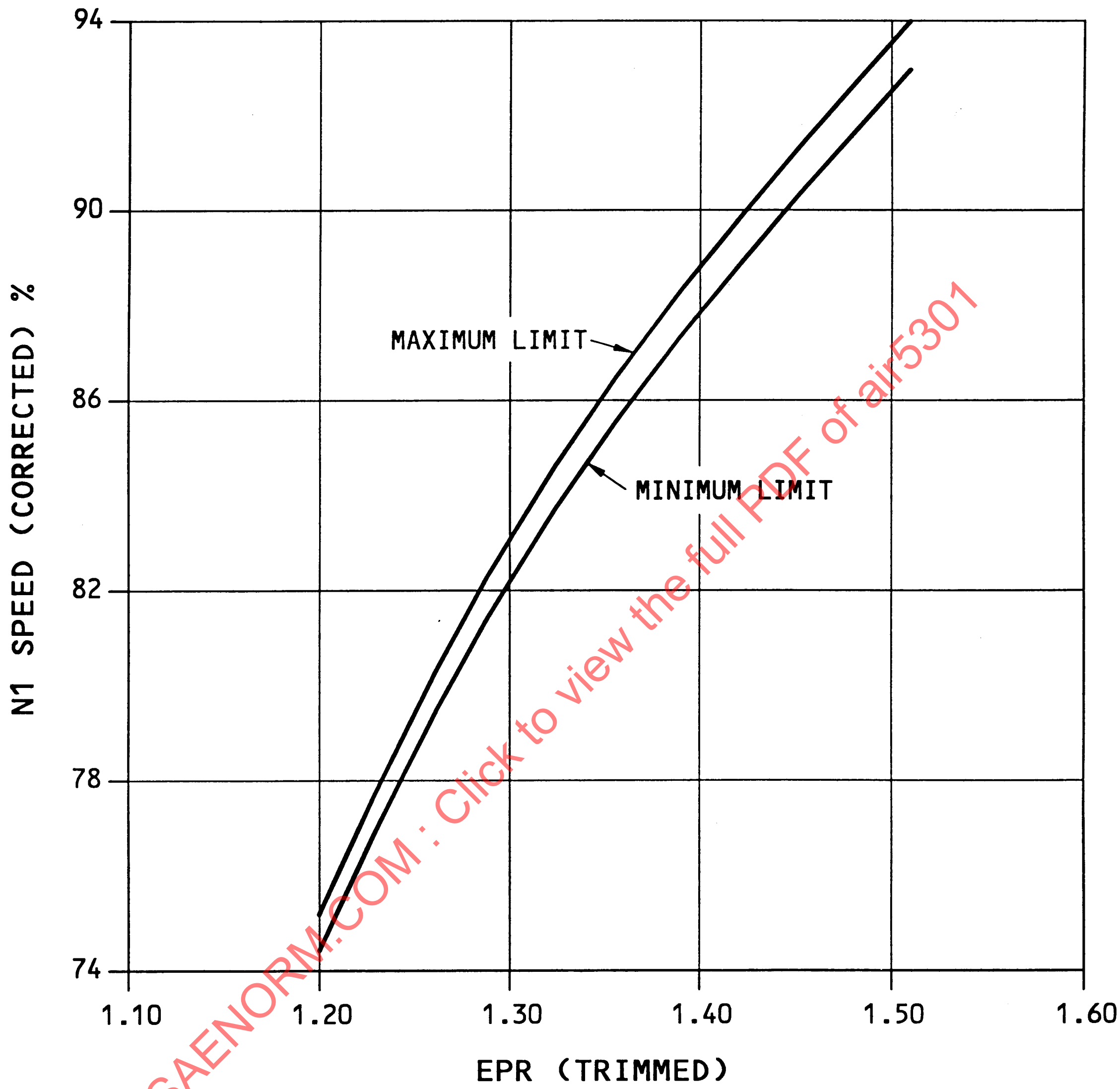
FIGURE 4 (Sheet 3) - Example Data Sheet for Turbofan Engine Tests - Continued

GROUND POWER ASSURANCE PERFORMANCE TEST RECORD

MODEL:						ENGINE SERIAL NO:												
												OIL						
												ENGINE		PROP				
DATE	OPERATOR	A/C TAIL NO. MODEL NO.	POSI-TION	ALT(ft)	OAT (°C)	TORQUE ☐% ☐FTLB	ITT (°C)	ITT MARGIN	Ng (%)	Wf ☐Lb/hr ☐Kg/hr	PROP RPM ☐% ☐rpm	Press	Temp	Press	Temp	REASON FOR TEST	AUTHORIZED INIT.'S
		ITT MARGIN						SFCC MARGIN				Δ Ng					
AVERAGE																	

000C7P-154302

FIGURE 5 - Example Data Sheet for Turboprop Engine Tests



Corrected N1 Maximum Acceptance Limits

FIGURE 6 - Example Performance Curve for Turbofan Engine (usually used in conjunction with curves for other parameters such as fuel flow, exhaust gas temperature, etc.)

ENGINE PARAMETER TOLERANCE BANDS
(CORRECTED DATA IN AIRCRAFT)
STATIC

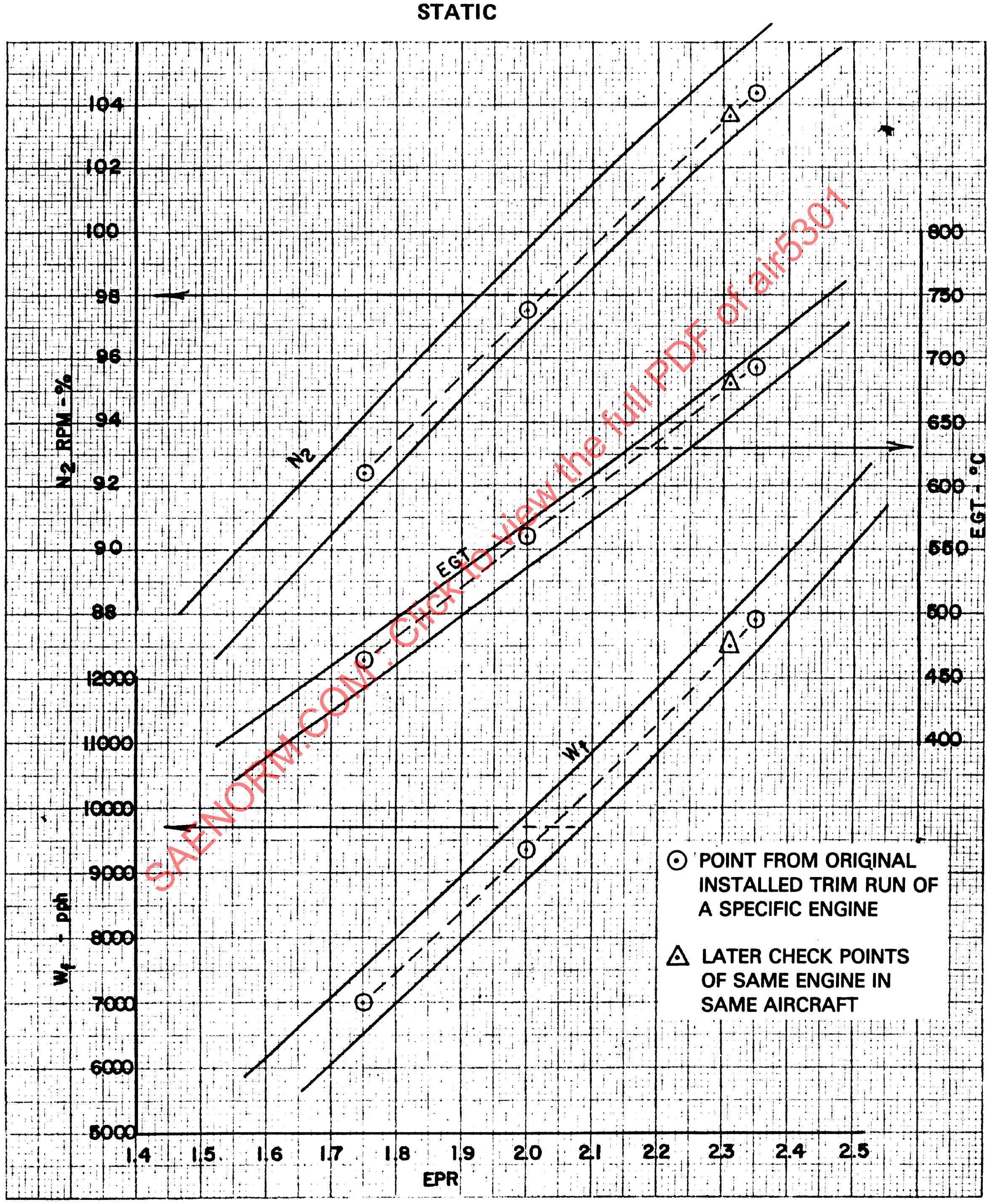


FIGURE 7 - Example Performance Curve for Turbojet Engine

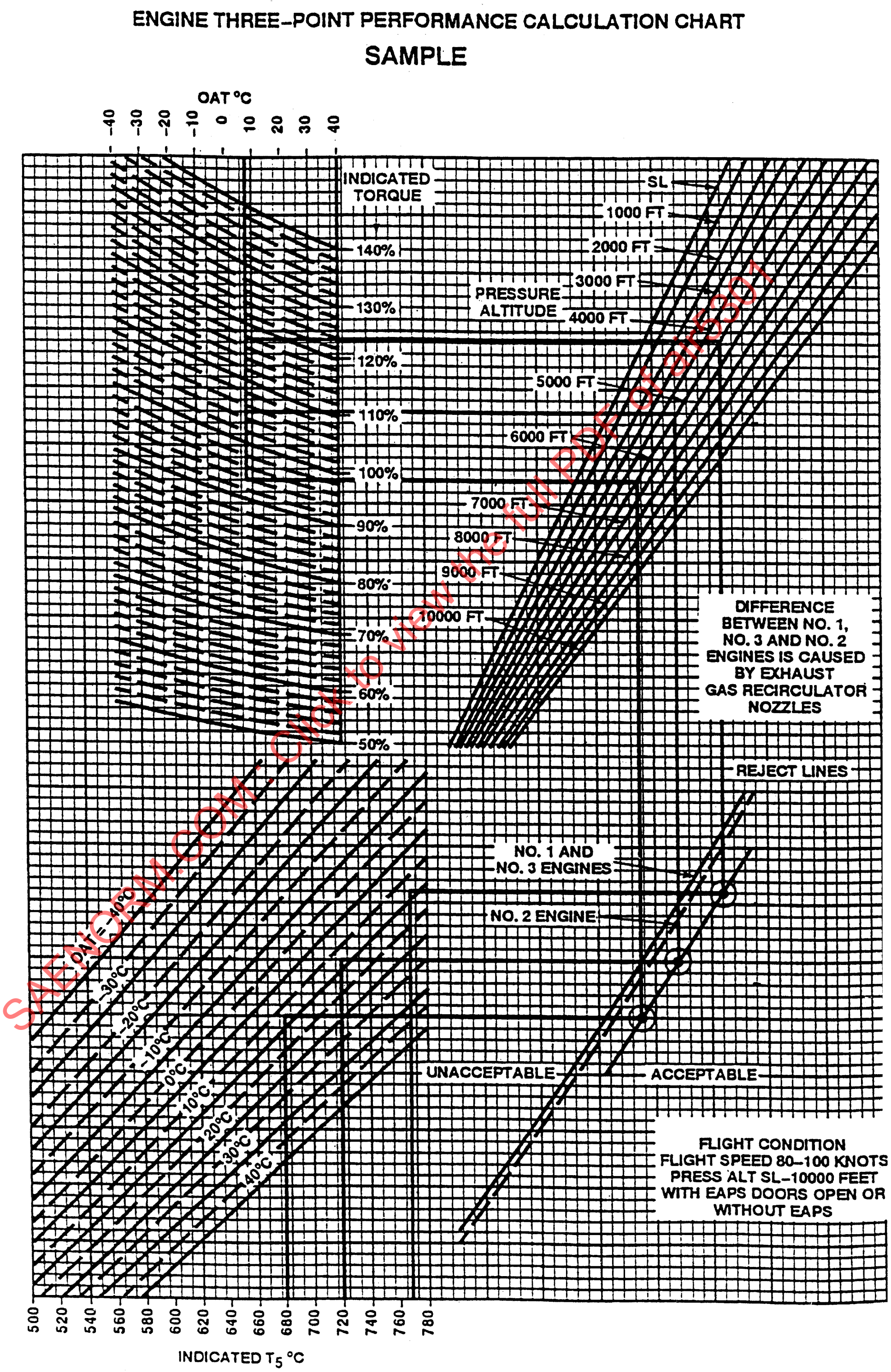


FIGURE 8 - Example Performance Curve for Turboshaft Engine

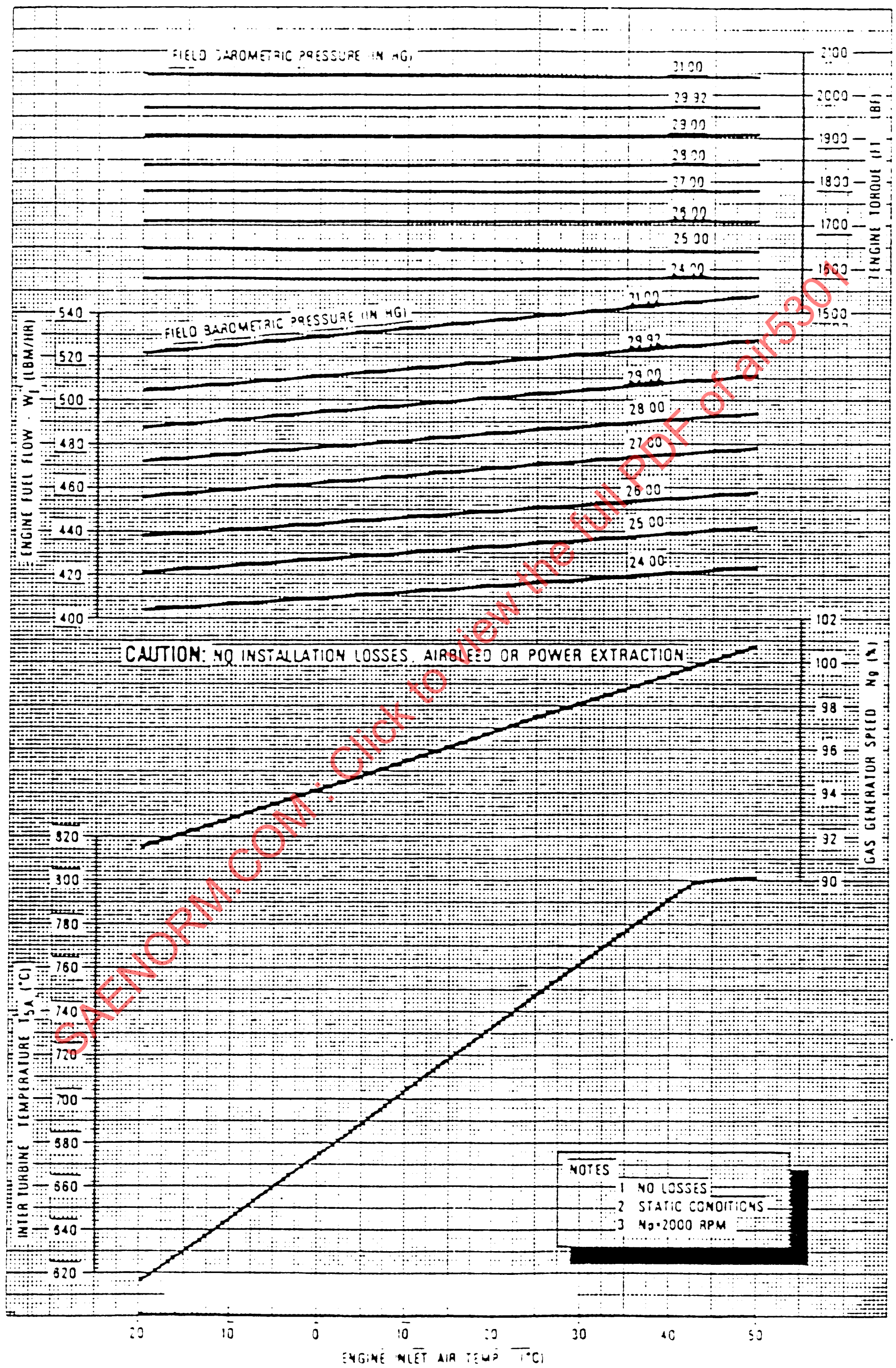


FIGURE 9 - Example Performance Curve for Turboprop Engine

6.1 (Continued):

Installed engine testing can be severely restricted by wind conditions. Examples are shown in Figures 10 and 11 from References 2.1.2 and 2.1.7 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 2.1.3). 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.

7. AIRCRAFT INSTALLED INSTRUMENTATION SYSTEMS:

All aircraft are equipped with at least the minimum allowable engine performance instrumentation required by the appropriate regulating authority. Most operators elect to add additional instrumentation and some kind of engine condition monitoring system which may only be monitoring one selected parameter or almost all of the same engine performance parameters monitored during ground on-the-wing installed or uninstalled engine test cell tests. The latest cockpit display and on-board-condition-monitoring systems have the same accuracies as remote ground based installed engine test equipment/systems and test cell instrumentation systems. Some small aircraft incorporate older, less accurate systems, possibly even autosyn type systems, but most operators upgrade these systems when they can to derive the safety and economic benefits of optimum performance. The cockpit displays range from autosyn analog instruments through analog-digital gages and horizontal or vertical tape/bar displays to the latest programmable “glass cockpit” CRT displays incorporated in the most recently developed military and airline aircraft. These microprocessor-controlled displays are programmable so that the flight crew can call up whatever parameter they desire to monitor, compare it to acceptable limits, cross-reference it to other parameters and in some cases call up a diagnosis of the cause of an out-of-limit indication. The actual display may be presented in analog, digital or performance curve formats.

The instrumentation systems are usually calibrated on a calendar or flight hour periodic basis. The display instrument may be independently calibrated in a calibration laboratory, but it must then be calibrated with the total system in the aircraft to ensure that the complete system end-to-end from the engine mounted transducer through the display is acceptable. Some turboprop and turboshaft engine torque systems cannot be end-to-end calibrated due to the inaccessibility of the transducer or the design of the system, e.g., close coupled strain gages.

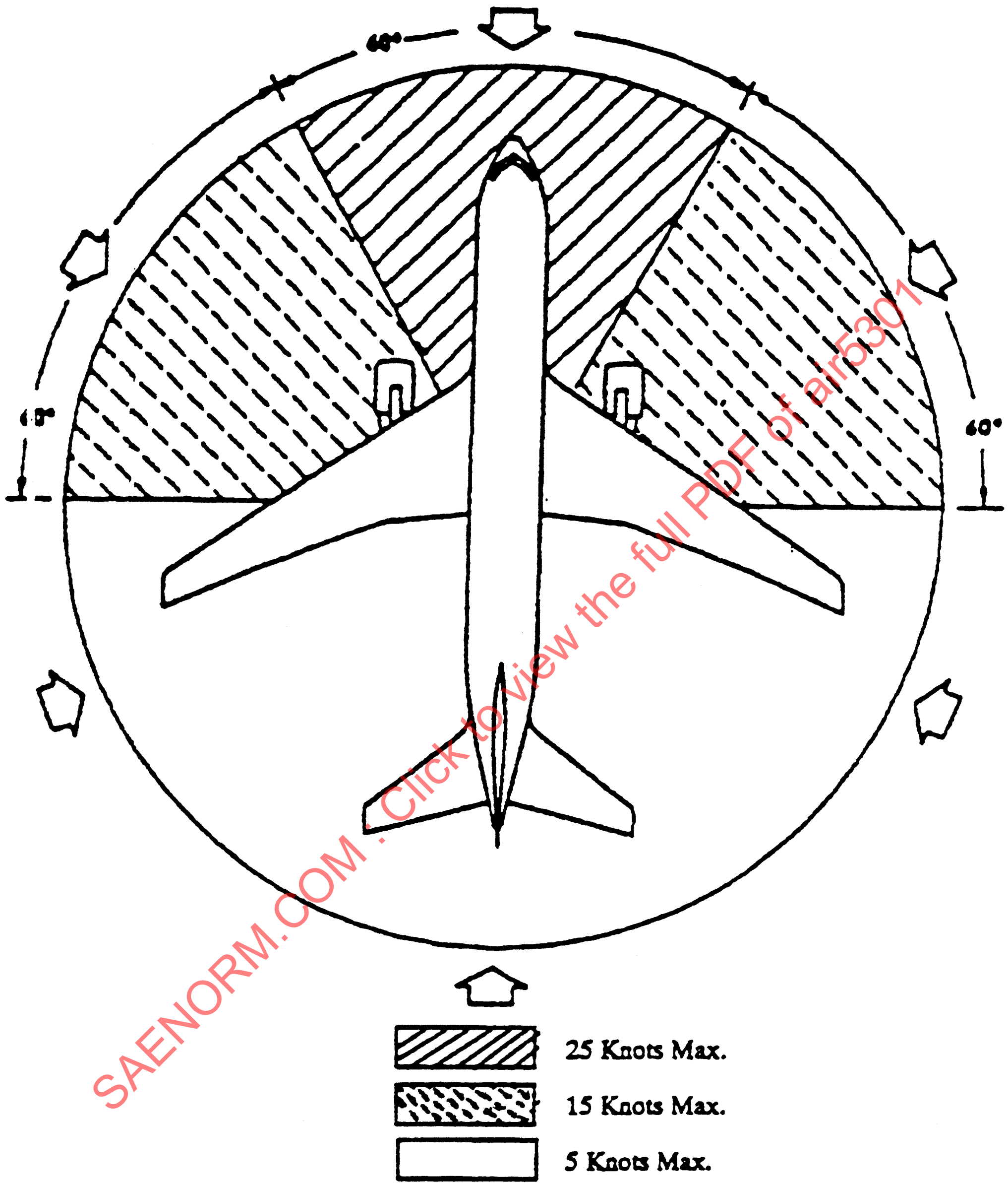


FIGURE 10 - Maximum Permissible Wind Speed and Orientation for a Twin Engine Aircraft

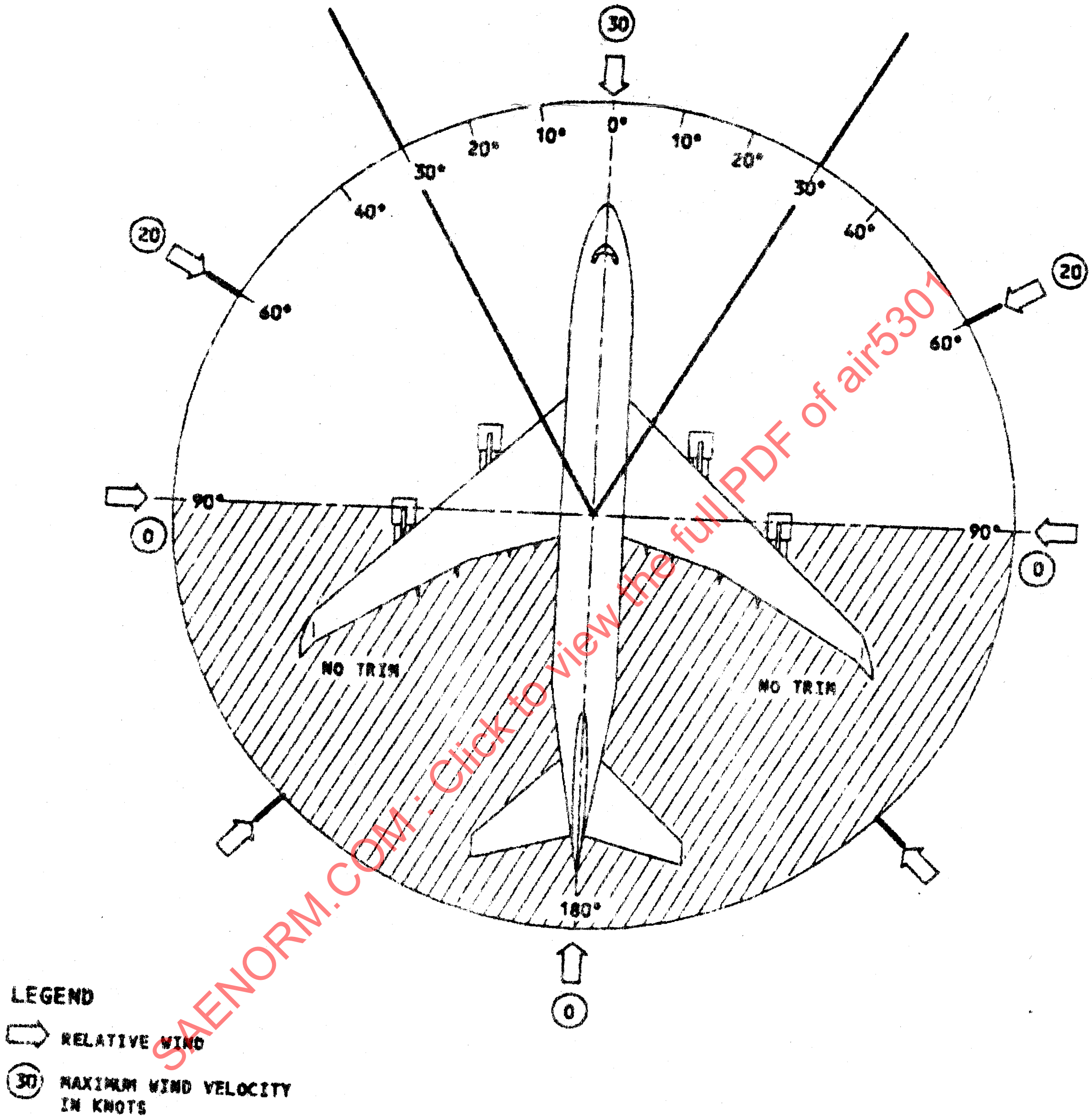


FIGURE 11 - Maximum Permissible Wind Speed and Orientation for a Four Engine Aircraft

8. EXISTING GROUND-BASED DATA ACQUISITION/INSTRUMENTATION SYSTEMS FOR ON-THE-WING INSTALLED ENGINE TESTING:

Data acquisition/instrumentation systems that exist today are capable of acquiring the same data during installed engine test as is recorded in engine test cell tests. The degree of accuracy is also equivalent with exception of thrust as previously stated in Section 3. These installed engine test systems can display real time data, correct the recorded data to baseline references and provide data printouts. The data readouts can be compared with cockpit instruments and on-board-conditioning-monitoring systems data to enhance troubleshooting and trend analysis and provide cross checks of each system's accuracy. This capability opens up the possibility of being able to correlate on-the-wing engine tests to baseline uninstalled engine tests except for thrust measurement.

The ground based systems are capable of measuring propeller, fan, compressor and turbine rotor speeds, compressor discharge pressure and temperature, turbine inlet, inter-turbine and exhaust gas temperatures, variable geometry stator vane and exhaust nozzle positions, engine pressure ratio, torque, vibration, fuel flow, ambient pressure and temperature and possibly more. Typical data system design requirements are shown in Table 4. The given criteria are important to avoid biasing the indicating system when the test instrument uses an existing sensor. Accuracy in Table 4 is given in terms of transducer output values (i.e., frequency or millivolts (mV)). Transducer range must be specified before the given accuracy values can be converted to engineering units. Typical flight line tester specifications and accuracies are shown in Table 5, Reference 2.1.9 except accuracies for the parameters with multiple units listed which would require accounting for too many variables.

This type of equipment has been used successfully since the 1950's for on-the-wing trim for installed turbine engines. Electronic instrumentation capabilities have been improved to the extent that an installed engine data acquisition/instrumentation system with identical capability to test cell instrumentation has been placed in service. This system not only has an equivalent test cell data acquisition system but includes engine diagnostics. Obviously, direct comparison of installed and uninstalled test data is enhanced and further improves the ability to correlate the two. Typical printouts of recorded turbofan/jet and turboprop data are shown in Figure 12.

The major difficulty encountered in employing on-the-wing test data acquisition/instrumentation systems is access to engine mounted sensors/systems. Some aircraft manufacturers have incorporated accessible test connection panels. Where this is not done the data acquisition system manufacturer has provided adapter assemblies to access the many required sensors.

Measurement/data uncertainty with state-of-the-art on-the-wing test is comparable with that achieved in fixed test installations. Determining a data acquisition system's overall accuracy requires combining all sources of error in the measurement chain. These measurement chains include as a minimum a sensor, wiring, signal conditioning, A/D converter, and data display. All sources of error in a measurement system are combined to obtain the expected error by the root-sum-square (RSS) method.

TABLE 4 - Typical Design Requirements for Electronic Data Display Systems

Thermocouple Inputs:	
Chromel-Alumel ISA Type K	
Range:	-40 to 1370 °C -40 to 2498 °F
Resolution:	1 °C or 1 °F
Accuracy:	±1 °C or ±1.8 °F
Iron-Constantan ISA Type J	
Range:	-40 to 550 °C -40 to 1022 °F
Resolution:	1 °C or 1 °F
Accuracy:	±1 °C or ±1.8 °F
Input impedance:	22 MΩ at DC minimum, includes open tc detection kt.
Common mode rejection ratio:	120 db minimum, 50 to 400 Hz with 1 K Ω source imbalance
Normal mode rejection:	60 db minimum, at 50 Hz, 3-pole, 60 db/decade filter
Input voltage limits:	
Normal mode:	120 V rms continuous
Common mode and channel to channel:	150 V rms continuous
Isolation, common mode and channel to channel:	10^{10} Ω shunted by 200 pf
Frequencies:	
Engine speed (from 70 Hz tachometer generator, magnetic pickup, etc.):	
Range:	5 to 120.0% or 10 to 30,000 rpm programmable
Resolution:	0.1% or 1 rpm
Accuracy:	±0.1% or ±1 rpm
Sensitivity:	
Low range:	0.5 V rms at 7 Hz, 1 V @ 70 Hz
High range:	0.1 V rms

TABLE 4 - Typical Design Requirements for Electronic Data Display Systems (Continued)

Filtering:	
Low range:	20 db/decade above 50 Hz
High range:	20 db/decade above 1 KHz
Input impedance:	45 K Ω
Common mode rejection ratio:	40 db
Input voltage limits:	
Normal mode:	150 V rms continuous
Common mode:	300 V rms continuous
Isolation, common mode and channel to channel:	10^{10} Ω shunted by 100 pf
Flow (from turbine flowmeters)	
Range: 3 Hz to 30 kHz	
Resolution:	
3 to 1200 Hz:	±0.01 Hz
1200 Hz to 30 kHz:	±1.0 Hz
Accuracy:	
3 to 1200 Hz:	±0.01 Hz
1200 Hz to 30 kHz:	±1.0 Hz
Sensitivity:	0.1 V rms
Input impedance:	45 K Ω
Common mode rejection ratio:	40 db
Input voltage limits:	
Normal mode:	150 V rms continuous
Common mode:	300 V rms continuous
Isolation, common mode and channel to channel:	10^{10} Ω shunted by 100 pf
Flow (from pulse phase mass flow transmitter)	
Range:	400 to 12,000 pph (Flowmeter Dependent)
Resolution:	±1 pph
Accuracy:	±20 pph
Sensitivity:	40 mV
Input impedance:	20 K Ω
Common mode rejection ratio:	40 db
Input voltage limits:	12 V peak continuous

TABLE 4 - Typical Design Requirements for Electronic Data Display Systems (Continued)

DC Voltage Signals:	
Low level (from strain gauge):	
Range:	-30 to +30 mV
Resolution:	3 µV
Accuracy:	±15 µV
Input impedance:	100 MΩ at DC minimum
Common mode rejection ratio:	100 db minimum
Normal mode rejection ratio:	60 db minimum at 50 Hz, 3-pole, 60 db/decade filter
Input voltage limits:	
Normal mode:	12 V peak continuous
Common mode:	20 V peak continuous
Isolation, common mode and channel to channel:	200 MΩ
Load cell excitation:	From test cell instrumentation
Resistance Temperature Detector (RTD):	
Range:	-55 to 70 °C -67 to 158 °F
Resolution:	0.1 °C (0.2 °F)
Accuracy:	
15 to 35 °C amb:	0.5 °C
59 to 95 °F amb:	0.9 °F
Input impedance:	100 MΩ exclusive of exc. ckt.
Common mode rejection ratio:	100 db
Input voltage limits:	
Normal mode:	12 V peak continuous
Common mode:	20 V peak continuous
Isolation, common mode and channel to channel:	200 MΩ
RTD excitation:	int. 3-wire lead, length compensated
High level pressure transducer:	
Range:	-1 to 10 V DC
Resolution:	0.625 mV
Accuracy:	±5 mV
Input impedance:	20 MΩ

TABLE 4 - Typical Design Requirements for Electronic Data Display Systems (Continued)

Common mode rejection ratio:	76 db minimum, 50 to 400 Hz with 1 K Ω source imbalance
Normal mode rejection ratio:	100 db minimum at 50 Hz, 1-pole, 20 db/decade filter
Input voltage limits:	
Normal mode:	-1 to 10 V peak continuous
Common mode:	20 V peak continuous
Isolation, common mode and channel to channel:	200 MΩ
Transducer ambient pressure:	
Range:	22 to 32 "Hga
Resolution:	0.05 "Hga
Accuracy:	±0.02 "Hga
Overpressure with calib. shift <0.1% FS:	42 "Hga
Range:	0 to 250 psia
Quantity:	1
Resolution:	0.2 psi
Accuracy:	±0.1 psi
Overpressure with calib. shift <0.1% FS:	375 psia
High level (from vibration monitor, cell pressure xducers, Dyno and Engine Torque, Position, or other equipment)[1]:	
Range:	-10.24 to +10.24 V
Resolution:	0.625 mV
Accuracy:	±5 mV
Input impedance:	20 MΩ
Common mode rejection ratio:	76 db minimum, 50 to 400 Hz with 1 K Ω source imbalance
Normal mode rejection ratio:	34 db minimum at 50 Hz, 1-pole, 20 db/decade filter
Input voltage limits:	
Normal mode:	12 V peak continuous
Common mode:	20 V peak continuous
Isolation, common mode and channel to channel:	200 MΩ

TABLE 4 - Typical Design Requirements for Electronic Data Display Systems (Continued)

AC Voltage Inputs:	
Range:	0 to 35 V AC rms
Accuracy:	±9 mV rms ±0.5% of rdg; frequency ±10%
Input impedance:	100 K Ω
Common mode rejection ratio:	36 db
Input voltage limits:	
Normal mode:	50 V rms (or 120% of range)
Common mode:	300 V rms continuous
Isolation, common mode and channel to channel:	10^{11} Ω shunted by 100 pf

[1] Changing the accuracy for signal conditioning units given in electrical units into engineering units depends on specifying the variable and sensor output. An example of a torque system using a 0 to 5 V DC 100 psi transducer for measuring torque on a 1575 SHP turboshaft engine with a 6580 rpm output shaft would have ±18 ft-lb accuracy or 1% full scale.

TABLE 5 - Typical Flight Line Tester Specifications[1,2]

Parameter	Range	Resolution	Units	Accuracy
TEMPERATURE ±1 °C				
ENG T/C's (CH-AL)	0 to 1350	1	°C	±1 °C
AUXTEMP (CH-AL)	0 to 1000	1	°C	±1 °C
AUXTEMP/TAMB (RTD)	Auto M00	0.1	°C	±1 °C
CAL SIGNAL (CH-AL)	0 to 1300	1	°C	±1 °C
SPEED				
RPM - 3 CHANNELS	0 to 10,000	1	RPM	10 RPM
	10,000 to 30,000	10	RPM	30 RPM
	0 to 120.0	0.1	%	±0.1%
FUEL FLOW	0 to 10,000	1	PPH	±10 PPH
	10,000 to 30,000	10	PPH	±30 PPH
PRESSURE				
PINT	22 to 32	0.01	IN HG	±0.02 IN HG
PEXT 1/PEXT 2[3]	0 to 999.9	0.1	IN HG, PSI, PCNT	SEE NOTE 3
	0 to 10,000	1	FT LB, IN LB, HP	SEE NOTE 3
	10,000 to 30,000	10	FT LB, IN LB, HP	SEE NOTE 3
EPR	0.800 to 3.500	0.001	RATIO	±0.01
VARIABLE ANGLE VANES	-90.0 to +90.0	0.1	DEGREE	±0.5
ACCEL/DECEL				
TIME	0 to 999.9	0.01	SECONDS	±0.01
RESISTANCE	0 to 40.00	0.01	OHMS	±0.01
INSULATION RESISTANCE	0 to 200	1	KOHMS	±0.01
TORQUE				
Voltage	0 to 120	0.1	%	±0.2%

NOTES:

1. Accuracy valid for ambient temperatures +10 thru +40 °C.
2. Accuracy given for data display and signal conditioning as value for full scale reading.
3. Changing the accuracy for signal conditioning units given in electrical units into engineering units depends on specifying the variable and sensor output. An example of a torque system using a 0 to 5 V DC 100 psi transducer for measuring torque on a 1575 SHP turboshaft engine with a 6580 rpm output shaft would have ±18 ft-lb accuracy or 1% full scale.

Programmed for Turbojet Engine	ENGINE TYPE 1		
Date/ID/Snapshot#	ID: 10319N36B #025		
Target EPR Setting	TRIM TGT: EPR 1.78		
Exhaust Pressure	PEXH	51.62	IN.HG.
EPR	PEXH/PAMB	1.754	
EGT	TEMP	556	DEG.C
Fan Speed	N1	100.0	PCNT.
Compressor Speed	N2	92.9	PCNT.
Ambient Temp	TAMB	22.3	DEG.C
Ambient Pressure	PAMB	29.43	IN.HG.
	STANDARD DAY READINGS		
Readings Corrected To Standard Day	TEMP	535	DEG.C
	N1	98.8	PCNT.
	N2	91.7	PCNT.

Programmed for Turboprop Engine	ENGINE TYPE 2		
Date/ID/Snapshot#	ID: 110151498 #001		
Target Torque Setting	TRIM TGT: TRQ1380FLB		
Torque	PEXT	1388	FT.LB.
ITT	TEMP	641	DEG.C
Gas Generator Speed	N1	91.1	PCNT.
Power Turbine Speed	N2	96.2	PCNT.
Ambient Temp	TAMB	20.7	DEG.C
Ambient Pressure	PAMB	29.38	IN.HG.

FIGURE 12 - Typical Turbofan/Jet and Turboprop Data Printouts

8. (Continued):

The impact of instrumentation accuracy on each engine test will differ with the purpose of the test. Performance accuracy and repeatability are needed to prevent making a decision to scrap a good engine or fly an unsafe engine. Measurement uncertainty is a specialty and can be very complex and is discussed in detail in Reference 2.1.10. However, when accuracy specifications on individual channels are given and periodic calibration is performed, existing ground-based data acquisition/ instrumentation systems for on-the-wing installed engine testing can be as accurate as any engine test cell systems.

9. CAPABILITIES OF ENGINE ON-BOARD-CONDITION-MONITORING SYSTEMS (EOBCMS):

Most of the information in this section was obtained from References 2.1.1 and 2.1.11 through 2.1.15. Current EOBCMS are capable of acquiring as much engine performance data, except thrust, as engine test cell instrumentation systems and to the same degree of accuracy during ground installed engine testing with some exceptions previously mentioned in Sections 3 and 8. The newer EOBCMS may be integrated in complete aircraft on-board-condition-monitoring-systems (OBCMS) which may be referred to by any number of acronyms such as ACMS (Aircraft Condition Monitoring System)/ DFDAS (Digital Flight Data Acquisition System)/APRS (Aircraft Power and Reporting System), etc. This section addresses only the engine monitoring systems. Every operator may not need all of the previously mentioned capability and will install what is appropriate for the type aircraft, flight profile and maintenance policy and practices used. The EOBCMS are designed to monitor the parameters that do not have inherent large errors in their measurement system unless the value added justifies the need. Table 6 lists the parameters normally monitored by EOBCMS. The systems usually include event counters to record time-related parameter thresholds specified by the engine manufacturer. Most systems provide limit exceedance audio and visual warnings to the flight deck crew. The new systems may also provide malfunction identification and flight crew corrective action notices on-board. Most systems require the use of a ground station analyzer to process the data. Many of the on-board systems can transmit data to a ground station analyzer that can diagnose causes of malfunctions and initiate preparations for corrective actions while the aircraft is still enroute.

EOBCMS provide the following benefits which can be used to increase the validity of on-the-wing installed engine testing:

a. Improves safety by providing time related parameter thresholds, event monitoring and limit exceedance warnings that prevent major/catastrophic failures from occurring.

b. Enhances on-condition maintenance practices because of the capability to accurately monitor a large number of performance parameters.

c. Enhances trend analysis programs that enables the operator to take preventative maintenance actions before major damage occurs.

d. Enhances power assurance validity by continuous monitoring of the related parameters specified by the engine manufacturer.

e. Provides accurate engine and/or component life usable data.

f. Reduces maintenance costs by providing malfunction analysis and corrective action instructions.

g. Monitors engine trim condition and provides corrective actions instructions.

h. Provides gas path performance analysis, in some cases down to the module level.

TABLE 6 - Typical Engine On-Board-Condition-Monitoring System Parameters for Ground Testing

Date and Time of Test
Rotor Speed
Propeller Speed
Compressor Inlet Temperature
Exhaust Gas/Turbine Inlet/Inter Turbine Temperatures
Ambient Temperature
Ambient Pressure
Compressor Inlet Pressure
Compressor Discharge Pressure
Compressor Bleed Status
Engine Pressure Ratio
Engine Torque
Oil Pressure
Oil Temperature
Fuel Flow
Vibration
Anti-ice System Status
Number of Starts
Operating Hours
Temperature Events
Speed Events
Cycle Counts

9. (Continued):

Combining remote ground based, cockpit and EOBCM systems data from on-the-wing installed engine ground tests should enhance the validity of the tests to compare favorably with uninstalled test cell testing. There appears to be no insurmountable difficulty in the way of correlating on-the-wing aircraft installed and uninstalled engine test cell tests. Inlet and exhaust duct effects can be accounted for by installation and performance engineering technology.

10. INSTALLATION EFFECTS ON ENGINE PERFORMANCE:

Installation effects on sea level static installed engine tests are mostly from inlet and exhaust duct losses, ground clearance, inlet screens and environmental control shelters/devices; and, in the case of helicopters, sand and dust particle separators. They are usually accounted for in the airframe and engine manufacturers performance curves. Some inlets cause a forward airflow along the outer skin of the nacelle then around the nacelle lip into the engine. It may be necessary to account for this forward pressure/scrubbing action when calculating net thrust. Some turboprop engines may have an actual ram pressure in the engine inlet which may need to be accounted for when calculating performance (References 2.1.16 and 2.1.17).

Inlet duct losses result from pressure decreases in the inlet caused by the velocity of airflow entering the engine. This can range from 0 to 6 or 7% pressure loss in commercial aircraft depending on the type of inlet and even greater if inlet screens are used during ground tests. Some military aircraft may have inlet duct losses as high as 20% (Reference 2.1.18). Inlet duct losses may not apply to turboprop aircraft that can experience a ram effect in the inlet and are normally not as severe in turboshaft engines because of lower airflow velocities in the inlet.

Exhaust duct losses are caused by using ducts of a different size than those recommended by the engine manufacturer. Different duct material and related coefficients of expansion may also affect losses. In most cases there is a band of duct sizes that can be used without significant losses being incurred.

Close ground proximity can cause distorted airflows into the inlet causing unstable performance. In the case of some turboprop engines, it can also cause detrimental fluctuating loads on the propeller blades.

Flow control shelters, inlet screens and particle separators can have significant effects on inlet pressures and temperatures depending on their design and in the cases of screens and sand and dust separators, their dirtiness can further aggravate these effects.

If used, exhaust noise suppressors may affect engine exhaust pressures.