Jet Engine Test Cell

This report presents results of aerodynamic and thermodynamic tests conducted on the first standard Navy air-cooled T-10 test cell. Objectives of the tests were to: (1) Determine if aerodynamic and thermodynamic design objectives for the standard T-10 test cells were met; (2) Obtain data for comparing analytical predictions and validating analytical modeling techniques, and (3) Obtain baseline data of cell performance for use in case of future changes in design or operations. Aviation engine test cell; Jet engine testing; Jet engine exhaust flow; Turbulent jets; Compressible jets.

The prototype scrubber and augmentation system designed for and operated in Black Point Test Cell Number 1 NARF-Jacksonville has abated emissions to the projected design level. The engines operated with the system were the J-79, TF-30, and J-52. Particulate emissions were reduced to the 0.002-0.005 gr/SCF level. The visible emissions fell well within the Ringleman 1/2 level after dissipation of the steam plume. No fallout was evident during operation of the system. It was further established that engine test performance was not affected by the TESI system. The scrubber system was mounted on the exhaust stack of the cell thus obviating the necessity for costly ducting and the requirement for ground utilization. The size requirement of the scrubber was reduced significantly with the use of a new augmenter design that decreased the induced air to jet exhaust flow ratio from values in the range of 2:1 to 0.4-0.6:1. This new augmenter can reduce the augmentation even further, thus providing the potential of retrofit of existing cells to accommodate engines larger than now being tested. Sound levels were reduced by the installation of the scrubber from 6-10 decibels (dBA), where the original sound level was of the order of 90-95 dBA.

The Air Force routinely tests turbine engines in fixed test cells, some of which have been cited by state pollution control officials for violations of opacity regulations. A previous theoretical study, CEEDO-TR-78-53, predicted that relatively low efficiency and low cost techniques could bring jet engine test cells into compliance with air pollution regulations. The system proposed included a water cooling spray and a mist eliminator followed by a medium efficiency, high velocity, throw-away type glass filter media. The most serious limitation of which velocity filtration is the aerosol mass loading the potential for rapid pressure drop build up across the filter. Since filter loading characteristics could not be theoretically predicted, the objective of this follow-on work was to experimentally test and report the filter loading characteristics of glass fiber filters for possible application to jet engine test cell exhaust plume opacity control. Two types of glass fiber media were tested: (1) two different medium efficiency pre-filter media, and (2) two different high efficiency final filter media.

The report presents published jet engine emission data, test cell emission data collected at McClellan AFB during the operation of a J-57 turbojet engine at idle conditions and discusses problems involved in sampling test cell emissions. It was concluded that the variability of existing data indicates a need for a more refined study of jet engine pollutant emission rates. (Author Modified Abstract).

The report summarizes the results of a survey and analysis of the application of conventional air pollutant abatement systems to the exhaust gas from jet engine test cells. The following methods for gas treatment were investigated: wet scrubbers, incinerators, electrostatic precipitators, filters, dry inertial collectors. The least costly methods for meeting present emission standards are water scrubbing systems. One of the most attractive of wet scrubbers using Koch Flexitrays is developed in detail. The report covers the associated problem of water supply and disposal. The report also includes research and development suggestions for test cell emission control. (Author).

This report presents the Fortran program TCNOISE (Test Cell NOISE). The program predicts noise emitted by jet engine test cells. It is to be used in conjunction with the Naval Facilities Engineering Service Center's jet engine test cell aerothermal performance computer model, reading output files from this code to acquire the flow properties necessary for the calculation of jet noise and surface noise. The theoretical basis of TCNOISE, instructions for running the program, example runs, and comparisons of program predictions with measured noise emissions are included in the report.

In order to ascertain what methods of effluent treatment would be applicable to jet engine test cells, a study was undertaken to assess current and projected exhaust gas treatment technology and to establish that technology which results in the most effective cleanup per dollar. Emission factor data for the most prevalent Air Force engines were gathered to determine what levels of pollutants were to be dealt with. A theoretical model of a test cell augmentor tube with liquid injection was developed to aid in estimating total system flow rates as a function of engine operating parameters. The Air Force test cell emission reduction program can be characterized as having three goals which are discussed. The first or immediate goal is one of reducing visible emissions. The second or near-term goal involves meeting particulate mass criteria such as might be promulgated by the Environmental Protection Agency. The third or future goal would be concerned with meeting the mass emission regulations for NOx. (Modified author abstract).

A computer program (written in FORTRAN for a CDC 6600) was developed to predict the plume opacity of jet engine test cells. The data input required for the model includes: the particle density, concentration, and size distribution in the exhaust gas, and the effective stack diameter. Previous data obtained for J-57 engines were used to test the model, and the difference between the theoretical and measured transmittance was generally within one percent. The program also predicts the theoretical effect of using electrostatic precipitators or venturi scrubbers to treat the exhaust emissions. These predictions indicate that control devices larger than the test cells would have to be installed to even achieve a minimal effect on the observed visibility. (Author).

The feasibility of utilizing a laser velocimeter (LV) in turbine engine testing in an altitude test cell was investigated. A one-component LV and associated environmental control system (ECS) were designed, fabricated, and installed in Test Cell J-2 of the Engine Test Facility (ETF). LV measurements made on the centerline of an F101 engine at one axial station downstream of the nozzle exit are presented and compared to the calculated exit velocity.

Design data are presented on the vibration levels and temperatures encountered by the LV over a range of engine operating conditions. It was found that sufficient natural seed material existed in the exhaust flow to allow the LV to characterize the exit velocity of a turbojet engine during altitude testing. (Author).
An in-stack diffusion classifier was field tested at Tyndall Air Force Base, Florida. Particle size distribution measurements were made on the exhaust stream from the engine test cell while running a J75-P17 jet engine. Samples were collected at the test cell exhaust plane using a University of Washington in-stack cascade impactor followed, in series, by an in-stack diffusion classifier being developed at University of Florida. In addition, total particulate samples were obtained using absolute filters to determine particulate mass concentration in the exhaust gases. Opacity readings of the plume were also taken during sampling. The procedures to collect significant data and the general problems encountered to generate a reasonable estimate of jet exhaust aerosol size distribution using a diffusion classifier are described in this report.
Test Devices, Inc. has completed the preliminary design for the Portable Static Test Facility (PSTF) for small, expendable, turbojet engines (50 - 1000 lb thrust) as part of the Phase I effort under SBIR contract DAAH01-94-C- RO32. The goal of providing a preliminary design for a development and test facility at a reasonable cost, assembled from standard, transportable modules and requiring minimum setup was achieved. During the Phase I activities a detailed analysis was performed that covered the description of engines to be tested, engine test procedures, general test specifications, test facility requirements and design considerations, installation, and engine control and test data requirements. From this a preliminary design for

the portable test facility was prepared, plus a conceptual installation design and a preliminary design for the engine control and data system. Turbojet engine testing, Engine test cell, Static test facility, Engine control system, Expendable jet engine, Test cell instrumentation.

For some time the U.S. Air Force has been concerned with NOx emissions from jet engine test cells operated by the Air Force. While there are no regulations limiting the NOx emissions of these facilities, such regulations could develop in the near future and would pose significant problems for the Air Force because no available technology is suited for application to jet engine test cells. This report describes laboratory studies of a new NOx control process based on the surprising ability of barium oxide to rapidly capture NO, a process that could be ideally suited to controlling NOx emission from jet engine test cells. Thus, experiments were done in which a simulated exhaust gas containing NO was passed through a bed of either granular barium oxide or barium oxide supported on high-strength alumina. Quantitative NO removals were achieved at space velocities ranging from 2010 to 28,000 v/v/hr temperatures from 21 deg C to 610 deg C, oxygen concentrations of 1.1 to 15.3 percent, and initial NO concentrations from 94 to 1700 ppm. When NO2 was present in the simulated exhaust, it was also removed. The barium oxide was able to capture NO and NO2 in amounts up to at least 23.5 percent of its initial weight. The practical implication is that NOx emissions of a jet engine test cell could be controlled by replacing the acoustic panels now used to decrease the cell's emission of sound with a set of panel bed filters filled with barium oxide. These panel bed filters would also absorb sound, could fit in the space in the test cell now occupied by the acoustic panels, and would remove NO and NO2 from the exhaust before it is discharged to the environment.

One such facility, is an L-shaped indoor testing facility for these large, high-bypass turbofan engines. However, within a testing facility, the engine does not draw only the air into the facility but also induces a second flow which is a consequence of the interaction between the engine exhaust and the cell environment and augmentor/diffuser tube. Understanding the physics and flow conditions of this facility would be beneficial to the research and testing community. Three control devices were evaluated in the laboratory to determine their ability to reduce visible emissions from jet engine test cells. The three control devices - a low-pressure drop wet scrubber, a wetted-sand filter, and a high-temperature, ceramic fabric baghouse - were tested on the exhaust of a small gas turbine engine with a variable resistive load. Three fuel mixtures were used in experimental runs: 100 percent kerosene, 100 percent toluene, and a 50/50 blend of kerosene and toluene. Smoke number measurements of the treated and untreated exhaust stream were compared to evaluate the reduction in visual emissions for each control device. None of the three devices tested indicated enough reduction in plume opacity to justify construction of full-scale test cell control systems. Recommendations were made for future evaluation of modified wetted sand filter and ceramic fiber baghouse control devices. (Author).
Jet Engine Test Cell Noise Reduction

Passive methods for decreasing jet engine test cell noise emissions are evaluated and compared. Such methods have the dual advantages of low cost and simplicity. In addition, the effect on the aerothermal performance of the test cell is minimal. Sound pressure levels were measured in and around test facilities equipped with various devices to further reduce noise. The data were supplemented with parametric studies of noise reduction techniques conducted using a 1/20th scale physical model of the Navy's standard T-10 jet engine test cell. Methods that attack the noise problem from outside and methods that attack the problem from inside the test cell are assessed, including trees and other vegetation, acoustic walls, core busters, and modifications to the exhaust stack. Mounting screens in the path of the jet and increasing the height of the exhaust stack are found to be the most effective.

The economics of thermal energy recovery in jet engine test cells is examined. A numerical model to simulate the test cell augmenter tube is developed. This model is employed to determine the feasibility of installing heat exchangers along the augmenter or at the augmenter exit and using these heat exchangers to generate steam or electricity from the thermal energy in the jet exhaust. In general, energy recovery is not practical. The exhaust is quickly diluted by the entrained augmentation air, decreasing temperature gradients necessary for heat transfer. Most test cells are used too infrequently to warrant the cost of the hardware. (Author).

This report summarizes the findings of low cost, relatively low efficiency emission control measures for reduction of jet engine test cell opacity to less than 20%. The recommended cost effective opacity reduction system consists of an effective water spray system; a glass fiber mist eliminator; a medium efficiency, high velocity, throw-away type glass fiber filter media; and a reduced test cell discharge area. The report discussed the following topics: control methods, opacity, scrubbers, demisters, and filters.

An investigation of the air quality impact of DoD turbine engine test facilities was performed. Emissions and pollutant dispersion from test cells and aircraft at six DoD installations were predicted using a sophisticated computer model. Predicted pollutant concentrations are compared to ambient air quality standards and measured ambient values for hydrocarbons, oxides of nitrogen, and particulates. Jet engine test cells have no significant impact on air quality for any pollutant at any location studied. Test cell pollutant concentrations are considerable less than the levels generated by aircraft operations and well below measured ambient air quality levels in the areas studied. Ambient carbon monoxide and sulfur dioxide levels resulting from test cell emissions are insignificant. Control of any pollutants generated by test cells would not measurably improve ambient air quality.

An automated Smoke Abatement System (ASAS) which injects a smoke abatement fuel additive into the fuel system of a gas turbine engine was developed for reducing test cell exhaust stack plume opacity caused by engine operation. The ASAS contains three major components: transmissometer to monitor plume opacity, logic/control unit which determines if opacity exceeds the standard, and variable speed pump which injects the optimum quantity of the smoke abatement additive. The difference between the plume opacity and standard regulates the speed of the pump and quantity of additive injected. The System maintained test cell plume opacity to a visual opacity of 20 percent or less during evaluation tests at two Naval Air Rework Facilities (NARF's). It is recommended that the ASAS be used to control plume opacity from those engines compatible with smoke abatement additives.

A computer model of the Coanda/Refraction Jet Engine Test Cell facility was developed using the PHOENICS computer code. The PHOENICS code was utilized to determine the steady aerothermal characteristics of the test cell during the testing of an F404 gas turbine engine with afterburner in operation. Computer generated aerothermodynamic field variables of pressure, velocity and temperature parameters were compared to operational field test data. Observations regarding compared results as well as system behavior are presented. Additionally, recommendations of the applications of PHOENICS to future modeling projects are made. Theses. (mjm).