

AEROSPACE INFORMATION REPORT

SAE AIR1813

REV. B

Issued 1982-06
Revised 1998-04
Reaffirmed 2007-11
Stabilized 2013-02

Superseding AIR1813A

The Coanda/Refraction Concept for Gas Turbine Engine Test Cell Noise Suppression

RATIONALE

This document has been determined to contain basic and stable technology which is not dynamic in nature.

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FOREWORD

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1. SCOPE:

- 1.1 Document provides information on how military/commercial/gas turbine engine test cell/system users may benefit from this unique Coanda/Refraction concept.
- 1.2 The information contains several factors which are considered essential for understanding the practical technical aspects of the concept. These are:
 - a. Operation Need
 - b. Concept Definition
 - c. Developmental Program
 - d. Program Results
- 1.3 Purpose:
 - 1.3.1 To present an advanced technology in suppression of gas turbine engine exhaust noise in ground run-up test cells/systems. The discussion herein is limited to turbojet and turbofan type engines, although the concept is equally applicable to turboshaft and turboprop types.
 - 1.3.2 To explain specific applications of this technique in various types of test cells.

2. REFERENCES:

- 2.1 ARP741 - Gas Turbine Engine Test Cell Correlation
- 2.2 NAVAL AIR ENGINEERING CENTER, LAKEHURST, NJ DESIGN DATA 92-136, 30 March 1979, Design Configuration Handbook, Test Cell System, Coanda/Refraction Noise Suppression Concept
- 2.3 NAVAL AIR ENGINEERING CENTER, LAKEHURST, NJ Technical Report 92-112, April 1979, Jet Engine Demountable Test Cell, Exhaust System Phase
- 2.4 NAVAL AIR ENGINEERING CENTER, LAKEHURST, NJ Technical Report 92-113, May 1979, Jet Engine Class "C" Test Cell Exhaust System Phase
- 2.5 NAVAL AIR ENGINEERING CENTER, LAKEHURST, NJ Technical Report 92-057, September 1975, Full-Scale Model Experimental Test Phase

3. TEST CELL/SYSTEM NOISE SUPPRESSION REQUIREMENTS:

3.1 General:

One of the most important problems in ground testing of turbojet/fan aircraft engines is the extremely high noise level energy radiated from the test location which endangers operating personnel hearing and disturbs nearby communities. The intense noise levels produced by modern day high performance jet aircraft is creating hazards, both physiological and psychological.

3.2 Test Cell/System Design:

- 3.2.1 Gas turbine engine test cells/systems have many design requirements to satisfy the complexity of aerodynamic, thermodynamic and acoustic performance characteristics. A delicate balance is necessary to assure that the gas turbine engine operates in a similar environment in the test cell/system as it does in the open air.
- 3.2.2 The physical dimensions and cross-sectional area of a test cell/system should be such as to assure that laminar air flow through the engine chamber is effected.
- 3.2.3 The principal structural components of the test cell/system are the primary air inlet, the engine chamber and the exhaust section. Each must be designed for its individual function and for its compatibility with the others, with respect to aerodynamics and acoustic performance. It is noted that the exhaust section includes the secondary air inlet and the exhaust stack.

3.3 Acoustic Properties:

The overall acoustic performance of a test cell is a composite effect based upon the residual noise contributions emitted from the inlet, engine chamber walls and the exhaust section.

- 3.3.1 Inlet noise is predominately high frequencies - mostly from the engine compressor.
- 3.3.2 Engine chamber noise is mostly mid-band frequency distributed.
- 3.3.3 Engine exhaust section noise is predominately low-frequency.

4. OPERATIONAL NEED:

4.1 General:

The need for advanced technology in a specific commodity area is usually based upon the time-reduced capability of the state-of-the-art equipment to function effectively. In the gas turbine engine test cell/system, engine exhaust total flow energy and proportional acoustic energy - especially in high-performance, afterburning military engines - have increased beyond the capability of noise suppression equipment which can function without extensive maintenance, replacement of components and reduced life-cycle expectancy.

4.2 Military Procurements:

Past equipment procurements and design studies have been limited to the state-of-the-art hardware and technology, which have not yet been developed for prolonged durability against the adverse effects of engine exhaust; viz high impact forces, excessive temperatures and entrained contaminants. Consequently, procurements of noise suppression equipment or test cell/system acoustic baffles have been diverse in origin and objectives, so that the existing acoustic support gear is not interchangeable. Despite procurement of suppressors designed for only one engine, the need exists for multi-engine usage. A diversity of equipment from different contractors lacks commonality to permit a practical, efficient logistics plan for support and replacement of deteriorating parts. The built-in replacement requirements of acoustic absorptive elements, and disadvantages in the state-of-the-art equipment due to corrosion required an improvement in noise reduction technology.

4.3 Disadvantages:

Several characteristics which tend to reduce the life-cycle effectiveness of the state-of-the-art exhaust noise suppressors are:

- 4.3.1 Current ground run-up noise suppressors utilize instream turning vanes and perforated collanders to direct the horizontal, high temperature jet exhaust upward. This equipment requires heavy structures to withstand the jet exhaust forces. Most internal components (including acoustic absorptive baffles) are subject to deterioration and frequent maintenance.
- 4.3.2 A necessary function of the ground run-up suppressor is to reduce the hot exhaust gas velocity to the extent that the noise created by the flow exiting from the suppressor is below the design criteria. In the state-of-the-art equipment, the necessary energy transfer is accomplished by the use of perforated collanders to break up the flow and mix it with cooler induced air, or by injecting large volumes of water into the exhaust plume. Both of these methods are poor for use with afterburning engines, because the flow damages suppressor components and because excessively large amounts of water are required to reduce the exhaust temperature to acceptable levels.

5. THE COANDA/REFRACTION CONCEPT:

5.1 General:

The COANDA/REFRACTION concept for gas turbine engine exhaust noise reduction depends, essentially, on a combination of aerodynamic/acoustic phenomena which occur simultaneously downstream from the engine exhaust nozzle.

5.2 Concept Definition:

The concept combines, for the first attempt in noise reduction applications, an aerodynamics phenomenon - The Coanda Effect - for jet exhaust bending/cooling without excessive structural requirements or turning vanes, and an acoustic principle - noise refraction by temperature/velocity gradients - for low-frequency tuned absorption.

5.3 The Coanda Effect:

A non-rigorous technical statement of the Coanda Effect, based upon the original work of Dr. Henri Coanda, A Rumanian aerodynamicist, is presented as follows:

- 5.3.1 A turbulent jet, exiting from a rectangular nozzle into an ambient fluid, entrains fluid from the ambient field. A surface placed near the exiting jet inhibits entrainment on that side of the jet, causing a low pressure region to exist between the jet and the surface. With a pressure gradient thus imposed across the jet, it deflects toward the surface, thereby decreasing the surface pressure even more, until the jet eventually attaches to the surface. If there is a step-gap between the jet and the deflection surface, a trapped vortex will form between jet and surface. This phenomenon is known as the Coanda Effect.
- 5.3.2 Coanda-deflected jets entrain greater quantities of secondary-air than undeflected jets. Due to the lower static pressure on the bounded side of the jet, the pressure drop across the nozzle is greater, thereby increasing the jet velocity on that side - the velocity of the bounded side being equal to that of the undeflected jet. The resultant average velocity in the deflected jet is greater than the undeflected jet, assuming equal nozzle exhaust pressure. Consequently, the deflected jet also possesses greater average momentum and greater eduction pumping efficiency than the free-jet mixing capability. As a side-effect to this greater-mass-airflow-entrainment, Coanda flow enhances jet ejector operation with lower ejector exit temperatures.

5.4 Acoustic Refraction:

Refraction of acoustic energy occurs naturally in all gas turbine engine exhaust streams. Noise refracts, or radiates, out of the exhaust along paths which are perpendicular to characteristic contours of equal flow velocity and equal temperature.

- 5.4.1 Locations of refracted noise patterns, relative to the deflected jet flow, are geometrically predictable for exploitation in noise reduction attempts.

5.5 Application to Noise Suppression:

Several factors for understanding the aerodynamics, thermodynamics and acoustics benefits derived from application to suppression of gas turbine engine exhaust noise in test cells are:

- 5.5.1 An additional feature of the Coanda Effect is that it is a natural fluid amplifier - the curved jet flow has a greater capability than normal jets for educting large volumes of ambient air from the immediate vicinity at the outer boundary of the deflected jet. In relation to jet engine testing this means that natural cooling of the superheated jet exhaust (caused by mixing and enthalpy exchange of educted ambient air with the rectangular jet core) is possible without the need for additional structural requirements of secondary air chambers. More important, it eliminates the need for cooling water and associated pump and piping systems. The actual ratio of cooling-to-primary-air was limited to ten-to-one in the experimental model tests.
- 5.5.2 Due to the proximity of a surface to the jet, a pressure gradient is formed which causes the jet to turn. This means that there are no components in the flow to create jet exhaust stagnation temperatures and pressures. The deflection surface may be film-cooled with entrained air from air slots along the surface.
- 5.5.3 The acoustic energy will now be refracted out of the exhaust flow. Acoustically tuned resonant chambers for absorption of specific frequency bands can be located adjacent to the high energy exhaust flow, instead of being located directly in the stream. This results in a significant increase in operating life, and provides a method for attenuating low frequencies.
- 5.5.4 The initial concept of a noise suppressor using the Coanda Effect and noise refraction principle is shown in Figure 1. This configuration consists of an adapter/transition section and a Coanda flow turning section. The adapter/transition section serves as an ejector - it converts the round primary jet exhaust, mixed with entrained cooling air at the inlet, into a rectangular sheet of hot gasses at its exit. The curved deflection surface then turns the rectangular sheet flow upward 90 degrees, while reducing the flow velocity and refracting a large portion of the internally generated noise downward and to the rear where acoustic resonant chambers are located.

6. PROGRAM RESULTS:

6.1 General:

As a result of the overall developmental program, an advanced technology concept was proven feasible and practical for suppression of gas turbine engine exhaust noise in test cells/systems. This report has presented an explanation of the Coanda/Refraction concept and a description of the research work. The tabulated data, charts and graphs are too extensive to be presented herein, but are available in technical reports, as indicated in the listing of references.

6.2 Test Cell Exhaust System:

The Coanda/Refraction system is an air-cooled, turbojet/fan engine exhaust noise suppressor which is attached to the aft wall of an engine test cell. The main components of the system are described as follows:

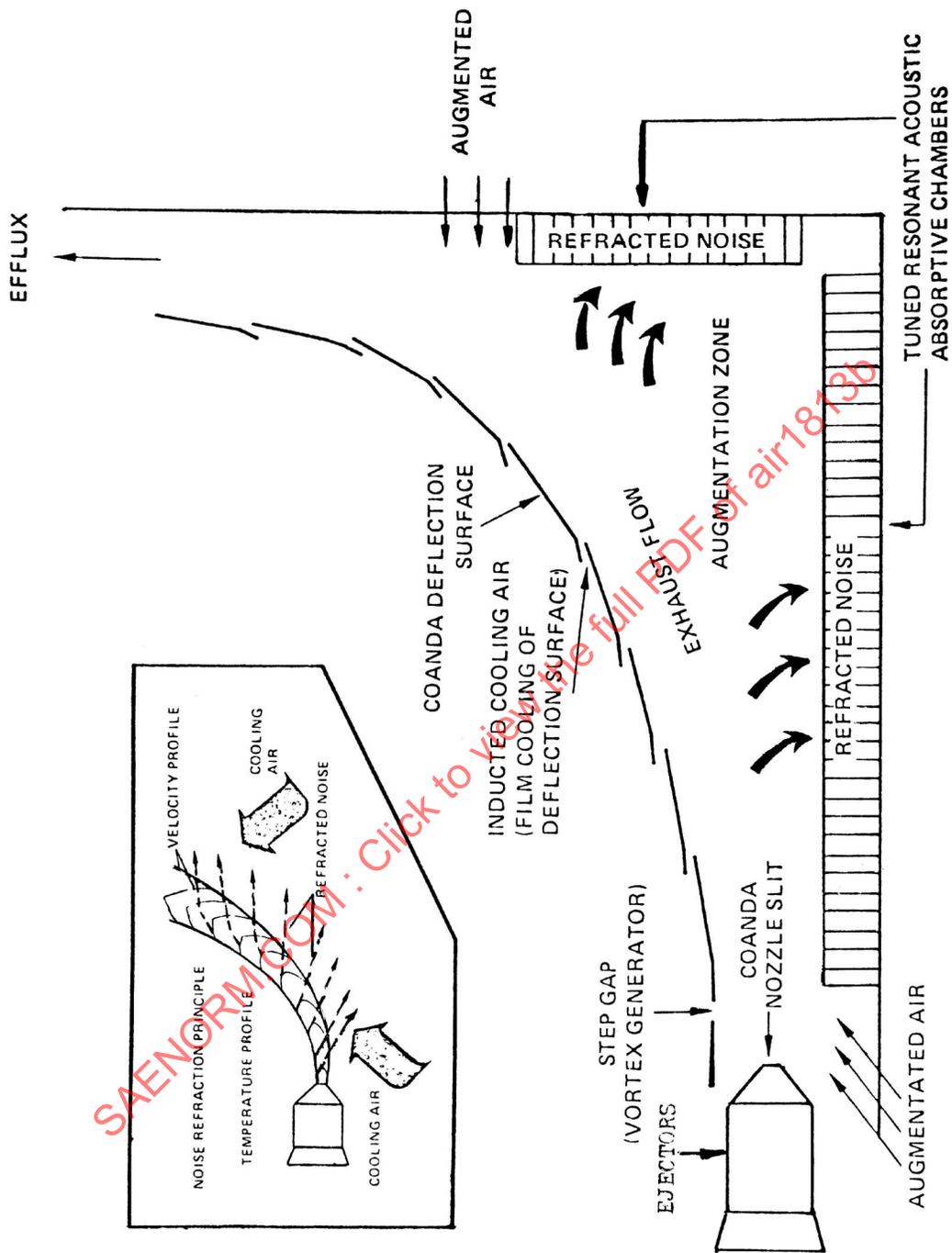


FIGURE 1 - The Coanda/Refraction Noise Suppression Concept

- 6.2.1 Iris Adapter: An adjustable operative device which can be used to control the amount of cooling air which is pumped through the engine chamber, across the engine and into the first stage ejector. The IRIS is located on the aft test cell wall, concentric with the engine longitudinal centerline and at the inlet of the first stage ejector. The IRIS is adjustable for each engine type. The IRIS is not needed in the standard design Coanda system. However, the adapter is recommended for use in larger, turbofan-type exhaust systems and smaller turbojet engines.
- 6.2.2 Ejectors: A three-stage set of augmentor devices which transition the hot engine exhaust from a round jet to a rectangular sheet flow suitable for introduction into the Coanda surface. The curve is logarithmic, instead of a constant radius to allow for better cooling air mixing with the primary engine exhaust core.
- 6.2.3 Coanda Deflection Surface: A curved surface directly downstream from the exit to the third ejector stage. The curve is a logarithmic, instead of a constant radius. This design allows for better cooling because of the more efficient mixing between hot exhaust gases and cool ambient air.
- 6.2.4 Acoustic Enclosure: A structure which surrounds the ejectors and Coanda surface while also supporting the secondary air intake and the exhaust stack. The hollow-design walls consist of an isolated inner wall and an outer wall which are designed to prevent excessive noise transmission through the structure. The side walls and back wall of the aft section (below the stack) of this enclosure should be acoustically treated with the broadband absorber panels set inside the isolated inner wall.
- 6.2.5 Secondary Air Intake: The secondary air intake is located in the upper part of the enclosure just forward of the exhaust stack. It permits the flow of ambient air into the enclosure for the purpose of mixing with and cooling the hot jet exhaust. The inlets are lined with acoustic panels, to limit airborne noise propagation from within the enclosure. Moreover, the inlets are sized to maintain acceptable pressures within the enclosure.
- 6.2.6 Exhaust Muffler (Stack): Acoustically lined and located at the aft end of the muffler section, this system provides the necessary noise attenuation for the mixed exhaust flow exiting into the atmosphere. A broadband acoustic absorber is used in the stack wall behind a multi-layered, perforated face sheet. The broadband absorbers, located in the aft end of the enclosure extending from the stack to the floor, are required to absorb noise refracted from the Coanda flow. The exhaust stack height may be designed to provide any desired far-field acoustic performance (within local site construction constraints), as explained in Reference 2.3.
- 6.3 Applications:
- 6.3.1 As a result of the final analytic design studies, functional noise suppression systems configurations have been identified for usage in ground run-up test facilities for Navy/Marine Corps turbojet/fan engines. These systems are also applicable in the present design form to USAF engines which are of the same types, but which differ only in model number from their counterparts in the Navy inventory.

- 6.3.2 The standard exhaust system for a prefabricated demountable type test cell is shown in Figure 2. This configuration is specifically designed to accommodate the exhaust airflow, temperature and pressure ratio parameters of the J52, J57 A/B, J79 A/B, TF30, TF30 A/B and TF41 engines. It is noted that the rear wall of the test cell engine enclosure is the forward wall and ejector inlet plane of the exhaust system. Also see Figures 3, 4, and 5.
- 6.3.3 Figure 6 shows the standard configuration which has been developed specially as a retrofit for replacement of deteriorated water-injection-type exhaust systems for the Navy standard concrete Class "C" test cell.

6.4 Advanced Technology:

In addition to these design configurations, a working technology has been formulated and presented in a Design Configuration Handbook. (For details refer to Reference 2.2.)

- 6.4.1 This technology is adequate for designing a specific "tailor-made" noise suppressor for any engine, or closely-related group of engines, in any type of ground run-up test cell enclosure, including Navy/Air Force test cells/systems and Naval Air Rework Facility test cells (which have a variety of nonstandard, unique configurations).
- 6.4.2 This is considered essential for design studies leading to a configuration for larger, high by-pass ratio turbofan engines, as well as the "PEGASUS" or F-402-RR-404 engine for the AV-8 Harrier aircraft.
- 6.4.3 This technique is equally applicable to commercial airlines engine test cells and engine manufacturers test cells.

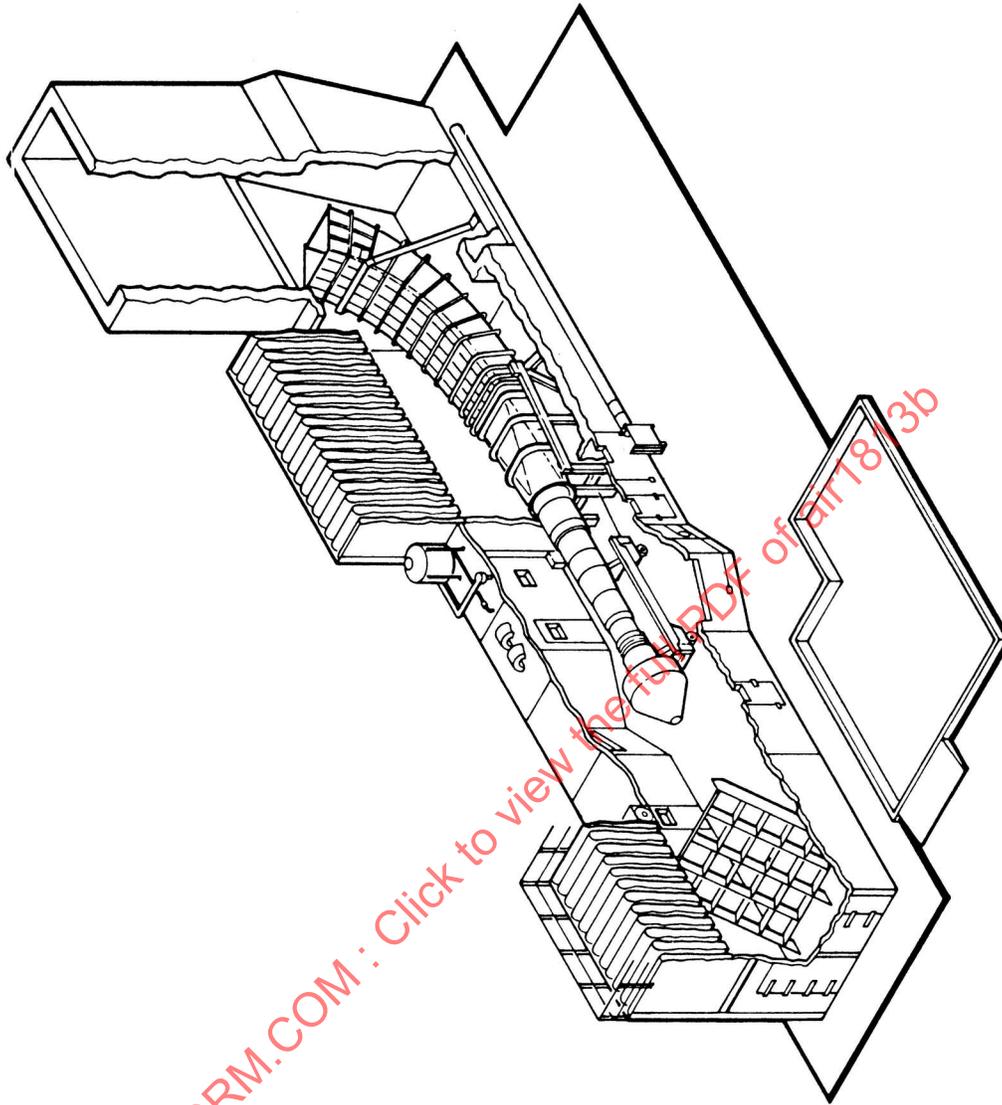
7. APPLICATION TO AIRCRAFT HUSH-HOUSES:

7.1 General:

Recent developmental work by the U.S. Navy has been successful in applying the proven technology as an exhaust suppressor system for aircraft acoustical enclosures - hush houses - where the entire aircraft is enclosed in a test cell during ground run-up engine checks. Although the basic application is similar to the test cell system, the actual design development for single and dual-engine aircraft is considerably more complicated. A brief summary of this program is presented below.

7.2 One-Sixth-Scale Model Configuration:

- 7.2.1 The model configuration shown in Figure 7 is the experimental set-up for the aircraft run-up enclosure (Hush-House) series of tests.



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FIGURE 2 - Test Cell
"Standard" Exhaust System



FIGURE 3 - Ejectors and Coanda Deflection Surface

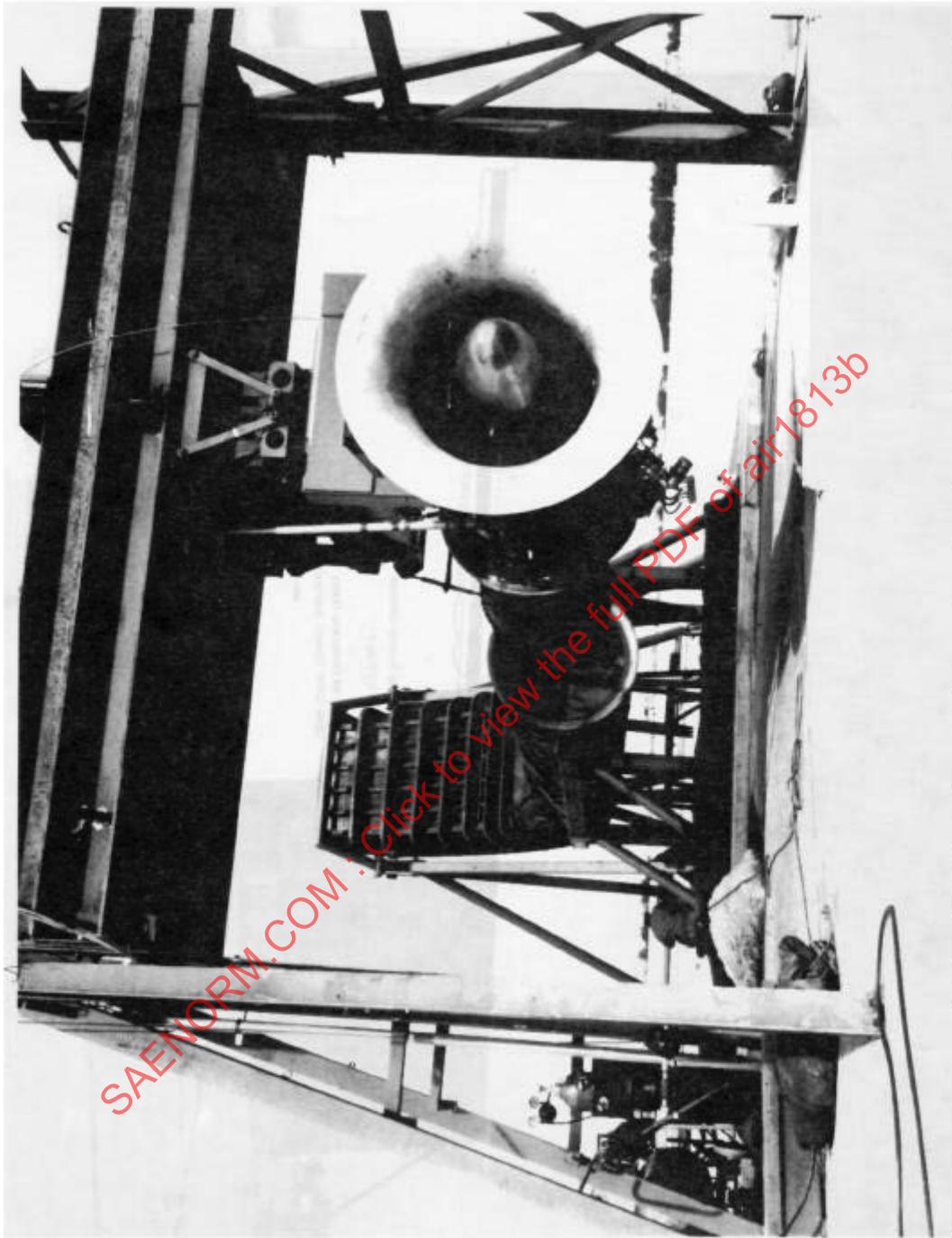


FIGURE 4 - J57 A/B Engine Aligned With Ejectors/Deflector



FIGURE 5 - Full-Scale Experimental Model Assembly

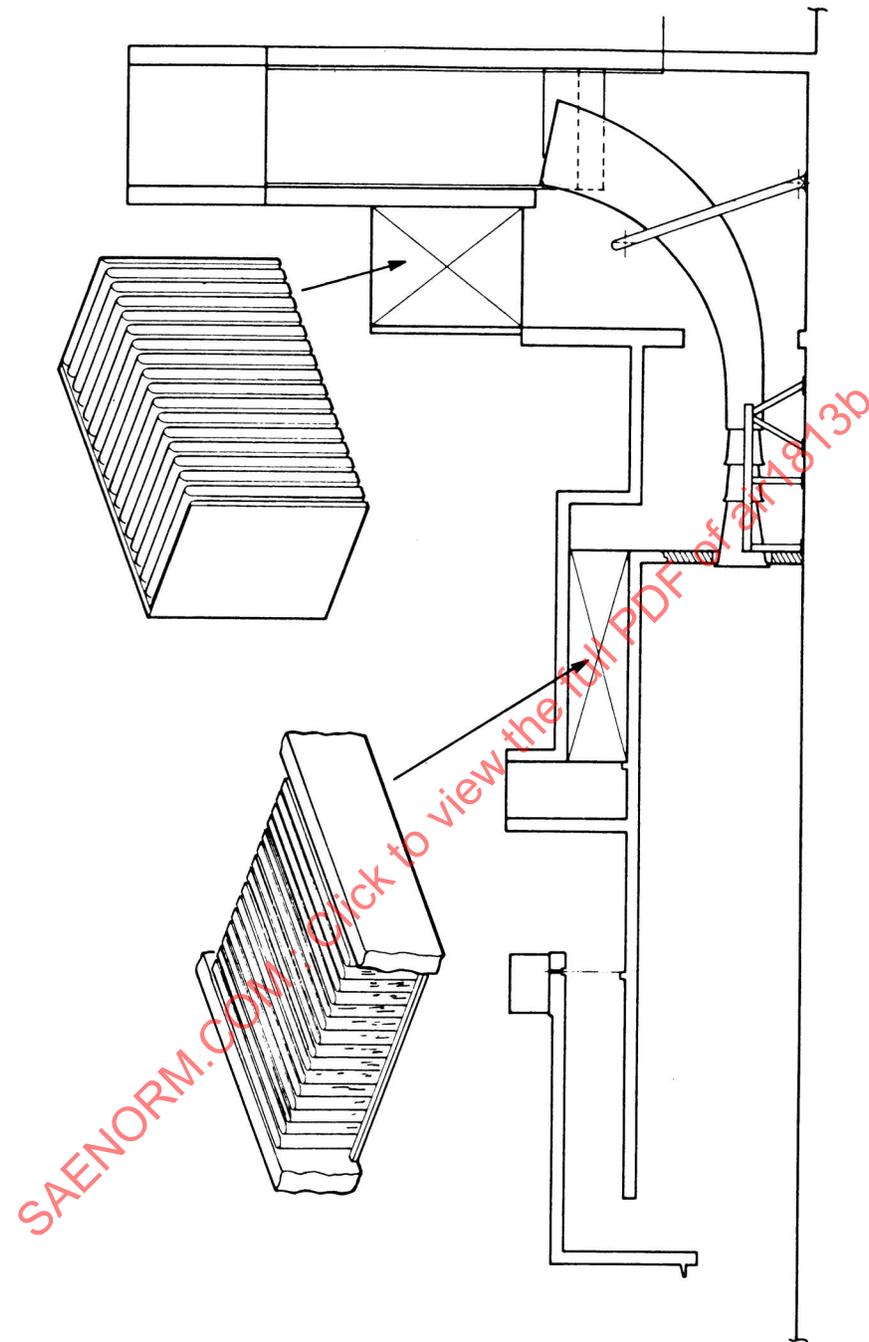


FIGURE 6 - "C" Cell Installation Noise Suppressor System
Coanda/Refraction

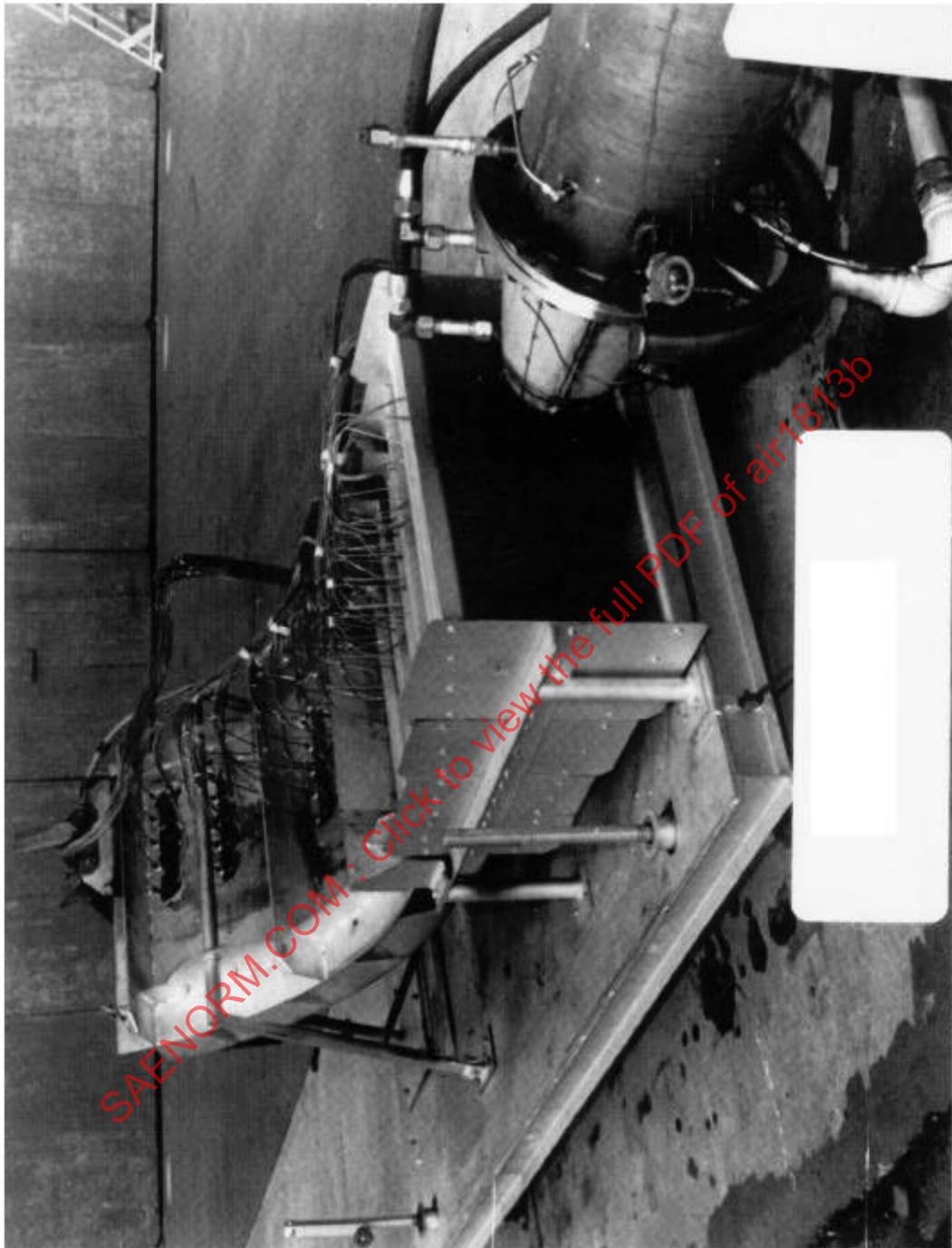


FIGURE 7 - Aircraft System Flat-Plate Ejector Model

7.2.2 In order to allow for the physical properties of single, as well as dual, engine aircraft, this flat-plate type ejector system was developed as another advanced technology feature to assure that the Coanda/Refraction concept was adaptable to the complex geometrical requirements of an exhaust system for a multi-aircraft Hush-House.

7.3 Flat-Plate Ejectors:

7.3.1 The hush-house exhaust system differs from the test cell exhaust system with respect to the basic transition/ejector configuration. Instead of the round-to-rectangular ejector geometry of the test cell system, the hush-house system incorporates an advanced technology flat-plate type ejector configuration.

7.3.2 Advantages are that the flat-plate ejectors are less sensitive to aircraft tailpipe movement during power-change surges of ground run-up tests, and dual-engine, as well as single-engine, aircraft can be accommodated on the same exhaust system without unnecessarily stringent and painstaking aircraft alignment/positioning.

7.3.3 The flat-plate system also assures that the mixed flow from two distinct exhaust nozzles of twin-engine aircraft (e.g., one engine at idle power and one engine at afterburner) will attach to the curved surface and deflect upward.

7.4 Summary of Results:

7.4.1 For complete aircraft ground run-up tests (in-airframe installed engines), a standard design configuration has been developed as a result of analytic studies, scale model tests and design studies.

7.4.2 This exhaust system for aircraft run-up enclosures (Hush-Houses) is shown in Figure 8. Here again, the exhaust system attaches to the rear wall of the standard aircraft acoustical enclosure. The range of Navy/Marine Corps single and dual engine aircraft for which this exhaust system configuration has been developed includes A-4, A-6, A-7, F-4, and F-14.

7.4.3 It is planned to develop a design configuration handbook for the hush-house flat-plate ejector system. Exhaust systems for other Navy, Marine Corps and Air Force aircraft types can be readily designed by using the technology from the handbook.

7.4.4 Hush-house exhaust noise suppressor systems for use during ground run-up tests, or in-airframe installed engine pre-flight trim checks, for commercial airlines and aircraft manufacturers can also be readily designed by using the technology from the handbook.

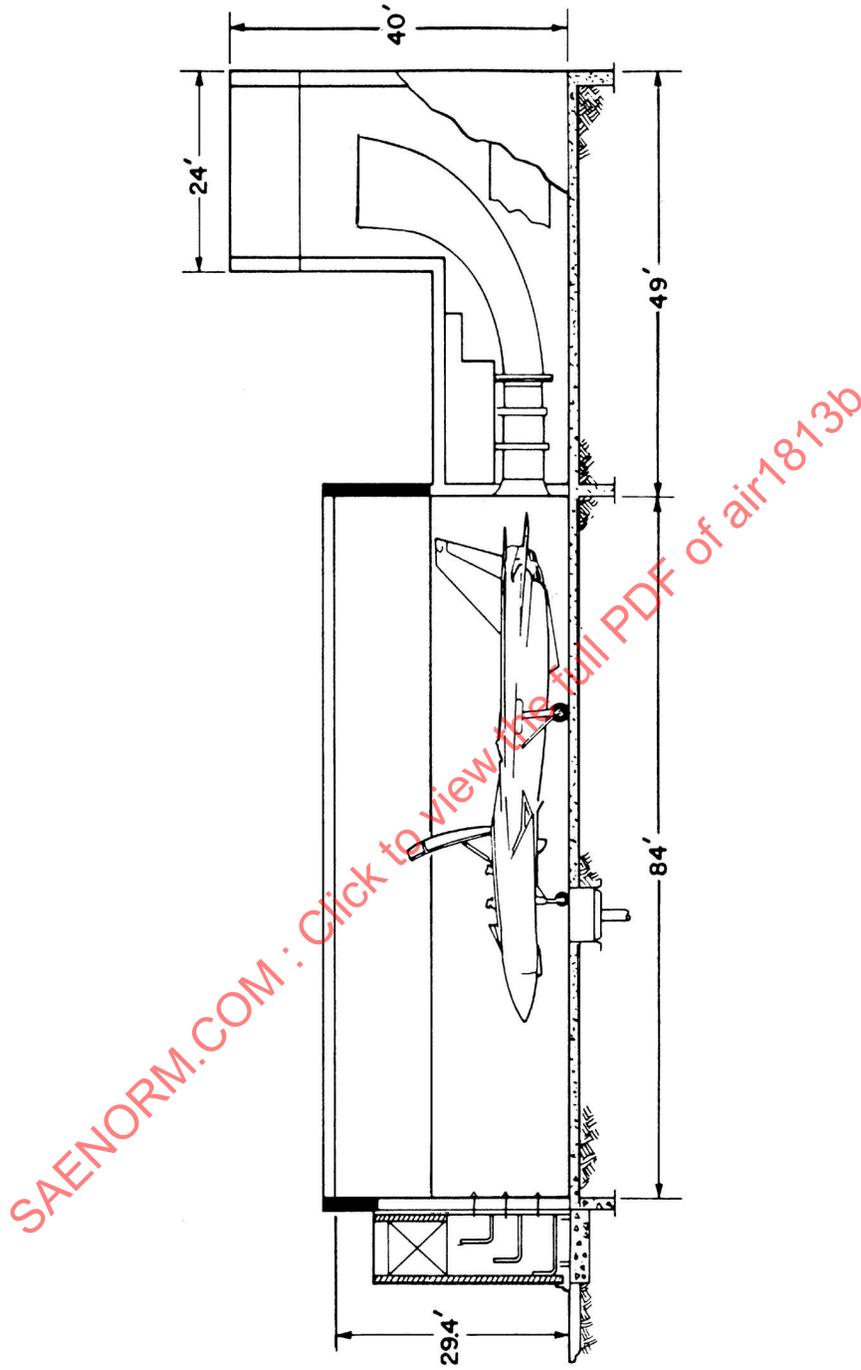


FIGURE 8 - Aircraft Hush-House Exhaust System