AEROSPACE INFORMATION REPORT

AIR4989 REV. A

Issued 1996-12
Reaffirmed 2007-11
Revised 2013-09

Superseding AIR4989

Design Considerations for Enclosed Turboshaft Engine Test Cells

RATIONALE

This revision is being issued to include suggestions to achieve improved aerodynamic performance and behavior.

FOREWORD

The purpose of this SAE Aerospace Information Report (AIR) is to assist those involved in designing new or significantly modified turboshaft 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 will add to the understanding of the significance of the aerodynamics of the engine test environment and the load absorption devices employed.

Turboshaft 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, aerodynamic, 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 call 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, turboshaft 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.

TABLE OF CONTENTS

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.

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.: "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, Neuilly Sur Seine, France, 1984.

2.1.2 NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION, PATUXENT RIVER, MARYLAND, Support Systems Department, Technical Report SY50-91-005, March 1991, "TECHEVAL of A/F37T-16(V)1 Test Facility", MCAS Tustin, California.

2.1.3 Karamanlis, A.I., Freuler, R.J., Lee, J.D., Hoelmer, W., and Bellomy, D.C.: "A Universal Turboshaft Engine Test Cell -- Design Considerations and Model Test Results", AIAA Paper Number 85-0382, Paper presented to the AIAA 23rd Aerospace Sciences Meeting, Reno, Nevada, January 1985.

2.1.4 Joint Report to Congress on the Environmental Protection Agency-Department of Transportation Study of Nitrogen Oxide Emissions and Their Control from Uninstalled Aircraft Engines on Enclosed Test Cells, dated September 1994.

2.1.5 Support Equipment Evaluation/Verification Technical Report 48L-95-027, 19 Oct. 1995, Techeval of Multi-Cabability 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, PATUXENT RIVER, MARYLAND, Support Systems Department Technical Report, Letter Report KS90037SY, October, 1990, "Development Tests of A/F37T-16(V)3 Test Facility", MCB Camp Pendelton, California.

2.1.7 NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION, PATUXENT RIVER, MARYLAND, Support Systems Department Technical Report, Letter Report 13600 SY53J/662, January 1993, "Technical Evaluation of A/F37T-16 1,2,3 Engine Test Facilities", MCAS Futenma, Okinawa.

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 (= Cp/Cv, where Cp is the specific heat of air at constant pressure, and Cv 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, Reference 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 augmenter 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 build-up. 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.

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), discussed further in 4.5.

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 re-circulation/re-ingestion by the engine. One favored method is to place extractor fans symmetrically about engine center line in the test cell rear wall such that ambient air flow 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 off-set exhaust nozzles, e.g., T58 & Gnome. Typically, if creating such artificial entrainment, the extractor fans should be optimized such that the air flow velocity is no more than 3 m/second (10 feet/second).

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.

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.

Fundamentally, the inlet stack should always be lower than the exhaust stack of a test facility. This is for two reasons. Firstly, the natural static pressure draw of flow through the test cell (chimney effect) should always be towards the exhaust. Secondly, when testing in a tail wind it should not be possible to re-ingest exhaust gas from the exhaust stack.

When testing turbo-shaft engines with fixed inlet duct arrangements and packages, such as marine and industrial applications, every effort should be made to re-create the reference datum conditions and not change the inlet profiles or static pressure loss characteristic.

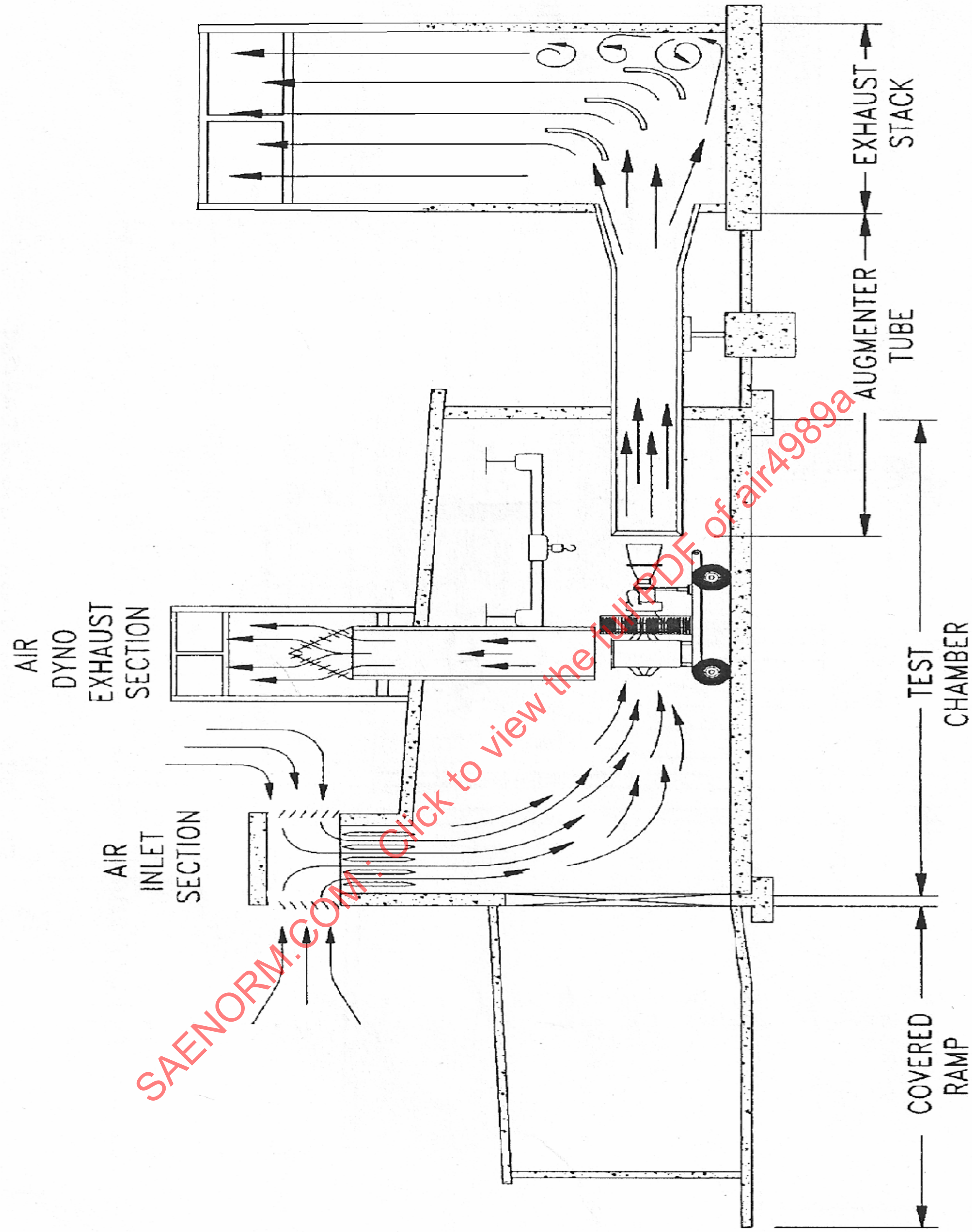

FIGURE 1 - AIR DYNAMOMETER EQUIPPED TEST CELL

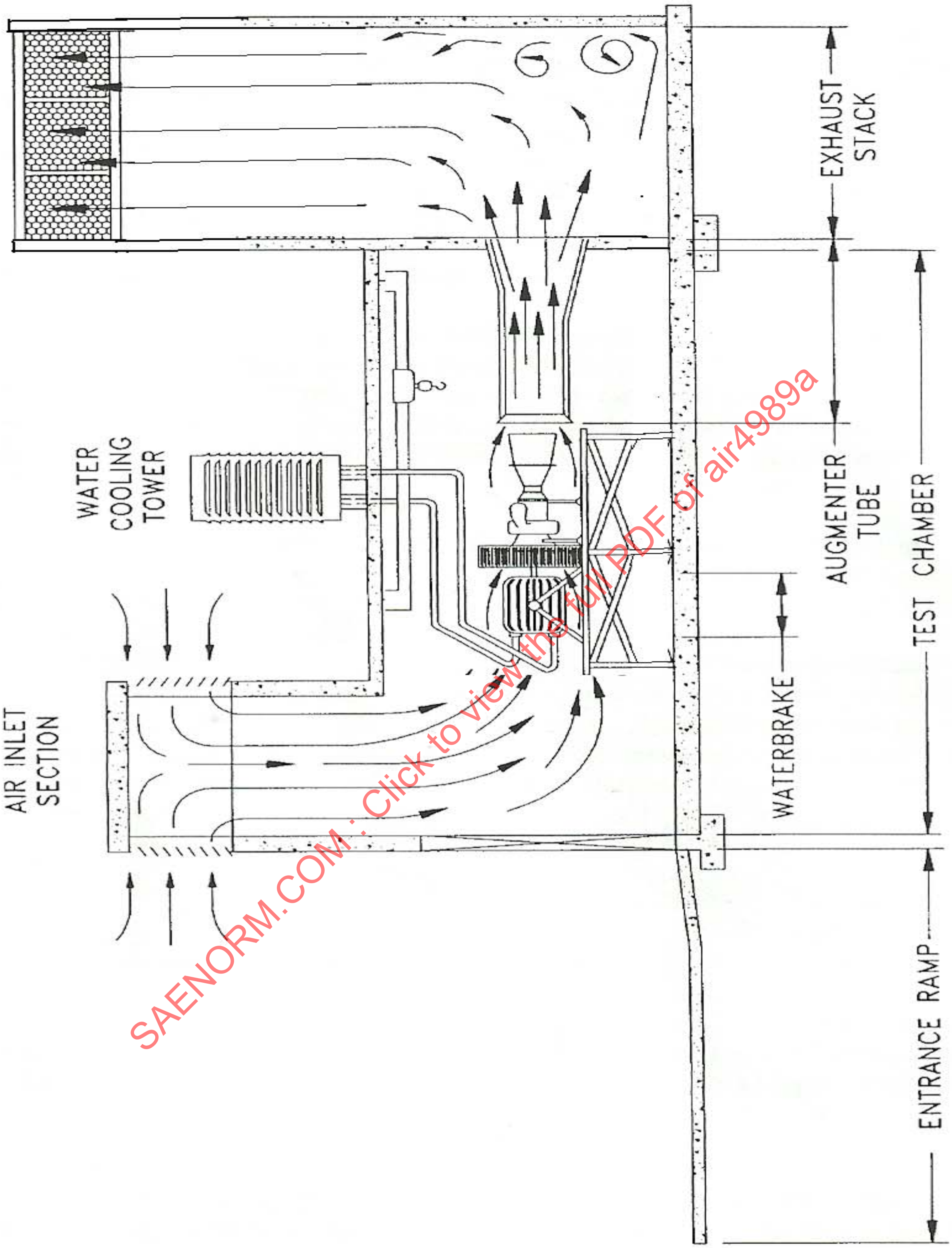

FIGURE 2 - WATER BRAKE EQUIPPED TEST CELL

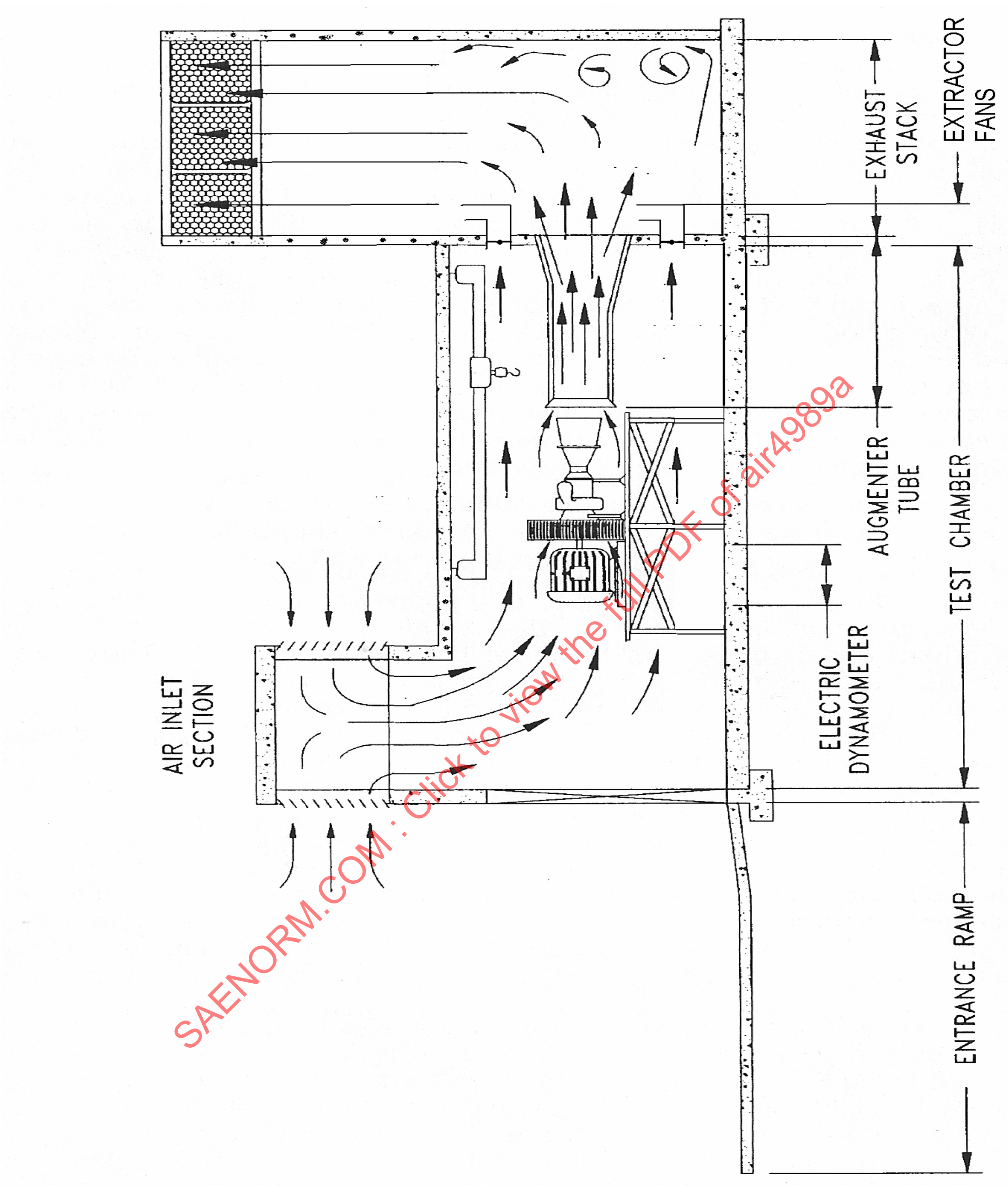

FIGURE 3 - ELECTRIC DYNAMOMETER EQUIPPED TEST CELL

4.2 Test Chamber

The purpose of the test chamber is to accommodate an engine and load absorption device mounting system and auxiliary equipment to support engine operation with adequate work space on all sides. There are a number of different types of load absorption devices such as water brakes, electric brakes and air dynamometers which are described in 4.4. These are generally close coupled to the engine and have the potential to cause vortices and excessive heat to the air flowing into the engine inlet which must be given adequate consideration during design efforts. While water brakes and electric brakes are satisfactory for use in OEM and fixed base overhaul and service facilities; they have not been useable at remote test sites because of the lack of adequate water or electrical services needed for stable load application. The U.S. Army and Navy field experience with these types of devices was not successful in past years but some closed loop designs, are in use and effective. Air dynamometers were developed and are successfully employed by the Army and Navy for both open air and enclosed test systems after overcoming some difficulty with the dynamometer exhaust spill-over ingestion into the engine. Full scale tests in three differently configured enclosed test cells at three different Navy locations have shown that exhaust baffle designs that vector the dynamometer exhaust sufficiently into the dynamometer exhaust stack correct this problem (Reference 2.1.2). Alternatively, dynamometer exhaust or steam (from water cooling) should be expelled externally, with a configuration that is not likely to allow re-ingestion by the test facility intake system.

As in the inlet section, all mechanical connection designs should be captive types. Instrumentation lines and hose trays/supports should be designed to avoid interfering with bypass air flows and/or becoming FOD or personnel safety hazards. The floor of the test chamber should incorporate a fuel, oil, water separator drain system to eliminate fuel/oil/water accumulation that would become fire, personnel and environmental safety hazards. The entire floor area should be free of any protrusions that could be tripped on. The design should include lighting and a method to provide very clear views from the control room of the entire engine and all umbilical connections during engine operations.

The ancillary service equipment such as lights, pumps, plumbing, fire extinguishing equipment, engine starting system etc. can also cause distorted airflows and generate unwanted heat in the chamber and should be kept to a minimum, recessed, or located externally when practical.

The positioning of the engine and load absorption device in the test chamber is also significant because it can dictate the position, length and configuration of the engine and air dynamometer exhaust ducts which radiate unwanted heat in the chamber that may be ingested into the engine. Although not always possible due to the need to floor mount dynamometers, positioning the engine symmetrically in the test cell is considered good practice. A high bypass flow might correct this condition but excessively high bypass flow can have an adverse effect on the performance of air dynamometers and engines with offset exhaust ducts as cited in Section 4. The high bypass flow may also affect inlet and exhaust airflows of air dynamometers and influence exhaust back pressure in engines with offset exhaust ducts. These effects may cause unstable engine operation high turbine inlet temperatures and erroneous engine and dynamometer torque indications.

Extractor fans can also be considered to improve test cell aerodynamics as described in Section 4. Figure 3 highlights a favored way of doing such using extractor fans fitted to the test cell rear wall symmetrically positioned about the engine center line to help produce higher bypass flows and artificial “forced entrainment”.

4.3 Augmentor/Diffuser

The primary purpose of the augmentor/diffuser or exhaust collector system is to capture the engine exhaust flow so that it may be directed into the exhaust stack and subsequently out to the ambient atmosphere. Equally important is its effect on the secondary or bypass flow in the test cell. This secondary flow is produced by the ejector pumping action resulting from the interaction of the engine exhaust flow in the augmentor and the test chamber airflow. The effectiveness of this pumping action is influenced by a number of factors including the engine nozzle/augmentor relative positions, diameter ratio, the augmentor shape/configuration/entrance, the pressure losses in the exhaust system, and the length of the augmentor tube or exhaust collector system (Reference 2.1.3). In some cases such as when a new engine model test is required it may be necessary to employ an inlet, exhaust or cell extractor fans to provide adequate bypass flow through the primary chamber as described in Section 4.

The area/axial distance relationship of the engine exhaust pipe to the augmenter collector duct may be critical in achieving a balanced performance that is not affected by either engine performance or power turbine re-matching relative to a reference datum. One method to help quantify and optimize this is to use static pressures fitted to both the engine exhaust pipe external and internal walls (circumferentially). The external static's give a measure of ejector effectiveness and the internal static's a measure of residual energy left in the exhaust gas. The latter will either provide a means to optimize the configuration relative to reference datum, or help understand why there is a difference and hence, justify the use of an appropriate correction factor. It is recommended that the test facility augmenter collector duct is telescopic, and hence adjustable to enable possible optimization of the axial gap.

The length of the exhaust collector influences the degree to which the extremely hot exhaust gases are mixed with the cell bypass flow. It is the success of this mixing process, combined with the availability of sufficient cooling air that is the key to air-cooled engine test facilities exhaust system durability.

Recent experience with enclosed Navy turboshaft engine test cells has shown the need for an augmentor area to engine exhaust nozzle area ratio of adequate magnitude to facilitate adequate cell bypass flow to attain reasonably stable test chamber inlet flow and to dissipate radiated and or exhaust heat from the engine and load absorption devices, especially air dynamometers. Proper design is also a function of engine nozzle exit to augmentor entrance spacing, length and shape of the augmentor and flow resistance in the exhaust stack. Also the test cell engine augmentor/exhaust duct radiates a significant amount of heat and should be kept as short, within the test chamber, as practical while still providing an adequate diffusion/mix of engine exhaust gases and bypass air to preclude damage to exhaust systems from asymmetrical heat distribution, (hot spots). The exhaust collector system should produce an exhaust flow which is as uniform as possible in temperature and pressure at the collector exit.

Mechanical connections should be made with captive devices or welds where appropriate that will not preclude reasonable maintenance practices. The design should provide easy access and adequate electrical service and lighting in this area to facilitate inspection and repair work.

4.4 Load Absorption Devices

There are many types of load absorption devices as stated in 4.2. The most commonly used are water brakes and electric dynamometers, and in the U.S. military, air dynamometers, which are described in the following paragraphs.

4.4.1 Air Dynamometers (See Figure 1)

Air dynamometers are basically air pumps/compressors mechanically coupled to the engine by a torque shaft. A torque measuring device/system is included in the design. The air dynamometer consists of a housing, rotor, measurable air volume control shroud and its stepper motor and chain drive. Air dynamometer designs eliminate the need for fluids, pumps, plumbing, heat exchangers, extensive electrical wiring, load banks, reduction gear boxes, water cooling towers, etc. The test cell operator applies loads to the engine by opening and closing the shroud assembly to increase or decrease the load respectively. Since some engine tests require very rapid changes in engine load, be sure to select an air dynamometer that incorporates the required capability.

4.4.2 Water Brakes (See Figure 2)

As the name implies water is used as the load/energy transfer medium. This is usually accomplished by water exchange between a rotor and stator assembly, either airfoil, cup shaped or flat plate. The load application is obtained by controlling the water flow through the water brake and includes some sort of cooling system. The water system may be open or preferably closed loop. Most water brake systems include a torque/SHP measuring system. Some systems resort to inertia flywheel to simulate helicopter rotor or propeller loads. Ambient weather conditions should also be considered when designing water dynamometer systems. Cold climates may dictate that the water supply be placed inside the cell rather than outside due to concerns about freeze protection.

4.4.3 Electrical Load Banks (See Figure 3)

Another common load absorption device is the electrical load bank. In this system the load is absorbed by an electric generator that is connected to a resistive load bank. Power absorption is varied by changing the resistive load on the generator. In general this configuration would require a reduction gearbox between the engine under test and the generator. Also, air cooling is required for the load bank.

4.4.4 Eddy Current Dynamometers

Eddy current dynamometers are also used to test turboshaft engines. They operate in the following manner: Controlling the electromagnetic coupling between the driven rotor and adjacent stator develops a retarding torque in the rotor and a reaction torque in the stator.

The retarding torque is proportional to the strength of the eddy current fields and is controlled by adjusting the excitation current in the field coil. The reaction torque can be measured by trunnion mounting the stator and connecting a load cell to ground. A water cooling system is required to dissipate the heat generated by the eddy current. An eddy current equipped test cell drawing would be similar to Figure 3, the Electric Dynamometer equipped test cell, except that load bank would be deleted and a cooling tower included.

4.5 Exhaust Stack

The purpose for the exhaust stack is to direct the hot exhaust gases up and away from ground levels outside the test cell and away from the test cell inlet to preclude ingestion of the exhaust gases which will cause unstable/inaccurate engine performance. Another purpose is to reduce the noise emanating from the stack. The exhaust stack would normally include a flow redistribution device by which the horizontal flow is redirected from the augmentor/diffuser system into the stack and upwards through an acoustic silencer package at the stack exit. The combination of the flow-redistribution device and an acoustic silencer package controls the resonances and noises within the stack and results in achieving the desired sound levels outside. Particulate and gaseous emissions control has become a significant concern in recent years, especially the control of Nitrogen Oxide (NO_x), which reportedly adversely affects the earth's ozone layer. Particulate control technology exists and has been employed in various forms, (scrubbers, electrostatic screens), with some success in some industrial facilities. However, practical cost effective gaseous emission control technology for engine test cells is not currently available. This is discussed in the U.S. Environmental Protection Agency and Department of Transportation Joint Report to Congress on the "Study of Nitrogen Oxide Emissions and Their Control from Uninstalled Aircraft Engines in Enclosed Test Cells" dated September 1994, Reference 2.1.4. Local noise and emission regulatory issues still may have to be considered in the design of the exhaust stack and the best available control technologies employed.

Once again, the design should incorporate captive mechanical connectors to avoid connectors coming loose and being ejected from the exhaust stack creating a safety hazard in the adjacent area. The design should incorporate easy access to the exhaust stack lower area and a catwalk to provide safe access to the upper area. Reasonable access to acoustic panels/baffles/material should be provided. The acoustic panels that are in the exhaust gas path especially should be designed to be easily accessible for repair or replacement. The exhaust section floor should incorporate a drain system to prevent rain water and fuel residue accumulation. The drain system design should conform to environmental regulations.

Fundamentally, the exhaust stack should always be higher than the inlet stack of a test facility. This is for two reasons. Firstly the natural static pressure draw of flow through the test cell (chimney effect) should always be towards the exhaust. Secondly, when testing in a tail wind it should not be possible to re-ingest exhaust gas from the exhaust stack.

When testing turbo-shaft engines with fixed exhaust duct, volute arrangements and packages, such as marine and industrial applications, every effort should be made to re-create the reference datum conditions and not change the exit profiles or static pressure loss characteristic.

4.6 Air Dynamometer Exhaust System

Air dynamometers were developed by the U.S. Navy primarily for open air engine test systems and have been used with reasonable success for 15 years. The advent of environmental noise issues dictated a need to apply these dynamometers to enclosed turboshaft test cells, requiring the design of an exhaust system for the dynamometer as well as the engine. A number of designs were employed that did not adequately capture the air dynamometer exhaust. The resulting heat buildup in the test chamber was ingested into the engine inlet causing unstable and inaccurate engine performance. A series of full scale tests were performed, which showed that the dynamometer exhaust was not captured by the exhaust duct resulting in little or no aspiration flow and consequent dynamometer exhaust flow spill-over into the test chamber. Exhaust deflector baffles were developed and after a series of tests, (References 2.1.2, 2.1.5, 2.1.6, and 2.1.7) were refined to eliminate the problem. Obviously air dynamometer exhaust duct design must be given major consideration for the above reason and, as with engine exhaust ducting within the test chamber, the length and number of angles in the dynamometer ducting should be kept to a minimum to eliminate unwanted radiated heat and facilitate unrestricted exhaust gas flow. Ideally this exhaust should be ducted either into the main test cell exhaust system or externally, avoiding re-ingestion by the intake.

5. FACTORS FOR EVALUATING TEST CELL PERFORMANCE

Some of the more important factors which must be considered in the development of designs leading to desired engine operational stability and acoustic performance are described below. Many of these factors can be expressed in terms of measured or calculated parameters which are often used to quantify and evaluate the performance of the various engine test cell configurations. A generally accepted method of calculating the value for each parameter is also given.

5.1 Front Cell Velocity Distortion

The front cell velocity distortion factor or index, calculated from a grid of velocity measurements in a test cell plane upstream of the engine inlet or bellmouth, can be used as a general indicator of test cell airflow uniformity or quality. A typical minimum grid spacing might be a matrix of 5 x 5 measurement locations, or a total of 25 points located at the centers of equal areas. The velocity measurement plane should be located about three or four bellmouth throat diameters in front of the bellmouth entrance plane, yet not too close to any silencer baffles or flow-conditioning screen support frames in the inlet system or front cell region. A location in the front cell which is midway between the bellmouth and the last flow-conditioning device might also be chosen. The velocity distortion parameter is defined as follows:

$$FCv_{Dist} = \frac{V_{\max} - V_{\min}}{V_{avg}} \quad \text{(Eq. 1)}$$

where:

FCv_{Dist} = front cell velocity distortion index

V_{mas} = maximum velocity anywhere in the velocity measurement grid

V_{min} = minimum velocity anywhere in the velocity measurement grid

V_{avg} = average front cell velocity

5.2 Front Cell Temperature Distortion

Front cell temperature distortion can be calculated in the same way as velocity distortion is calculated and will indicate the uniformity of temperature distribution forward of the engine. Temperature measurements can be taken at the same location as the velocity measurements. The temperature distortion index is defined as follows:

$$FCt_{Dist} = \frac{T_{\max} - T_{\min}}{T_{avg}} \quad \text{(Eq. 2)}$$

where:

FCt_{Dist} = front cell temperature distortion index

T_{max} = maximum temperature anywhere in the plane of measurement

T_{min} = minimum temperature anywhere in the plane of measurement

T_{avg} = average front cell temperature

5.3 Front Cell Airflow

The front cell airflow is the amount of air flowing through the test cell in the region in front of the engine bellmouth. Normally, it is the amount of airflow entering the test cell through the cell inlet. The front cell airflow rate can be determined from the same grid of velocity measurements used to measure the front cell distortion, provided the cross-sectional area at the measurement plane is accurately known and a proper flow coefficient value is applied. It is calculated as follows:

$$W_{FC} = \frac{P_{FC}}{T_{FC}R} V_{FC} A_{FC} Cd_{FC} g \quad \text{(Eq. 3)}$$

where:

W_{FC} = front cell airflow rate

P_{FC} = front cell static pressure

T_{FC} = front cell static air temperature

V_{FC} = average front cell velocity

A_{FC} = front cell cross-sectional area

Cd_{FC} = front cell flow coefficient

R = gas constant

g = gravitational constant (for imperial unit calculation only)

5.4 Bellmouth Total Pressure Distortion

The engine bellmouth steady state total pressure distortion index is used to identify the relative severity of the engine inlet airflow field at the engine compressor face. An array of several rakes instrumented for total pressure measurement, with several probes or immersions per rake, should be used to quantify the total pressure distribution at the measurement plane. A typical instrumentation arrangement might consist of eight such rakes with five immersions per rake. The requirements for this test are detailed in the engine specification provided by the manufacturer. The distortion index is defined as follows:

$$BM_{Dist} = \frac{P_{max} - P_{min}}{P_{avg}} \quad \text{(Eq. 4)}$$