



AEROSPACE INFORMATION REPORT

AIR4989™

REV. B

Issued 1996-12
Reaffirmed 2018-11
Revised 2026-05

Superseding AIR4989A

Design Considerations for Enclosed Turboshift Engine Test Cells

RATIONALE

This revision is being issued to include additional technical considerations to the previous version, mainly related to the load extraction device configuration.

FOREWORD

The purpose of this SAE Aerospace Information Report (AIR) is to assist those involved in designing new or significantly modified turboshift engine test cells by documenting considerations compiled from a broad spectrum of industry and government technical specialists in this field. The intent is to provide a general discussion of the major design factors that impact the capability of the test cell when used to perform accurate, repeatable performance tests of an engine and to add to the understanding of the significance of the aerodynamics of the engine test environment and the load absorption devices employed.

Turboshift engines operating in a ground-level test cell can encounter a number of problems which are directly attributable to the characteristics of the test cell environment. Some of the more important factors which must be considered in the development of test cell designs leading to desired engine operational stability, aerodynamics, acoustic performance, and mechanical integrity are described. Test cell performance goals which typically might be used to define "excellent" cell performance are included. When these cell performance goals are achieved, stable and repeatable engine operation can be assured.

Since there is no need for an aerodynamic thrust correction, it is often a misconception that turboshift engine correlation only concerns the metrology associated with measurement (including torque/power). This is not true, and if the engine inlet and exit pressure/temperature profiles are not optimum for the installation, or comparable with the reference datum test facility, there is the possibility of either the engine performance or power turbine re-matching to produce a different or inconsistent performance, with correction factors being applied for unknown reasons. This aspect needs to be considered during the design process.

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TABLE OF CONTENTS

1.	SCOPE.....	3
1.1	Purpose.....	3
2.	REFERENCES.....	3
2.1	Applicable Documents.....	3
2.2	Symbols and Abbreviations.....	4
2.2.1	Parameters.....	4
2.2.2	Abbreviations.....	4
2.2.3	Subscripts.....	5
3.	TECHNICAL BACKGROUND.....	5
4.	TEST CELL SYSTEM DESIGN CONSIDERATIONS.....	6
4.1	Inlet Plenum.....	6
4.2	Test Chamber.....	11
4.3	Augmentor/Diffuser.....	11
4.4	Load Absorption Devices.....	12
4.4.1	Air Dynamometers (see Figure 1).....	12
4.4.2	Water Brakes (see Figure 2).....	13
4.4.3	Electrical Load Banks (see Figure 3).....	13
4.4.4	Regenerative Electric Brakes.....	13
4.4.5	Eddy Current Dynamometers.....	13
4.5	Exhaust Stack.....	13
4.6	Air Dynamometer Exhaust System.....	14
5.	FACTORS FOR EVALUATING TEST CELL PERFORMANCE.....	14
5.1	Front Cell Velocity Distortion.....	15
5.2	Front Cell Temperature Distortion.....	15
5.3	Front Cell Airflow.....	16
5.4	Bellmouth Total Pressure Distortion.....	16
5.5	Bellmouth/Engine Inlet Temperature Distortion.....	17
5.6	Cell Bypass Ratio.....	17
5.7	Cell Depression.....	17
6.	GENERAL TEST CELL REQUIREMENTS AND GOALS.....	18
7.	CONCLUSIONS.....	19
8.	NOTES.....	19
8.1	Revision Indicator.....	19
APPENDIX A	AIRFLOW EQUATIONS.....	20
Figure 1	Air dynamometer equipped test cell.....	8
Figure 2	Water brake equipped test cell.....	9
Figure 3	Electric dynamometer equipped test cell.....	10

1. SCOPE

This SAE Aerospace Information Report (AIR) developed by a broad cross section of personnel from the aviation industry and government agencies is offered to provide state-of-the-art information for the use of individuals and organizations designing new or upgraded turboshaft engine test facilities. This document is also applicable to turboprop engines tested with a dynamometer as load absorption device, as they are basically tested as turboshaft engines. For propeller-equipped turbofan testing facilities design considerations, see 2.1.7.

1.1 Purpose

- a. To provide guidelines for the design of state-of-the-art ground-level enclosed test facilities for turboshaft engine testing
- b. To address the major test cell engine load absorption device physical, aerodynamic, and acoustic characteristics which can influence operation, performance, accuracy, and stability of an engine under test
- c. To consider acoustic and environmental effects and methods to control them

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 Ashwood, P.F. et al. (1984). *Operation and performance measurements on engines in sea level test facilities* (AGARD Lecture Series Number 132) (AGARD-LS-132). Advisory Group for Aerospace Research and Development, North Atlantic Treaty Organization.
- 2.1.2 Naval Air Warfare Center Aircraft Division. (1991). *TECHEVAL of A/F37T-16(V)1 test facility* (Technical report SY50-91-005).
- 2.1.3 Karamanlis, A.I., Freuler, R.J., Lee, J.D., Hoelmer, W., and Bellomy, D.C. (1985, January 14-17). *A universal turboshaft engine test cell - Design considerations and model test results* [Conference paper]. 23rd Aerospace Sciences Meeting, Reno, Nevada, USA. <https://doi.org/10.2514/6.1985-382>.
- 2.1.4 U.S. Environmental Protection Agency and U.S. Department of Transportation. (1994). *Study of nitrogen oxide emissions and their control from uninstalled aircraft engines in enclosed test cells*. (EPA-DOT Joint Report to Congress).
- 2.1.5 Support Equipment Evaluation/Verification Technical Report 48L-95-027 (1995). *Techeval of Multi-Capability Turboshaft/Prop Engine Test Facility Complex, A/F37T-16(V) 1, 2 and A/F37T-19(V) 2, 3*.
- 2.1.6 Naval Air Warfare Center Aircraft Division. (1990). *Development tests of A/F37T-16(V)3 test facility* (Technical report KS90037SY).
- 2.1.7 Naval Air Warfare Center Aircraft Division. (1993). *Technical evaluation of A/F37T-16 1,2,3 engine test facilities* (Technical report 13600 SY53J/662).
- 2.1.8 AIR5295 - Design Considerations for Enclosed Turboprop Engine Test Cells
- 2.1.9 AIR5026 - Test Cell Instrumentation

2.2 Symbols and Abbreviations

The following parameters, abbreviations, and subscript notations are used in this document.

2.2.1 Parameters

A	cross-sectional area
C_d	flow coefficient
g	gravitational constant
M	Mach number
P	pressure
R	gas constant
T	temperature
V	velocity
W	airflow rate
α	cell bypass ratio
γ	ratio of specific heats (= C_p/C_v , where C_p is the specific heat of air at constant pressure, and C_v is the specific heat of air at a constant volume)

2.2.2 Abbreviations

AIAA	American Institute of Aeronautics and Astronautics
AGARD	Advisory Group for Aerospace Research and Development
BM	bellmouth
ENG	engine
FC	front cell
FOD	foreign object damage
ft/s	feet per second
L/D	length-to-diameter ratio
m/s	meters per second
OEM	original equipment manufacturer
rpm	revolutions per minute
SHP	shaft horse power
TOR	torque

2.2.3 Subscripts

amb	ambient condition
avg	average
Dist	distortion
flow	flow function
max	maximum
min	minimum
s	static
t	total

3. TECHNICAL BACKGROUND

A ground-level turboshaft engine test cell may be defined as an enclosed structure with an engine and load absorption device mounting mechanism which is intended to provide conditions for stable, repeatable, and accurate engine performance testing. Turboshaft engines operating in a test cell can encounter a number of problems which are directly attributable to the characteristics of the test cell environment. These problems can be as minor as unsteady engine speed and SHP variations that lead directly to increased uncertainty about other engine performance measurements since many engine performance parameters are referenced either to engine inlet conditions at the compressor or to the engine rpm (see 2.1.1). In these cases, the engine performance is unstable and not repeatable and often can cause an unnecessary test rejection and subsequent costly rebuild. In the worst situations, more severe problems such as excessive turbine inlet temperatures and stalls may occur, which can result in serious engine damage and catastrophic failure.

The above problems are generally caused by pressure or temperature distortions arising from aerodynamic characteristics peculiar to the flow field of the test cell. More specifically, the problems are related to the design of the load absorption device, cell inlet and exhaust systems, and the cell bypass ratio, which is the ratio of the airflow bypassing the engine to that which directly enters the engine inlet or bellmouth. Cell bypass air is generated by the ejector pumping action of the engine exhaust velocity in the augmentor tube. In some cases, this ejector is very weak as the power turbine extracts most of the work from the hot gas. In some test cells, inlet, exhaust, or cell extractor fans may be needed to increase the bypass flow and evacuate heat buildup. This can sometimes be described as "forced entrainment." When one test cell is used for several types of engines differing in configuration/orientation, engine SHP level, bellmouth inlet flow requirements, and exhaust temperatures, the probability of distorted flows is increased. And although poor cell inlet designs can obviously contribute to distortions in the flow, it is often the case that insufficient cell bypass flow is primarily responsible for distorted flow and the recirculation of exhaust gas to the engine intake, which should be avoided. Often, one of the most common aerodynamic problems is an unacceptable inlet temperature profile as a result of hot gas recirculation.

It is also important to highlight that the selection of the load extraction devices and ancillary systems is key for stable operation of the engine under test. The proper device can help reduce or eliminate speed or torque oscillations in steady state operation and also during transient maneuvers (like slams), where over-speed or over-torque conditions can be reached.

A modern ground-level turboshaft engine test cell must be able to accommodate a wide range or mix of engine types with differing SHP levels. Such a facility must also provide an aerodynamic environment of good quality for the operation of the engine, have small errors due to test cell interference effects and instrumentation inaccuracies, and include acoustic treatment to minimize environmental disturbances. The facility may also have to include features for compliance with local air pollution standards recognizing the limitations of existing gaseous emission control technology, especially related to Nitrogen Oxide (NO_x), which is discussed further in 4.5.

The scope of this document does not include the definition of the test facility instrumentation. A detailed description of the system is included in 2.1.9.

4. TEST CELL SYSTEM DESIGN CONSIDERATIONS

General design concepts or features for an engine test cell to accommodate turboshaft engines are shown in Figures 1, 2, and 3. It should be noted that the configurations in the figures are not necessarily optimum ones but rather are intended only to illustrate the major features of such engine test cells. The major structural elements or sections of the cell are the inlet plenum, the test chamber, the engine augmentor/diffuser or exhaust collector, an exhaust stack, and in the example air dynamometer equipped cell, an associated exhaust system for the dynamometer. Each must be tailored for its specific function and at the same time be compatible with the other elements to achieve proper aerodynamic and acoustic performance of the entire test cell system. Each will be described in terms of its purpose and functional considerations.

The design of turboshaft engine test cell inlet and exhaust systems is obviously of basic significance. However, a third basic element that affects the facility design is the load absorption device that enables the turboshaft engine to develop its rated power during sea level testing. While the airflow through a test cell is a direct function of the inlet and exhaust system designs, the flow field is significantly affected by the load absorption device type, configuration, and mounting position.

The turboshaft test cell bypass ratio is critical to aspirating the heat buildup in the test chamber that results from heat radiating from the engine, load absorption device, and associated exhaust ducting for each. Because the exhaust energy from a turboshaft engine is low, the ejector pumping action of the exhaust system is sometimes not adequate to evacuate the test chamber. The best method of achieving acceptable bypass ratio is with the use of extractor fans that can be fitted in the intake, exhaust systems, or cell (including roof), depending on the configuration or nature of the problem, such as cell ventilation or hot gas recirculation/re-ingestion by the engine. One favored method is to place extractor fans symmetrically about engine centerline in the test cell rear wall such that ambient airflow can be encouraged through the test cell in a preferred axial flow path to create a higher bypass flow as an artificial "forced entrainment" that is capable of expelling unwanted hot air or gas (see Figure 3). When doing this, every effort should be made to avoid any adverse effects on radial engine intakes, air dynamometers, or engines with left- or right-hand offset exhaust nozzles, e.g., T58 and Gnome. Typically, if creating such artificial entrainment, the extractor fans should be optimized such that the airflow velocity is no more than 3 m/s (10 ft/s).

4.1 Inlet Plenum

The primary purpose of the inlet plenum or system is to provide a uniform flow of air in sufficient quantity to the test chamber. Secondary purposes are to control the propagation of noise which emanates from the front of the engine and to isolate the test chamber from the effects of crosswinds. In some situations, it may be desirable to heat the inlet air to minimize the effect of very cold ambient temperatures. Also, for certain engines, there is a requirement that the inlet air be cooled to near standard day temperature when operating at high ambient temperatures. In any event, ambient wind conditions should be considered when selecting a site and orienting a test cell.

Erosion-resistant concrete should be used in "brick and mortar" designed test cell inlets. The inlet design should ensure that all mechanical component connections are secured with captive nuts, bolts, pins, etc., to reduce foreign object damage (FOD) potential. The design should provide relatively easy access to the entire inlet to facilitate periodic inspections. Acoustic treatment should not lose its effectiveness when subject to rain/sleet/snow. Depending upon the precipitation levels at the test facility site, a drainage system may be required at the inlet plenum floor.

The components which are generally used in test cell inlet systems are screens to enhance uniform flow, turning vanes for vertical inlet stacks with a 90-degree bend, acoustic surface treatment, and silencer baffles. A vertical inlet stack with its 90-degree bend screens and turning vanes provides both good acoustic control and a uniform front cell flow while isolating the test chamber from the effects of outside winds. For adverse wind conditions, thrust engine scale model test results and full-scale experiences have demonstrated the beneficial insensitivity-to-crosswind effects produced by the use of an "egg-crate" structure in the top portion of a vertical inlet stack. This, or the use of screens, would probably be effective in turboshaft test cells. A properly designed horizontal inlet system might be used when acoustic requirements are not too restrictive and the prevailing ambient wind conditions do not pose a major concern, but a horizontal inlet system can have a greater potential for allowing foreign objects or debris into the test chamber. While a horizontal inlet might be more susceptible to crosswind effects than a vertical inlet and require some acoustic treatment, it eliminates the need for an expensive vertical inlet stack and turning vanes. The FOD hazard potential is less severe with turboshaft engines because of the low airflow forward of the intake relative to thrust engines and is further minimized with the use of screens. A cost/benefit analysis of the vertical vice horizontal inlets is certainly worth considering during the conceptual design phase.