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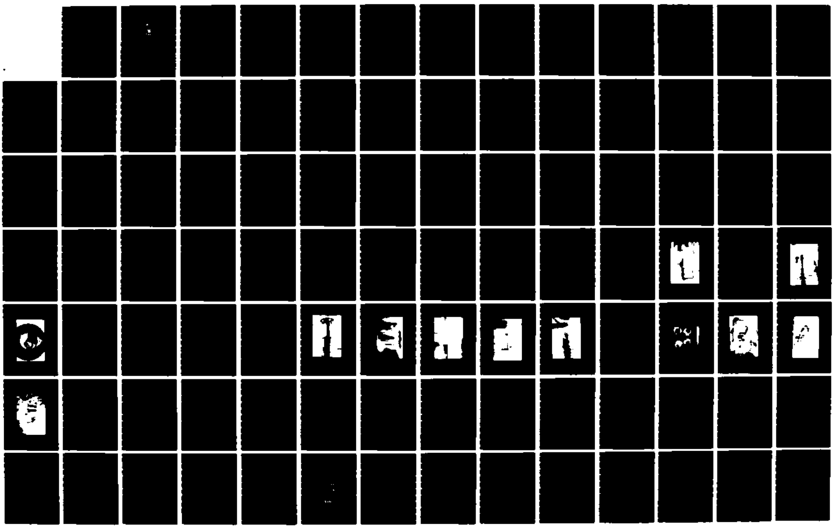

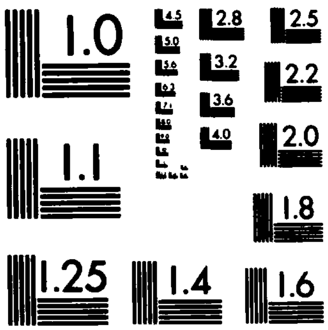

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THESIS

DESIGN AND TESTING OF
SCALED EJECTOR-DIFFUSERS FOR
JET ENGINE TEST FACILITY APPLICATIONS

by

James William Molloy

September 1983

Thesis Advisor: P.F. Pucci

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Scaled Ejector-Diffusers For Jet Engine Test Facility Applications

by

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Commander, United States Navy
B.S., United States Naval Academy, 1969

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requirements for the degree of

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and
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ABSTRACT

Design, fabrication and cold flow testing of a modeled jet engine test facility was conducted in an effort to provide an inexpensive vehicle to study geometric variations in diffuser geometry which could improve system efficiency. The design is based on Mach number similitude and consists of two configurations currently in use at the Naval Air Propulsion Center, Trenton, New Jersey. A constant area diffuser and a variable area diffuser with translating centerbody were modeled. Baseline mapping of the operating characteristics for each diffuser with representative scaled engines was conducted to provide a reference against which alternative geometries would be evaluated. The constant area plus two variants were tested. A five-sixths and two-thirds reduction were studied to investigate the potential for increasing efficiency for a specific engine diffuser combination at NAPC. Secondary flow provisions were incorporated into the design to allow variation of this parameter. The modeling results were consistent with theory and the test apparatus produced repeatable results. A two dimensional double ramp (wedge) capable of being translated in a rectangular duct was suggested as an alternative diffuser geometry.

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NOMENCLATURE

A^*	Nozzle Throat Area (L^2)
Ae	Nozzle Exit Area (L^2)
Ad	Second Throat Area (L^2)
H_t	Specific Fan Work (L^2T^{-2})
L/D	Length to Diameter Ratio
M	Mach Number
$\dot{m}$	Mass flow (MT^{-1})
P/ρ	Flow Energy (LT^{-2})
PT8	Total Nozzle Pressure ($ML^{-1}T^{-2}$)
P14	Exhaust Pressure ($ML^{-1}T^{-2}$)
PS9	Cell Pressure ($ML^{-1}T^{-2}$)
P_o	Stagnation Pressure ($ML^{-1}T^{-2}$)
$V^2/2g_c$	Kinetic Energy (LT^{-2})
Z	Potential Energy (LT^{-2})
β	Orifice to Pipe Diameter Ratio
η_{aej}	Air Ejector Efficiency
η_f	Fan Efficiency

I. INTRODUCTION

The ability to efficiently exercise control over the energies entrained within a supersonic airstream has been the quest of aerodynamicists for several decades. The designers of wind tunnels, jet inlets, gas dynamic lasers and jet engine test facilities have each addressed the gas dynamics of this topic. Each design has had to incorporate a method to decelerate the flow, generally, through a mechanical device such as a diffuser. The complexities of treating the recompression of a real fluid in the presence of a boundary layer have defied analytic modeling of a supersonic diffuser to any great extent. The design approaches taken have been empirically based, which has led to a wide variety of diffusers tailored to meet the unique operating environment at a particular facility. This study is sponsored by one such facility challenged with one of the consistent fascinations of modern engineering: how to extend the limits of one's design in the presence of new technology or shifting economic variables.

A. PROBLEM FORMULATION

Ground testing of jet engines has long been an integral part of the design and maintenance practice in both the military and commercial avaition industries. Organizations, chartered with the testing of these engines, strive to generate a test envelope which closely approximates the operating envelope which the engine will encounter in service. Advances in engine technology have imposed added demands upon the test engineer to extend the test envelope accordingly. This challenge has proven a classic cost effectiveness exercise, wherein, as higher altitude testing at increased power is pursued from one end of the spectrum, the attendant cost of exhausting the effluent in an innocuous manner to the environment spirals. The economic challenge continues to compound over the life cycle of the facility as energy costs associated with demands on the exhausters escalate.

Test cell philosophy has focused foremost on achieving a sufficiently flexible design which will accommodate a wide range of engines. Large exhaust mechanisms, capable of handling a wide range of exhaust states, were adequate when the motive energy cost was only a small fractional cost of the total price of testing. Strategies to enhance pressure recovery prior to the exhauster were developed but optimization of the design in this regard was not a bonafide concern. The present testing scenario reveals that the associated costs in exhausting the effluent rivals any of the other cost variables and percentage improvements in efficient pressure recovery through retrofit of the original design merit consideration.

A typical test cell design is as depicted in Figure 1. The engine to be tested is mounted on a test bed and located in the test cell such that the exhaust will be vented into an augmenting tube which acts as an ejector-diffuser assembly.

The kinetic energy of the exhaust stream is converted by the diffuser into a pressure for presentation to the exhauster. Each cell is nominally equipped for secondary flow in which secondary air is entrained with exhaust jet gas to provide engine cooling and dilute the combustion products. Allowance is made for relative positioning of the test bed and diffuser to reconcile potential problems with pressure gradients under conditions of secondary flow which may influence the operating envelope.

B. LITERATURE SURVEY

Several searches were conducted to survey the available literature for supersonic ejector-diffuser studies and theoretical discussions germaine to this investigation. An online computer search of several national data bases was conducted using the keyword, keyphrase approach. Results of the search revealed over 10,000 documents generally associated with the broad topic area, of which, a highly focused search indicated over 300 documents with relevant material. A hardcopy of the latter with a brief synopsis of each report, was procured for further review. The survey was restricted to English or English translations but evidence of many foreign papers on the subject was apparent. In no respect is the review considered all-inclusive.

A synopsis of the most recognized works gives a flavor for the approach adopted. In 1949, pioneer work, which appears as a baseline in most studies related to supersonic diffusers is attributed to Neumann and Lustwerk {Ref. 1}. This study included a one-dimensional theoretical analysis, and an experimental modeling with flow visualization by Schlerin photography of a constant area diffuser. A "transverse shock" was observed and categorized as the operative mechanism controlling diffusion. An optimum diffuser with an L/D of 10 was identified. In 1958, Lukasiewicz {Ref. 2}, studied data from several existing wind tunnel diffusers, concluding that fixed geometry diffusers can approach the pressure recoveries established from normal shock theory. Pressure recovery, far in excess of that obtainable with a constant area diffuser, was established for systems which employed variable area diffusers. In 1954, Hastings {Ref. 3} established the beneficial effect in diffuser performance of auxiliary ejection to partially evacuate test cells. Numerous additional studies with specific design goals have been conducted to optimize test facility operation. The most extensive noted were those conducted by Panesci and German {Ref. 4}, for Arnold Engineering Development Center in the 60's in which variable geometry diffusers with a centerbody were employed. Here again, pressure recovery far in excess of that achievable with constant area diffusers was observed.

Generalized studies to characterize pertinent parameters governing the flow phenomenon in rectangular diffusers were conducted by Merkli {Ref. 5} in 1976 and Waltrip and Billig {Ref. 6} in 1973. Merkli focused upon Mach number, diffuser length, boundary layer and Reynolds number as controlling parameters. Reynolds effects were discounted as minimal with Mach number and diffuser length the significant parameters. Waltrip and Billig corroborated previous works establishing 8 - 12 tube diameters as the required recovery zone. They also focused on an oblique shock system as the governing mechanism.

Ginoux {Ref. 7} compiled an excellent summary of a short course in Supersonic Ejectors conducted at the von Karman Institute. The short course was an attempt to focus on the most advanced initiatives and progress in theoretical modeling and design of high efficiency ejectors.

C. RESEARCH OBJECTIVES

The Naval Air Propulsion Center at Trenton, New Jersey, as a major jet engine test facility, has experienced the technological advances in engine design which have approached the design limits of their ejector-diffuser assemblies exacting a heavy burden on power consuming exhauster machinery to maintain simulated altitudes. As an adjunct to a much larger study, a cold flow modeling of their existing plant was sponsored by the center. The principal goal, assuming satisfactory modeling of the test facility, was to test alternative diffuser geometries in anticipation of enhancing overall efficiency. The modeling process was such that, Mach number similitude could be maintained, any efficiency increases over the baseline would be due largely to geometric effects.

As discussed in the general treatment on diffuser theory, the two principle types of diffusers, a fixed area and a variable area, were modeled. In both diffusers recompression of the supersonic flow is accomplished by a complex-shock mechanism under the influence of a boundary layer, with post shock subsonic diffusion following recognizable theory. The experimental technique devised was to establish the diffuser characteristic on a non-dimensional basis as a baseline against which 'new' geometries may be judged. Operating envelopes for each diffuser design would be duplicated as far as practicable with the same engines. Whereas the phenomenon by which recompression occurs would not be directly studied, a pressure histogram along the diffuser was recorded in order to postulate the character of the operative mechanism. It was anticipated that attempting to control the shock mechanism would likely provide the largest gains in efficiency as opposed to manipulating the subsonic diffusion process.

The scope of the investigation would be guided by studying only those configuration changes which could readily be retrofitted into the existing space limitations of the parent facility. Conceptual designs would be unbounded by any environmental or stress-related constraints, allowing a sponsor's cost benefit analysis to sort out those aspects of new design proposals.

Despite successful construction of a highly flexible model, a major portion of the stated objectives could not be accomplished within the timeframe alloted to this phase of the study. As baseline testing proceeded into the variable geometry diffuser, Figure 2, an unanticipated heating and vibration phenomenon was observed. The extent and nature of the phenomenon was not readily ascertainable but was in evidence only with the use of the centerbody configuration. The problem was of such proportion as to potentially taint the conclusiveness of future work involving devices imbedded in the jet stream. A separate detailed study of the phenomenon was ordered and a new set of objectives was established in concert with the sponsor.

In an effort to optimize test cell geometry for one of the more heavily tested engines (F404), a series of liners which would reduce the cross section for diffusion were designed for insertion into the full scale straight tube diffuser. Engines were tested in anticipation of achieving better diffuser efficiency by seeking to optimize the ratio of nozzle area to diffuser cross section for the highest pressure recovery.

The details of the model design and testing in the context of this narrower objective are contained in the thesis proper. The conceptual work related to the original objective with a proposal for an alternative method of diffusion are discussed in Appendicies A and C.

II. THEORY AND ANALYSIS

Pressure recovery in a supersonic jet engine test facility is accomplished by a mechanical device called a diffuser. Two types of diffusers are recognized, the fixed or constant area diffuser and the variable geometry diffuser. The fixed geometry normally is associated with fairly constant input parameters such as mass flow rate, stagnation temperature and pressure. The variable area geometry is utilized where fluctuations in fluid characteristics or engine geometry (such as variation in exhaust area accompanying jet engine testing from the non-afterburning to afterburning mode) are an integral part of the testing. Each type of diffuser may serve an ancillary role to eject secondary air used in cooling the engine assembly and test cell.

In each diffuser the operative mechanism which accomplishes the first order pressure recovery from supersonic to subsonic conditions is a shock system. Subsequent pressure recovery must follow the guidelines for subsonic diffusion. Projecting an improvement in efficiency accompanying any alternative geometry would require a projection of the probably shock patterns and the interaction of that shock system with a postulated boundary layer. This interaction, in simple geometries, has not been conclusively researched; hence, this type of approach in the presence of complex geometries is not warranted. Analytic models to guide the design of a new geometry for jet engine testing abound in the literature but generally assume the most convenient of assumptions. The model is generally one dimensional steady state using a simplified control volume and serves to bound the expectations only. Academic interests aside, a purely empirical approach is warranted. The approach adopted herein calls for establishment of baseline models of proper similitude with the existing facility from which characteristic curves can be drawn and against which alternative designs may be mapped and contrasted.

Acceptance of any observed change in system efficiency merits consideration only if dynamic similarity of the flow field has been verified between the baseline model and the parent facility. With supersonic compressible flow, Shapiro {Ref. 8}, is replete with support documentation illustrating the role of Mach number as the significant parameter in characterization of the flow. Merkli {Ref. 5}, in a series of experiments with rectangular constant area supersonic diffusers, concluded that Reynolds number has little effect on the pressure recovery. Mach number, as the ratio of kinetic energy to internal energy, was thus chosen as the best parameter upon which to base model development. Geometric compatibility was governed by the constraints of the engines to be tested and the limits imposed by the available air supply at the model test facility. The influence of temperature between cold ambient testing and prototype testing with hot exhaust gases would be addressed in the discussion of results as how it might impact the operative pressure recovery mechanism. Appendix A provides a more detailed study of modeling/scaling considerations peculiar to this study.

A. FLOW CHARACTERIZATION

Flow at the exit plane of the nozzle achieves supersonic proportions whose Mach number may be approximated by analyzing a Prandtl-Meyer corner flow from the nozzle exit to diffuser entrance. The increase in area from the exit plane to the diffuser allows the jet to expand supersonically as it fills the available volume. A Prandtl-Meyer expansion may also be utilized to estimate the pre-shock Mach number. Shocking, due to perturbation of the jet stream with the boundary layer as reported in several other workd {Ref 8} will assume an oblique character. The oblique shock system will, upon attainment of subsonic conditions, blend into a turbulent, well-mixed stream which would diffuse in accordance with subsonic theory. The oblique shock system would be expected to migrate along the diffusers length for a given geometry of diffuser, in some proportion to the driving pressure. The oblique shock system, as discussed by Shapiro, {Ref. 8}, will either be strong or weak as governed by the stability of the flow, the nature of the boundary layer interaction and a multiplicity of lesser related factors. Pressure variations caused by area change conceivably promote an alternating compression and expansion character to the flow wherein the jet may tend to pulse. Restricting the flow to a constant area would tend to damp out this type of behavior. Figure 3 illustrates the anticipated character of the flow.

B. OPERATING CHARACTERISTICS

The operation of the variable area ejector-diffuser provides insight into the complexities involved when designing or redesigning a new pressure recovery mechanism. Utilizing the simplified arrangement of Figure 4 to guide the discussion, the operation of this device may be described. As the total pressure is increased, flow in the nozzle accelerates until sonic conditions (M=1) are attained at the throat. Increasing total pressure or holding total pressure at this level and reducing the back pressure will cause a normal shock to stand in the supersonic region of the nozzle. A further lowering will cause the shock to pass into the test cell and into the diffuser. With a second throat, once the shock has been swallowed, the diffuser is considered started after which exhaust pressure may be raised shifting the shock to zones where stagnation pressure loss is less. A minimum loss will occur if the shock is located at the second throat. This may be accomplished by adjusting the axial position of the centerbody. The minimum flow area of the diffuser, Ad, must be greater than A* or the cell would become choked and altitude simulation could not proceed. The band of pressures, where cell pressure is independent of exhaust pressure, establishes the operating range of the diffuser. Conservatively, the shock is maintained upstream of the throat to preclude reverting to a higher cell pressure due to fluctuations in the flow field.

C. ENERGY CONSIDERATIONS

The presence of a shock wave arising from the supersonic starting process represents an increase in entropy at the expense of stagnation pressure. The entropy rise (pressure loss) is greatest across a normal shock as opposed to that across several oblique shocks. A simple illustration using Figure 5 makes the point. For a flow of Mach 2.0 at the diffuser entrance, a one-dimensional normal shock gives a stagnation pressure ratio across the shock of .721 with a post shock Mach number of .475. Using a device to diffuse the flow in oblique steps, then allowing for a normal shock, should increase the stagnation pressure ratio compared to the normal shock alone.

Choosing turning angles of 6 degrees for each of two successive redirections of the flow followed by a gradual turn prompting a normal shock yields an overall stagnation pressure ratio of .951. The pair of oblique shocks increases the stagnation pressure rise by a factor of 1.32. In the limit, an infinite number of small oblique shocks will tend towards an ideal recompression.

III. EXPERIMENTAL APPARATUS

Each of the scale model altitude test facilities constructed consisted of a common test cell, and an exhaust plenum with a variable diffuser assembly as illustrated in Figures 6 and 6a. Primary and secondary air were provided by a common source, an Allis-Chalmers twelve stage axial compressor. Exhaust plenum pressure was controlled by an air ejector driven by the common air supply from the axial compressor.

A. TEST CELL/ENGINE ASSEMBLY

The test cell, Figures 7, 7a, and 8, housed engines and provided a plenum for secondary air flow. The cell was fabricated from aluminum and of cylindrical design measuring 15 inches in length and 12 inches in diameter (I.D.). The upstream flange assembly (1) provides a mating surface for the primary air piping, structural support for a cantilevered engine housing (2) and an air seal assembly. Dry silicon rubber seals guarding against air intrusion are prescribed owing to the vacuum created for altitude simulation. A 3 inch diameter penetration (3) at the base is provided for secondary flow connections. The downstream flange (4) accommodates diffuser assembly attachment and incorporates a similar air sealing arrangement. Ports for direct sampling of cell pressure and remote connectors for engine pressures were provided.

The engine assembly, also of aluminum, consists of 3 inch (I.D.) entrance piping (5) which in addition to its flow straightening function served as the support for the engine mounting assembly (6). The mounting assembly served to transition the flow from the entrance piping to the 2 inch (I.D.) conformal entrance duct. The mounting assembly introduced one element of versatility via a variable spacer ring (7). The spacer ring allows for 2 inches of horizontal realignment of engines should variation in standoff distance to the diffuser be required. The engine mounting surface (8) was machined to provide a retaining collar and indented for set screw assembly of engines.

B. EXHAUST PLENUM

Interfacing beweeen the exhaust air ejector assembly and the diffuser assemblies was an exhaust plenum 3 foot by 3 foot in cross section by 4 feet long. The plenum houses a remotely operated traversing mechanism used to dirve the multiple angle centerbody assembly which is peculiar to the variable diffuser geometry. A maintenance access/inspection port is provided to assist in alignment. A six inch access connects to the air ejector piping to provide closure with the atmosphere and a means of back pressure control.

C. DIFFUSER ASSEMBLIES

Two scaled diffuser assemblies, Figures 2 and 9, were developed to establish the baseline against which alternative designs can be compared.

1. Straight Tube Diffuser

The model consists of a 15.25 inch long 2.71, inch (I.D.) cylindrical ejector-diffuser. Pressure taps were installed to record the pressure recovery process and are illustrated in Figure 10. Taps were placed at one (1) inch intervals along the length of the diffuser. Sealing was achieved by rubber seals in the end flanges. The length to diameter ratio was 5.62.

Two variations of this geometry, Figures 9a and 9b, were developed to investigate extending the operating envelope of the test cell to enhance efficiency and economy of operation. As depicted in Figures 9a, 9b, and 11 inserts were added to achieve a 5/6 and 2/3 reduction in diameter. Two end inserts (9) were included to allow investigation of sudden expansion versus gradual diffusion in the end section.

2. Variable Area Diffuser

Variable area diffusion was developed by traversing a multiple angle conical centerbody (Figures 2 and 12) within a 24 inch long cylindrical to conical diffuser. The overall length to inlet diameter ratio was 6.92.

The centerbody was 16.5 inches long having a leading cone of half angle 19.8 degrees and three trailing truncated cones of 10.8, 8.9, and 2.6 degrees, respectively, with a cylindrical afterbody. Centering was provided by a reinforced spider (10) which provided bearing support for 3/4 inch steel drive shaft. The shaft was coupled to an electrically operated drive mechanism, Figure 13, which was remotely activated, allowing travel of 6 inches with positive mechanical and electrical limits. Positioning circuitry generated a plus/minus 5 volt output which is remotely retrieved at the principal operating station.

The cylindrical to conical diffuser (8 degrees half angle) was equipped with static pressure taps longitudinally located along the wall, as shown in Figure 14.

The integrated centerbody and diffuser permitted wide variation in the flow area presented to the jet, including introduction of a variable second throat. Variation in flow area with axial position of the centerbody is shown in Figure 15.

D. ENGINES

Two sets of engines, Figure 16, were developed to model the F404 and the TF30 engines tested at NAPC. The engines were scaled to simulate the IRP and max A/B mode of testing. IRP represents Intermediate Rated Power which represents the highest power level without afterburner. This term is used synonymously with non-afterburning throughout the thesis. A/B refers to the maximum afterburning mode.

E. AIR SUPPLY

Compressed air from the Turbopropulsion Laboratory's Allis-Chalmers, twelve stage axial compressor, Figure 17, was utilized in all model testing. Maximum discharge pressure of this machine was approximately 3.0 atmospheres at 15.0 lbm/sec mass flow rate.

Primary and secondary air, as previously shown in Figure 6a, were supplied to the engine model and test cell, respectively, through three inch I.D. piping. A six inch I.D. suction line was attached to the exhaust plenum to simulate the effect of the exhaust air pumps used in the full scale test facility. Primary and secondary air flows and exhaust plenum pressure were controlled by pneumatically operated valves set remotely by differential pressure transmitters.

F. INSTRUMENTATION

A forty-eight (48) port pressure scanner, a Scanivalve, shown in Figure 18, (with an automatic stepping feature) allowed using a single pressure transducer for sensing many system pressures. Geofarth, {Ref. 9}, documents the logic and associated hardware for this system. The Scanivalve was employed as a computer peripheral to permit near simultaneous logging of system pressures. Approximate sampling of one (1) pressure tap/second was representative of the acquisition rate. The Scanivalve measured the differential pressure between the nominated source and a known reference. One Scanivalve port was open to the atmosphere and zeroed against an input reference signal. All other pressures were referenced against this port to give a precise 'gage' measurement which becomes a transducer output for conditioning and subsequent measurement by a digital voltmeter. Pressures were sampled across primary and secondary orifices for mass flow calculation, total pressure at engine inlet, engine throat, test cell plenum, fifteen (15) diffuser locations and the exhaust plenum. Atmospheric pressure was read from an absolute pressure Bourdon gage and manually recorded. Pressure taps were sized in accordance with Reference 10. Metering orifices, with β = .7 were utilized. In order to minimize the pressure drop in the primary flow system, the engine nozzles were calibrated using the flow rate indicated by the primary flow orifice. After calibration the orifice was removed.

Temperatures were measured using copper-constantan (Type T) thermocouples. An ice point reference was included in the design. Primary and secondary temperatures at 6 diameters downstream of the orifices were recorded. Temperature of the inlet air stream in the vicinity of the total pressure centerbody was also sampled. Thermocouple levels were input upon demand (computer controlled) to a Hewlett Packard 349A Scanner and relayed to a Hewlett Packard 3455 digital voltmeter for subsequent recording. Three portable digital voltmeters were employed in monitoring and modifying the controllable parameters.

G. DATA ACQUISITION

An integrated automatic data acquisition system was employed to record fluid properties. The Hewlett Packard HP-IB Interface Bus under the control of a Hewlett Packard

9830A calculator with HP9867B Mass Storage Unit and several peripheral options comprised the system. A computer program, Appendix H, adapted from the original work of Geopfarth {Ref. 9} controlled the data acquisition and storage process. Raw data were stored in mass memory with a hard copy backup. It was anticipated the data could be transferred to IBM 3033 for processing but communication problems necessitated that the data be hand input into the IBM files.

IV. EXPERIMENTAL PROCEDURES

Control over system operation was performed from a remote operating station, Figure 19. Three differential pressure transmitters (11), (12), (13), provided positive control over primary air, secondary air and exhaust pressure. These transmitters regulated a 0-15 psig signal to three remotely operated valves. Dedicated pressure transducers provided direct reading of nozzle total pressure, cell pressure and exhaust pressure and were remotely monitored on digital voltmeters (14), (15), (16). A preliminary check list for system checkout and an operating guide are provided in Appendix D. Output from the scanivalve controller (17) could be selectively monitored as desired. Total pressure regulation, once the primary valve was open fully, consisted of remotely manipulating the compressor air bypass.

Each engine and diffuser combination was tested over the entire range of deliverable pressures as mapped against exhaust pressures from atmospheric to full exhauster capacity. A matrix of total pressure versus exhaust pressure was generated prior to each run to optimize the time to record data and to identify the set points for each run. Typically, total nozzle pressure, PT8, was set at the prescribed value; exhaust plenum pressure, P14, was established; a manual code was input into the computer to order data acquisition. Back pressure, P14, was then stepped a predetermined amount and the process repeated until exhauster limits were reached. Total pressure was then advanced and the cycle repeated. Setting the secondary air flow to a given fraction of the primary air flow required an iterative process of controlling both flows because of their common supply. This required an inordinate amount of time and was not done. Instead, the secondary flow was incremented when desired. If additional data was required a dedicated run for secondary flow was contemplated.

Repeatability of the data was challenged both on a random basis through the course of a test sequence and on separate dates to establish the limits of experimental uncertainty. Leakage checks were conducted prior to and during the course of each test.

V. DISCUSSION OF RESULTS

As established in response to the work definition provided by the sponsor, the goal of the study was to design, fabricate and test a cold flow model of the NAPC Test Facility for further utilization in testing alternative diffuser geometries. Detailed objectives were:

1. Model the NAPC test facility using Mach number similitude and scaled geometry.

2. Design/construct the model to allow for the greatest variation in test parameters.

3. Model a representative set of engines spanning the operating extremes of the actual test cells being studied.

4. Establish a data base against which alternative geometries may be compared and provide a basis of comparison.

5. Quantify and interpret the controlling parameters which influence diffuser efficiency as a prelude to alternate geometry proposals.

6. Provide a conceptual model(s) from which the second phase of the study may proceed.

7. Specifically evaluate cross sectional variations in the straight tube diffuser to improve range and/or efficiency when testing the F404 engine.

8. Explore overall systems efficiency considerations in the context of new design initiatives.

A. MODEL DESIGN/CONSTRUCTION

The model was designed as detailed in Appendix A. The success of the design/construction process is measured only in subjective terms. The parent facility as detailed in Appendix C did not possess the scope of instrumentation to provide a characteristic mapping which would allow a direct comparison. The operating variables, exhaust pressure/cell pressure ratio and nozzle total pressure/cell pressure ratio as shown in Figures 20 and 21, did, however, follow theory and closely match the general shape and bounds of model data provided by NAPC. The full scale facility performance will be different from that of the model due to thermal variations, leakage, working gas, surface roughness and machinery support structure. Having satisfied Mach number and geometric similitude it was reasonable to assume any substantive improvements in performance observed from model studies should translate well to the parent facility.

The maximum altitude achievable by the design was approximately 45,000 feet. The total pressure limitation of the Allis Chalmers was the dominant factor in this regard. Figures 21a and 22 show started operation of the ejector-diffuser only with the TF30 and F404 in the afterburning mode. This altitude limitation also derives from the need to scale according to the largest engine. This limitation will obviously preclude a full determination of the useable feasible range of new geometries. This limitation may also mask some benefits of new geometries thus resulting in a more conservative estimate of performance than what might occur in practice.

B. ENGINE DESIGN

The test engines chosen were the TF30 and F404 whose characteristics were noted in Appendix C. The afterburning mode of the TF30 was utilized as the set point for the match with the compressor. A top end mass flow, with the TF30 in A/B, of 1.863 lbm/sec was expected and a maximum of 1.75 lbm/sec was observed. Precise measurements of the final nozzle diameters indicates an error of less than ½ to 1 percent in the area ratios between planning estimates and the machined product. The engine design should thus provide over 95% coverage of the operating range of the parent facility.

C. DATA BASE

The 2.71 inch scaled straight ejector-diffuser was established as the baseline diffuser against which alternative geometries may be contrasted. A non dimensional graphical representation was chosen as a preliminary method to interpret the test results. A gross survey of ejector-diffuser performance, under the influence of a parametric change relative to the baseline, can be readily observed. A detailed investigation may then be ordered to quantify any observable improvements in ejector-diffuser performance. Ideally, a real time performance map versus the baseline should be incorporated into the data acquisition package to allow an interactive optimization during new geometry testing. Figures 23 and 24 are catagorized as the baseline for each engine tested. Improved performance will be evidenced by a relative displacement of any new curve vertically up and/or horizontally to the left. This equates to operating with higher pressure recovery for a given PT8/PS9 which are the input specifications of any test program. The influence of parametric variations made during this study are presented in this manner for illustration. While conveying no additional information, an alternative representation of the operating characteristic by PS9/PT8 versus PT8/P14 is exemplified by Figure 25.

D. PARAMETRIC VARIATIONS

1. Ae/A*

This ratio is a naturally varying parameter when afterburning engines are tested due to their variable exhaust geometry. In the F404 the ratio varies from 1.21 at IRP to 1.58 at maximum A/B. In the TF30, this variation ranges from 1.03 to 1.20. It was anticipated that, as Ae/A* increased for a given diffuser geometry and nozzle total to cell pressure ratio, (PT8/PS9), pressure recovery would increase. The higher Mach number at the diffuser entrance would govern the increase. Table 5.1 illustrates this fact for two runs with the F404; Figure 26 graphically conveys the same information.

Table 5.1

Engine	F404 Non A/B	F404 A/B
Run No.	24	29
PT8/PS9	11.84	11.85
P14/PS9	3.045	4.119

The operating envelope for any variable geometry engine necessitates that testing must span a broad range of power levels. As power is adjusted from IRP to maximum afterburner the exhaust to throat area ratio varies widely. Figure 23, for the F404, and Figure 24, for the TF30, illustrate that for a fixed nozzle total to cell pressure ratio, the exhauster requirements decrease in response to better pressure recovery. The porportion, in which the pressure recovery increase occurs, appears characteristic of the engine-ejector-diffuser match achieved by the design. The F404 full scale ejector diffuser combination shows less variation than the more closely matched TF30 full scale combination. Similarly, to maintain altitude while testing from IRP to max A/B the exhauster must also vary it's operating set point to accommodate the varying demand. When a single test cell configuration must accommodate testing more than one class of engine, significant complications are introduced into achieving a near optimum design. Any retrofit of the parent facility must detail how the new geometry accommodates this parameter.

2. Secondary Flow

Secondary flow is injected into the test cell as a cooling medium for the engine. The added mass saps performance from the diffuser as a pressure recovery device. The diffuser entrains the additional low velocity, low energy flow with that of the high energy jet under complex flow conditions requiring greater exhauster work to sustain cell pressures. The postulate in the case of secondary flow is that, for a given nozzle total pressure and a given exhaust pressure, injection of secondary air increases the cell pressure. Secondary flow will result in a lowering of PT8/PS9 or, conversely, less efficient pressure recovery. The experimental results are strongly supportive of this statement. As shown in Figure 27, the operating curve shifts lower as losses increase at the price of mass ejection.

A detailed study of secondary effects, using the F404 in A/B with the 2/3 and full scale diffuser, was conducted as follows. Nozzle total to cell pressure ratio (PT8/PS9) was fixed while secondary flow was gradually increased. Table 5.2 for the full scale shows only minor variation in pressure recovery for typical amounts of secondary flow. Large amounts of secondary flow have a more adverse impact but this is purely of academic interest as 8 percent secondary represents an upper bound on practical cooling requirements. In marked constrast, the performance of the F404 and the two-thirds diffuser suffers a significant penalty in pressure recovery. Table 5.3 and Figure 28 detail this observation.

Table 5.2

Engine	F404 A/B	F404 A/B
% $\dot{m}_s$	0	8
Run	47	46
PT8/PS9	7.58	7.56
P14/PS9	1.951	1.939

Table 5.3

Engine	F404 A/B	F404 A/B
% $\dot{m}_s$	0	4
Run	30	2
PT8/PS9	12.71	12.75
P14/PS9	4.265	3.257

Expenditure of exhauster power will be required to achieve the same pressure in the presence of the added mass. A nonlinear variation in the loss of PT8/PS9 is anticipated due to the complex nature of mixing subsonic and supersonic streams. The two-thirds diffuser, having an L/D which more nearly matches the optimum suggested in the literature, more efficiently recovers pressure. This suggests that secondary flow effects become more prominent as the diffuser design becomes more efficient. The penalties in power consumption due to secondary flow effects are not linear, and this observation results in wide variations in systems efficiency as discussed in Section F.

3. AD/A*

In applying the Law of Continuity to the nozzle-cell-diffuser, a minimum diffuser area may be determined. The minimum area in a diffuser is specified by $Ad = A^* \, p_{oy}/p_{ox}$ where p_{oy}/p_{ox} is the stagnation pressure ratio for a shock diffuser entrance Mach number. Allowing for an expansion to Mach 3.0 in the diffuser, A_d (min) ranges from A* to 3.04A*. Matching the engine to diffuser permits upward variation in A_d from 6.67 (in^2) for the TF30 and 1.93 (in^2) for the F404. The full scale A_d is 5.768 (in^2) which is below the minimum for the TF30 but lower Mach numbers are experienced with this engine. Optimum performance for constant area diffusers, from original model studies reported by NAPC, ranges from Ad/A* = 3.5 to 4.0. Neither of the engine extremes approaches this ratio with the TF30 being more closely matched while the F404 is undersized. As Ad/A* was varied from full scale to two-thirds, performance improved dramatically as can be seen in Figure 29. An Ad/A* of 6 - 7.5 appears to bound the gains in performance for the F404 A/B. An A_d of 2.5 (in^2) for the F404 should result in near optimal performance. No conclusions may be drawn for the non A/B case since improved performance occurs at the limit of Ad/A* tested. Static wall pressure profiles as shown in Figure 30 depict the observable changes as Ad/A* is varied from full scale to two-thirds for a fixed driving potential.

E. F404 IMPROVEMENT

The foregoing discussions have alluded to improvements in the F404 performance with variation in diffuser cross section, A_d. An Ad/A* between 6 and 7.5 appears optimal in that the two-thirds and five-sixths reductions improve pressure recovery at all power settings. These diffusers can also achieve lower altitudes than the full scale, if that is the objective. Full scale attains 25,800 feet while two-thirds and five-sixths achieve 40,250 and 43,400 feet, respectively. The two-thirds, as shown in Figure 31, is capable of fully started operation despite the constraints on driving potential observed in this test facility. The gain in efficiency should be significant as previously noted in Table 5.1. The exhauster can operate at higher pressures for the same cell pressure, an obvious advantage. A ceiling on the potential gains cannot be ascertained from the available data. As an example, the F404 in the non A/B mode for a PT8/PS9 of 6.6 would require a P14/PS9 of 1.5 for the full scale, 1.75 with the five-sixths and 2.05 for two-thirds. This permits a near doubling of exhaust pressure while maintaining cell pressure at test conditions. The F404 in the A/B mode for a near constant PT8/PS9 shows the same results. Figure 30 also shows recovery occurs earlier with fewer losses in the two-thirds diffuser. The five-sixths and full scale attain different levels of diffusion but clearly greater work must be performed with the full scale diffuser.

In the course of the detailed investigation, both the two-thirds and five-sixths configurations were terminated in an abrupt expansion to maintain a near equivalence in L/D. Two additional tests were conducted with tapered afterbodies, Figures 9a and 9b, to capitalize on subsonic diffusion. Both modes of F404 operation were tested and as expected diffusion is improved, as shown in Figures 32 and 33. The improvement at lower PT8/PS9 is barely distinguishable but shows distinct gains at higher levels. Since the tests were conducted on different dates, precise quantification was not attempted. The use of some geometry to enhance subsonic diffusion, such as the taper afterbody, merits consideration in any retrofit proposal.

F. SYSTEMS EFFICIENCY

The complexity of the diffusion process makes the task of measuring the cost benefit of a design change a subtly challenging endeavor. The gains derived from a geometric change must be integrated over the test cycle for each engine. A typical jet engine test represents a non steady state problem where the time at a given power level becomes a significant factor when evaluating power consumption costs. Assuming testing only at discrete power settings, the cost of testing at each setting can be placed on a cost/unit time basis and total cost summed by integrating over the time interval for the test.

The efficiency of the system includes not only the ejector-diffuser but must reflect the efficiency aspects of the exhaust heat exchanger, the exhaust control valves and exhausters themselves. It is postulated that only one match of test conditions and these system components exists. A shift off design as prompted by new flow conditions such as higher power or secondary flow will dramatically influence overall power consumption since it is in direct proportion to the individual efficiencies of each component. An illustration, utilizing a much simplified model for the generalized case of testing with secondary flow and, making an allowance for auxiliary exhaustion of the secondary, provides a simple cost basing example. The test set up is as shown in Figure 36. An energy balance across a simple fan is utilized in this case for illustration only. The total work done by the fan per pound of working substance is H_t where

$$H_t = \frac{P_2}{\rho} - \frac{P_1}{\rho} + \frac{V_2^{\,2}}{2g_c} - \frac{V_1^{\,2}}{2g_c} + Z_2 - Z_1$$

which reduces for Delta Z = 0 to

$$H_t = \frac{P_{02} - P_{01}}{\rho}$$

Fan total efficiency is often expressed as the ratio of the work done on the gas divided by the input shaft work or:

$$\eta_f = \frac{C \times \dot{m} \times H_t}{kw} \quad ; (C = \text{constant for unit consistency})$$

Fan efficiency as a function of capacity follows a general variation as shown in Figure 35.

As operation shifts off design in either direction efficiency decreases substantially. Testing engines not properly matched must pay severe penalties in the cost of power consumption. Added mass alone provides a proportion increase as well. Capacity is observed to vary with the speed of a fan, static pressure with speed squared and required power with speed cubed.

The cost per lbm is equal to

$$\frac{Kw}{\dot{m}} = \frac{C \times (P_{02} - P_{01})}{\rho \, \eta_f}$$

An auxillary ejector employed solely to remove secondary flow must operate between cell pressure and something close to atmospheric. The cost per lbm for an auxiliary ejector would follow a similar discussion and may be described as

$$\frac{\text{Power (kw)}}{\dot{m}_s} = \frac{P_{atm} - P_{cell}}{\rho \, \eta_{aej}}$$

The combined work for the system to be more efficient must be less than the work of the original system without the auxiliary. Optimizing on a cost basis thus becomes quite complex. As observed, with an oversized diffuser, the system pays little penalty in terms of pressure (PS9) for exhausting secondary flow. The added mass does, however, exact a direct cost from capacity considerations. A properly matched diffuser will cause a shift of the exhauster to an even less efficient setting and higher attendant costs. Similarly, the IRP testing setting pays a lower price in the presence of secondary flow than maximum A/B. The time factor then becomes crucial to assess total cost. An efficient auxiliary ejector could, coupled with a matched ejector-diffuser, markedly improve overall efficiency by eliminating extreme fluctuations in diffuser efficiency and in turn controlling the variations in the time the exhauster must spend off design.

In the absence of an auxiliary ejector, testing philosophy alone could be altered to improve efficiency. If the time intervals at a test condition (i.e., IRP) are of sufficient duration, consideration could be given to reconfiguring the cell for each major power level with a more closely matched diffuser. This could be accomplished by designing a series of pre-sized liners which could be inserted in the full scale diffuser.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. The cold flow ejector diffuser model developed within the context of the study provides a versatile, although specifically tailored test bed, upon which geometric variations of the parent test facility may be experimentally evaluated.

2. A complex interdependency of geometric parameters which influence the pressure recovery mechanism exists. New designs should, therefore, attempt to incorporate as many degrees of freedom as practicable to allow optimization of the pressure recovery process.

3. When designing retrofits against a baseline model a real time graphical presentation of the performance curves, for old versus new, will enhance optimization by allowing the results to direct the conduct of the investigation.

4. Substantial improvements in pressure recovery when testing the F404 engine can be achieved through an alteration of the length to diameter ratio of the constant area ejector diffuser currently in use.

B. RECOMMENDATIONS

1. Upon successful resolution of the variable area diffuser vibration phenomenon, modify the test facility to accommodate the phenomenon and map the performance of that diffuser.

2. Using the results of the combined constant area and variable area studies, design, construct and test alternative geometries.

3. Modify the test facility by adapting the test cell for a separately driven ejector and evaluate in greater detail the added mass effect.

4. Modify the test facility to receive its secondary air input from an external source to preclude cross talk between primary and secondary flows.

5. Explore the possibility of including Schlerin photography to aid the investigative process and better document the geometric influences of new diffuser concepts. This would permit a realistic interpretation of the boundary layer interactions.

6. Data acquisition must be upgraded to accommodate data transfer to the in-house IBM 3033. A dedicated phone line with modem would be the first initiative warranted. A real time feedback to help focus the investigation is strongly recommended.

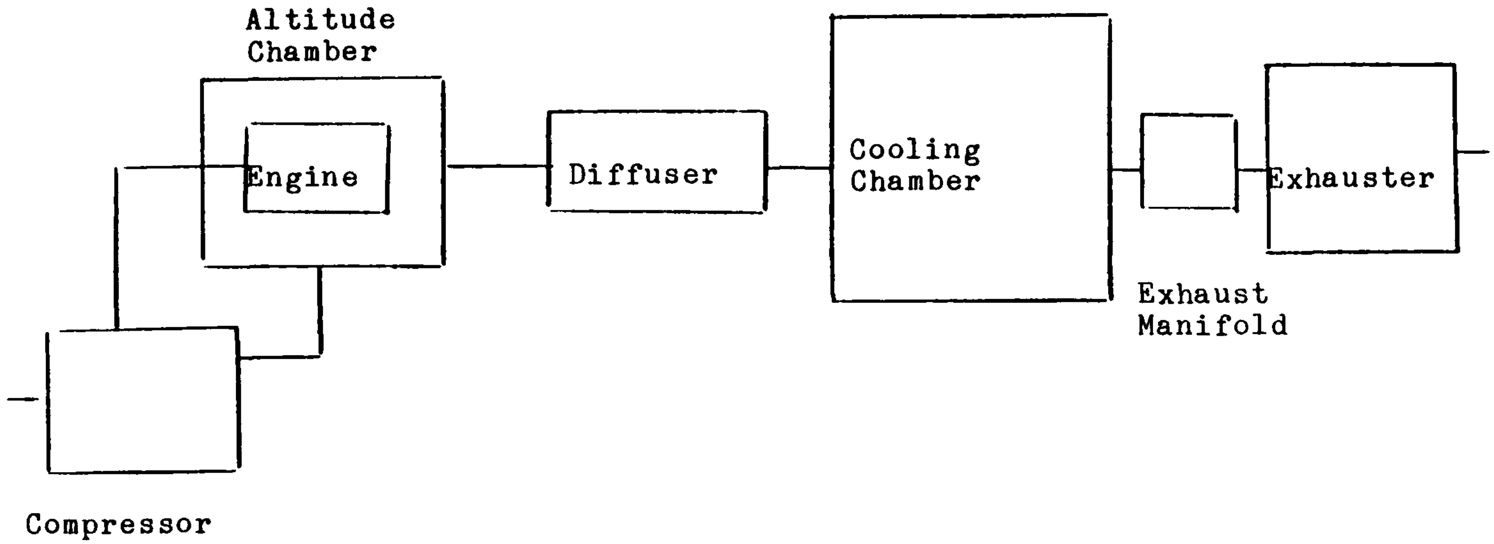


Figure 1. Typical Turbojet Test Cell

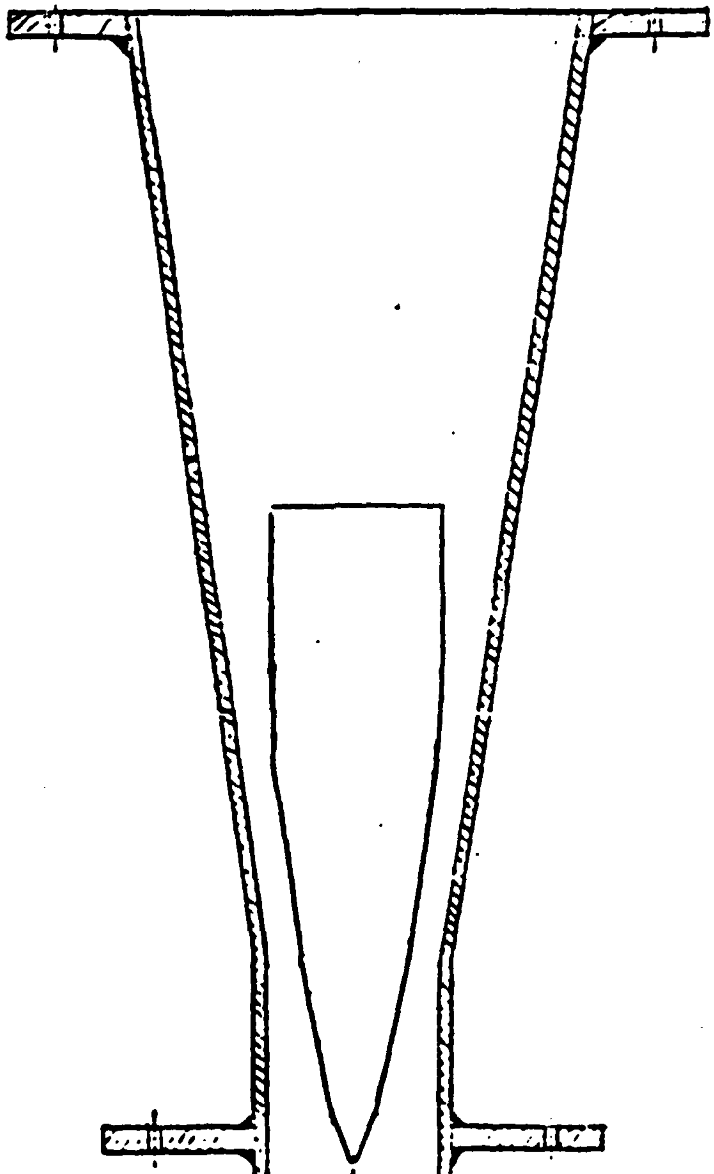


Figure 2. Variable Geometry Diffuser With Centerbody

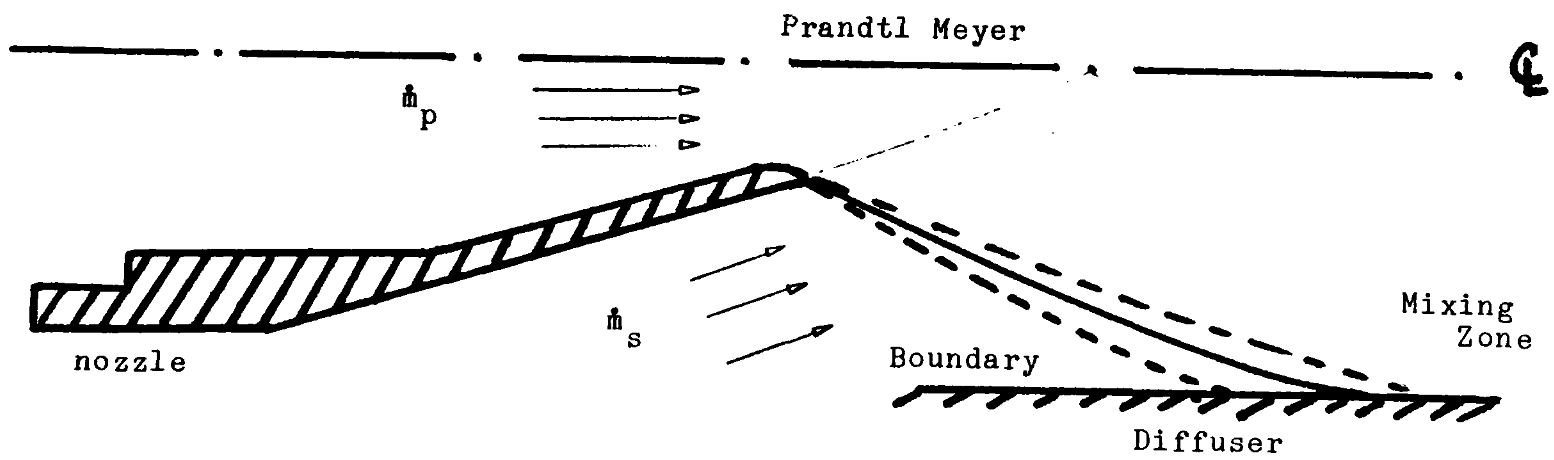


Figure 3. Generalized Flow Characterization of Expanding Jet with Secondary Flow

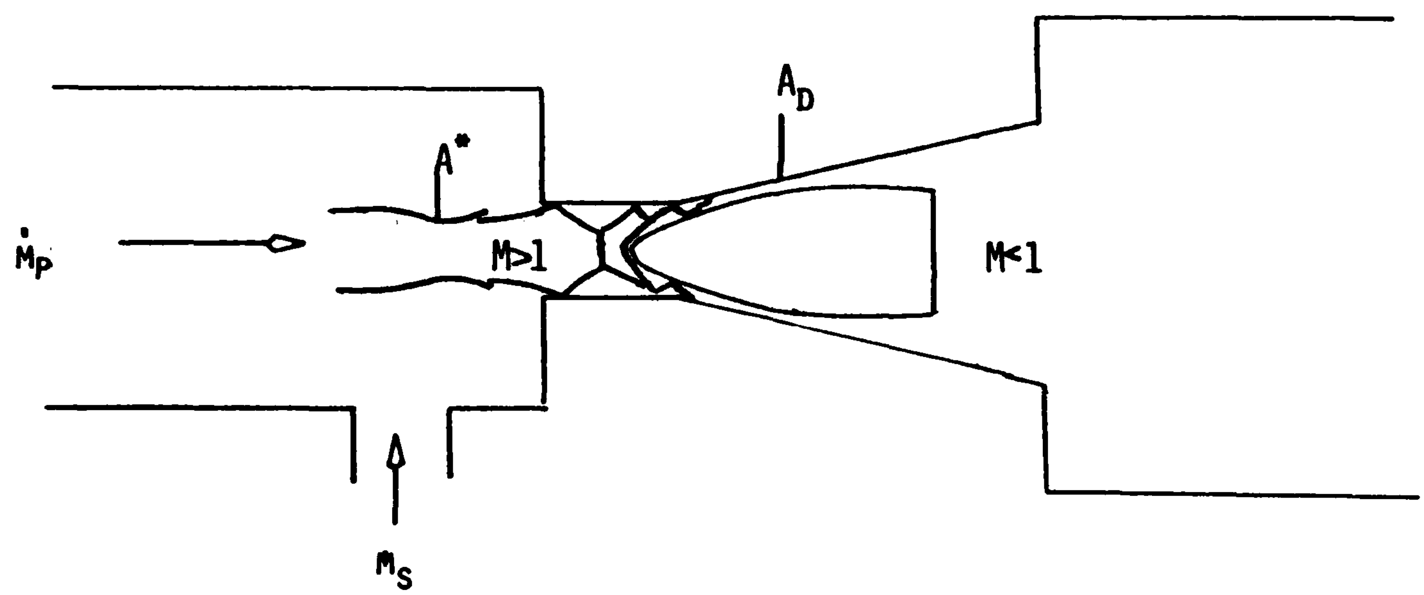
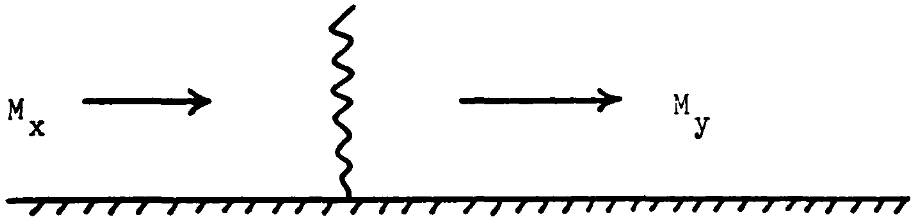
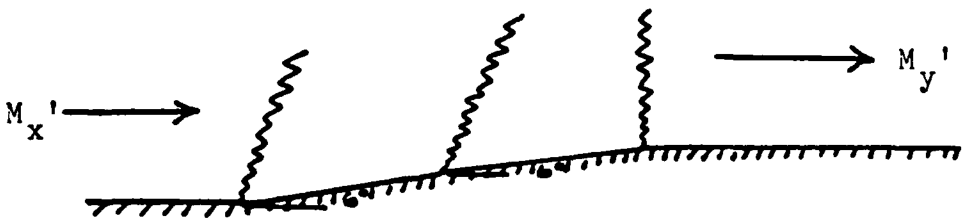


Figure 4. Simplified Test Cell



Normal Shock



Double Wedge With Oblique Shock

Figure 5. Shock Strength Model

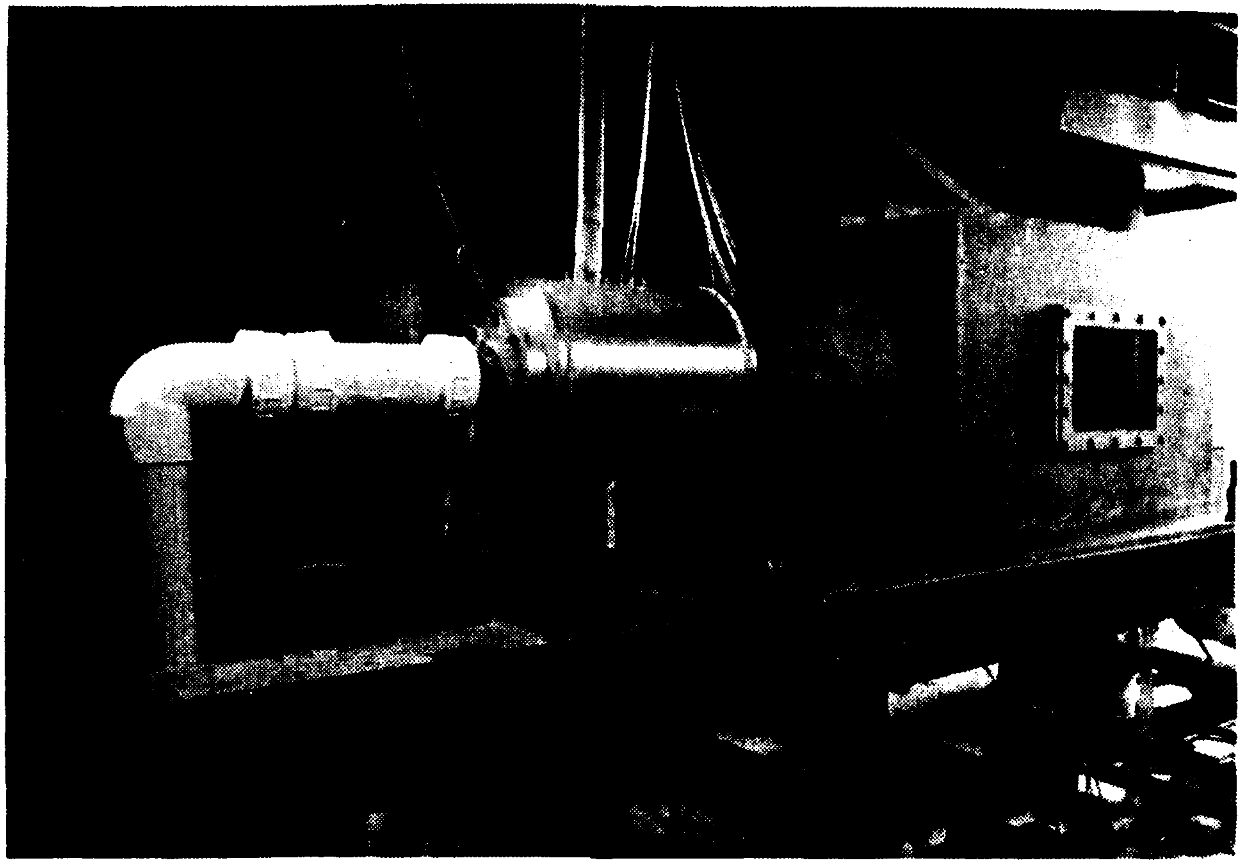


Figure 6. Scale Model Test Facility With Straight Tube Diffuser

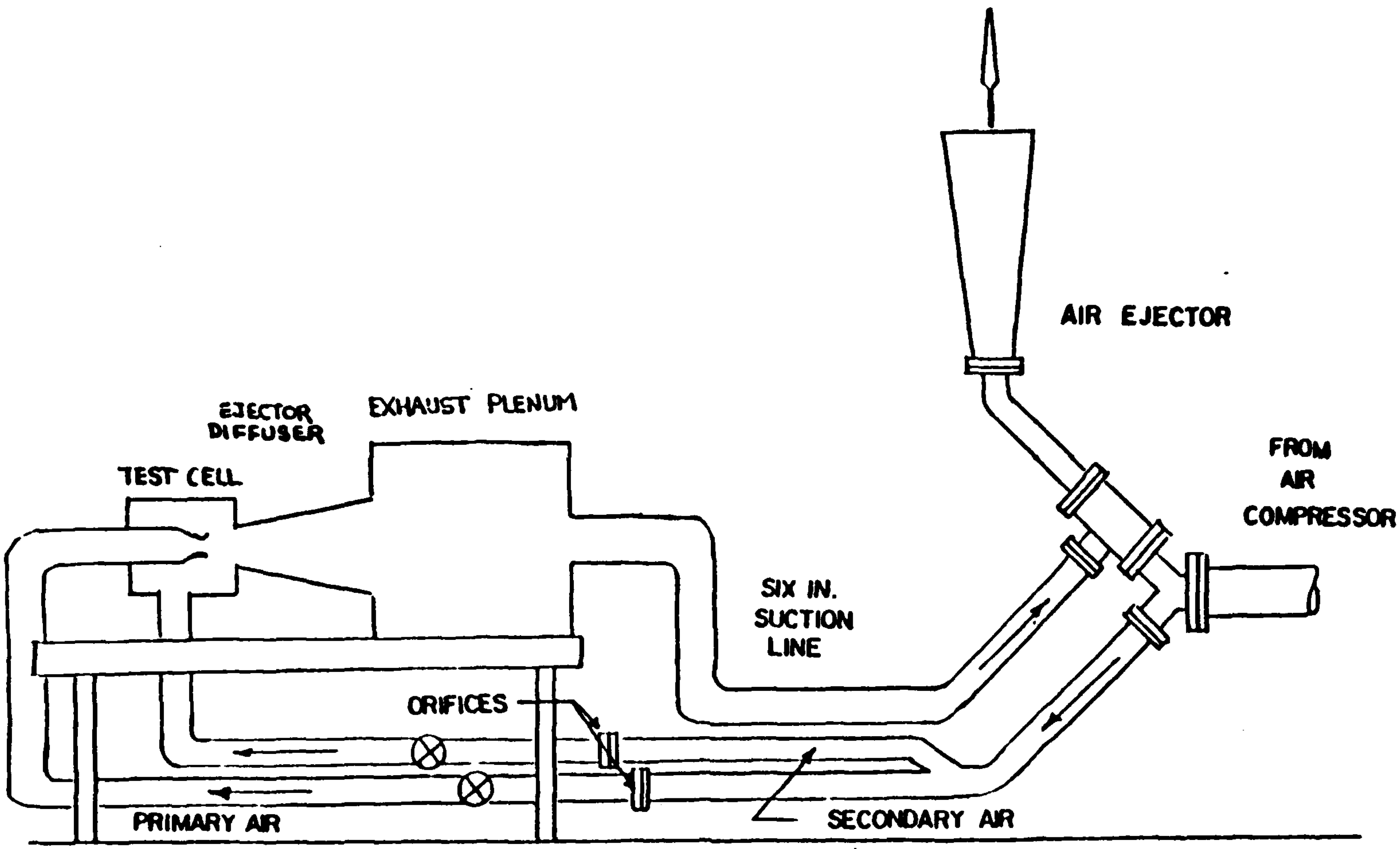


Figure 6a. Model Test Facility Schematic

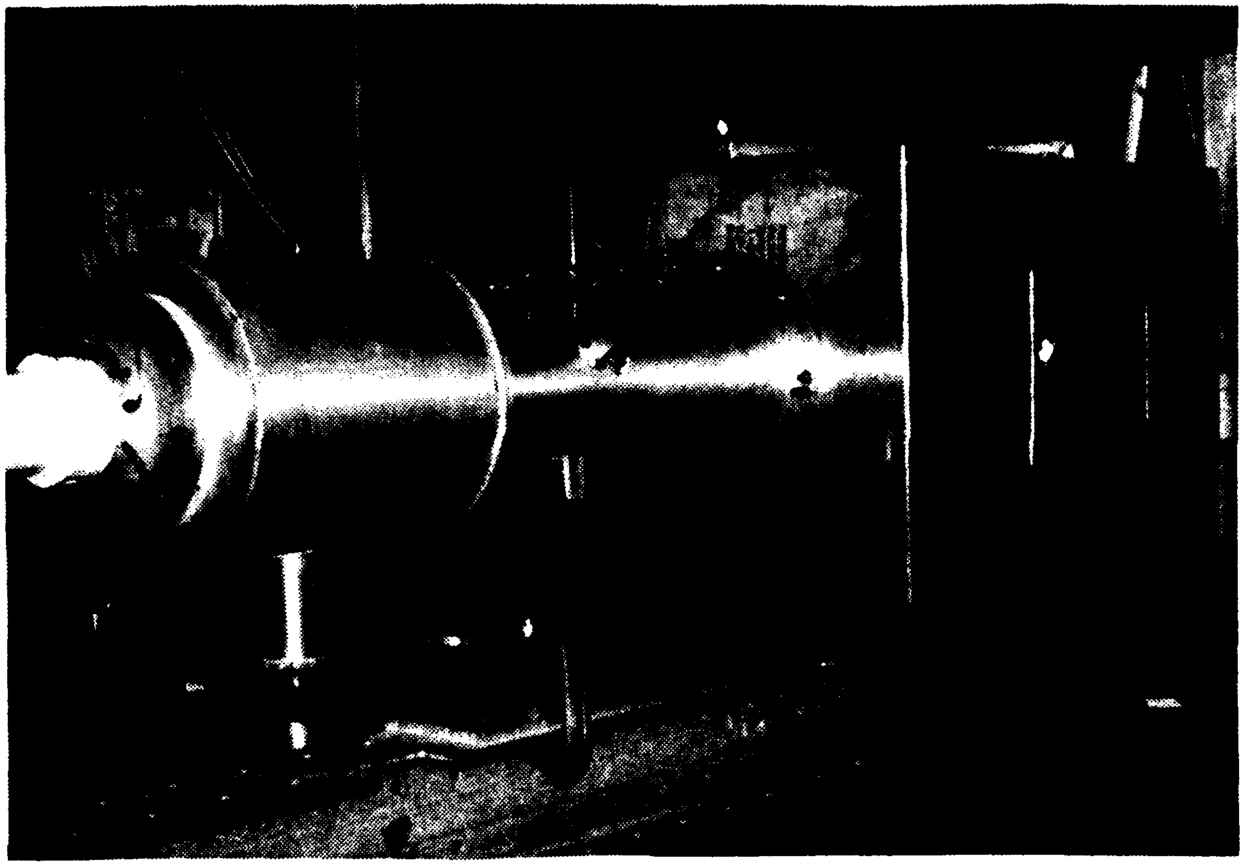


Figure 7. Scale Model Test Cell With Variable Area Diffuser

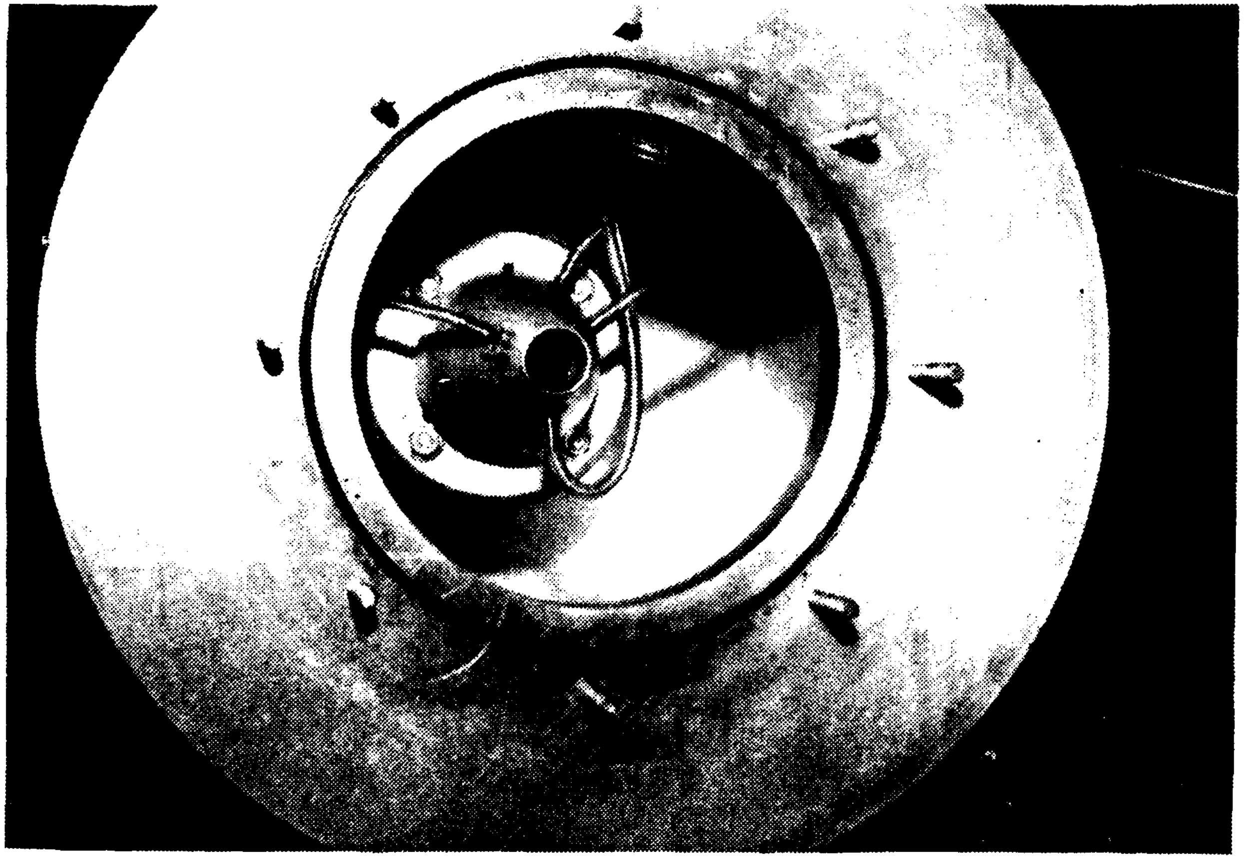


Figure 7a. F404 Engine Assembly

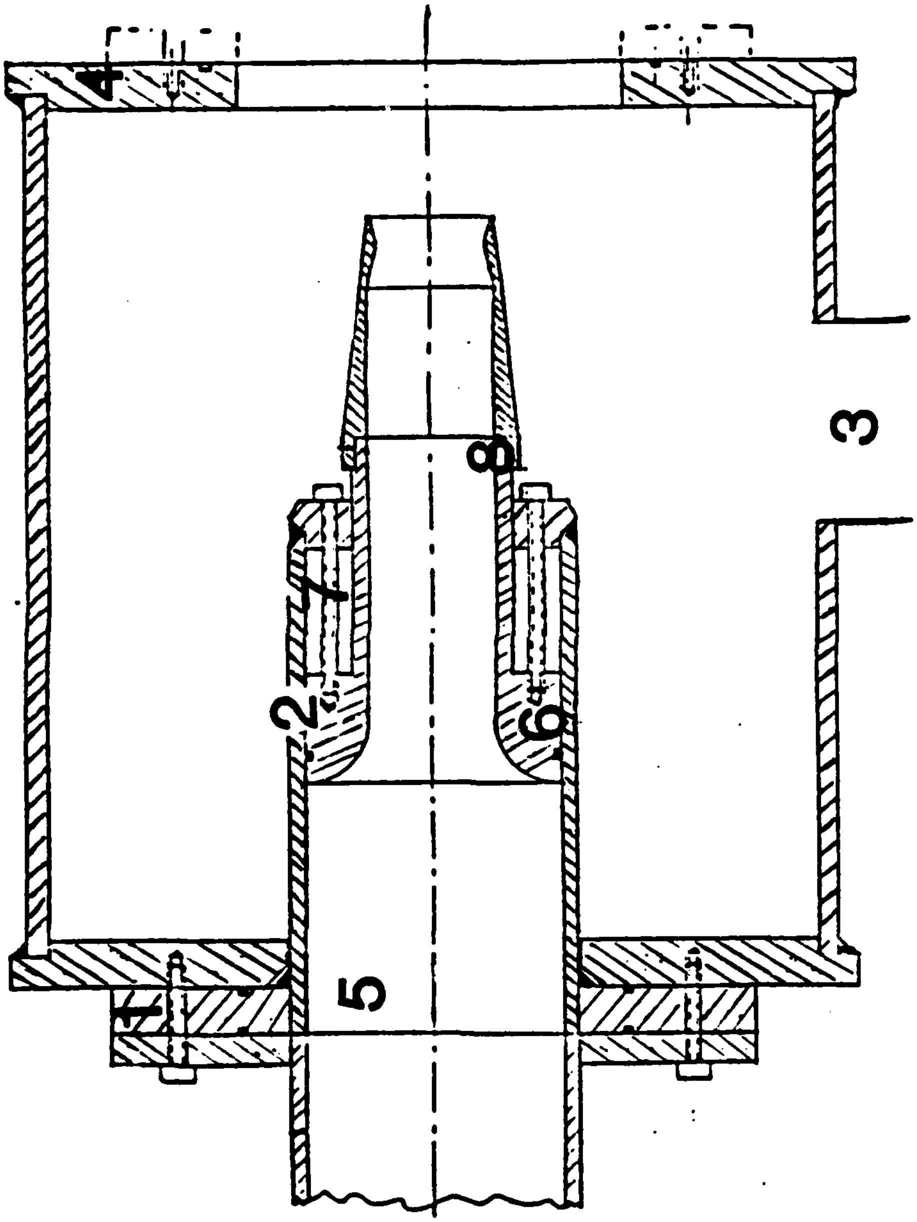


Figure 8. Test Cell Cross Section

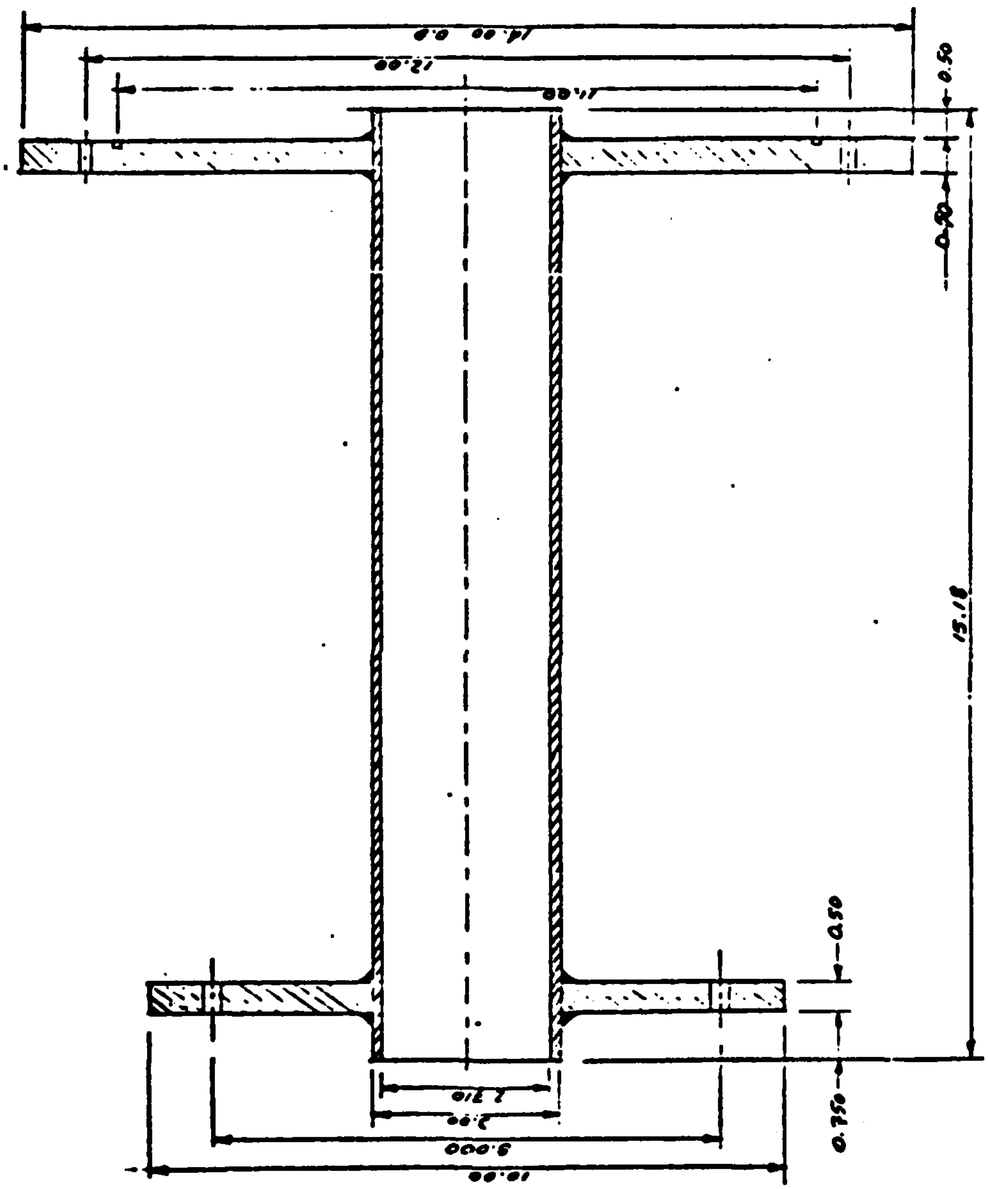


Figure 9 . Straight Tube Diffuser (Full Scale)

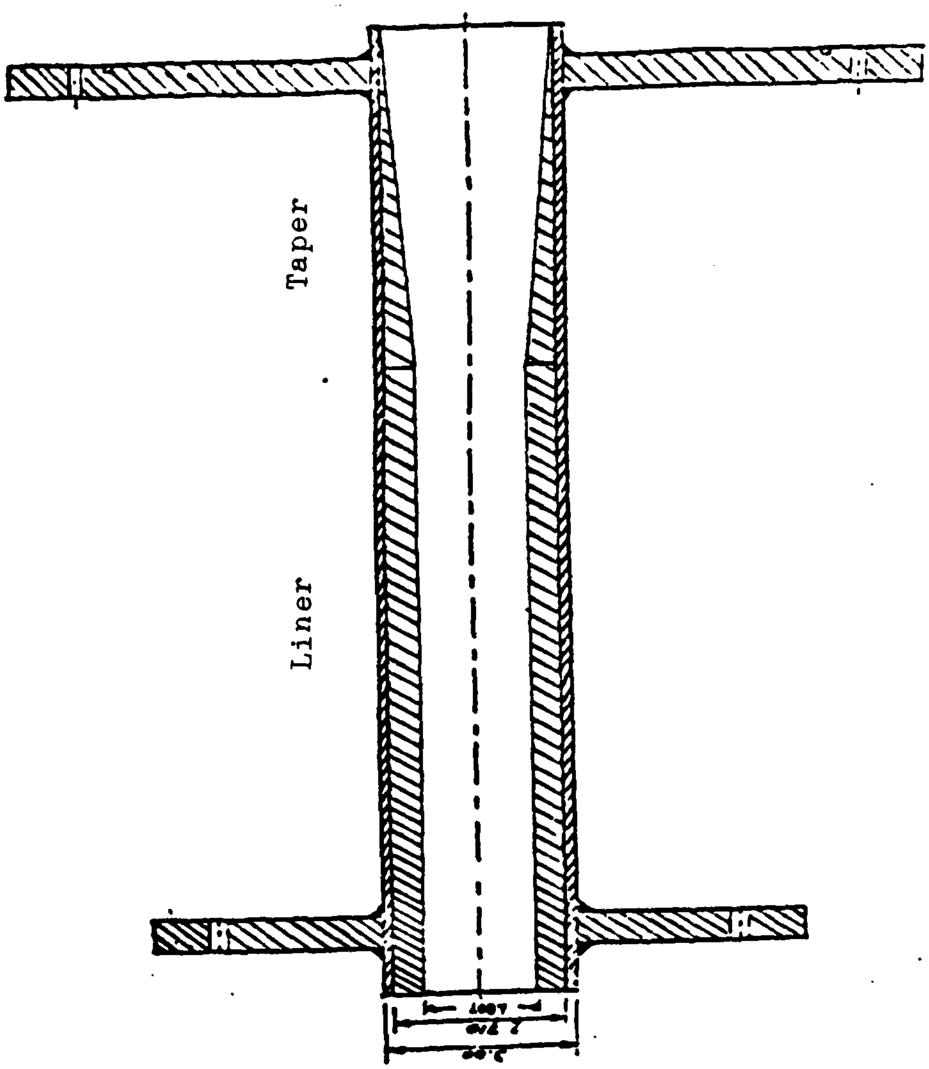


Figure 9a. Straight Tube Diffuser (Two-Thirds)

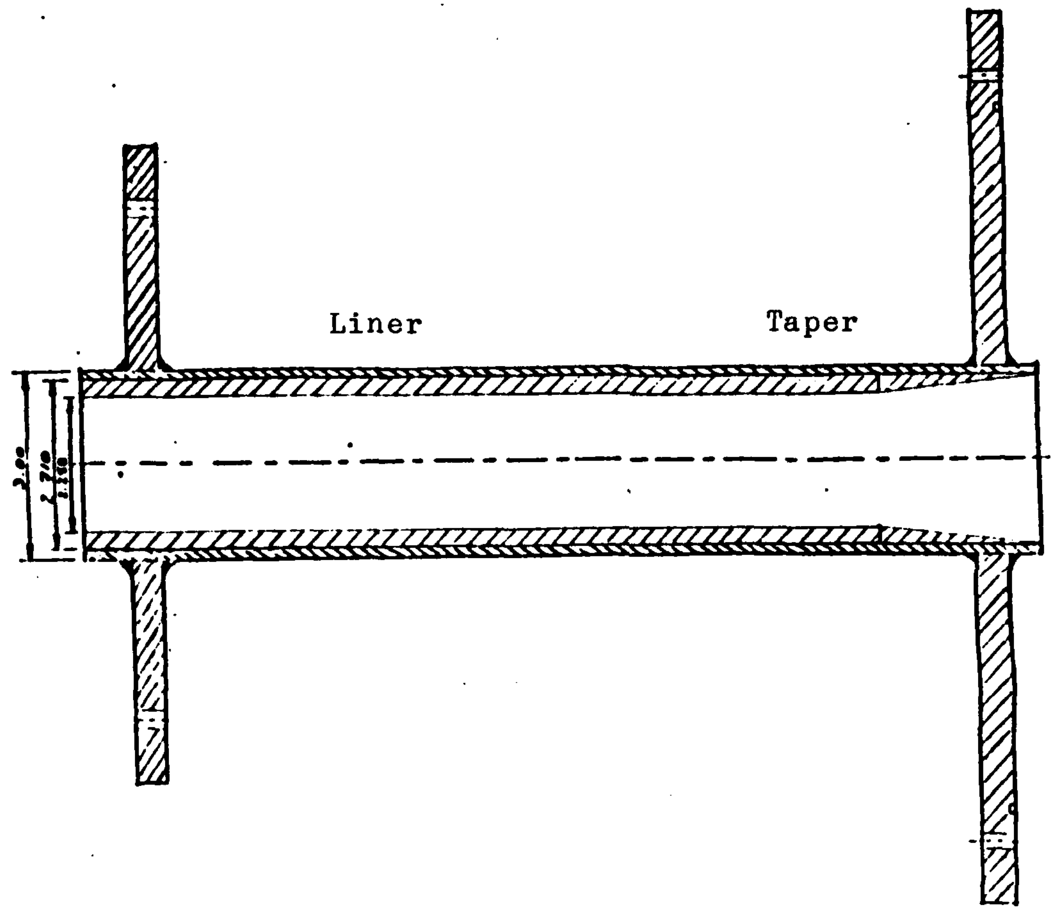


Figure 9b. Straight Tube Diffuser (Five Sixths)

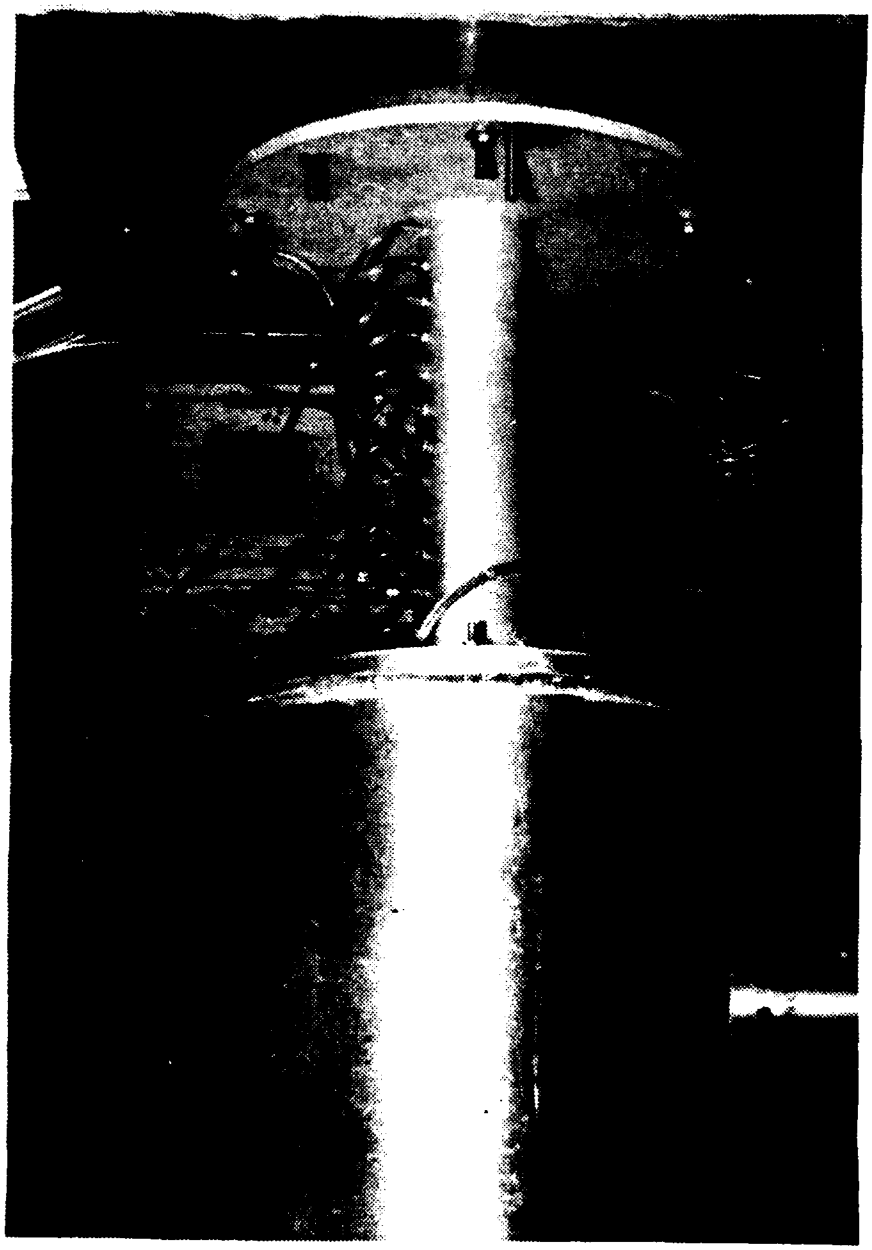


Figure 10. Pressure Tap Arrangement

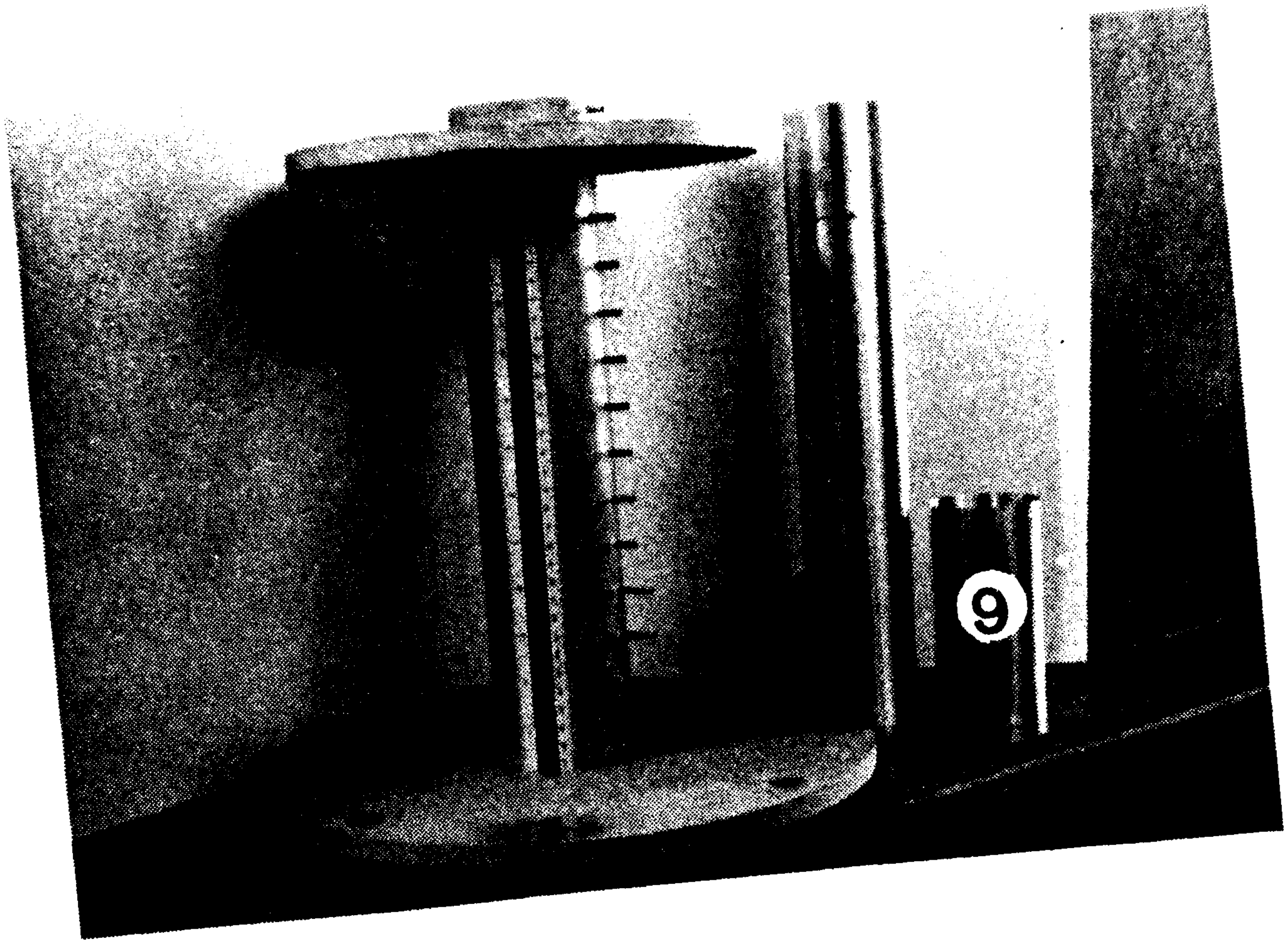


Figure 11. Constant Area Diffuser With Inserts

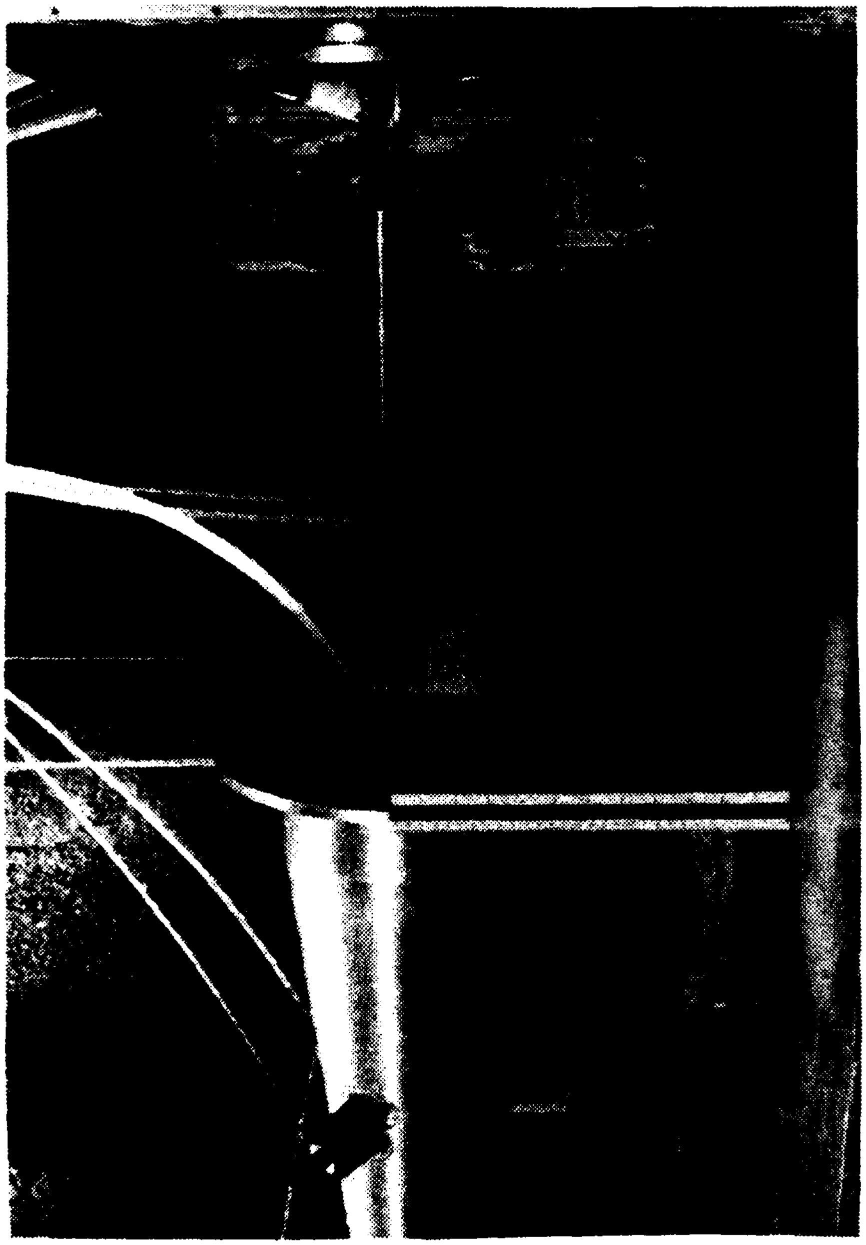


Figure 12. Variable Area Diffuser Exploded View

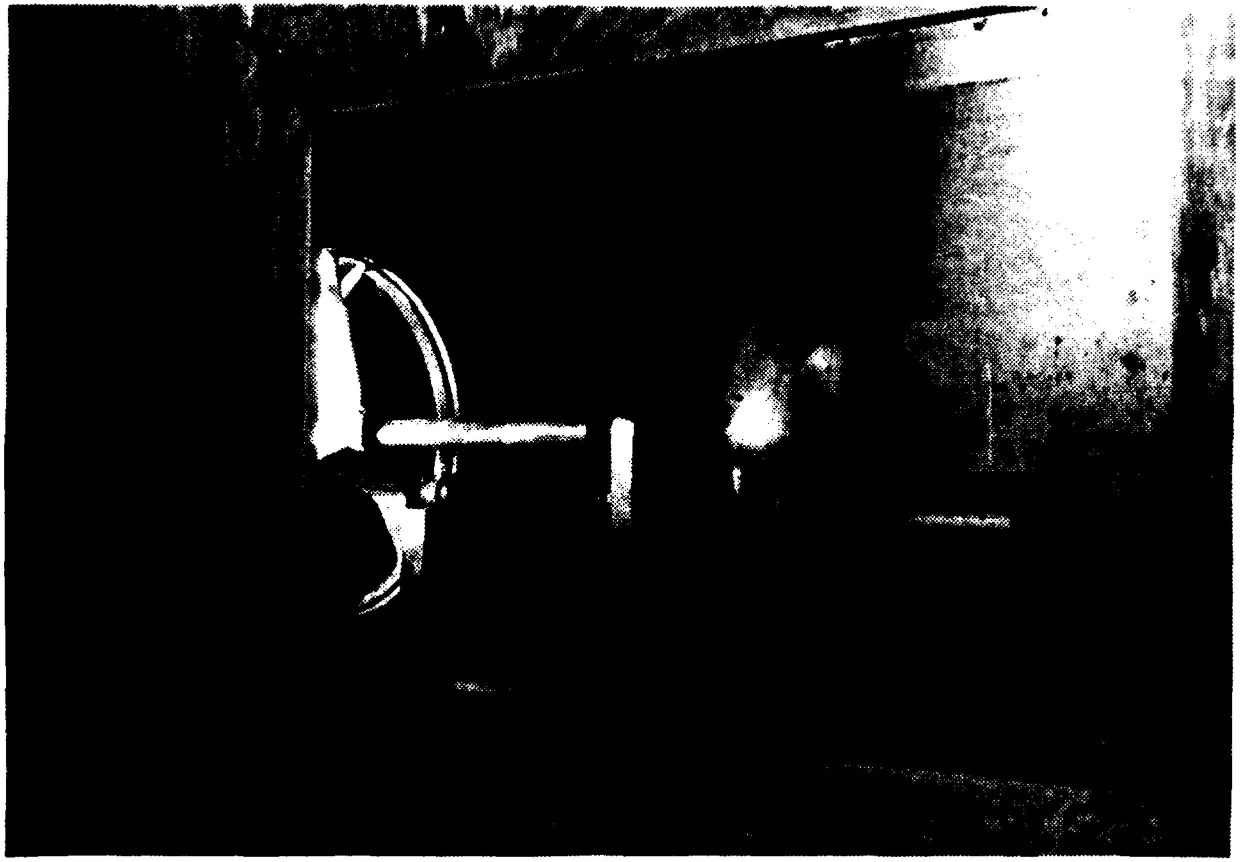


Figure 13. Remotely Operated Drive Mechanism

Figure 14. Pressure Taps (Variable Area Diffuser)

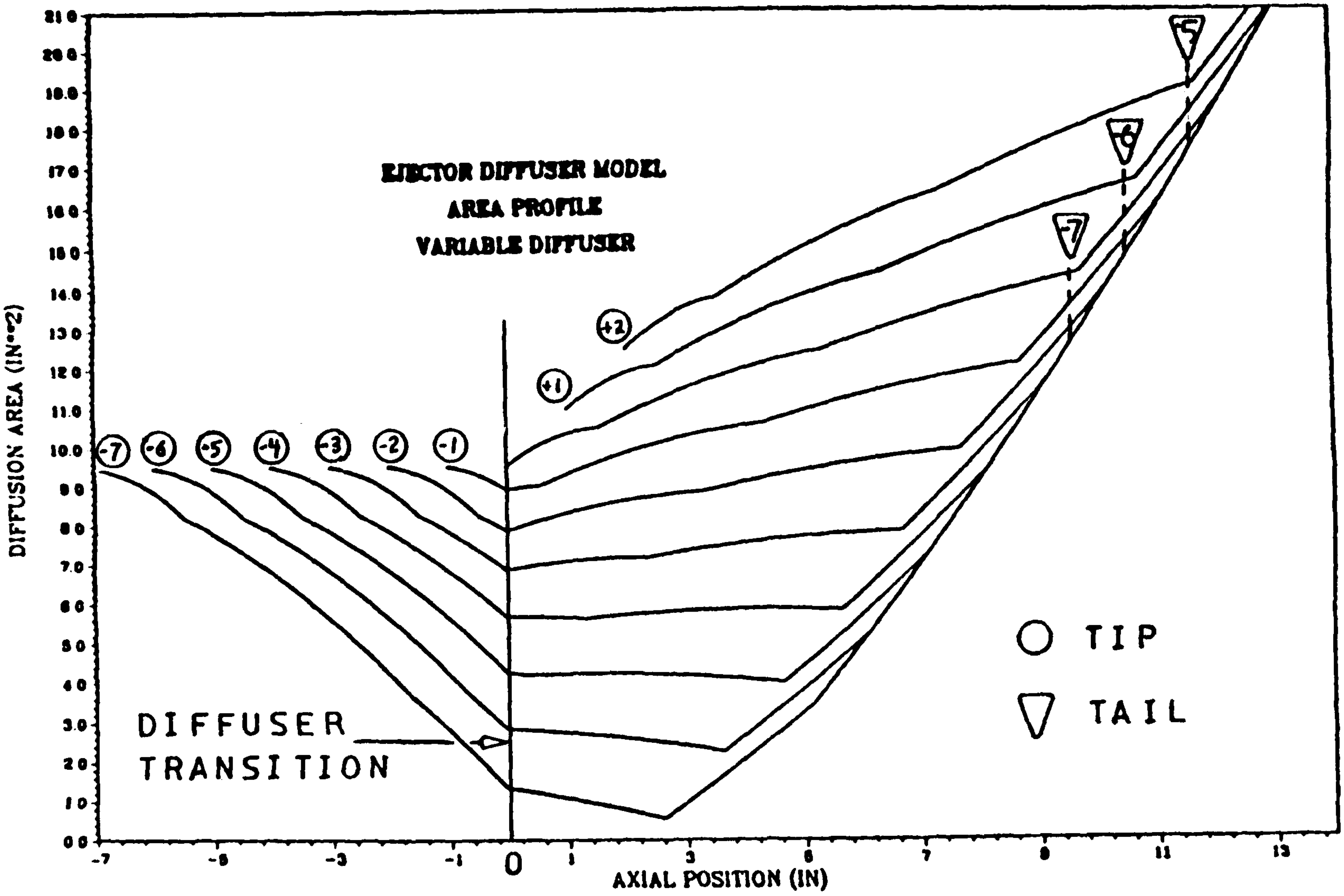


Figure 15. Variable Area Profile

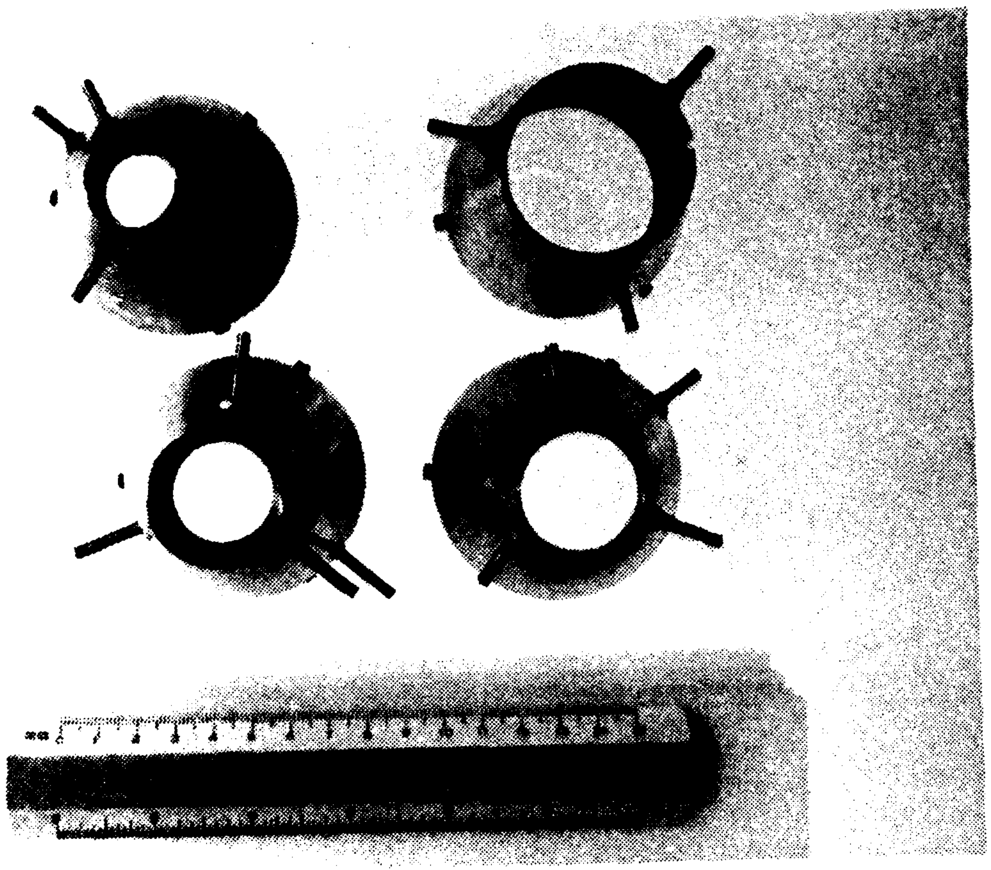


Figure 16. Test Engine Models

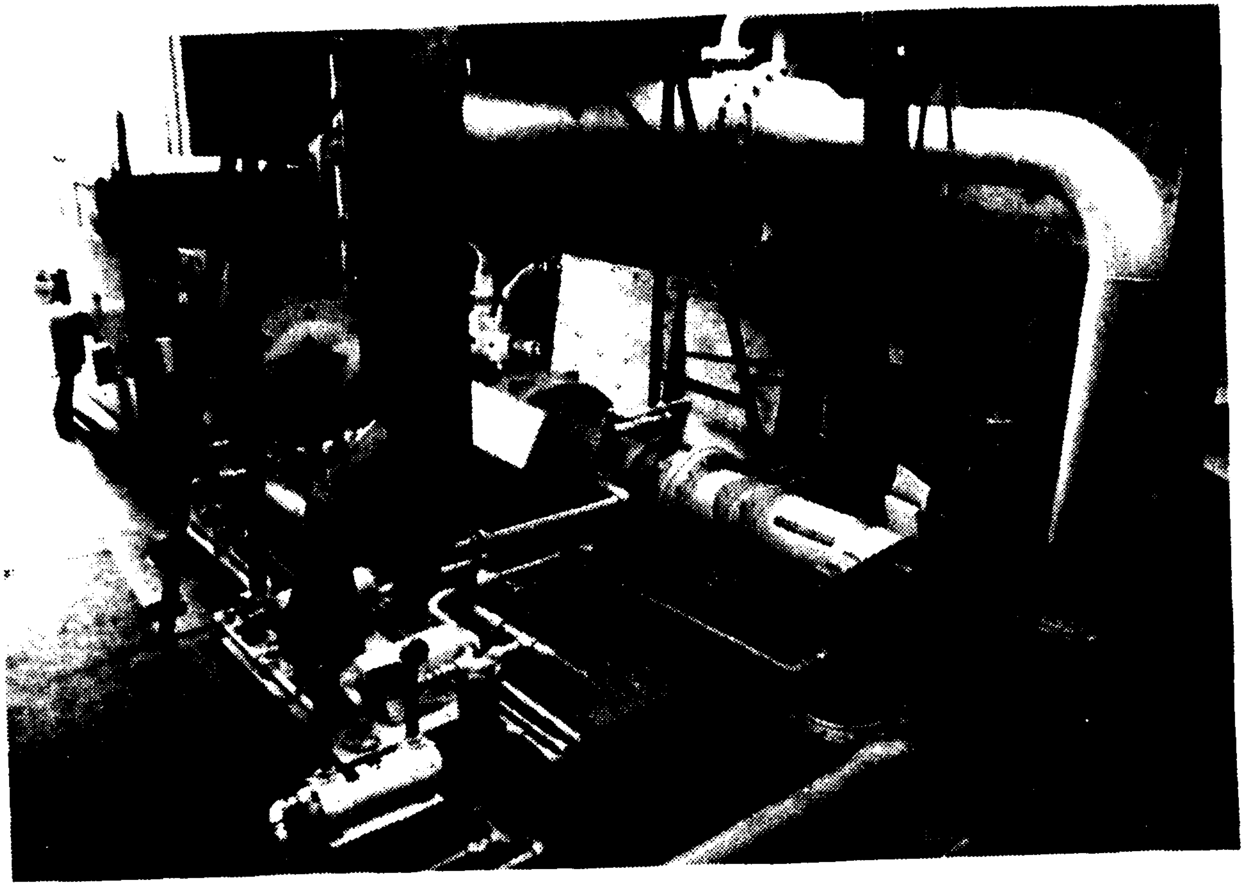


Figure 17. Allis Chalmers Twelve Stage Compressor

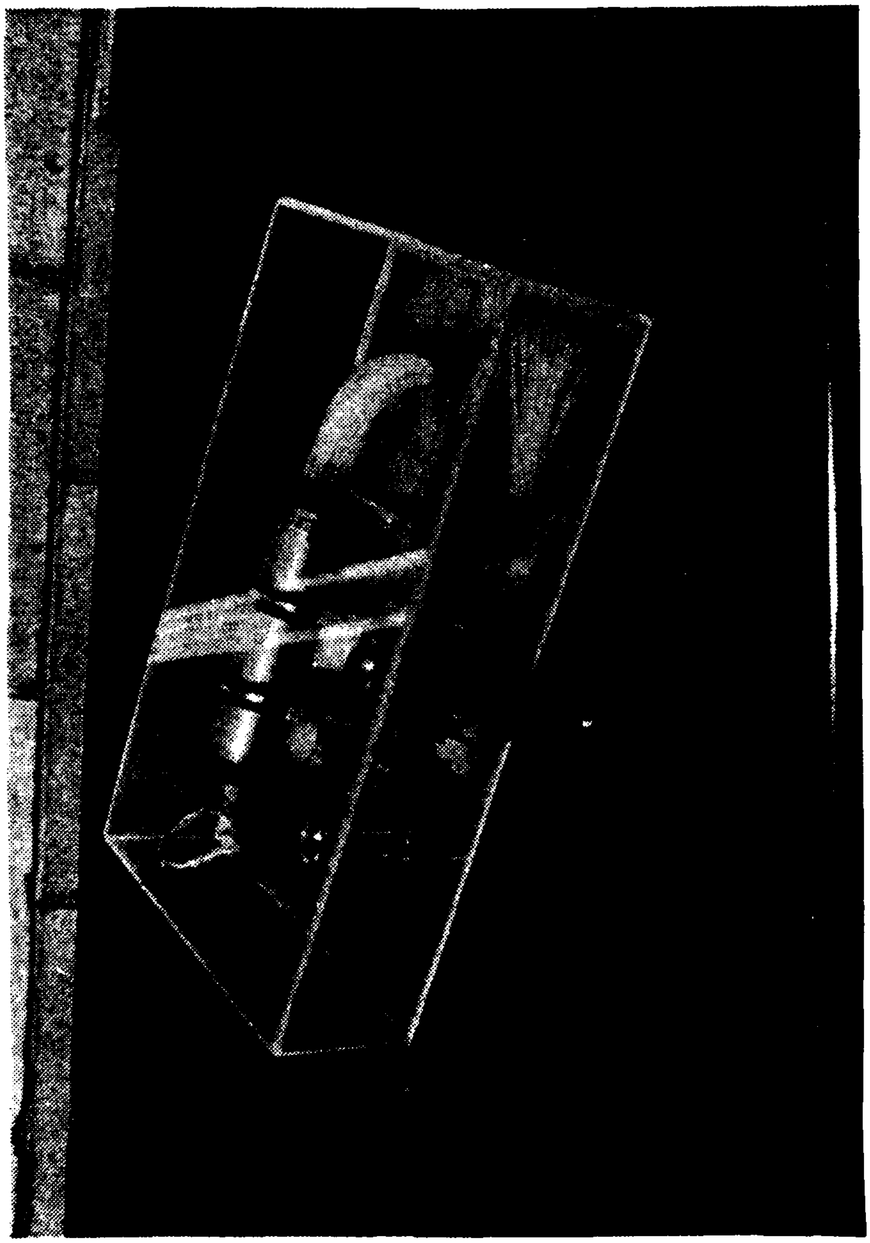


Figure 18. Scanivalve Pressure Scanner

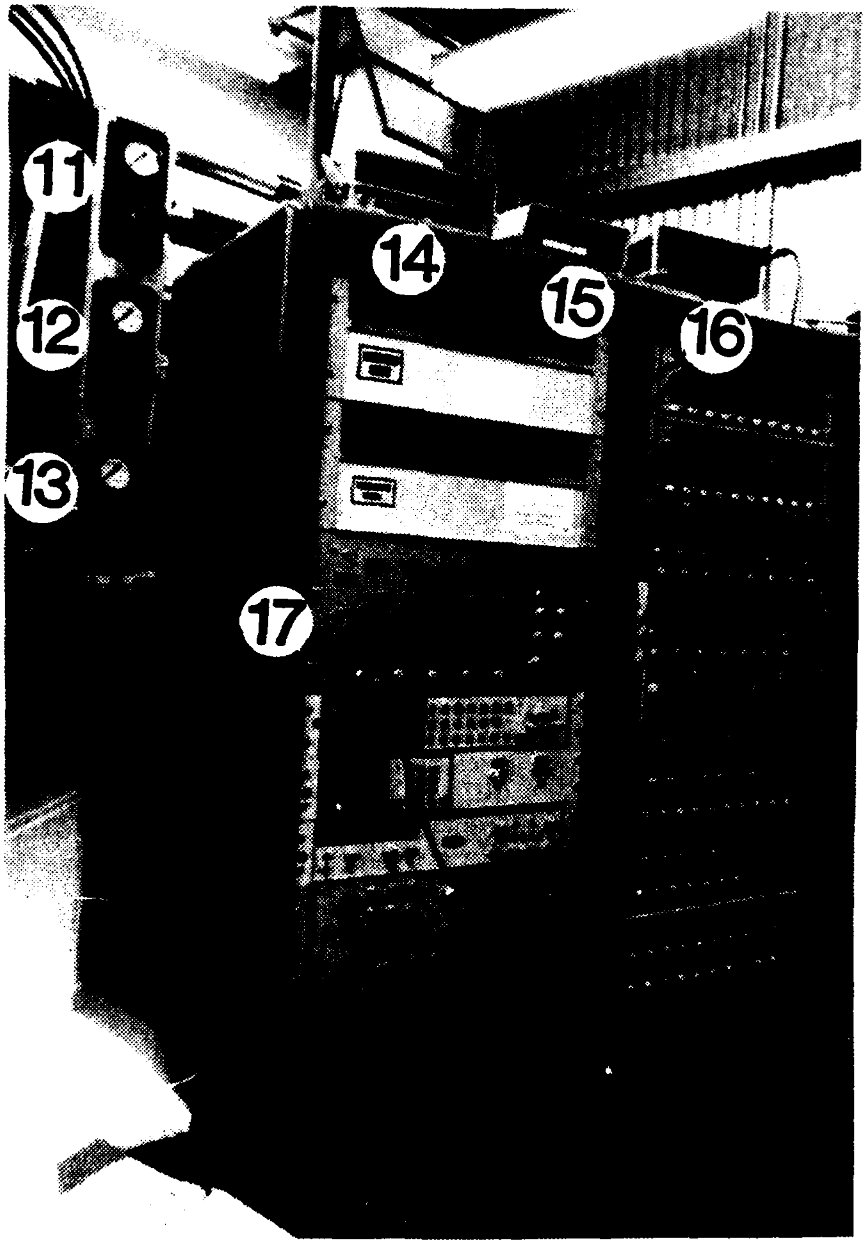


Figure 19. Model Test Facility Remote Operating Station

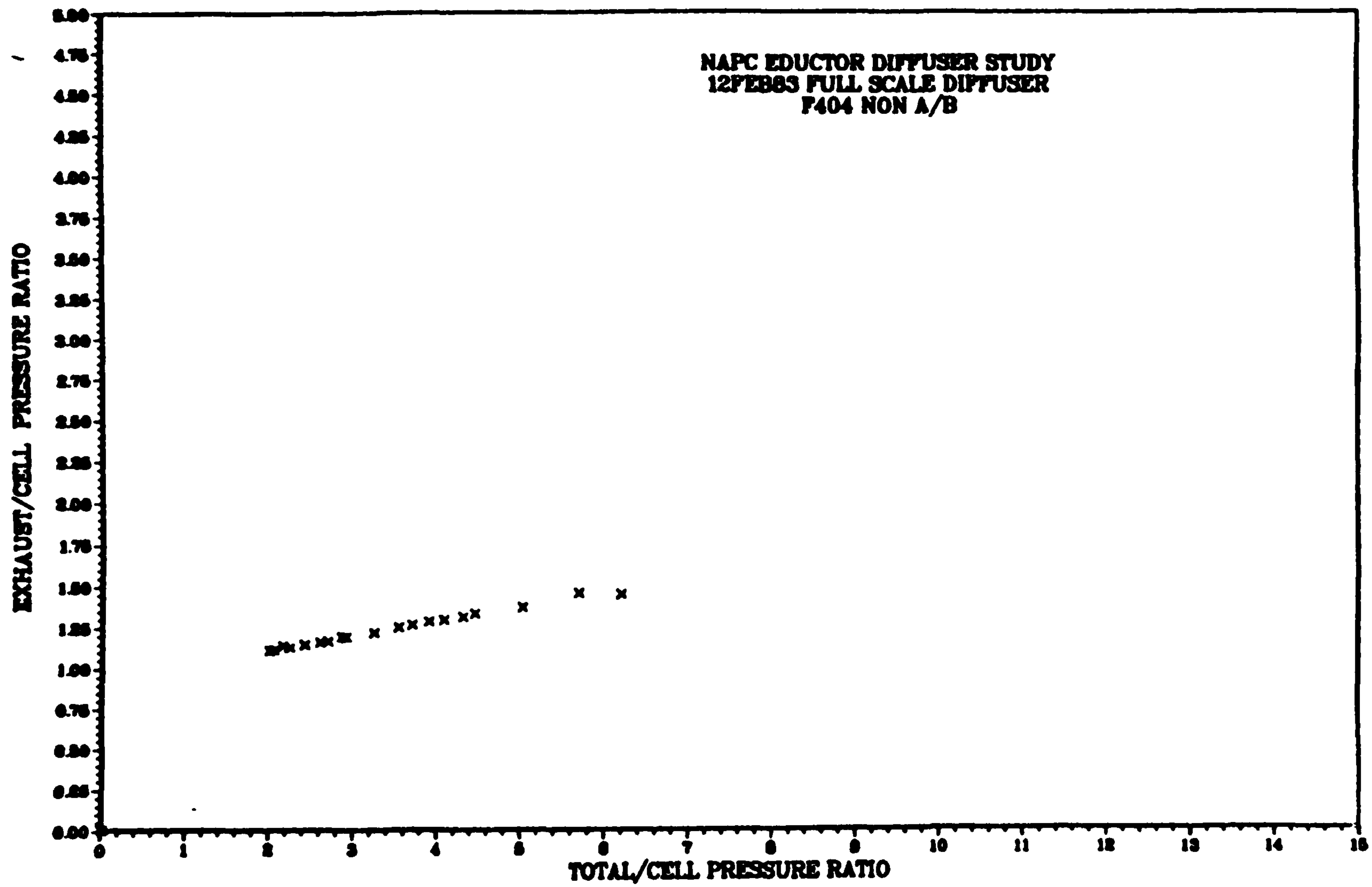


Figure 20. Operating Curve (F404 Non A/B)

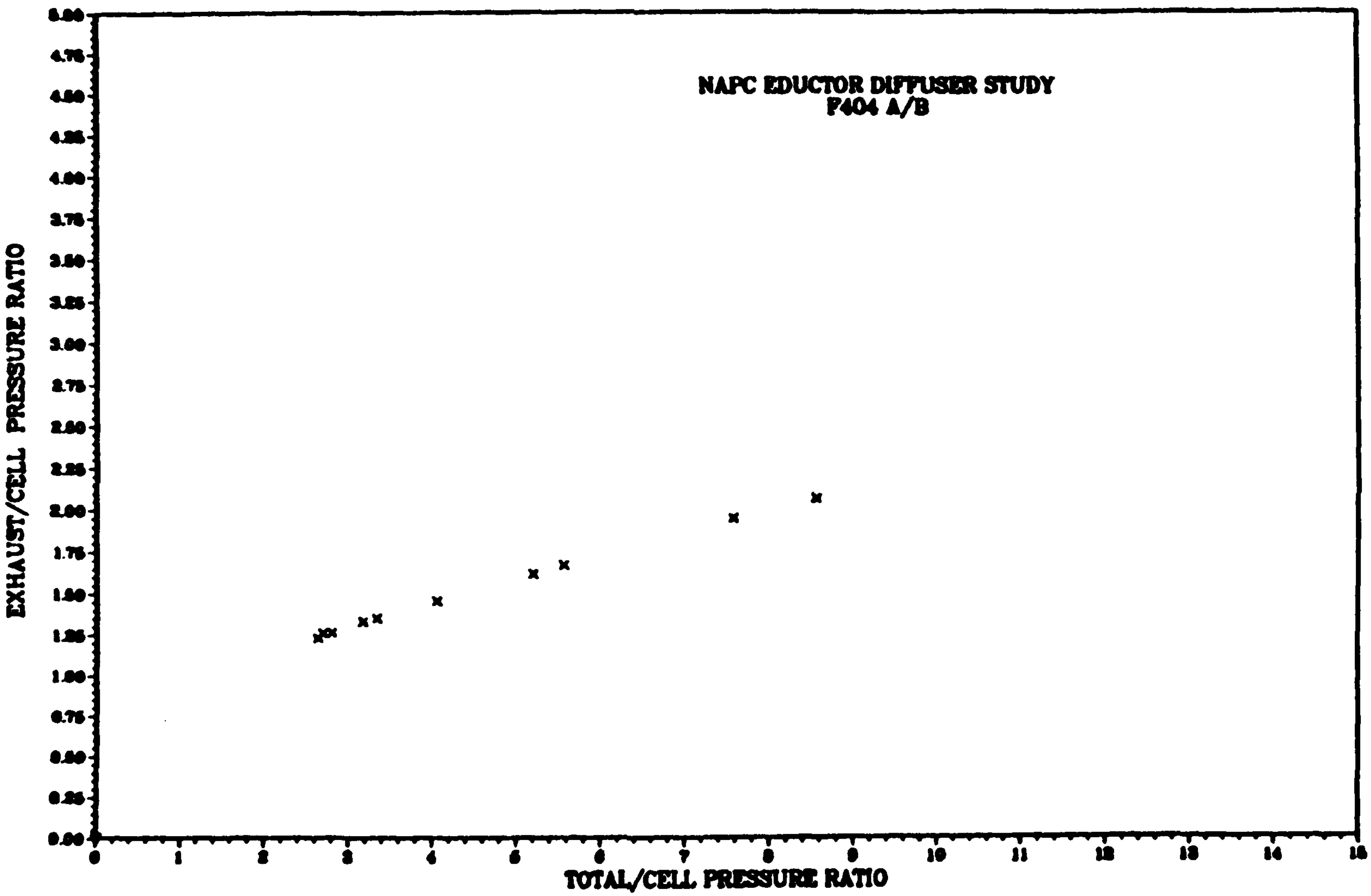


Figure 20a. Operating Curve (F404 A/B)

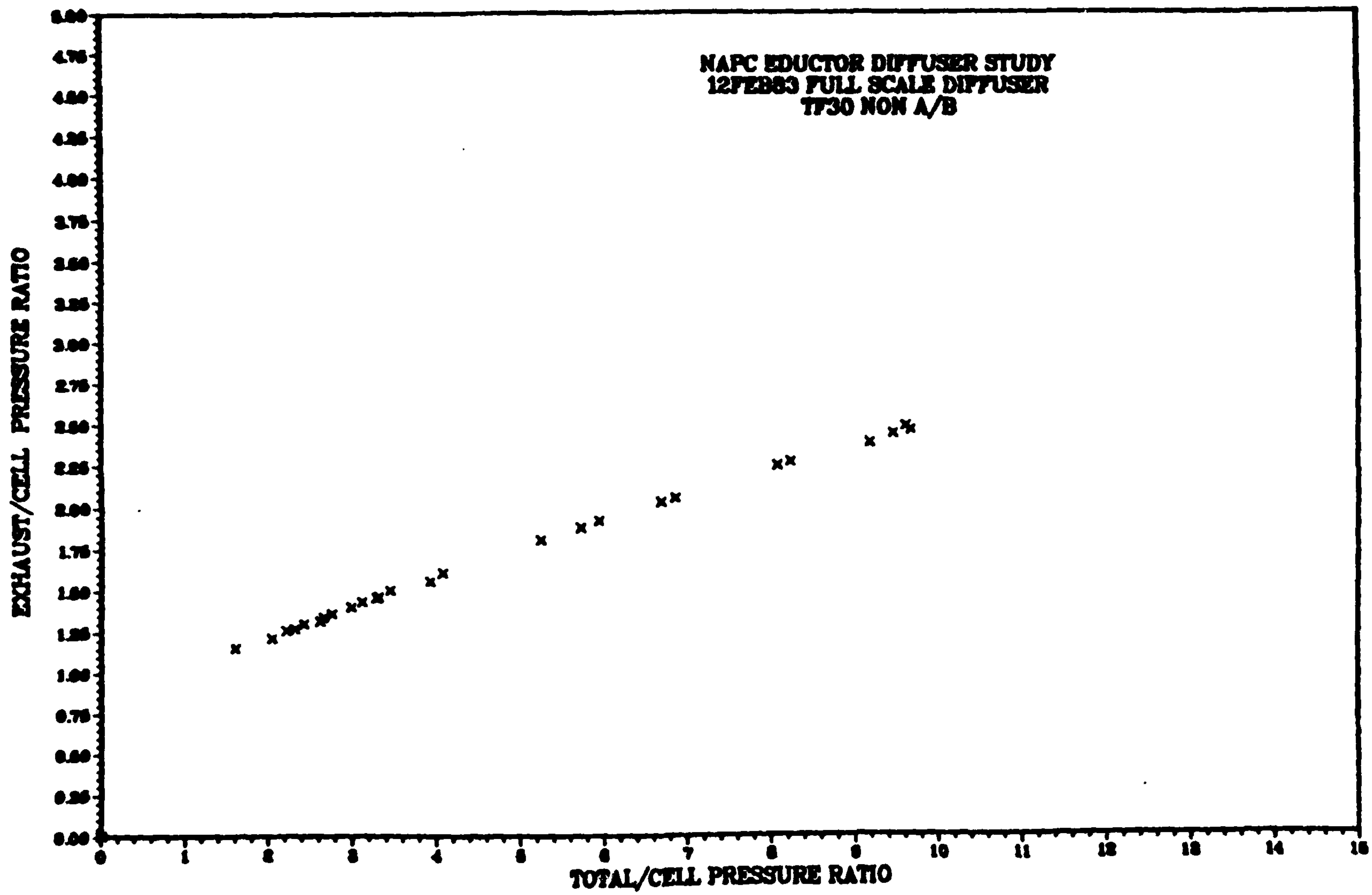


Figure 21. Operating Curve (TF30 Non A/B)

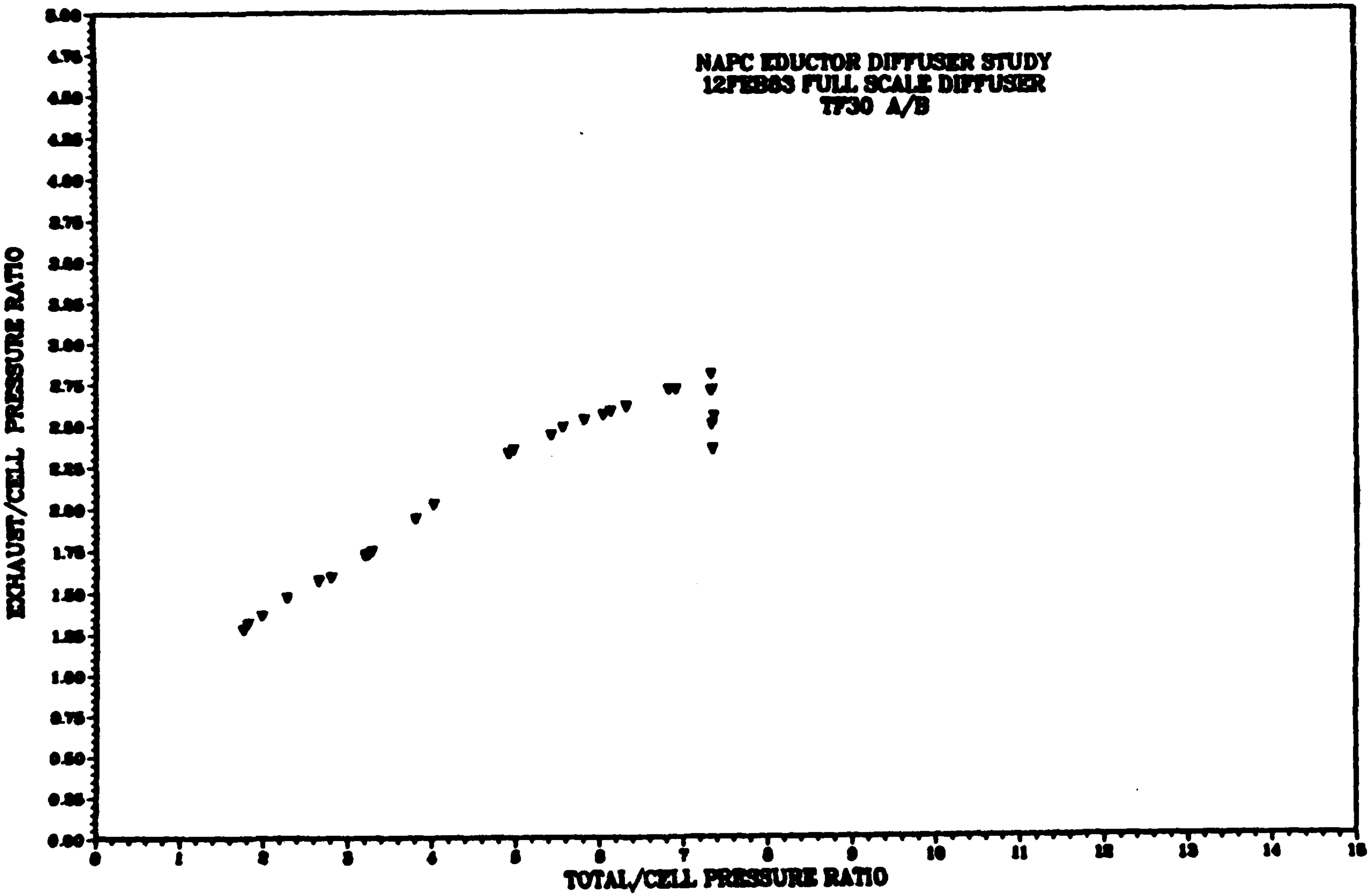


Figure 21a. Operating Curve (TF30 A/B)

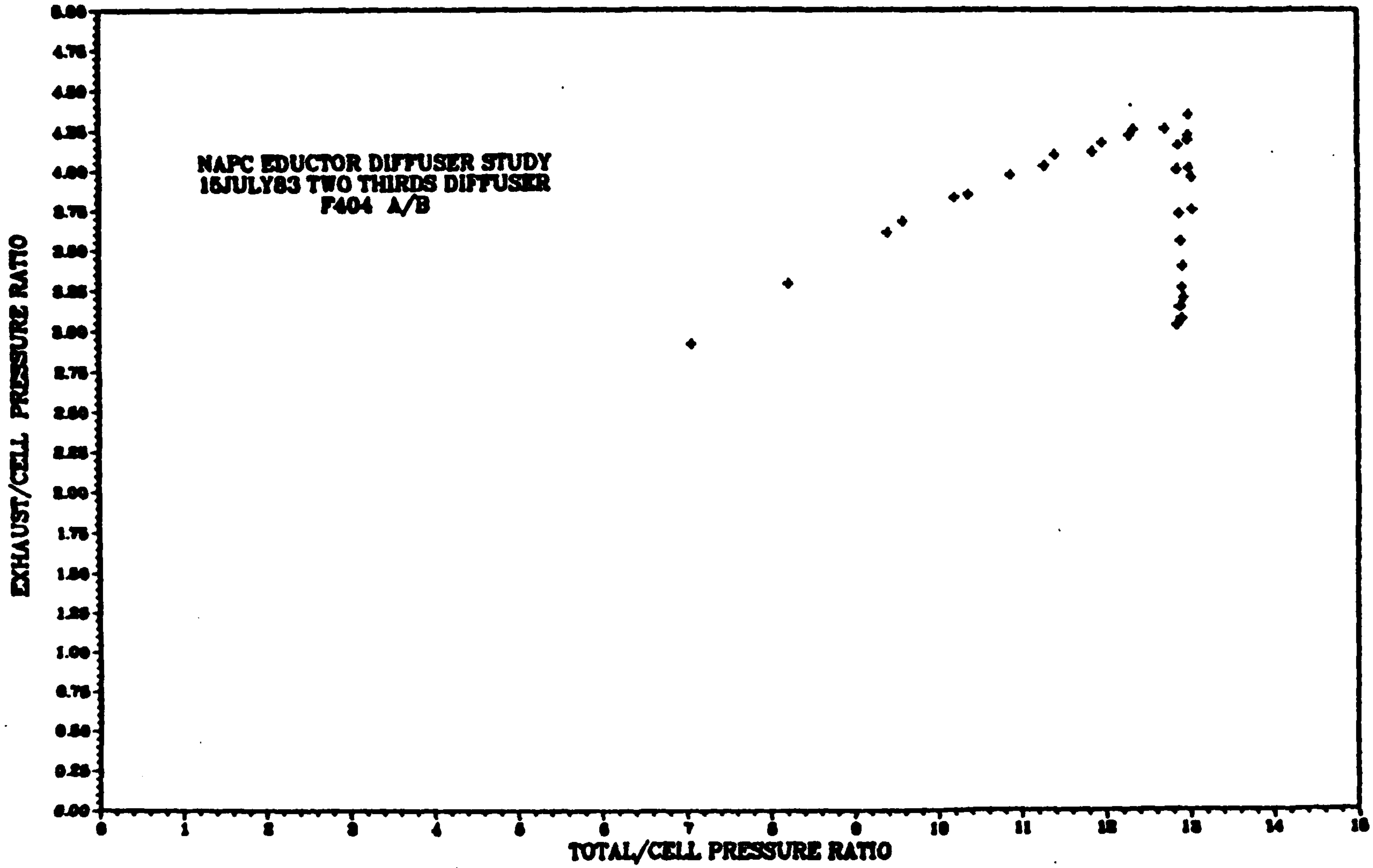


Figure 22. F404 Fully Started

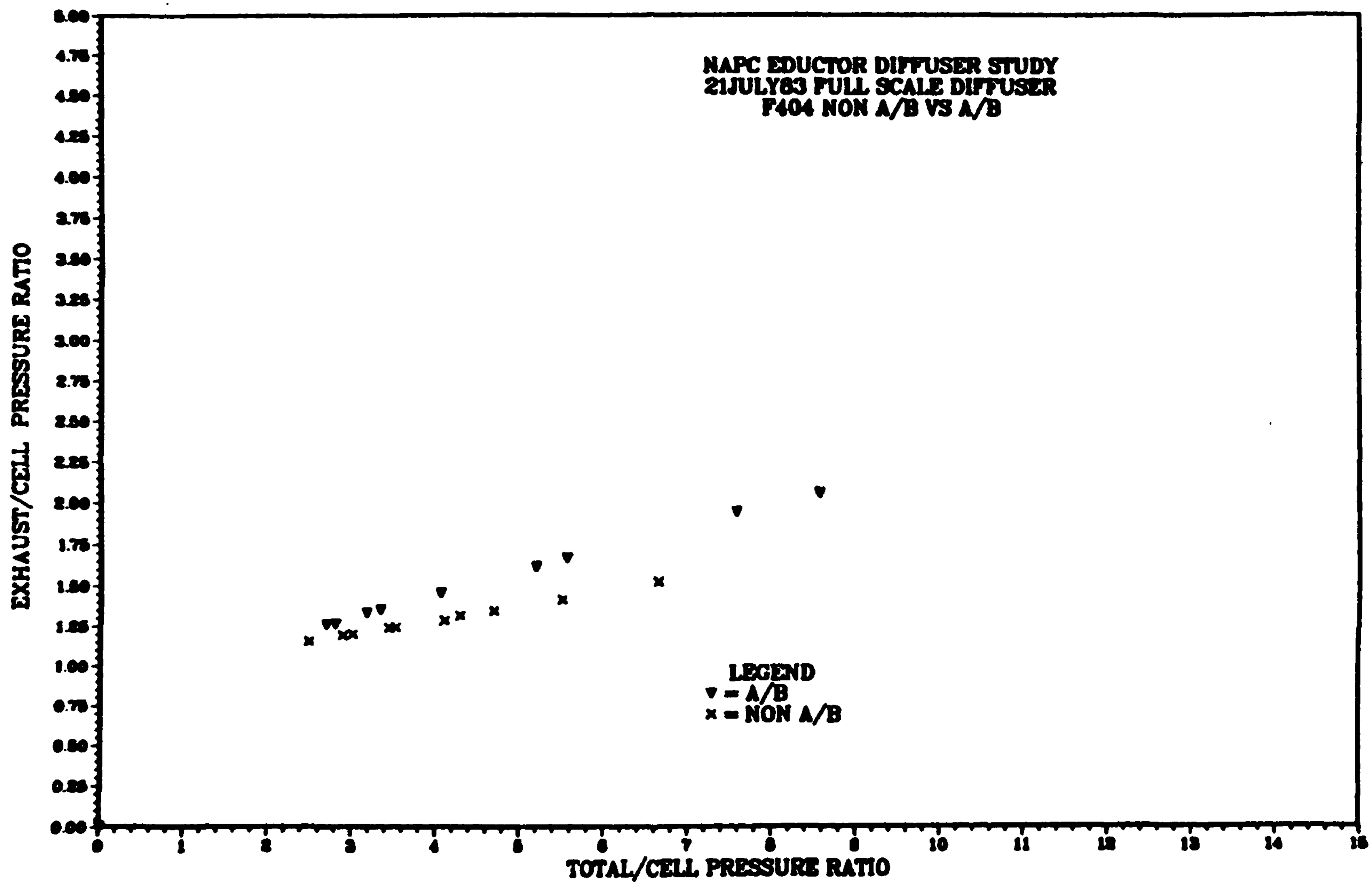


Figure 23. F404 Baseline

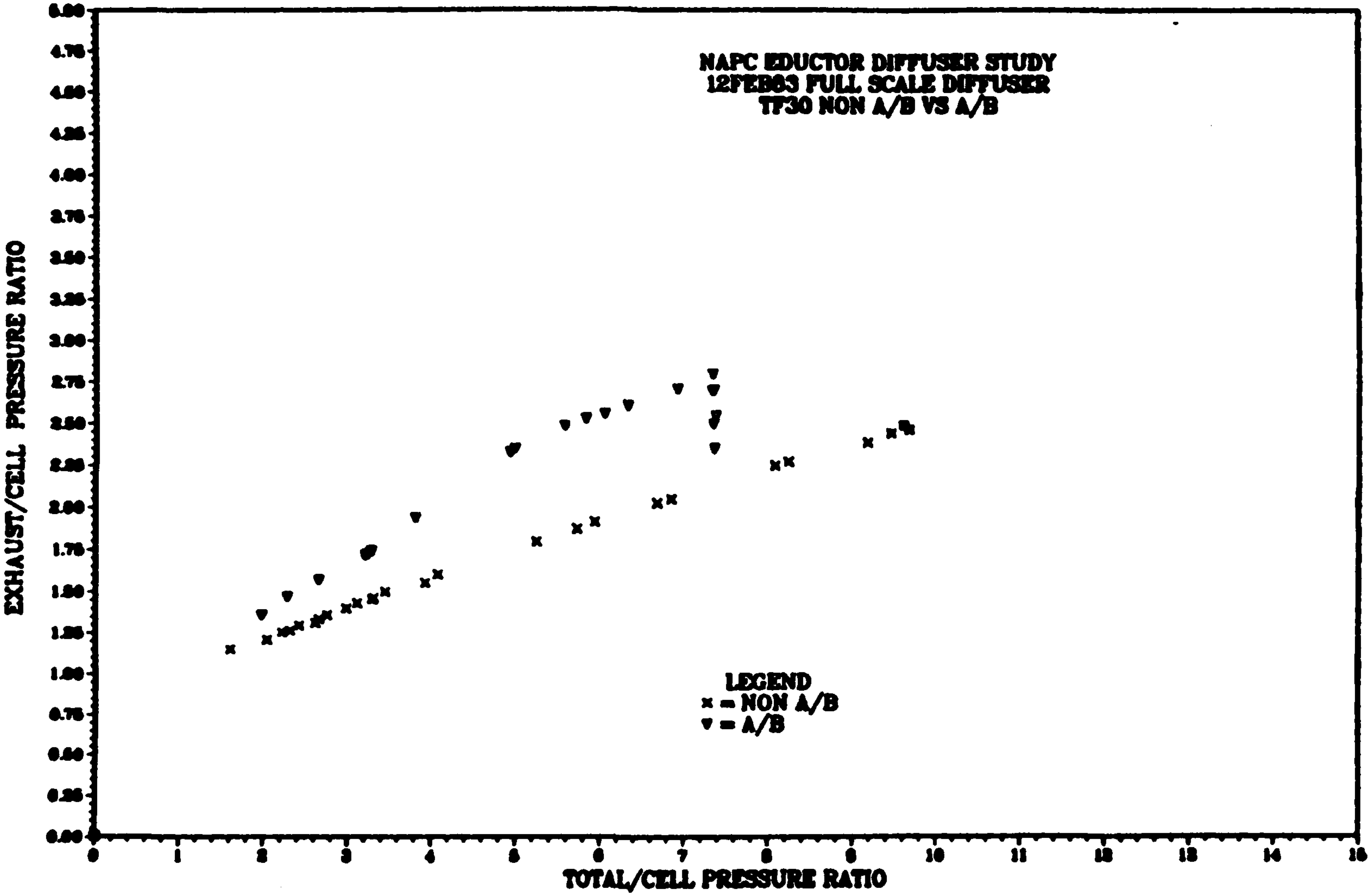


Figure 24. TF30 Baseline

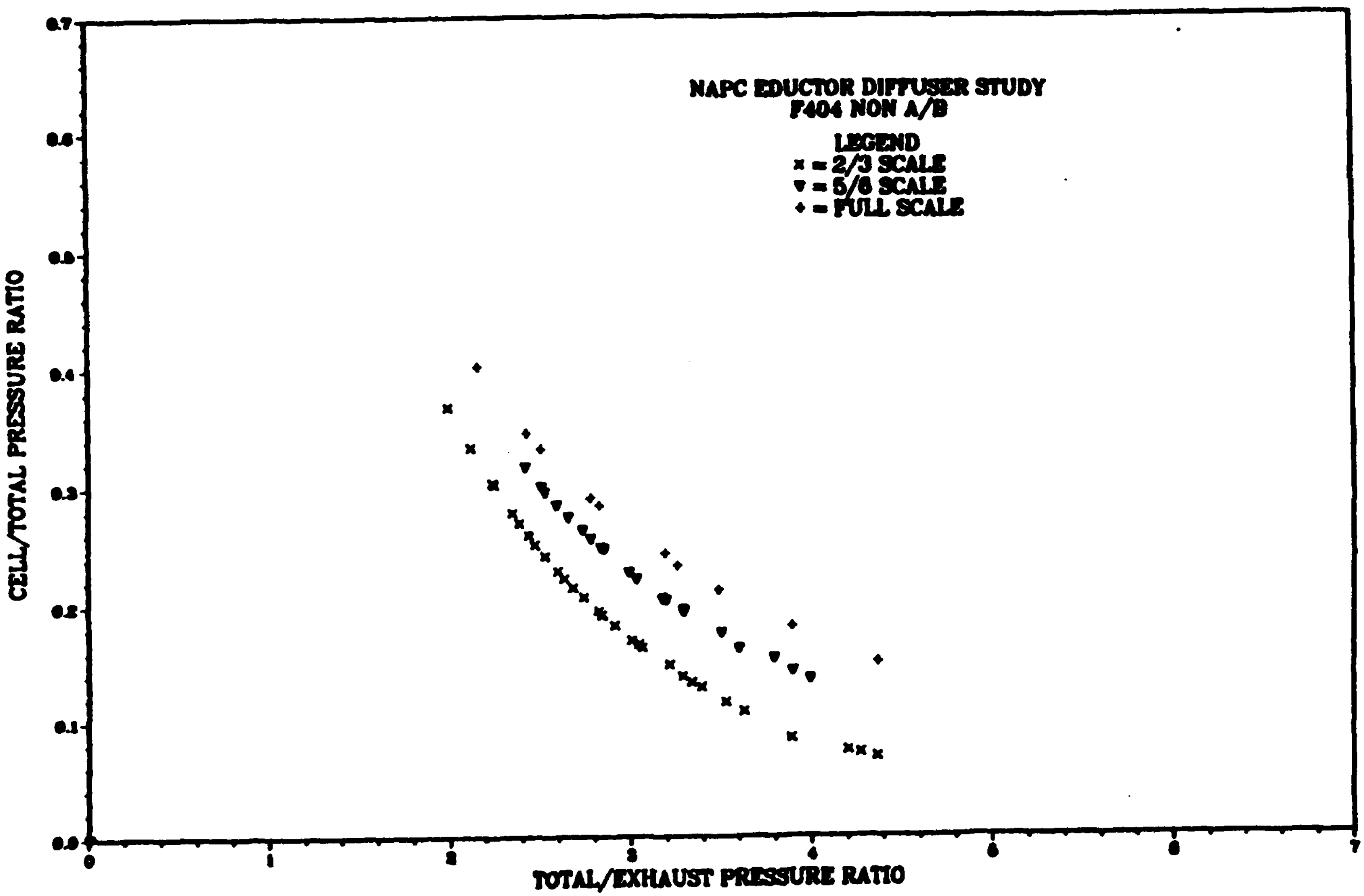


Figure 25. Optional Presentation of Operating Curves

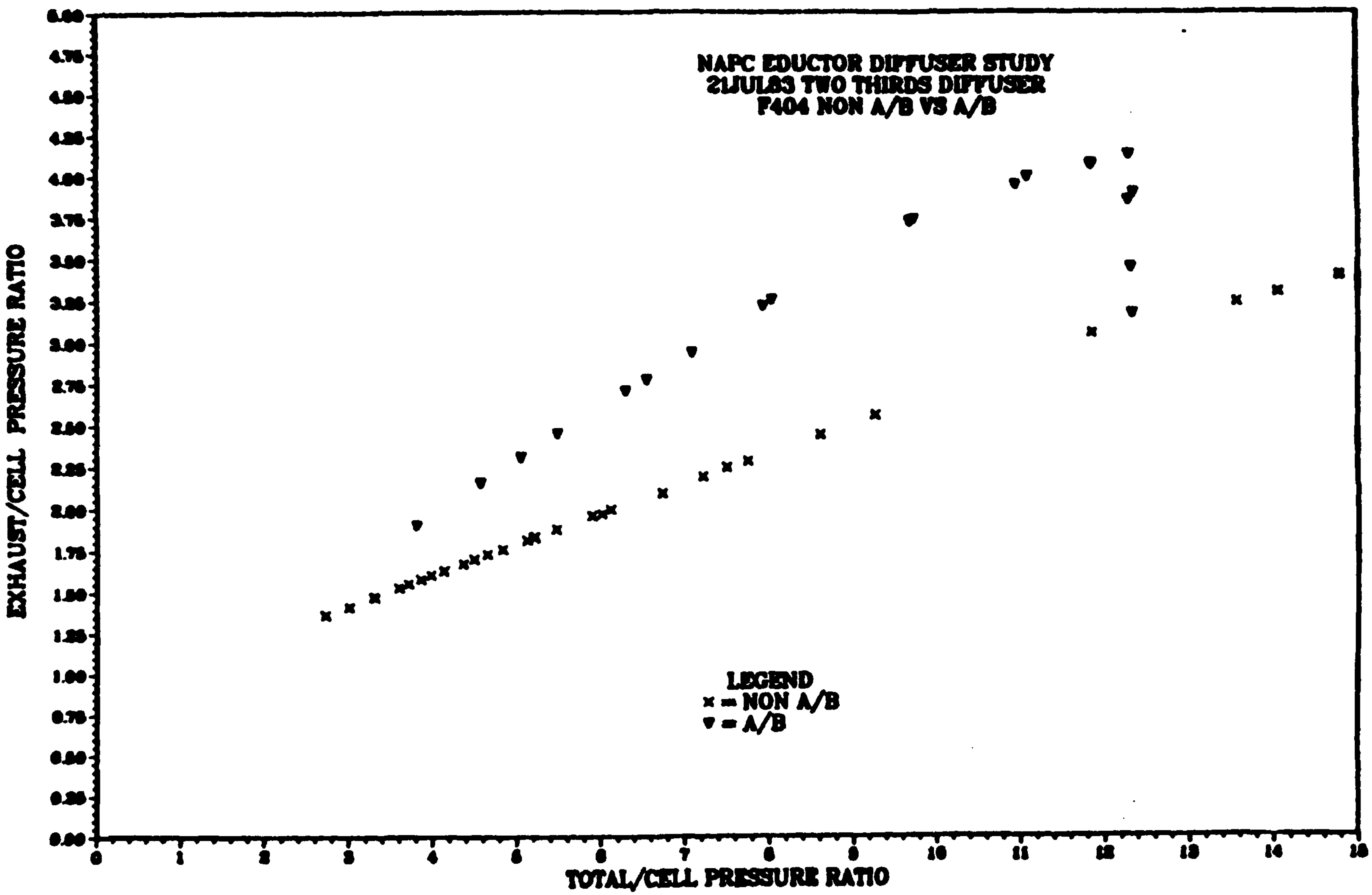


Figure 26. AE/A* Effects

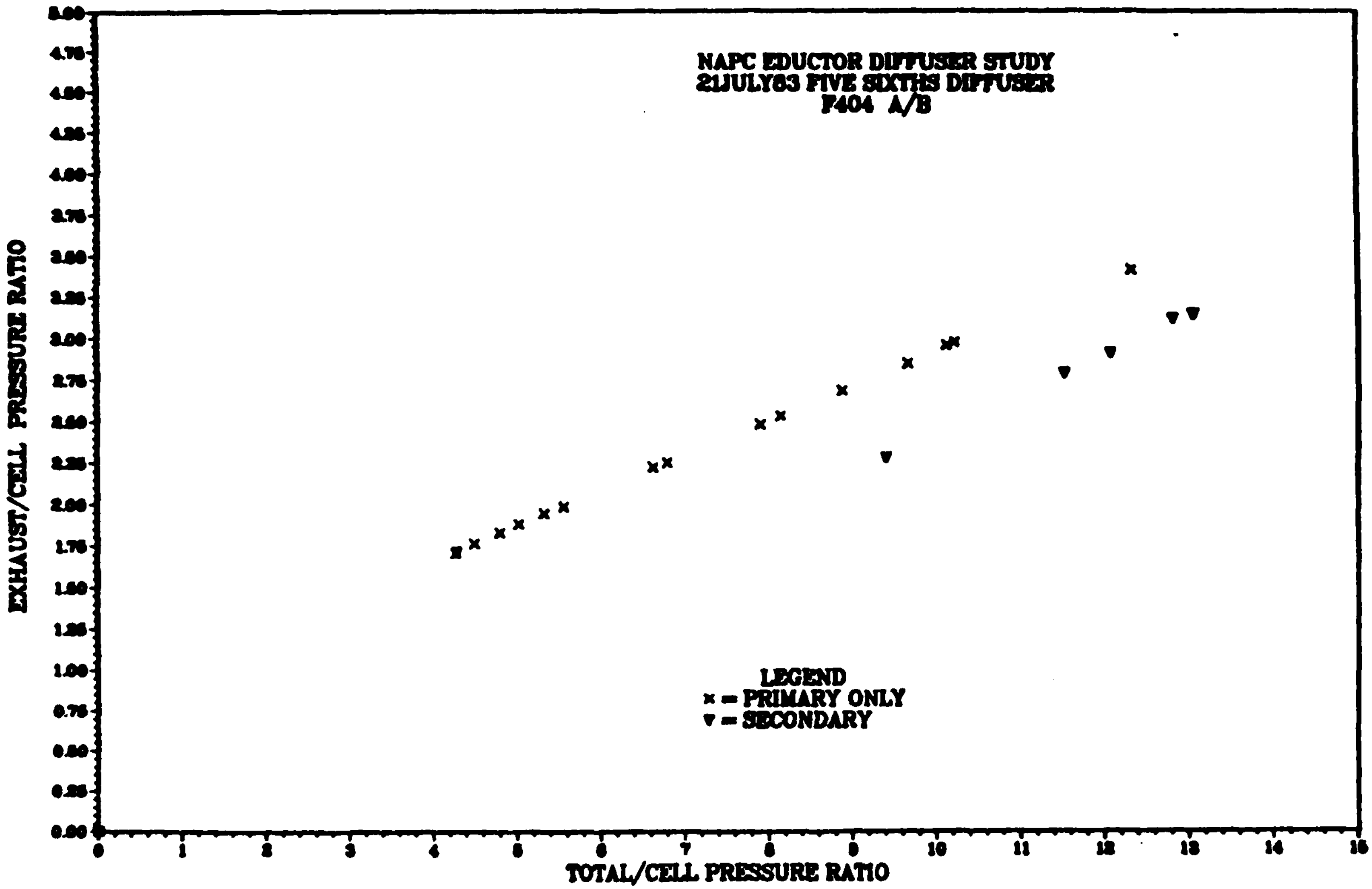


Figure 27. Secondary Flow Effects (Five-Sixths)

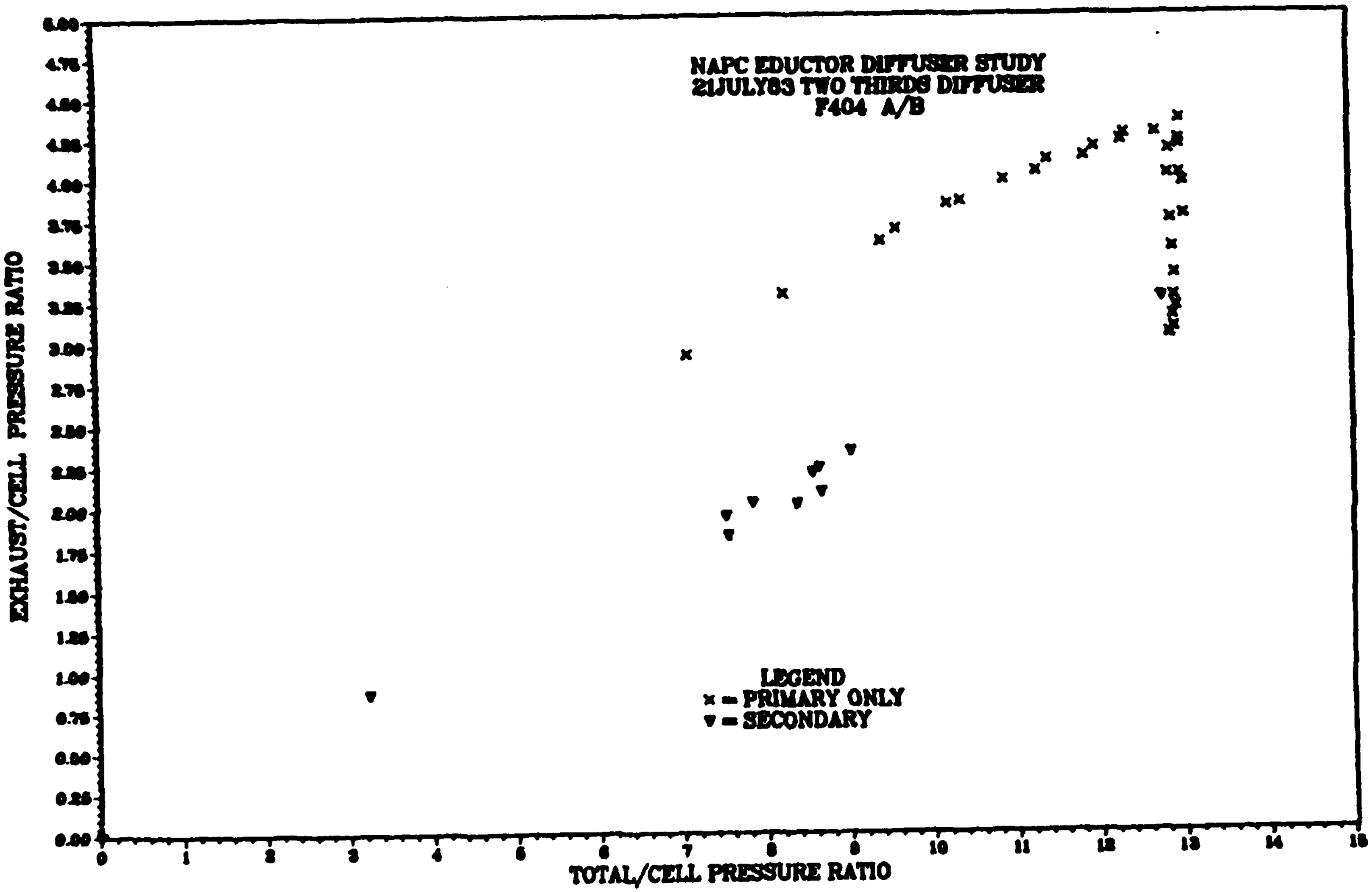


Figure 28. Secondary Flow Effects
(Two-Thirds)

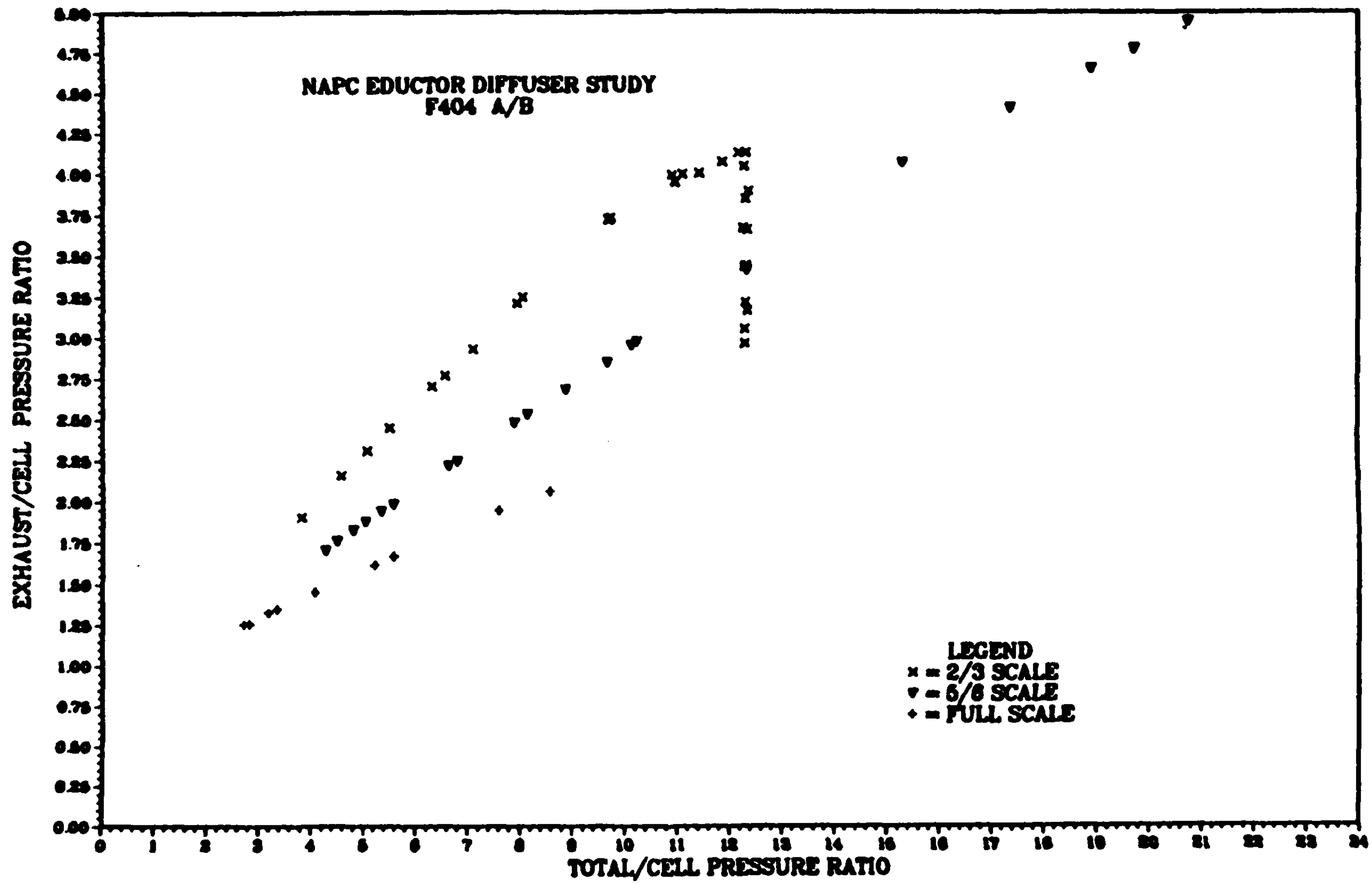


Figure 29. AD/A* Effects

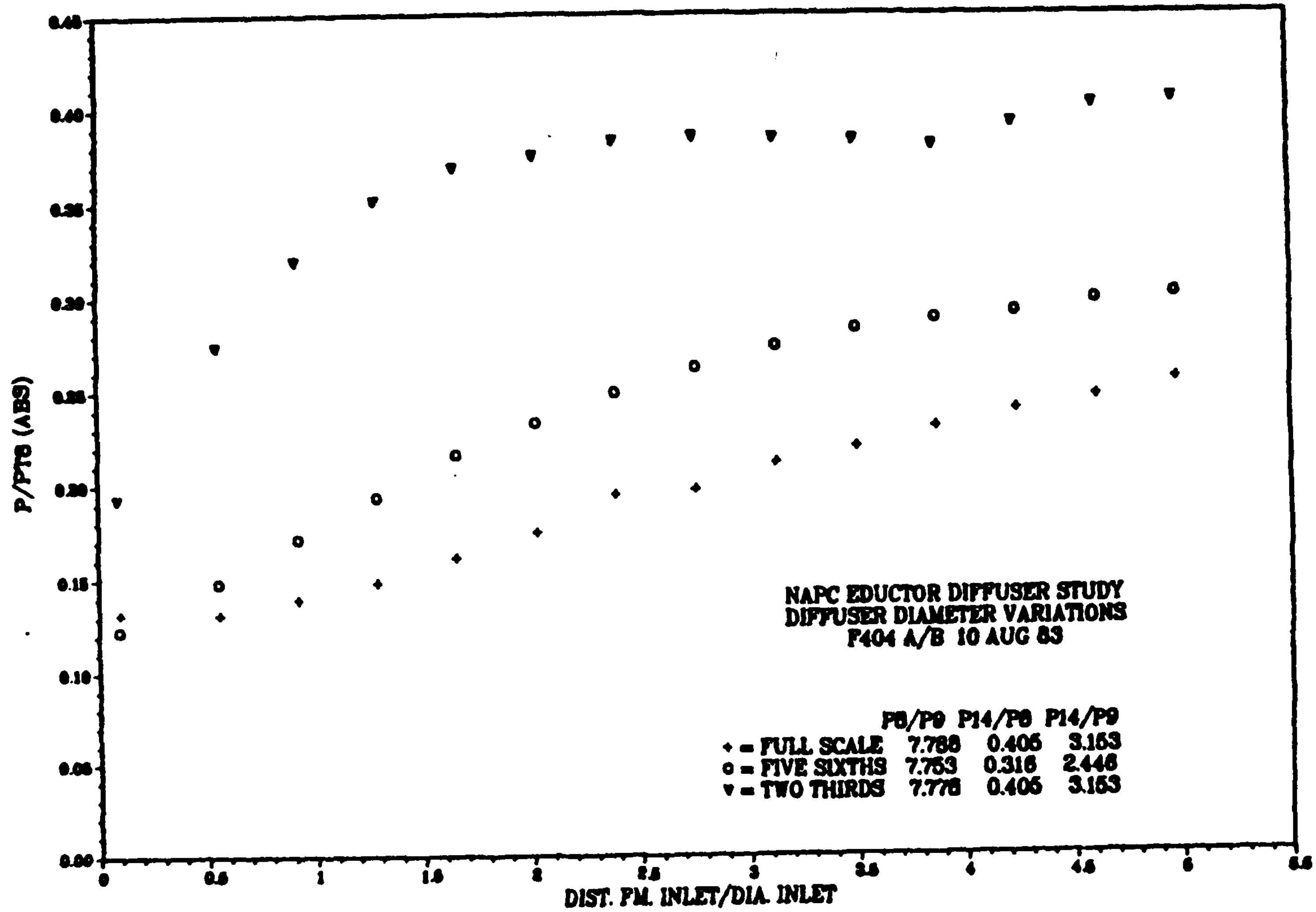


Figure 30. Static Pressure Profiles

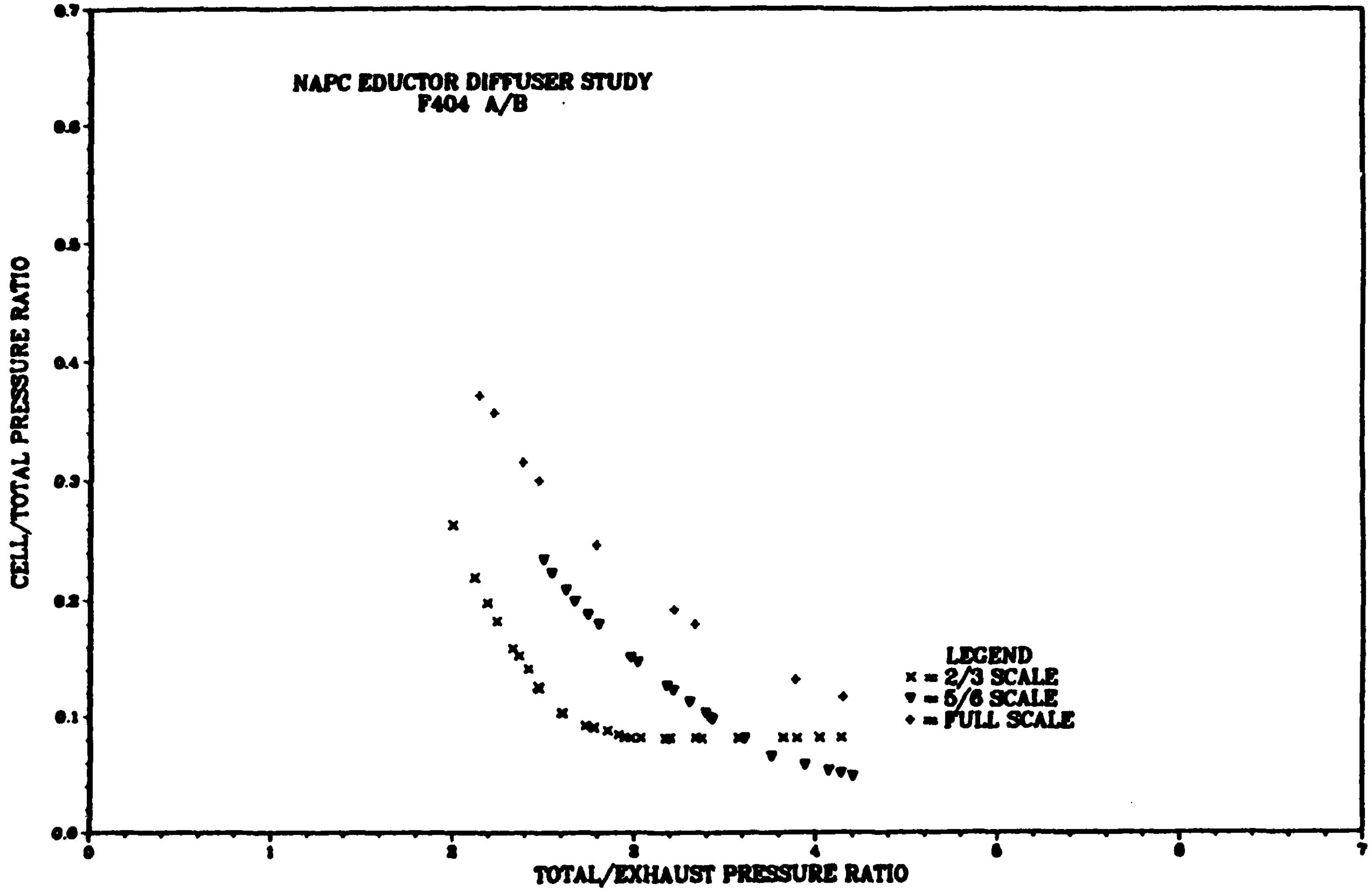


Figure 31. F404 Improvement Summary

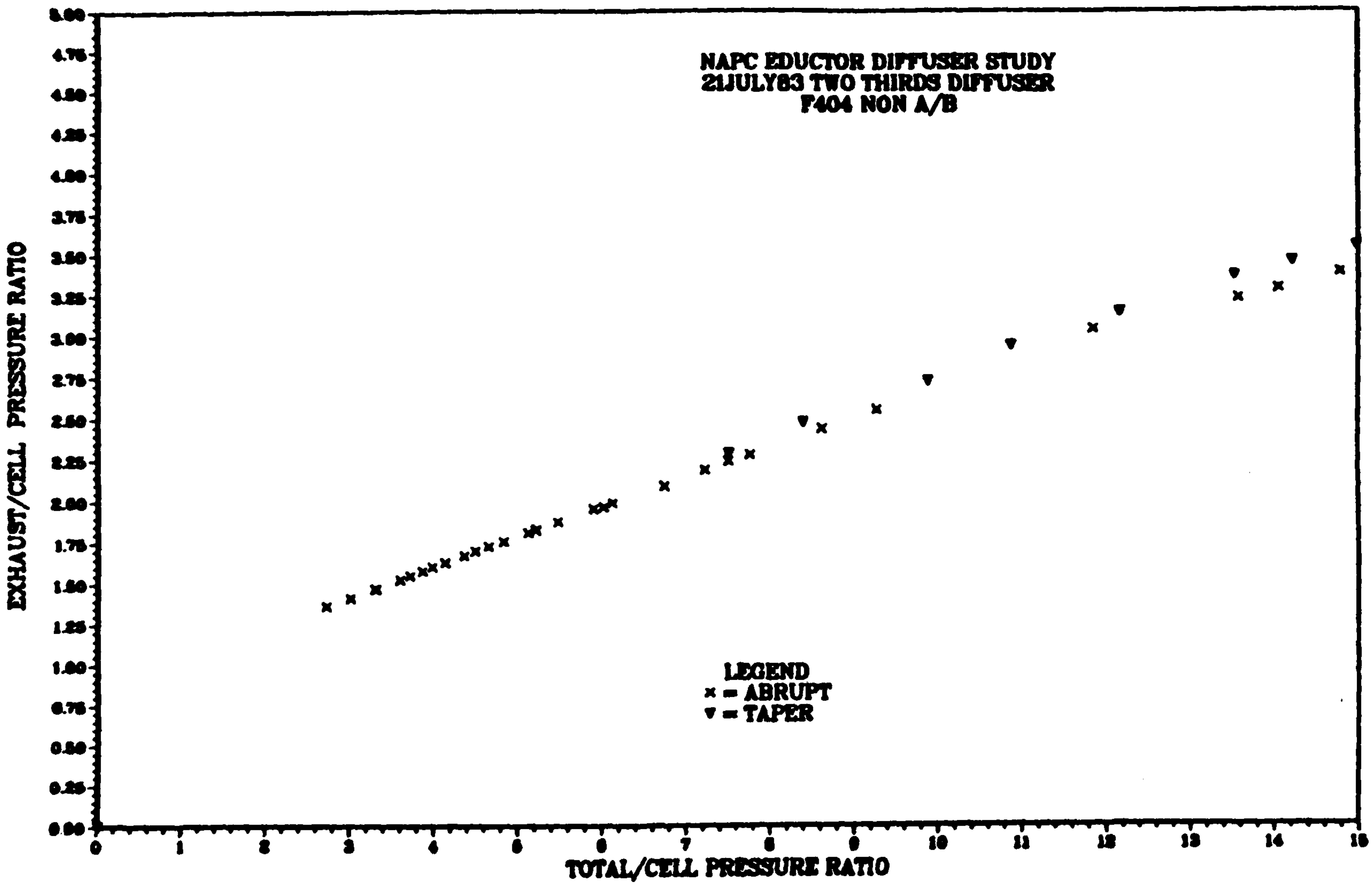


Figure 32. Taper Effects (F404 Non A/B)

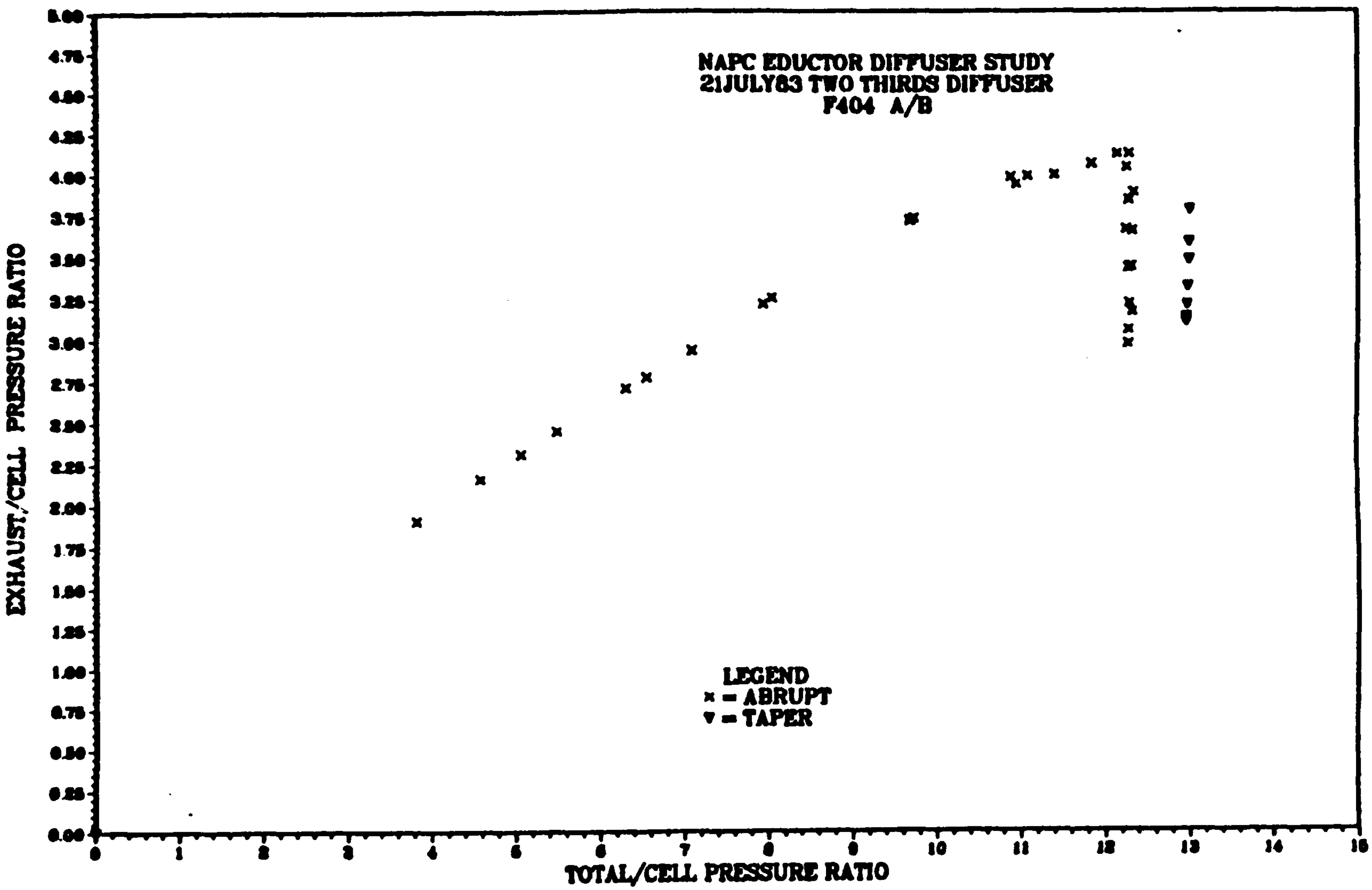


Figure 33. Taper Effects (F404 A/B)

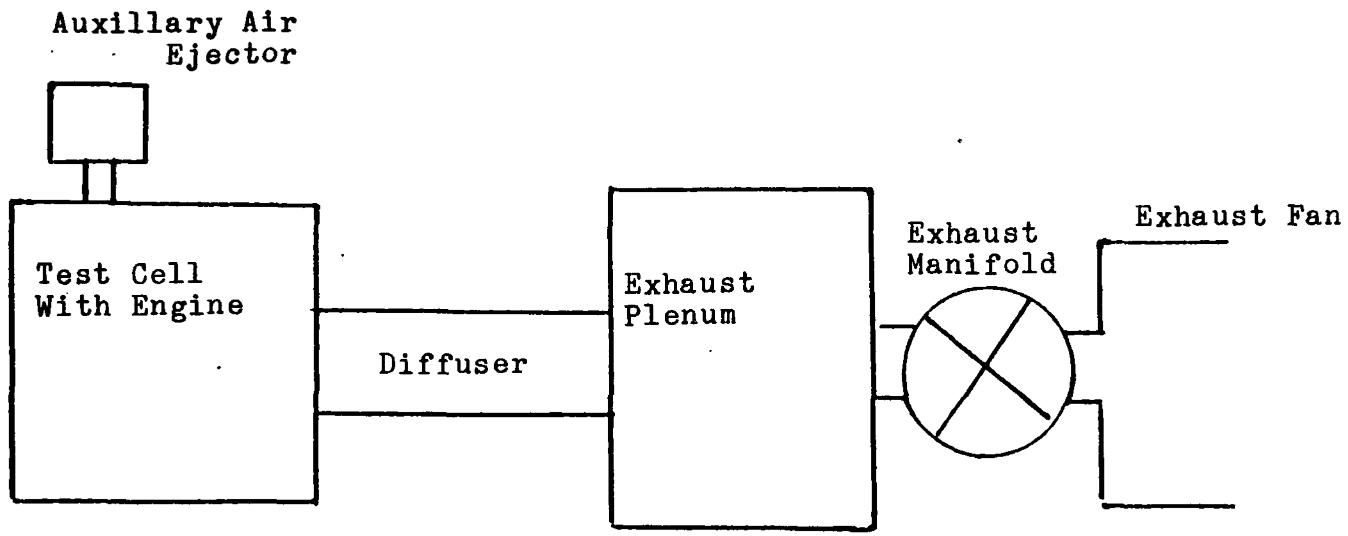


Figure 34. Test Facility Illustration

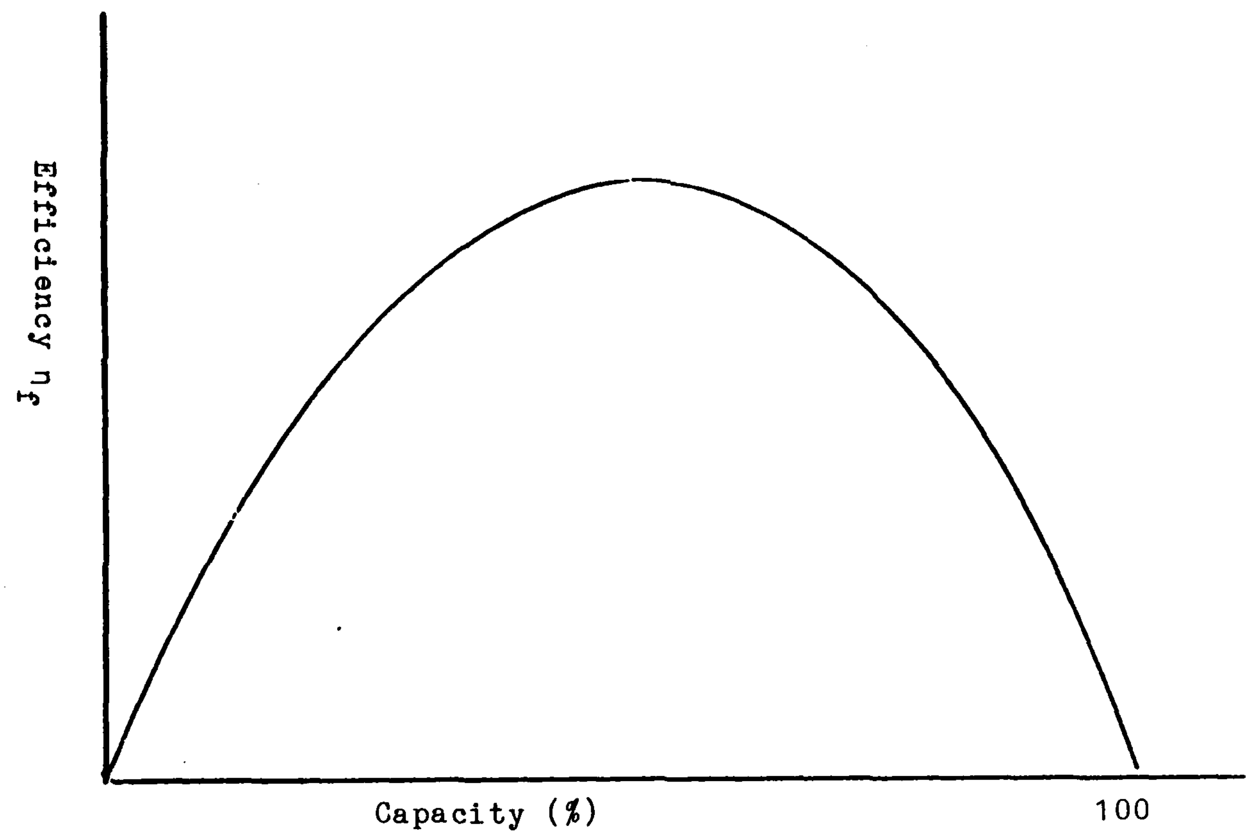


Figure 35. Generalized Exhaust Fan Efficiency

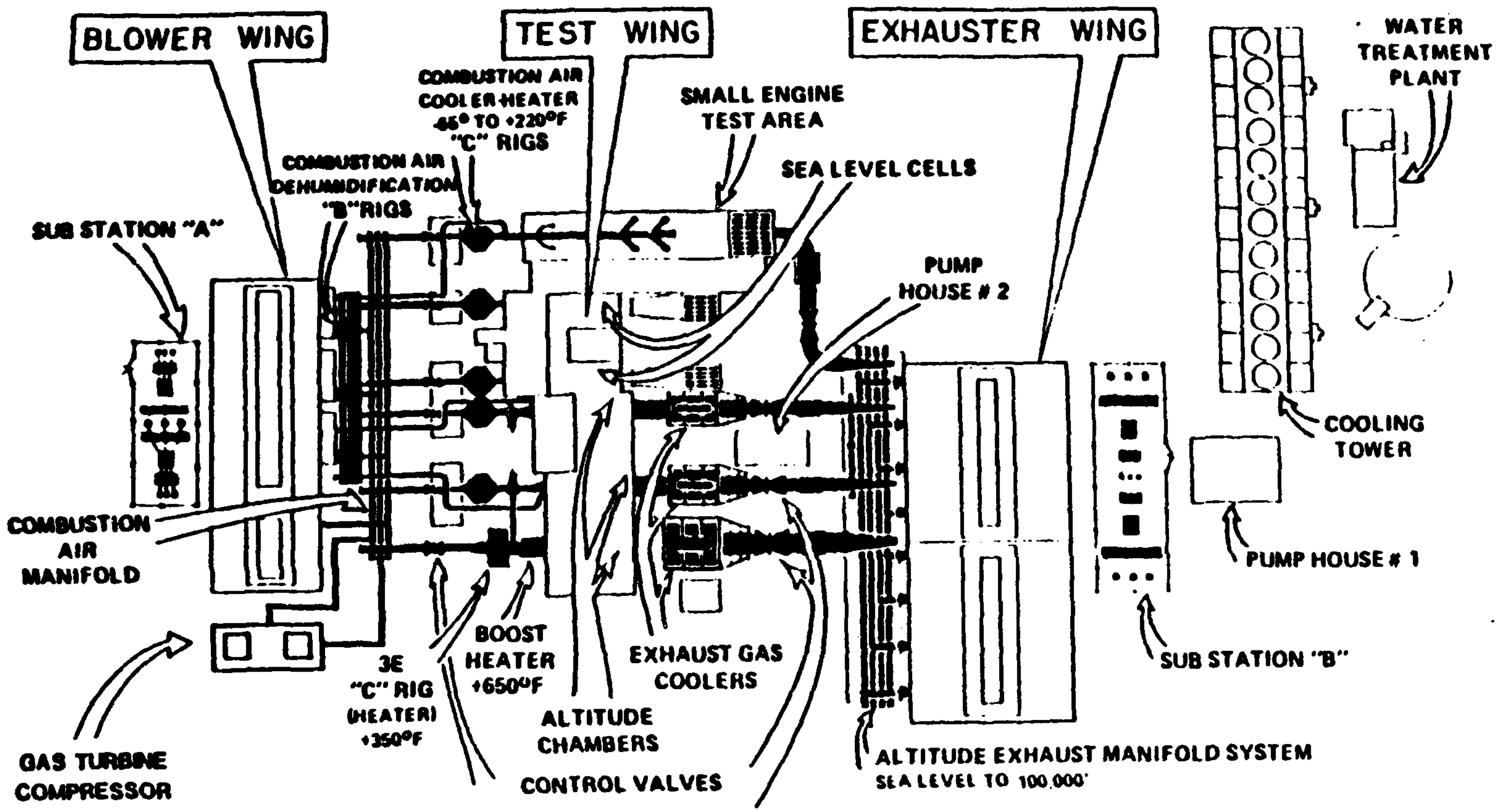


Figure 36. Engine Test Facilities

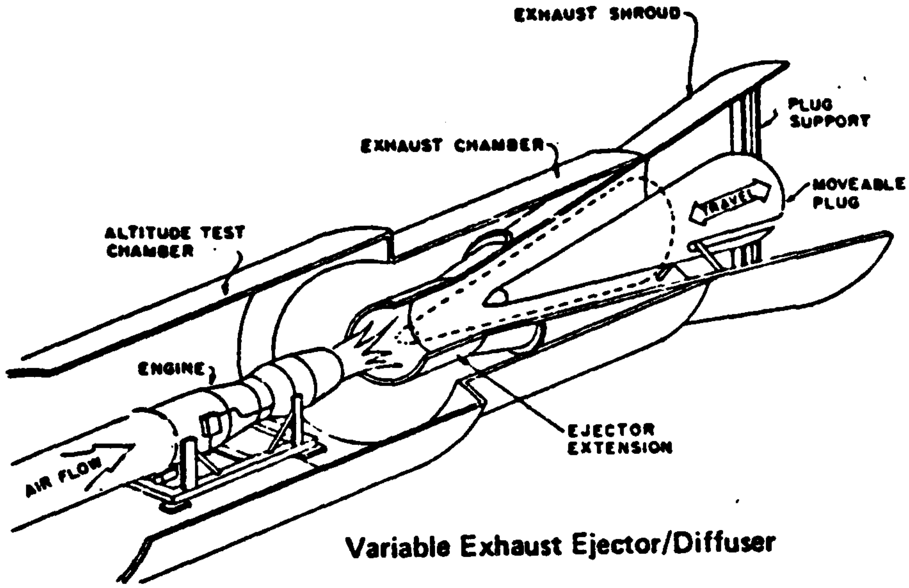


Figure 37. Variable Exhaust Ejector Diffuser

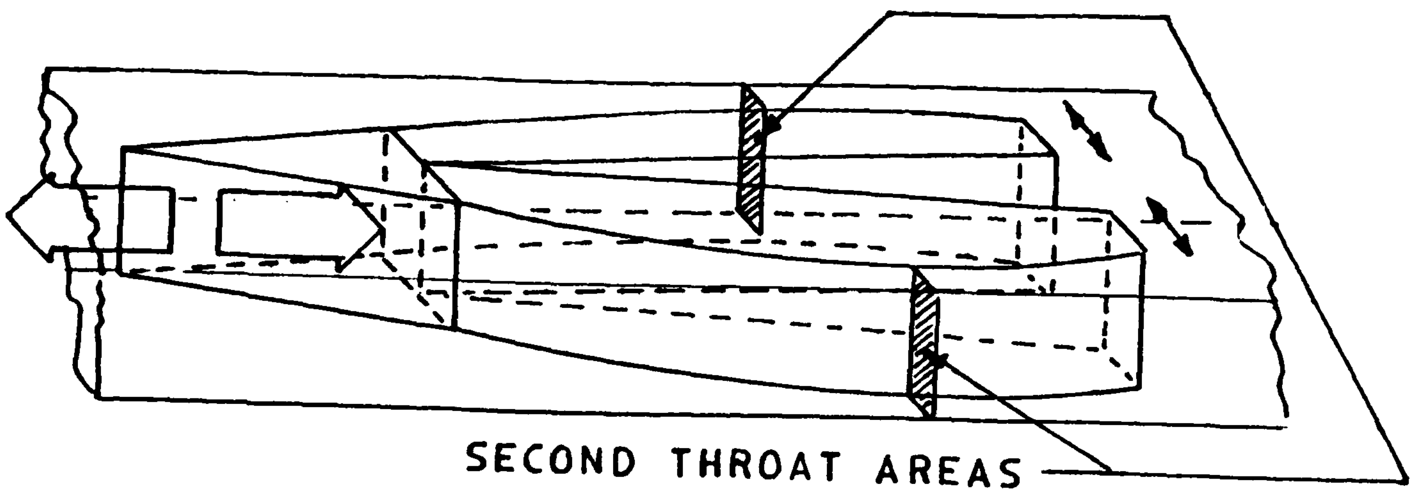


Figure 38. Conceptual Wedge Design

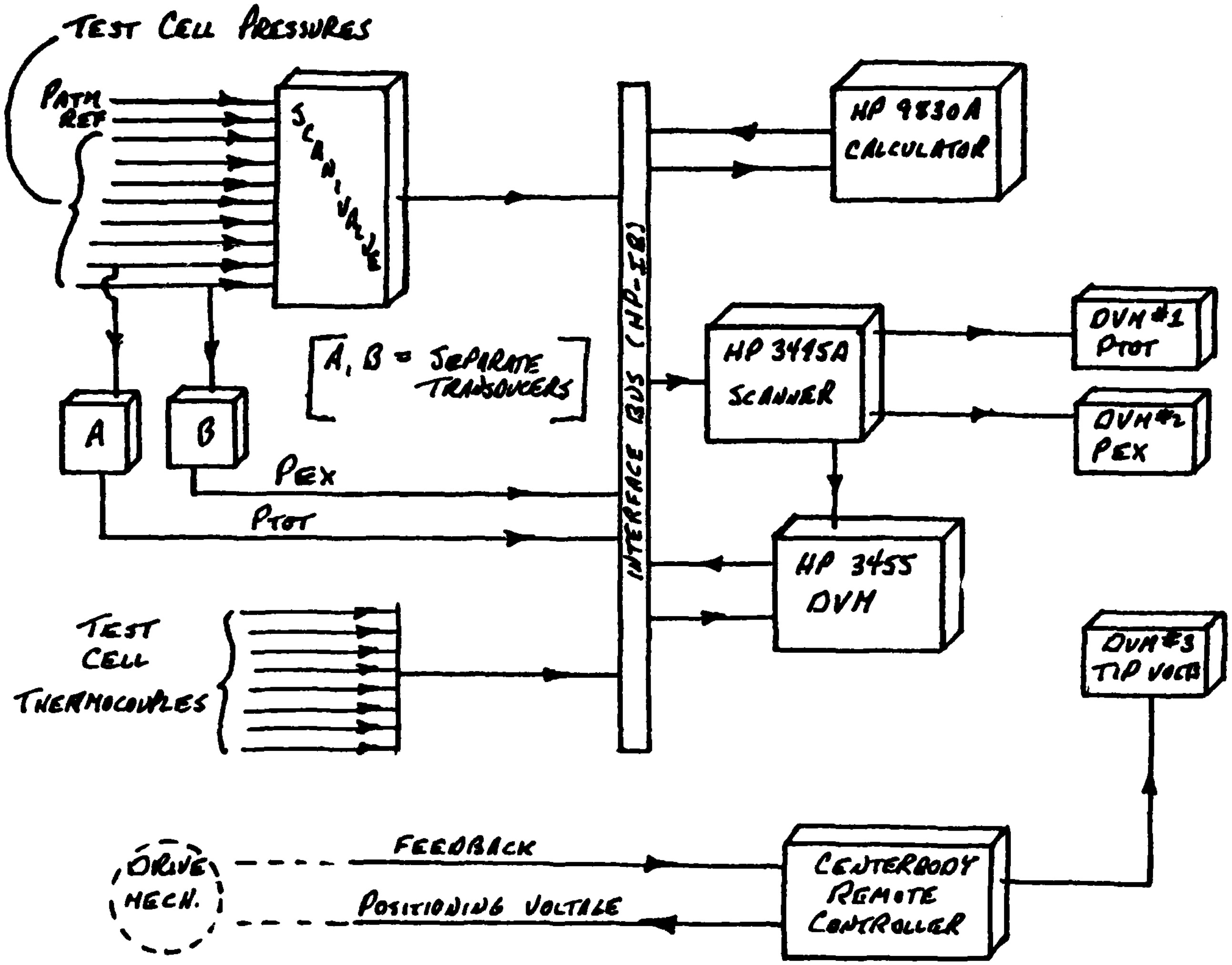


Figure 39. Instrumentation Schematic

APPENDIX A

DEVELOPMENT

Design of a subscale altitude test facility to approximate the salient features of the parent facility at the Naval Air Propulsion Center was governed by a multiplicity of interwoven factors. The underlayment for the design was the motive air supply; compressed air from an Allis Chalmers twelve-stage axial compressor (Figure 17). The dictates of the air supply qualified several engines from the family of engines tested by NAPC as candidates for scaled testing. The candidate engines elected, as listed in Table B.3 were, from a first cut, the most likely to give a broad representation of existing test frames suitable for comparative analysis with alternative ejector-diffuser geometries. Two afterburning engines were elected to span the operating range of the test facility from zero induced secondary flow to five (5) percent secondary flow. The choice of engines provided the vital ingredient upon which scaling of the facility could proceed.

Scaling. Scaling to achieve Mach number similitude was elected consistent with past studies by Merkli {Ref. 5} and Bevilaqua and Combs {Ref. 11}. The geometry of a scale model may easily match the prototype but simultaneous matching of Mach and Reynolds numbers is impossible. A match in

Mach number will present a model with a smaller Reynolds number. A match of Reynolds number induces a higher Mach number in the model. Noting that large Reynolds numbers, consistent with fully turbulent flow, are characteristic of the prototype, any variations in Reynold number would affect scaling only if a shift to less than fully turbulent flow was created. At a projected mass flow rate for the model of .5 lbm/sec, a simple calculation results in a Reynold number in excess of 1E6 thus relegating Reynolds effects to second order. It bears observation, however, that any flow phenomena which are sensitive to Reynolds number such as separation and reattachment will not result in agreement between model and prototype. Any improvement in diffusion which results from a geometric change must address this consideration.

Once Mach number had been established as the scaling parameter the cold flow model carried with it a significant scaling bonus. Mach number will ratio out any thermal effects since temperature appears as a dependent variable in both the stream and sonic velocities which comprise the ratio. In the context of this study, an order of magnitude difference between cold flow and hot flow temperatures will fail to elevate Reynolds effects beyond second order. At worst, an error within the range of computational accuracy is anticipated due to temperature extremes between model and prototype with the model outperforming the prototype. Work conducted by Welch {Ref. 16} with subsonic exhaust stack ejectors using Mach number scaling shows deviations of less than 1%

between hot and cold flow model test results. An order of magnitude in temperature variation occurred in these studies.

The TF30 in the afterburning mode, having the largest throat area, governed the compressor-engine match. One dimensional isentropic nozzle flow theory for choking requires that mass flow obey the following expression:

$$\dot{m} = \frac{A^* \times P_o}{\sqrt{T_o}}$$

The available air supply had the capacity to deliver 2.65 atmospheres and 12.0 lbm/sec at 600 degrees R. 2.65 atmospheres would be the maximum achievable ratio of total pressure to exhaust pressure under atmospheric conditions in the nozzle exit. This ratio was below the desired test range but could be boosted by utilizing an exhauster to lower exhaust pressure at the expense of air flow to drive the apparatus.

A survey of ejectors previously driven by this compressor revealed one design with a convergent-divergent nozzle, operating with half (½) an atmosphere back pressure, capable of pumping 2.0 lbm/sec with the exhauster drawing 8.85 lbm/sec. The total flow of 10.85 lbm/sec was well within the capability of the compressor and 2.0 lbm/sec was chosen as the design mass flow rate for an expected ratio of total pressure to exhaust pressure of 5.70. For 2.0 lbm/sec at 2.65 atmospheres and 600^o R, a throat diameter (d*) was computed to be 1.735 inches. Conservatively, a primary nozzle throat of 1.675

inches was chosen, which resulted in an $A^* = 2.204$ (in^2) and mass flow equal to 1.863 lbm/sec.

The TF30 has an actual throat area of 7.5 (ft^2) and diameter of 3.09 ft. Dividing this by the throat of the model, a scaling factor of 22.139 was derived. Full scale drawings of the test cell and diffuser assemblies to be modeled were scaled using this factor. License was taken to modify supports or stiffeners to accommodate fabrication and assembly. Detail drawings of the scaled model are included as Appendix F.

APPENDIX B

NAPC TEST FACILITY IMPROVEMENT PROGRAM

The Naval Air Propulsion Center is a major jet engine test facility, located in Trenton, New Jersey. It is the only facility in the nation capable at one site of testing turbojet/turbofan, turpoprop/turboshaft engines under sea level, altitude and environmental conditions.

Engine Testing. The engine facility is composed of three major divisions: the Blower Wing, Test Wing and Exhauster Wing. A schematic is presented as Figure 36.

Blower Wing. The Blower Wing contains centrifugal air compressors and air conditioning systems which provide air to the test engine under the same conditions experienced by an aircraft in flight. Four 6,000 horsepower centrifugal blowers, one 30,000 horsepower gas turbine powered axial compressor, 5,000 tons of refrigeration, and an oil-fired indirect air heater are utilized to provide air flows up to 700 lbm/sec, at pressures up to five atmospheres and at air temperatures ranging from -65°F to +650°F. With these inlet conditions to the engine, the center can simulate flight velocities up to three times the speed of sound.

Test Wing. The Test Wing contains eleven test cells and their associated control rooms. Three of these cells are large altitude chambers, four are small altitude chambers for turboprop/turboshaft/auxiliary power unit testing, two

AD-A136 745 DESIGN AND TESTING OF SCALED EJECTOR-DIFFUSERS FOR JET ENGINE TEST FACILITY APPLICATIONS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA J W MOLLOY SEP 83 2/2

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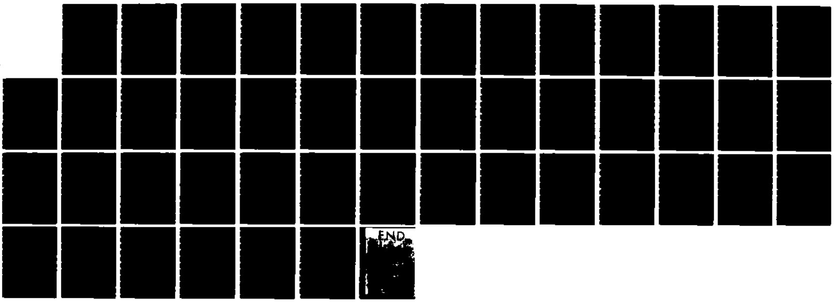
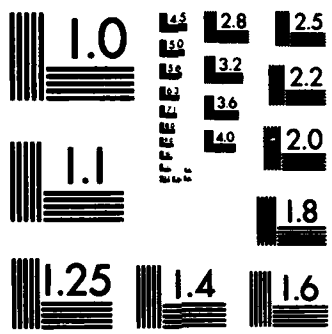




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

are large sea level test cells, one all purpose test tunnel and a helicopter transmission test facility. Test cell capabilities are summarized in Table B.1.

Exhauster Wing. The Exhauster Wing contains the air pumping machinery required to produce low pressure in the altitude test cells. Fourteen of these pumps with a combined power of 56,000 horsepower are utilized in conjunction with Test Chamber exhaust ejectors to simulate altitudes up to 100,000 feet. Table B.2 summarizes the performance parameters of ejector-diffuser (Figure 34) accompanies the large engine testing with straight tube diffusers accommodating smaller engines. Two of the engines which span the range of operation are the TF30 and the F404, whose characteristics are shown in Table B.3.

Facility Improvement Program. In January of 1982, an initiative to reduce the power consumption costs, directly related to engine testing, was proposed.

The stated objective was: Improve ejector-diffuser performance in NAPC altitude test cells to minimize exhauster power costs.

The appraoch proposed was:

Phase I. Survey the community for current advancements in ejector-diffuser performance, high-temperature materials applications and related functional fields. Examine alternate extended variable geometry ejector-diffuser concepts which will provide optimum performance by accommodating engine nozzle throat area variation.

TABLE B.1

CONDITIONS		3E	2E	1E	1W	2W	3W	4W	5W	6W
Airflow (lb./sec.)		700	430	430	350	350	100	100	100	100
Inlet Temp. (^{o}F)	Cold	-65	-65	-65	-65	-65	-65	-65	-65	-65
	Hot	+650	+390	+390	+220	+220	+220	+220	+220	+220
Mach Number		3.0	2.4	2.4	1.1	1.1	1.1	1.1	1.1	1.1
Altitude (ft)		100,000	80,000	80,000	S.L.	S.L.	80,000	80,000	80,000	80,000
Test Area	Length (ft)	30	18	18	56	56	15	20	17	17
	Width/Diam.(ft)	17	14.5	14.5	23	23	8	10	10	10
	Height (ft)	----	----	----	14	14	8	----	10	10

Table B.2

MASS FLOW	:	50 - 300 LB/SEC
VELOCITY	:	SUPERSONIC AT ENGINE NOZZLE WITH OBLIQUE SHOCKING TO SUBSONIC IN DIFFUSER
ENGINE NOZZLE EXHAUST TEMP	:	$1000^{\circ}F$ - $3500^{\circ}F$ (CORE)
ENGINE NOZZLE PRESSURE RATIO	:	3 - 14
ENGINE NOZZLE AREA	:	200 - 1200 in^2
OPTIMUM DIFFUSER AREA TO ENGINE NOZZLE THROAT AREA RATIO	:	3½ - 4
SECONDARY AIR TO PRIMARY AIR MASS FLOW RATIO	:	.08 - .15
TEST CELL ALTITUDE PRESSURE	:	1 - 14.7 psia
SECONDARY AIR TEMPERATURE	:	$100^{\circ}F$ - $200^{\circ}F$

Table B.3

Engine	Max. Thrust	Stages	MDOT	CPR
TF30	20,900	16	242	19.8:1
F404	16,000	3F,7C	140	25:1

Phase II. Select one or two of the most feasible concepts and evaluate performance with cold flow model testing. Select the optimum concept and confirm mechanical and aerodynamic performance with hot flow model testing. Analyze full-scale implementation cost versus potential power savings and determine payback period.

Phase III. Design, fabricate, install, test and evaluate a full-scale ejector-diffuser in one NAPC altitude test cell. Convert the remaining two NAPC test cells to full-scale ejector-diffuser.

APPENDIX C

DIFFUSER PROPOSALS

Proposals to modify the baseline diffuser geometries were developed with emphasis towards providing control over the shock mechanism. The design limitations were imposed by maintaining geometric similarity of the flow paths and the range of engines to be tested. Whereas simplicity would be incorporated where feasible, no constraints were imposed on the design with resepct to strength, thermal effects, vibration or leakage.

Translating Wedge. A double hinged wedge in a rectangular duct was the first proposal considered. This assembly is shown in Figure 38. The two dimensional wedge was expected to provide more positive control over the strength of the shock system compared to the cone centerbody. All of the experimenters who have investigated a second throat diffuser have concurred that an optimum second throat size and axial position relative to the nozzle exit exist. The wedge would allow a finer control of the size versus axial position of the second throat than the cone assembly. The current centerbody notably couples the size of the second throat with the axial position of the centerbody. The translating wedge provides uncoupling of these variables with an expectation that the optimum can be approached by adjusting the second ramp to facilitate starting, then translating the wedge to move the second throat to a position of lower Mach number, which should improve performance. The wedge would then be mapped against the baseline configurations for analysis. Current design techniques call for running a matrix at various settings, shutting down, reviewing the data, developing a new matrix based upon judgement and repeating the cycle. Cost and time consumption without achieving any guarantee of an optimum are a natural by-product of this process. As the number of independent variables increases, the test matrix becomes much more complex with the possible permutations following combinatorial theory. A simplified matrix of the test process as shown in Table C.1 leads one to recognize the merit of online evaluation. A real time mapping of pressure ratios would be prescribed for evaluating this model. This would permit detailed investigations when a point of significance was reached. Typically, once starting was confirmed, the wedge angles and/or their axial positions could be varied and the effect noted.

Auxiliary Mass Ejection. The deleterious effect of secondary flow gives rise to the possibility of equipping the test cell with an auxiliary ejector. This proposal, while not new, has oft been dismissed as being not cost effective. The recent cost spiral in exhauster power consumption opens the topic for renewed consideration. As observed in the baseline studies, the power setting of the engine has a dramatic effect on exhauster requirements and therefore, a direct bearing on power consumption costs. The

Table C.1

Optimization Goal	PT8	PS9	P14	Variable Size A_d	Position A_d	$\dot{m}_s$
STARTING	H	V	A	H	H	H
STARTING	H	V	H	A	H	H
STARTING	H	V	H	H	A	H
STARTING	H	V	H	A	A	H
STARTING	H	V	A	A	H	H
PRESSURE RECOVERY	H	H	A	H	H	H
PRESSURE RECOVERY	H	H	H	A	H	H
PRESSURE RECOVERY	H	H	H	H	A	H
PRESSURE RECOVERY	H	H	H	A	A	H
PRESSURE RECOVERY	H	H	A	A	H	H
PRESSURE RECOVERY	H	H	A	H	A	H

H = HOLD CONSTANT

V = LET VARY

A = ADJUST

efficiency of the exhauster, when operating at off-design conditions, will be less, and the blend of an efficient auxiliary ejector to allow the prime exhauster to function at or near design should enhance overall efficiency. The ramifications of this approach are detailed in the discussion of results.

APPENDIX D

EXPERIMENTAL PROCEDURE

System Checkout. The Allis-Chalmers compressor is maintained and operated by TPL personnel. Twenty minutes of prelubrication is required on the compressor prior to start followed by approximately twenty minutes of warmup before the compressor is ready to assume the load of supplying air to the experimental apparatus. During this time it is prudent to accomplish the following checks and tasks:

1. Examine all pressure taps, tubing, and connections to Scanivalve port manifold and the two dedicated pressure transducers. Verify instrumentation is connected in accordance with Figure 39.

2. Turn on thermocouple ice point reference, and examine all thermocouples for broken wires or loose connections.

3. Hand test all PVC couplings for tightness and check to see that the primary and secondary root valves are open.

4. Turn on the HP-9830A Calculator and printer, HP-9867B Mass Memory Storage Unit, Scanivalve Multiplexer (S/V MUX), PH-3495A Scanner, HP-3455 Digital Voltmeter, Scanivalve control power supply, and the three separate digital voltmeters used for monitoring centerbody drive voltage, engine test cell pressure, and exhaust chamber pressure.

5. Load the program "VIBTEM" (Table I) into the memory of the HP-9830A calculator. Run the program once to ensure there are no anomalous readings from any thermocouple or pressure tap.

6. Read and record atmospheric pressure from the Wallace and Tiernan gage.

Procedure to Conduct Data Runs. Control of the experiment is exercised at the remote operating station. (Figure 19). ******WARNING****** FAILURE TO OPEN THE EXHAUST VALVE FIRST CAN RESULT IN OVERPRESSURIZATION OF THE SYSTEM. The system is brought on line by opening the exhaust valve fully and then the primary air may be cut into the system. Monitoring of total and exhaust pressure on the digital voltmeters allows setting of test point pressures in accordance with the test matrix.

APPENDIX E

SECOND THROAT DIFFUSERS

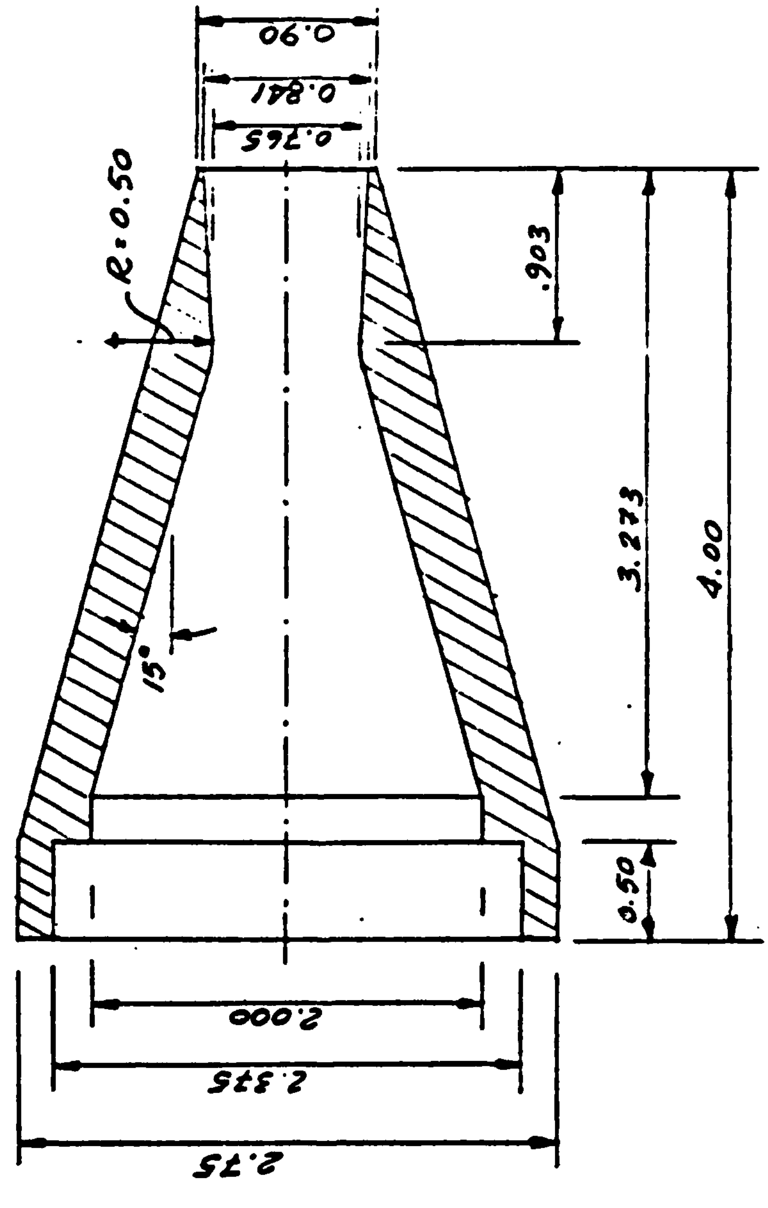
Second throat ejector-diffusers have had wide acceptance in gas turbine engine testing due to their ability to provide systems flexibility to cope with the variabilities involved in altitude testing. A variable area second throat geometry such as that shown in Figure 38 was developed when sizing and location of the optimum second throat was loosely defined. The idealization of the process is well understood, as detailed by Shapiro {Ref. 8} in his discussion of supersonic wind tunnels. The objective is to seek the maximum exhaust pressure at which the ejector-diffuser once started, can be maintained. A brief description of the operation permits an appreciation of the phenomenon involved. As mass flow through the nozzle is accelerated, the flow becomes supersonic and will cause a decrease in cell pressure by mixing. Exhaust pressure is lowered until a minimum cell pressure is attained with the ejector-diffuser then being considered "started." At this point, the shock stands upstream of the secondary throat and cell pressure becomes independent of exhauster pressure. Exhaust pressure may then be increased to the point where cell pressure begins to rise. This establishes the system's operating range. The variable geometry with a conical centerbody evolved to accommodate the complex mix of parameters required to approach even near optimum operation. This concept, while attractive, couples a decrease in second throat area with a change in axial position of that throat,losing a degree of freedom which may be exploited for further gains. Although the goal of the design is to alter the second throat, the centerbody itself will influence the character of the shock system and, thus, may also be in direct competition with second throat effects as related to pressure recovery. Adding a degree of freedom here may also improve performance.

The final design of the variable diffuser utilized by NAPC was formulated in the early 60's, and the rationale behind the final geometry is not well defined. A best estimate is that the design was a compromise between model test studies and manufacturing ease and costs. The need to optimize the design for small percentage improvements in exhauster back pressure were likely secondary.

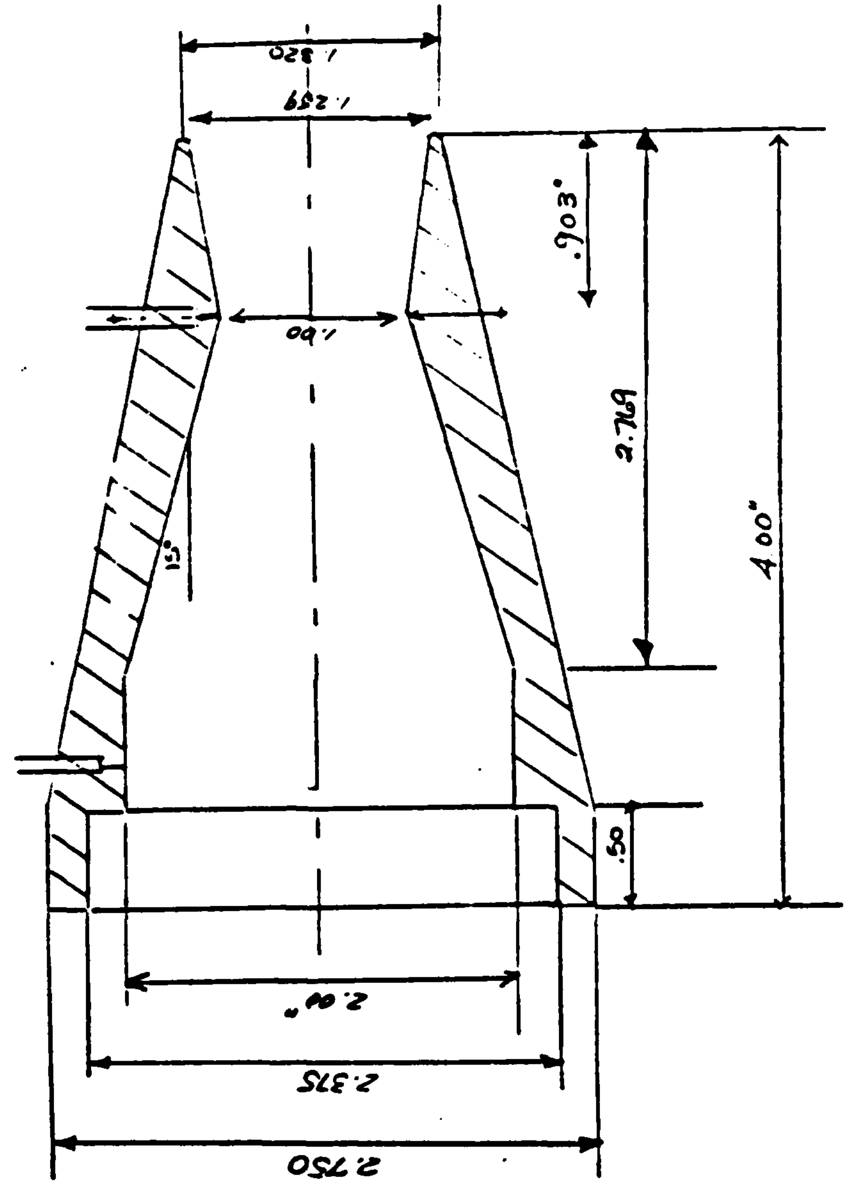
APPENDIX F

SCALED DRAWINGS

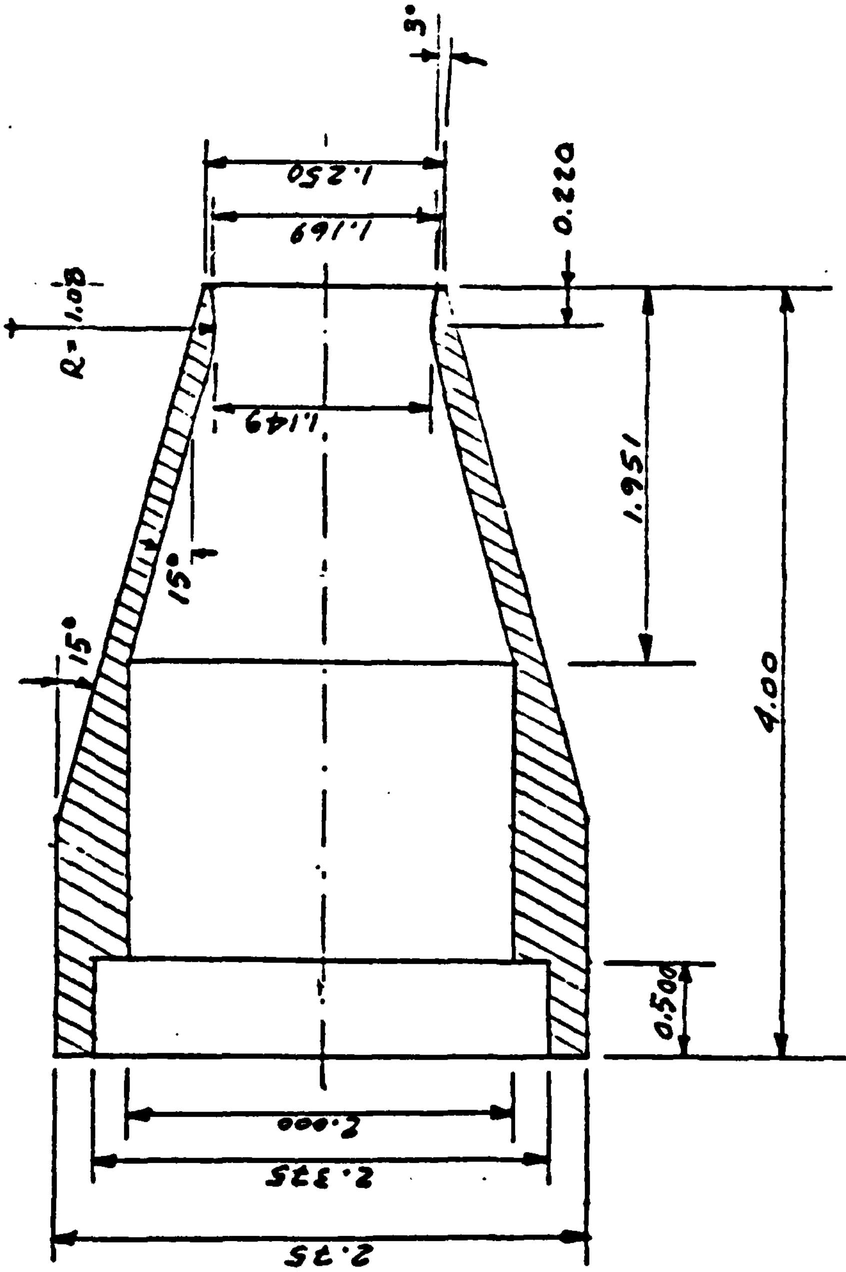
The scaled drawings in this Appendix represent the principal components of the design. All linear dimensions are in inches and angular measurements in degrees.



F404 Non A/B



F404 A/B



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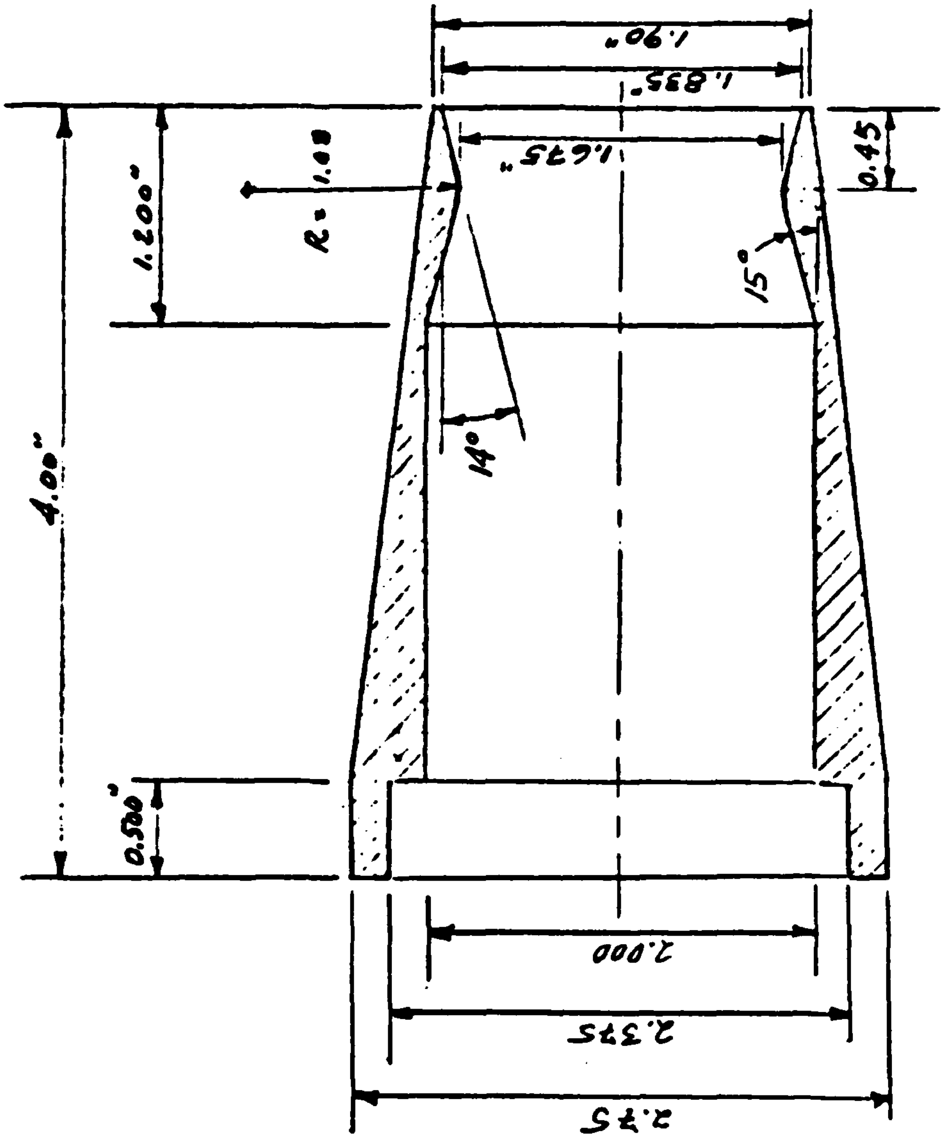
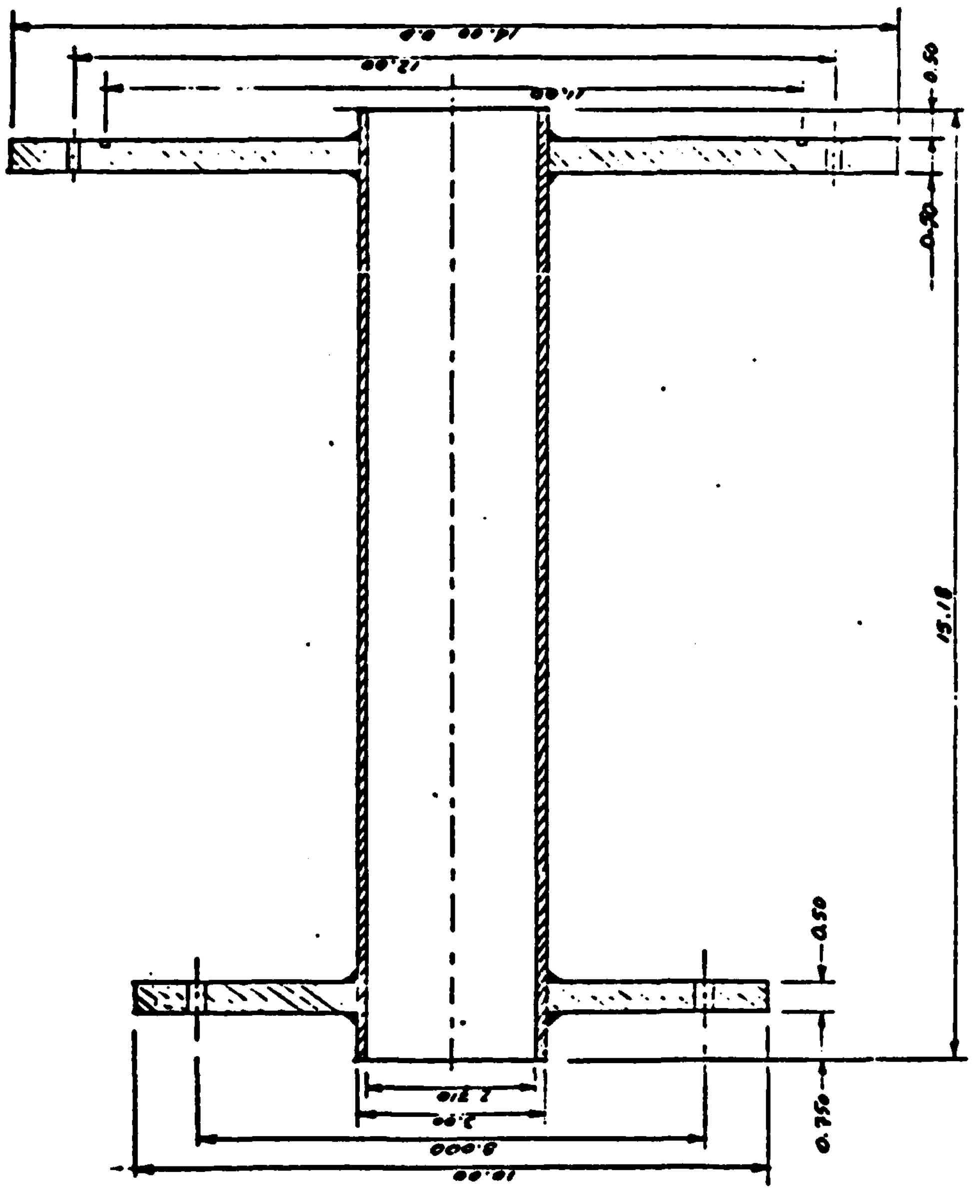
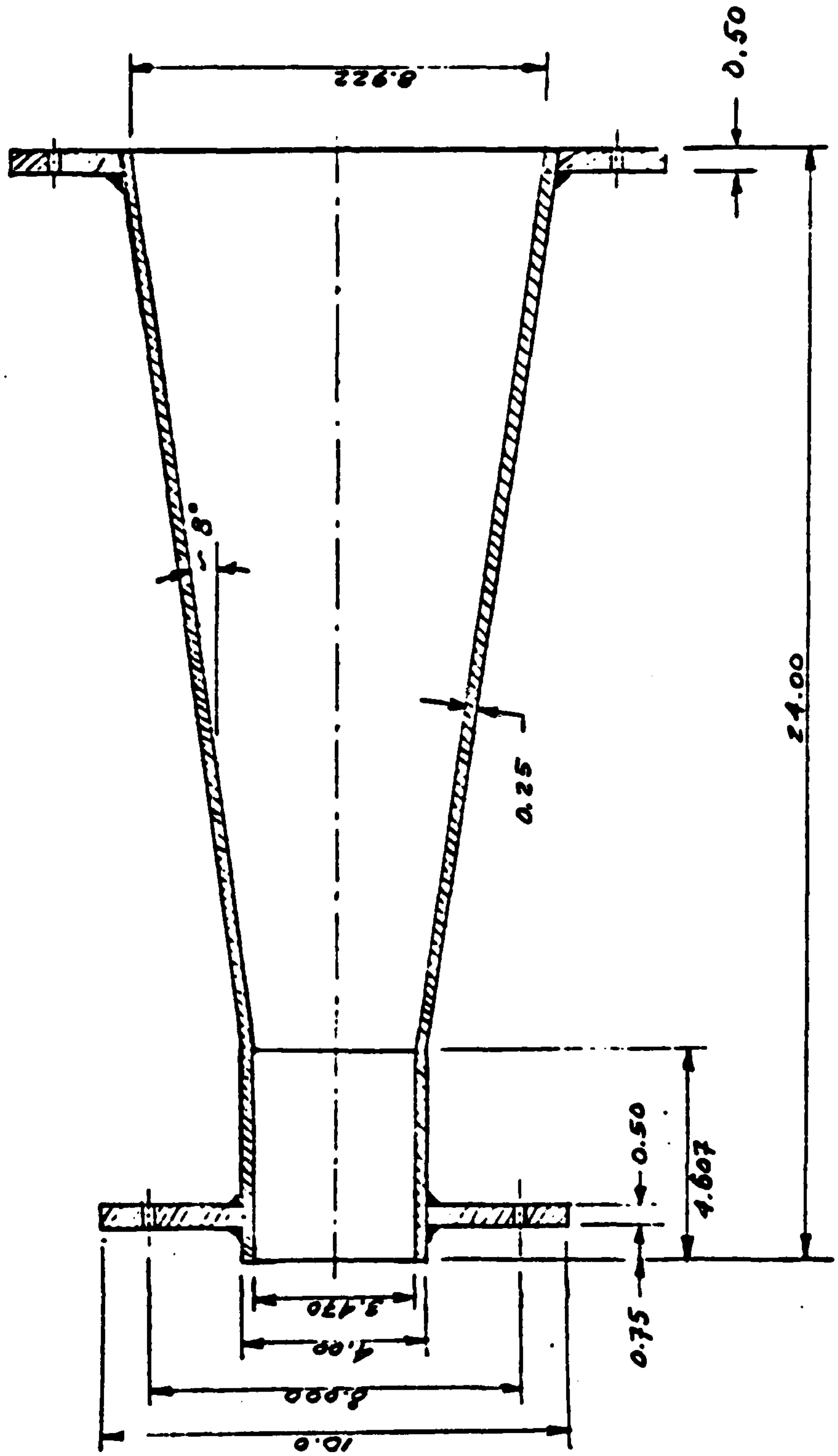


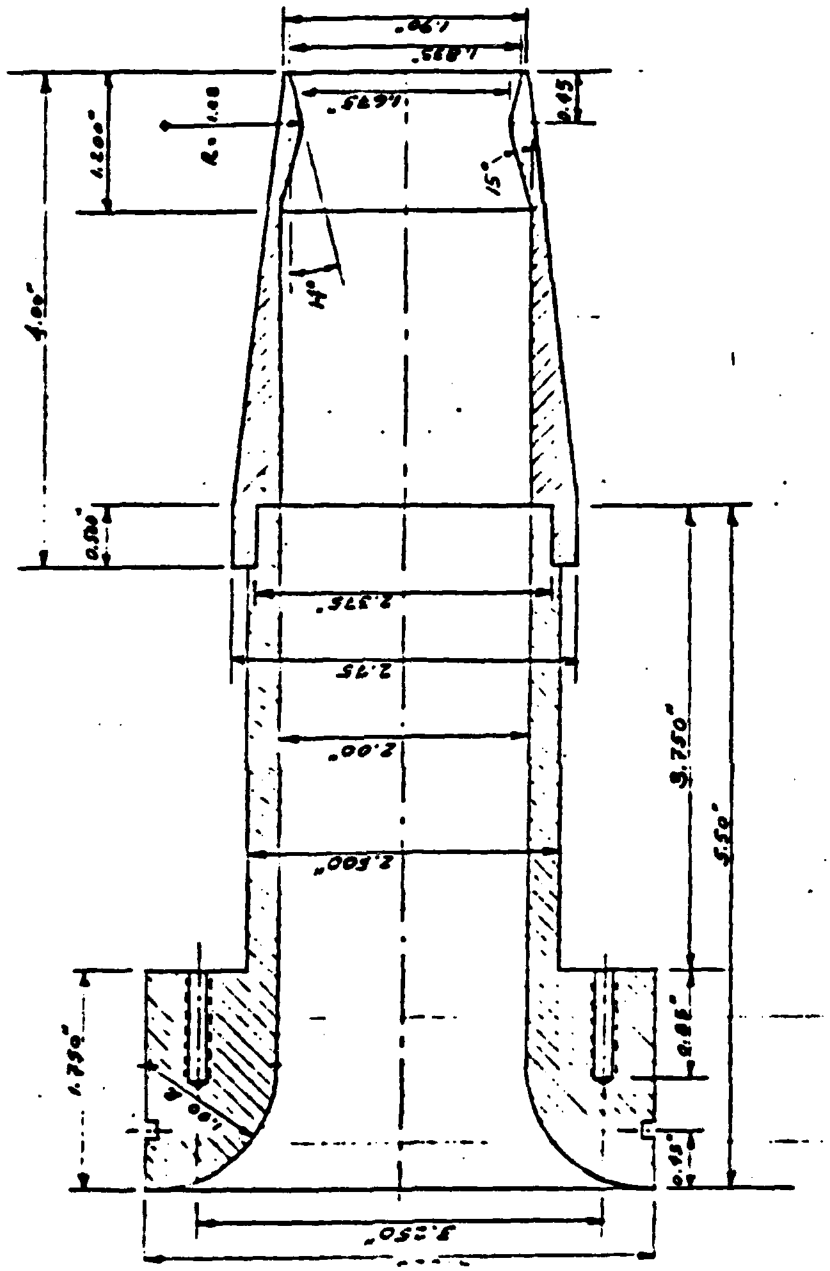
TF30 A/B



Constant Area Diffuser



Variable Area Diffuser



Engine Mounting

APPENDIX G

DATA TABLES

This appendix summarizes the reduced data collected during the course of this study. One set of raw data is included to summarize the details of the data acquisition process. The following abbreviations and units refer only to the data contained herein.

Abbreviations and Units

P ATM	Atmospheric Pressure (in. Hg)
P 01S P 02S	Secondary Orifice Pressures Upstream (in. H20)
P 03S P 04S	Secondary Orifice Pressures Downstream (in. H20)
P 01P P 02P	Primary Orifice Pressures Upstream (in. H20)
P 03P P 04P	Primary Orifice Pressures Downstream (in. H20)
P TOT	Total Pressure - PT8 (in. H20)
P TST	Inlet Static Pressure (in. H20)
P CEL	Cell Pressure - PS9 (in. H20)
P THS	Nozzle Entrance Pressure (in. H20)
P THT	Nozzle Throat Pressure (in. H20)
P D#_	Diffuser Wall Pressures (in. H20)
P EXH	Exhaust Pressure - P14 (in. H20)
T PRI	Primary Orifice Temperature (R)
T SEC	Secondary Orifice Temperature (R)

T TOT	Total Temperature (R)
MASS FLOW	(lbm/sec)
P STAG	(in. H20 abs.)
T STAG	(Degrees R)

DATE OF RUN 7/15/1983
ENGINE TESTED MODEL F404 WO/AFTER BURNER
DIFFUSER TESTED 2/1 SCALE
REFERENCE DATA FILE RUN5A

RUN NUMBER

	1	2	3	4	5	6	7	8	9	10
P ATM	29.78	29.78	29.78	29.78	29.78	29.78	29.78	29.78	29.78	29.78
P O1S	-12.60	-12.30	-12.00	-11.00	-11.00	-11.00	-11.00	-13.00	-14.00	-14.00
P O2S	-12.60	-12.30	-12.00	-11.00	-11.00	-11.00	-11.00	-13.00	-14.00	-14.00
P O3S	-12.60	-12.30	-12.00	-11.00	-11.00	-11.00	-11.00	-13.00	-14.00	-14.00
P O4S	-12.60	-12.30	-12.00	-11.00	-11.00	-11.00	-11.00	-13.00	-14.00	-14.00
P O1P	756.00	704.00	655.90	603.10	553.80	506.30	453.30	403.70	401.70	452.70
P O2P	756.70	703.80	655.50	601.80	553.60	508.20	454.20	401.50	401.70	452.80
P O3P	763.20	711.50	649.50	597.50	548.70	502.80	448.00	398.80	398.20	449.70
P O4P	763.20	711.50	649.50	597.50	548.70	502.80	448.00	398.80	398.20	449.70
P TOT	749.20	698.60	650.70	599.40	550.10	504.60	450.00	400.30	398.60	449.60
P TST	750.20	698.50	650.40	598.80	549.50	504.80	448.20	399.70	397.20	448.50
P CEL	-186.00	-178.70	-165.00	-154.50	-141.10	-131.60	-121.40	-110.20	-162.80	-176.60
P THS	739.60	688.10	640.90	591.00	543.50	499.10	443.40	393.60	393.50	443.70
P THT	2.70	-15.20	-31.50	-49.10	-66.00	-81.60	-101.10	-118.70	-119.70	-102.10
P THT	1.50	-16.10	-32.60	-50.60	-67.90	-84.20	-103.50	-121.30	-121.70	-103.70
P D#1	-163.40	-154.90	-147.10	-145.00	-115.49	-109.50	-103.50	-87.90	-157.00	-170.20
P D#2	-110.70	-105.50	-96.80	-95.10	-52.50	-50.20	-46.60	-37.70	-124.90	-127.80
P D#3	-79.70	-74.70	-64.70	-56.10	-24.30	-26.40	-21.10	-15.90	-100.10	-101.30
P D#4	-56.80	-52.80	-43.80	-36.90	-8.80	-10.70	-10.20	-8.40	-81.00	-78.70
P D#5	-36.10	-34.80	-27.60	-22.50	-7.80	-8.70	-9.00	-7.20	-68.10	-65.00
P D#6	-24.70	-24.20	-18.30	-14.60	-7.20	-7.70	-8.60	-7.80	-59.70	-60.60
P D#7	-16.60	-17.70	-12.30	-10.50	-5.80	-6.80	-7.80	-6.80	-54.80	-56.80
P D#8	-13.80	-14.40	-10.50	-9.60	-6.70	-7.80	-8.20	-6.80	-53.40	-56.20
P D#9	-11.80	-12.90	9.20	-8.80	-3.50	-5.20	-7.70	-6.80	-53.10	-55.30
P D#11	-11.30	-13.20	-9.80	-9.20	-7.10	-8.10	-8.80	-7.20	-52.80	-55.80
P D#12	-12.80	-14.50	-11.30	-10.40	-8.80	-9.50	-9.60	-7.80	-53.90	-56.70
P D#13	-5.40	-7.50	-5.00	-5.10	-3.60	-5.30	-5.50	-4.50	-49.80	-52.10
P D#14	-2.40	-4.80	-2.20	-2.30	-1.30	-2.80	-3.90	-2.90	-48.10	-49.60
P D#15	-2.40	-2.30	-2.60	-2.60	-2.40	-2.60	-2.40	-2.70	-2.90	-3.00
P EXH	-0.40	-4.30	-0.90	-0.80	-0.40	-1.80	-2.90	-2.10	-47.30	-48.90
T PRI	569.10	568.10	566.20	566.70	566.20	565.90	566.70	567.30	567.80	569.00
T SEC	528.80	528.70	528.30	528.80	528.80	528.00	528.70	528.70	528.70	528.70
T TOT	560.30	559.40	556.[illegible]	558.40	557.90	557.40	558.40	558.70	558.80	559.80

DATE OF RUN 7/15/1983
ENGINE TESTED MODEL F404 WO/AFTER BURNER
DIFFUSER TESTED 2/1 SCALE
REFERENCE DATA FILE RUN56

	RUN NUMBER									
	11	12	13	14	15	16	17	18	19	20
P ATM	29.78	29.78	29.78	29.78	29.78	29.78	29.78	29.78	29.78	29.78
P O1S	-15.00	-15.00	-16.00	-16.00	-16.30	-16.00	-16.00	-15.00	-15.00	-17.00
P O2S	-15.00	-15.00	-16.00	-16.00	-16.00	-16.00	-16.00	-15.00	-15.00	-17.00
P O3S	-15.00	-15.00	-16.00	-16.00	-16.00	-16.00	-16.00	-15.00	-15.00	-17.00
P O4S	-15.00	-15.00	-16.00	-16.00	-16.00	-16.00	-16.00	-15.00	-15.00	-17.00
P O1P	501.30	553.50	602.40	654.30	705.00	758.90	781.90	780.20	780.00	819.00
P O2P	502.30	553.30	601.60	653.90	702.90	760.10	781.10	781.00	778.00	819.70
P O3P	498.00	549.00	596.00	648.20	698.00	752.30	775.80	775.40	773.50	812.30
P O4P	498.00	549.00	596.00	648.20	698.30	752.30	775.80	775.40	773.50	812.30
P TOT	498.20	550.40	597.60	649.10	699.33	752.70	774.10	774.80	773.20	810.70
P TST	497.00	550.40	596.60	649.60	697.90	754.90	776.20	776.00	775.50	813.60
P CEL	-188.50	-201.60	-211.60	-232.00	-243.50	-253.20	-255.50	-323.70	-192.00	-201.10
P THS	490.70	541.60	587.10	637.80	687.50	741.30	764.20	766.50	765.00	803.70
P THT	-85.40	-67.30	-51.30	-33.20	-16.30	2.30	9.90	8.20	11.30	24.60
P THT	-86.30	-68.00	-51.60	-33.40	-16.10	2.40	10.10	10.40	9.80	23.40
P D#1	-181.10	-184.90	-193.60	-212.50	-226.60	-230.90	-232.70	-237.40	-169.80	-177.40
P D#2	-139.50	-142.80	-149.00	-163.00	-174.30	-172.60	-172.00	-208.30	-114.70	-117.70
P D#3	-103.90	-117.10	-122.30	-134.70	-143.30	-134.60	-137.40	-165.00	-79.20	-82.20
P D#4	-81.10	-95.50	-98.80	-106.00	-119.00	-110.70	-111.20	-146.90	-50.80	-53.30
P D#5	-68.60	-78.30	-83.40	-86.10	-101.00	-93.50	-91.60	-143.30	-30.10	-29.30
P D#6	-61.90	-68.90	-73.20	-79.10	-87.60	-83.90	-83.20	-143.10	-22.60	-22.30
P D#7	-59.00	-63.00	-64.60	-72.20	-77.50	-76.40	-76.00	-147.60	-17.50	-16.30
P D#8	-57.90	-60.60	-62.30	-70.90	-77.20	-73.70	-73.30	-146.00	-14.50	-14.40
P D#9	-57.00	-59.40	-61.30	-70.80	-74.70	-73.20	-71.30	-144.90	-13.40	-14.30
P D#11	-57.20	-59.40	-61.00	-71.50	-74.10	-73.50	-72.60	-143.90	-13.60	-14.50
P D#12	-58.60	-60.40	-62.30	-73.60	-76.30	-74.80	-73.50	-145.90	-15.10	-16.10
P D#13	-53.40	-54.20	-56.00	-66.30	-68.80	-67.10	-65.30	-142.00	-7.80	-8.60
P D#14	-51.10	-52.20	-53.00	-62.10	-66.50	-62.80	-61.50	-135.10	-4.10	-4.00
P D#15	-3.00	-2.90	-3.10	-2.90	-2.80	-3.20	-3.00	-2.90	-2.40	-2.50
P EIN	-49.80	-50.60	-51.80	-61.00	-63.40	-60.10	-59.30	-130.80	-2.30	-2.40
T PRI	570.00	571.70	572.10	573.00	573.10	572.80	572.50	571.90	571.10	569.60
T SEC	528.70	529.10	529.10	529.30	529.20	529.10	529.00	529.00	528.90	529.00
T TOT	560.60	562.80	563.10	564.00	564.10	564.00	563.70	563.10	562.10	561.30

DATE OF RUN 7/15/1983
ENGINE TESTED MODEL F404 WO/AFTER BURNER
DIFFUSER TESTED 2/3 SCALE
REFERENCE DATA FILE BUN5C

RUN NUMBER

	21	22	23	24	25	26	27	28	29	30
P ATM	29.78	29.78	29.78	29.78	29.78	29.78	29.78	29.78	29.78	29.78
P 01S	-18.00	-17.00	-17.00	-16.00	-16.00	-14.00	-13.00	-13.00	-11.00	-8.00
P 02S	-18.00	-17.00	-17.00	-16.00	-16.00	-14.00	-13.00	-13.00	-11.00	-8.00
P 03S	-18.00	-17.00	-17.00	-16.00	-16.00	-14.00	-13.00	-13.00	-11.00	-8.00
P 04S	-18.00	-17.00	-17.00	-16.00	-16.00	-14.00	-13.00	-13.00	-11.00	-8.00
P 01P	818.10	817.50	756.40	704.40	656.50	606.90	554.40	505.60	453.90	402.00
P 02P	817.80	816.50	757.40	706.00	657.30	607.10	555.30	505.40	454.60	402.00
P 03P	811.00	810.30	751.10	699.00	649.90	601.70	550.10	500.50	450.70	399.30
P 04P	811.00	810.30	751.10	699.00	649.90	601.70	550.10	500.50	450.70	399.30
P TOT	810.30	808.70	751.80	700.00	650.60	602.70	551.30	501.10	451.10	399.80
P TST	813.60	810.20	751.90	700.20	650.10	602.20	550.70	500.50	450.80	399.60
P CEL	-266.40	-325.60	-322.40	-314.30	-293.50	-267.90	-251.00	-233.30	-216.50	-198.30
P THS	803.30	802.30	745.20	692.10	642.60	596.30	546.30	494.80	445.40	395.20
P THT	22.30	20.10	-0.30	-17.60	-33.10	-48.30	-66.00	-83.80	-101.30	-118.90
P THT	23.40	23.50	4.90	-12.90	-30.20	-45.80	-64.30	-84.40	-98.80	-116.70
P D#1	-234.00	-227.60	-238.10	-266.10	-267.20	-248.80	-235.40	-219.40	-202.10	-191.20
P D#2	-162.90	-213.90	-197.40	-202.40	-207.60	-200.60	-189.10	-174.80	-164.90	-149.90
P D#3	-126.80	-175.50	-156.00	-176.50	-176.20	-165.70	-156.20	-151.70	-140.60	-126.10
P D#4	-103.00	-151.10	-187.70	-181.90	-151.40	-145.00	-133.50	-131.50	-121.80	-106.20
P D#5	-89.20	-151.40	-143.50	-151.10	-143.90	-130.50	-122.30	-117.10	-107.00	-94.20
P D#6	-83.10	-151.70	-145.30	-147.30	-134.10	-120.50	-112.80	-105.90	-98.40	-87.00
P D#7	-77.70	-149.50	-144.20	-141.80	-129.20	-114.60	-106.90	-99.80	-92.20	-83.20
P D#8	-75.50	-145.20	-143.60	-142.50	-127.80	-113.50	-103.70	-97.60	-89.90	-82.10
P D#9	-76.70	-146.40	-144.00	-137.00	-128.30	-111.20	-103.00	-96.10	-90.20	-82.70
P D#11	-76.60	-147.50	-143.80	-140.00	-127.50	-111.90	-104.30	-97.60	-90.00	-82.20
P D#12	-79.00	-148.80	-144.20	-144.80	-131.40	-112.50	-103.00	-97.10	-90.50	-83.00
P D#13	-70.40	-142.30	-140.70	-135.50	-121.90	-106.30	-99.40	-91.80	-84.80	-78.90
P D#14	-64.40	-135.70	-136.50	-127.40	-117.80	-100.70	-96.10	-89.60	-83.30	-77.20
P D#15	-2.40	-2.30	-1.90	-2.20	-2.60	-2.30	-2.50	-2.40	-2.00	-1.80
P EXH	-62.40	-128.80	-131.70	-122.90	-115.90	-100.60	-94.60	-88.30	-81.80	-76.80
T PRI	568.40	567.00	563.50	561.90	560.40	558.70	557.60	556.20	554.90	551.50
T SEC	528.90	528.70	528.60	528.50	528.30	528.00	528.70	528.70	529.00	528.70
T TOT	560.30	559.10	555.50	554.20	552.60	550.90	549.80	548.20	547.10	543.00

DATE OF RUN 7/15/1983
ENGINE TESTED MODEL F404 WO/AFTER BURNER
DIFFUSER TESTED 2/3 SCALE
REFERENCE DATA FILES RUN5

RUN NO.	MASS FLOW PRI	MASS FLOW SEC	P STAGNATION	T STAGNATION	PT8/PS9	PS14/PT8	PT14/PS9
1	0.41446	0.00000	1157.082	560.10	5.215	0.352	1.836
2	0.39668	0.00000	1106.482	559.10	4.828	0.365	1.761
3	0.38015	0.00000	1058.582	557.20	4.358	0.384	1.676
4	0.36157	0.00000	1007.282	557.70	3.975	0.404	1.607
5	0.34402	0.00000	957.982	557.20	3.591	0.425	1.527
6	0.32777	0.00000	912.482	556.90	3.303	0.445	1.470
7	0.30794	0.00000	857.882	557.70	2.995	0.472	1.414
8	0.28994	0.00000	808.182	558.30	2.715	0.502	1.363
9	0.28921	0.00000	806.482	558.80	3.291	0.447	1.471
10	0.30717	0.00000	857.482	560.00	3.708	0.419	1.552
11	0.32430	0.00000	906.082	561.00	4.130	0.395	1.632
12	0.34247	0.00000	958.282	562.70	4.645	0.373	1.732
13	0.35921	0.00000	1005.482	563.10	5.123	0.354	1.814
14	0.37731	0.00000	1056.982	564.00	6.010	0.328	1.972
15	0.39520	0.00000	1107.182	564.10	6.735	0.311	2.096
16	0.41437	0.00000	1160.582	563.80	7.503	0.300	2.248
17	0.42212	0.00000	1181.982	563.50	7.757	0.295	2.288
18	0.42259	0.00000	1182.682	562.90	14.049	0.234	3.291
19	0.42231	0.00000	1181.082	562.10	5.471	0.343	1.879
20	0.43630	0.00000	1218.582	560.60	5.893	0.333	1.961
21	0.43661	0.00000	1218.182	559.40	8.610	0.284	2.442
22	0.43658	0.00000	1216.582	558.00	14.785	0.229	3.392
23	0.41745	0.00000	1159.682	554.50	13.566	0.238	3.231
24	0.39937	0.00000	1107.882	552.90	11.839	0.257	3.045
25	0.38207	0.00000	1058.482	551.40	9.262	0.276	2.555
26	0.36534	0.00000	1010.582	549.70	7.219	0.304	2.195
27	0.34710	0.00000	959.182	548.60	6.114	0.327	1.997
28	0.32935	0.00000	908.982	547.20	5.207	0.352	1.831
29	0.31159	0.00000	858.982	545.90	4.488	0.380	1.704
30	0.29389	0.00000	807.682	542.50	3.854	0.410	1.580

DATE OF RUN 7/18/1983
ENGINE TESTED MODEL F404 WO/AFTER BURNER
DIFFUSER TESTED 2/3 SCALE
REFERENCE DATA FILES RUN8

RUN	MASS FLOW	MASS FLOW	P	T	PT8/PS9	PS14/PT8	PT14/PS9
1	0.43434	0.02553	1212.267	559.80	16.214	0.225	3.643
2	0.43351	0.04704	1210.267	560.10	13.497	0.226	3.055
3	0.43337	0.08314	1209.567	559.80	11.213	0.228	2.558
4	0.43250	0.08758	1209.367	561.90	10.978	0.228	2.503
5	0.43143	0.10699	1206.467	562.00	9.900	0.232	2.292
6	0.39682	0.06241	1110.367	562.70	8.704	0.257	2.240
7	0.39653	0.07799	1109.467	562.60	8.801	0.259	2.280
8	0.39500	0.06076	1105.267	562.70	8.685	0.260	2.260
9	0.39839	0.05279	1114.767	562.70	12.350	0.255	3.145
10	0.39750	0.03281	1112.267	562.70	12.644	0.254	3.210
11	0.37496	0.00000	1011.167	522.00	7.503	0.306	2.297
12	0.43529	0.00000	1211.267	556.40	15.903	0.226	3.598
13	0.42653	0.00000	1186.167	555.70	14.983	0.237	3.554
14	0.41745	0.00000	1159.567	554.40	14.216	0.243	3.461
15	0.41047	0.00000	1139.267	553.50	13.520	0.249	3.369
16	0.40659	0.00000	1114.067	539.20	12.153	0.259	3.148
17	0.39727	0.00000	1083.367	534.00	10.859	0.271	2.944
18	0.38959	0.00000	1059.667	531.20	9.870	0.277	2.730
19	0.38209	0.00000	1033.767	525.50	8.386	0.296	2.483

DATE OF RUN 7/21/1983
ENGINE TESTED MODEL F404 W/AFTER BURNER
DIFFUSER TESTED 5/6 SCALE
REFERENCE DATA FILES RUN9

RUN NO.	MASS FLOW PRI	MASS FLOW SEC	P STAGNATION	T STAGNATION	PT8/PS9	PS14/PT8	PT14/PS9
1	0.42512	0.00000	1184.874	558.20	5.374	0.296	1.589
2	0.42555	0.00000	1186.674	558.80	4.108	0.347	1.425
3	0.29044	0.00000	809.574	558.30	3.118	0.416	1.298
4	0.32587	0.00000	910.074	560.50	3.916	0.357	1.397
5	0.42323	0.05289	1181.474	560.00	7.335	0.240	1.760
6	0.42319	0.09865	1181.774	560.40	7.099	0.240	1.706
7	0.42408	0.12426	1184.974	561.10	7.080	0.243	1.720
8	0.42286	0.13677	1181.474	561.00	6.539	0.242	1.581
9	0.42024	0.17806	1174.674	561.50	6.233	0.242	1.506
10	0.41978	0.22370	1173.574	561.70	5.857	0.245	1.433
11	0.39312	0.00000	1086.374	548.60	4.663	0.320	1.494
12	0.39413	0.00000	1088.074	547.50	6.353	0.268	1.702
13	0.39419	0.00000	1087.174	546.40	3.591	0.379	1.360
14	0.38575	0.00000	1062.074	544.50	3.487	0.386	1.346
15	0.38563	0.00000	1060.674	543.40	4.392	0.333	1.465
16	0.38601	0.00000	1060.374	542.00	5.912	0.278	1.645
17	0.37808	0.00000	1037.174	540.50	4.262	0.339	1.445
18	0.37872	0.00000	1036.674	538.10	5.539	0.288	1.598
19	0.37963	0.00000	1034.874	533.60	3.388	0.395	1.337
20	0.37214	0.00000	1012.574	531.60	3.261	0.404	1.316
21	0.42617	0.00000	1187.574	558.00	1.765	0.240	0.423
22	0.41944	0.00000	1166.874	556.10	7.290	0.242	1.762
23	0.41945	0.00000	1166.474	555.70	5.114	0.304	1.553
24	0.41974	0.00000	1167.274	555.70	4.005	0.353	1.412
25	0.40884	0.00000	1135.674	554.40	5.004	0.308	1.542
26	0.40953	0.00000	1136.774	553.60	7.075	0.252	1.785
27	0.41036	0.00000	1138.074	552.60	3.853	0.362	1.395
28	0.40153	0.00000	1111.974	551.00	3.693	0.372	1.373
29	0.40127	0.00000	1110.574	550.30	4.794	0.317	1.518
30	0.40170	0.00000	1110.974	549.50	6.842	0.262	1.793

DATE OF RUN 7/27/1983
ENGINE TESTED MODEL F404 WO/AFTER BURNER
DIFFUSER TESTED 5/6 SCALE
REFERENCE DATA FILES RUN12

RUN NO.	MASS FLOW PRI	MASS FLOW SEC	P STAGNATION	T STAGNATION	PS9/PT8	PS14/PT8	PT14/PS9
1	0.29395	0.00000	799.232	530.80	3.152	0.413	1.302
2	0.33018	0.00000	906.032	540.80	4.039	0.350	1.414
3	0.36530	0.00000	1006.232	545.00	5.149	0.304	1.563
4	0.36421	0.00000	1005.032	547.00	4.016	0.352	1.415
5	0.36556	0.00000	1009.832	548.20	3.329	0.398	1.326
6	0.37246	0.00000	1029.632	549.00	3.377	0.396	1.336
7	0.37253	0.00000	1030.932	550.20	4.390	0.334	1.467
8	0.37290	0.00000	1032.432	550.70	5.672	0.286	1.620
9	0.38044	0.00000	1054.232	551.70	6.160	0.278	1.712
10	0.38083	0.00000	1056.732	553.20	4.496	0.330	1.482
11	0.38135	0.00000	1059.032	554.10	3.510	0.385	1.352
12	0.38900	0.00000	1081.332	555.20	3.643	0.376	1.370
13	0.38876	0.00000	1080.832	555.40	4.897	0.313	1.532
14	0.38894	0.00000	1081.932	556.00	6.501	0.190	1.233
15	0.39711	0.00000	1105.332	556.70	7.003	0.257	1.796
16	0.39679	0.00000	1105.132	557.40	4.859	0.315	1.530
17	0.41233	0.00000	1107.732	518.00	3.794	0.877	3.329
18	0.40473	0.00000	1129.132	559.30	3.907	0.359	1.404
19	0.40437	0.00000	1128.332	559.50	5.100	0.303	1.548
20	0.40359	0.00000	1126.732	560.10	7.382	0.250	1.849
21	0.42493	0.07165	1191.732	565.30	7.551	0.235	1.772
22	0.42425	0.10576	1190.432	565.90	7.533	0.232	1.749
23	0.42588	0.10397	1195.732	566.60	7.325	0.233	1.709
24	0.42549	0.07104	1194.632	566.60	7.341	0.233	1.714
25	0.41279	0.00000	1153.032	560.70	7.837	0.242	1.896
26	0.42874	0.03959	1200.632	563.60	8.605	0.228	1.965
27	0.42788	0.06336	1198.532	563.90	8.811	0.231	2.031
28	0.42798	0.06089	1199.432	564.50	8.646	0.230	1.990
29	0.42676	0.04015	1196.532	565.00	7.798	0.232	1.811
30	0.42622	0.07289	1195.132	565.10	7.539	0.234	1.763
31	0.41275	0.00000	1153.532	561.30	5.362	0.298	1.597
32	0.41339	0.00000	1156.032	562.00	4.040	0.351	1.418
33	0.42829	0.00000	1198.432	562.70	4.351	0.336	1.463
34	0.42843	C.00000	1199.132	563.00	5.803	0.282	1.638
35	0.42857	0.00000	1199.732	563.20	8.531	0.231	1.968

DATE OF RUN 7/15/1983
ENGINE TESTED MODEL F404 W/AFTER BURNER
DIFFUSER TESTED 2/3 SCALE
REFERENCE DATA FILES RUN6

RUN NO.	MASS FLOW PRI	MASS FLOW SEC	P STAGNATION	T STAGNATION	PT8/PS9	PS14/PT8	PT14/PS9
1	0.55921	0.00000	1058.982	558.90	9.576	0.384	3.677
2	0.57222	0.00000	1084.582	559.90	10.205	0.376	3.832
3	0.58470	0.00000	1110.482	562.20	10.878	0.365	3.974
4	0.59461	0.00000	1130.082	563.00	11.405	0.359	4.098
5	0.60975	0.00000	1160.882	565.00	11.970	0.349	4.176
6	0.61949	0.00000	1181.482	567.00	12.335	0.345	4.258
7	0.62031	0.00000	1184.582	568.50	12.837	0.236	3.035
8	0.60486	0.00000	1157.382	570.80	12.877	0.244	3.147
9	0.61804	0.00000	1182.082	570.30	12.893	0.238	3.075
10	0.59415	0.00000	1136.782	570.70	12.921	0.248	3.204
11	0.43700	0.00000	830.982	563.60	8.221	0.400	3.288
12	0.42597	0.00000	809.082	562.30	7.067	0.413	2.919
13	0.45092	0.00000	858.782	565.40	9.398	0.384	3.607
14	0.52991	0.00000	1006.582	562.40	12.293	0.343	4.222
15	0.54319	0.00000	1032.982	563.70	12.996	0.335	4.348
16	0.58017	0.00000	1060.882	520.50	12.988	0.325	4.223
17	0.56795	0.00000	1081.582	565.30	12.987	0.323	4.192
18	0.60663	0.00000	1109.382	520.60	12.993	0.309	4.018
19	0.59375	0.00000	1133.182	567.80	13.028	0.304	3.965
20	0.62434	0.00000	1192.482	568.70	13.035	0.289	3.763
21	0.57942	0.00000	1108.982	571.10	12.898	0.253	3.268
22	0.56578	0.00000	1082.882	571.10	12.910	0.264	3.402
23	0.55240	0.00000	1057.082	570.90	12.894	0.276	3.564
24	0.53910	0.00000	1031.282	570.50	12.878	0.290	3.737
25	0.52779	0.00000	1008.782	569.50	12.854	0.312	4.013
26	0.51441	0.00000	983.282	569.60	12.873	0.323	4.162
27	0.46185	0.00000	880.982	567.20	10.367	0.371	3.851
28	0.47538	0.00000	907.582	568.20	11.277	0.358	4.032
29	0.48701	0.00000	930.182	568.70	11.852	0.348	4.119
30	0.50042	0.00000	955.882	568.80	12.714	0.335	4.265
31	0.43321	0.00000	807.782	541.60	3.654	0.503	1.839
32	0.44672	0.00000	834.182	543.20	4.022	0.487	1.960
33	0.45838	0.00000	857.582	545.30	4.467	0.473	2.113
34	0.47171	0.00000	883.882	547.00	4.941	0.460	2.275
35	0.48437	0.00000	908.982	548.70	5.427	0.448	2.433
36	0.49640	0.00000	933.482	551.00	5.802	0.436	2.530
37	0.50867	0.00000	959.882	554.90	6.387	0.422	2.697
38	0.52165	0.00000	984.982	555.60	7.072	0.413	2.918
39	0.53310	0.00000	1007.582	556.70	7.788	0.405	3.153
40	0.54633	0.00000	1033.782	558.00	8.616	0.395	3.402

DATE OF RUN 7/18/1983
ENGINE TESTED MODEL F404 W/AFTER BURNER
DIFFUSER TESTED 2/3 SCALE
REFERENCE DATA FILES RUN7

RUN NO.	MASS FLOW PRI	MASS FLOW SEC	P STAGNATION	T STAGNATION	PT8/PS9	PS14/PT8	PT14/PS9
1	0.57149	0.28564	1094.467	571.80	3.226	0.270	0.872
2	0.57969	0.02132	1110.067	571.70	12.750	0.255	3.257
3	0.57875	0.07583	1108.267	571.70	9.013	0.259	2.332
4	0.57916	0.08140	1108.967	571.60	8.626	0.259	2.235
5	0.58026	0.08329	1111.167	571.70	8.550	0.258	2.207
6	0.57943	0.10179	1109.967	572.10	7.824	0.259	2.026
7	0.57858	0.09737	1107.767	571.50	7.517	0.259	1.945
8	0.61619	0.10481	1179.967	571.70	7.541	0.243	1.829
9	0.61813	0.09172	1182.667	570.70	8.354	0.241	2.017
10	0.61897	0.08882	1184.267	570.70	8.653	0.241	2.088
11	0.61646	0.08415	1178.867	570.10	8.638	0.242	2.093
12	0.61794	0.07191	1180.667	569.10	8.981	0.241	2.165
13	0.61799	0.01741	1180.467	568.80	12.920	0.240	3.098
14	0.61997	0.00000	1181.567	566.20	12.960	0.240	3.105
15	0.60890	0.00000	1159.067	564.80	12.955	0.242	3.133
16	0.59645	0.00000	1134.567	564.00	12.971	0.247	3.208
17	0.58386	0.00000	1109.167	562.50	12.978	0.256	3.318
18	0.57100	0.00000	1084.267	562.00	12.990	0.268	3.480
19	0.55889	0.00000	1059.867	560.50	12.994	0.276	3.588
20	0.54873	0.00000	1037.867	557.50	13.011	0.291	3.784

DATE OF RUN	7/21/1983
ENGINE TESTED	MODEL F404 W/AFTER BURNER
DIFFUSER TESTED	5/6 SCALE
REFERENCE DATA FILES	RUN10

RUN NO.	MASS FLOW PRI	MASS FLOW SEC	P STAGNATION	T STAGNATION	PT8/PS9	PS14/PT8	PT14/PS9
1	0.61597	0.24687	1180.774	572.90	6.122	0.251	1.535
2	0.62206	0.03094	1189.974	570.50	17.636	0.238	4.195
3	0.62315	0.06856	1192.574	571.00	13.696	0.242	3.310
4	0.62122	0.10580	1188.374	570.50	11.899	0.244	2.901
5	0.62111	0.09869	1188.774	571.10	11.939	0.244	2.913
6	0.62158	0.10393	1189.374	570.80	12.005	0.244	2.933
7	0.62074	0.10197	1188.274	571.30	11.150	0.245	2.731
8	0.61900	0.15032	1186.074	572.40	9.182	0.246	2.256
9	0.61728	0.16775	1183.074	572.70	7.729	0.247	1.910
10	0.62208	0.00000	1188.374	568.90	17.770	0.241	4.282
11	0.43765	0.00000	815.474	540.80	3.917	0.414	1.623
12	0.48922	0.00000	916.274	546.50	5.416	0.359	1.946
13	0.53935	0.00000	1013.074	549.70	7.753	0.316	2.446
14	0.53871	0.00000	1013.674	551.70	5.404	0.359	1.941
15	0.53853	0.00000	1014.074	552.50	4.168	0.404	1.684
16	0.54733	0.00000	1032.374	554.40	4.333	0.398	1.724
17	0.54595	0.00000	1030.874	555.60	6.302	0.338	2.129
18	0.54901	0.00000	1037.574	556.60	9.443	0.290	2.742
19	0.55964	0.00000	1058.774	557.80	11.043	0.281	3.107
20	0.55987	0.00000	1059.874	558.50	6.580	0.332	2.184
21	0.58377	0.00000	1109.774	563.30	5.077	0.370	1.877
22	0.59630	0.00000	1135.074	564.80	5.396	0.362	1.954
23	0.59782	0.00000	1138.574	565.40	8.324	0.306	2.551
24	0.60921	0.00000	1161.174	566.30	16.786	0.246	4.131
25	0.55779	0.00000	1056.674	559.30	4.545	0.388	1.764
26	0.57274	0.00000	1085.274	559.60	4.824	0.379	1.827
27	0.57333	0.00000	1086.774	560.00	7.222	0.320	2.314
28	0.57328	0.00000	1086.874	560.20	13.472	0.270	3.639
29	0.58323	0.00000	1107.674	562.20	14.754	0.259	3.821
30	0.58308	0.00000	1108.374	563.20	7.635	0.316	2.415

DATE OF RUN 7/27/1983
ENGINE TESTED MODEL F404 W/AFTER BURNER
DIFFUSER TESTED 5/6 SCALE
REFERENCE DATA FILES RUN11

RUN NO.	MASS FLOW PRI	MASS FLOW SEC	P STAGNATION	T STAGNATION	PT8/PS9	PS14/PT8	PT14/PS9
1	0.53896	0.00000	1008.532	545.50	4.264	0.400	1.706
2	0.54933	0.00000	1030.432	548.20	4.483	0.393	1.762
3	0.54499	0.00000	1025.232	551.40	6.617	0.336	2.223
4	0.54404	0.00000	1024.532	552.60	10.111	0.293	2.958
5	0.55954	0.00000	1054.932	553.90	12.319	0.277	3.414
6	0.55926	0.00000	1055.532	555.10	6.787	0.332	2.251
7	0.56062	0.00000	1059.032	556.10	4.791	0.382	1.829
8	0.57113	0.00000	1080.332	557.60	5.019	0.375	1.881
9	0.57100	0.00000	1081.132	558.70	7.890	0.315	2.485
10	0.57039	0.00000	1080.632	559.40	15.299	0.266	4.074
11	0.58312	0.00000	1105.732	560.40	17.377	0.254	4.412
12	0.58386	0.00000	1107.232	560.50	8.134	0.311	2.532
13	0.58541	0.00000	1111.432	561.80	5.325	0.365	1.942
14	0.59627	0.00000	1133.632	563.40	5.556	0.357	1.985
15	0.59721	0.00000	1135.532	563.50	8.869	0.303	2.686
16	0.59738	0.00000	1136.432	564.10	18.930	0.246	4.651
17	0.60809	0.00000	1157.732	565.00	19.746	0.242	4.773
18	0.60751	0.00000	1157.232	565.60	9.657	0.295	2.848
19	0.62015	0.00000	1182.532	566.80	10.209	0.292	2.976
20	0.61936	0.00000	1180.932	566.70	20.779	0.238	4.945
21	0.61445	0.02569	1175.432	570.50	20.325	0.242	4.915
22	0.44917	0.02913	822.732	522.30	4.278	0.401	1.715
23	0.61699	0.02472	1177.232	567.50	20.462	0.241	4.930
24	0.61762	0.02083	1179.032	568.10	20.601	0.239	4.914
25	0.61468	0.08787	1174.332	569.00	13.058	0.241	3.145
26	0.61153	0.09214	1168.732	569.40	12.811	0.243	3.117
27	0.61012	0.09408	1166.232	569.60	11.520	0.242	2.790
28	0.61294	0.15071	1171.632	569.60	9.393	0.243	2.283
29	0.61216	0.08287	1170.232	569.70	12.073	0.241	2.911
30	0.61216	0.08319	1170.732	570.20	13.047	0.241	3.141
31	0.49139	0.00000	905.132	528.30	5.692	0.355	2.021
32	0.54141	0.00000	1006.332	538.10	8.206	0.305	2.503
33	0.54052	0.00000	1007.432	541.10	6.206	0.345	2.140

DATE OF RUN 7/27/1983
ENGINE TESTED MODEL F404 W/AFTER BURNER
DIFFUSER TESTED FULL SCALE
REFERENCE DATA FILES RUN13

RUN NO.	MASS FLOW PRI	MASS FLOW SEC	P STAGNATION	T STAGNATION	PT8/PS9	PS14/PT8	PT14/PS9
1	0.43665	0.00000	807.663	532.80	3.169	0.420	1.331
2	0.43572	0.00000	807.363	534.70	2.693	0.467	1.258
3	0.43590	0.04401	808.363	535.60	2.537	0.487	1.236
4	0.43460	0.04261	806.463	536.30	3.149	0.422	1.328
5	0.43507	0.04260	807.863	537.00	3.172	0.420	1.334
6	0.43486	0.04533	808.063	537.80	2.390	0.509	1.216
7	0.43276	0.01828	804.463	538.20	2.631	0.467	1.229
8	0.43267	0.03321	804.363	538.30	3.031	0.424	1.284
9	0.43380	0.06896	806.463	538.30	3.032	0.424	1.284
10	0.43290	0.06920	804.863	538.40	2.502	0.485	1.213
11	0.43288	0.05866	804.963	538.60	2.330	0.509	1.187
12	0.43189	0.07637	803.063	538.50	2.994	0.426	1.277
13	0.48919	0.08151	910.263	539.30	3.770	0.365	1.375
14	0.49033	0.08607	912.463	539.40	2.769	0.449	1.242
15	0.49103	0.07955	913.863	539.50	2.970	0.427	1.269
16	0.49081	0.06879	913.363	539.40	3.830	0.363	1.392
17	0.49041	0.06843	912.863	539.70	3.831	0.364	1.395
18	0.48998	0.07826	912.563	540.30	3.199	0.408	1.306
19	0.48934	0.00000	911.463	540.40	2.801	0.450	1.262
20	0.49093	0.05656	914.663	540.70	3.933	0.361	1.421
21	0.49283	0.05761	918.463	541.00	4.077	0.358	1.458
22	0.49149	0.02486	915.963	541.00	3.100	0.425	1.318
23	0.49269	0.00000	918.363	541.20	3.333	0.405	1.350
24	0.49172	0.03698	916.563	541.20	4.071	0.358	1.457
25	0.54071	0.05948	1007.963	541.30	5.061	0.316	1.599
26	0.54079	0.00000	1008.663	541.90	4.056	0.359	1.455
27	0.54037	0.02418	1008.063	542.10	3.648	0.384	1.401
28	0.54188	0.03491	1011.063	542.30	5.110	0.316	1.617
29	0.54173	0.03499	1010.963	542.50	5.058	0.316	1.599
30	0.54024	0.03075	1008.463	542.80	3.312	0.407	1.349

DATE OF RUN	7/27/1983
ENGINE TESTED	MODEL F404 W/AFTER BURNER
DIFFUSER TESTED	FULL SCALE
REFERENCE DATA FILES	RUN13

RUN NO.	MASS FLOW PRI	MASS FLOW SEC	P STAGNATION	T STAGNATION	PT8/PS9	PS14/PT8	PT14/PS9
31	0.53639	0.05794	1001.363	542.90	3.573	0.379	1.355
32	0.53677	0.05858	1002.263	543.10	4.673	0.323	1.507
33	0.53763	0.07841	1003.863	543.10	4.683	0.323	1.511
34	0.53806	0.07820	1004.663	543.10	3.543	0.381	1.349
35	0.53779	0.09365	1004.063	543.00	4.571	0.323	1.475
36	0.53754	0.09763	1003.963	543.40	3.169	0.408	1.293
37	0.59466	0.10641	1111.963	544.70	3.686	0.370	1.364
38	0.59547	0.09568	1112.863	544.10	6.236	0.261	1.626
39	0.59509	0.10402	1112.863	544.80	6.357	0.261	1.661
40	0.59466	0.08419	1112.863	545.60	4.255	0.339	1.444
41	0.59643	0.08077	1116.363	545.80	4.800	0.316	1.517
42	0.59407	0.06098	1112.163	546.00	6.490	0.260	1.690
43	0.59653	0.08313	1117.163	546.40	6.723	0.258	1.735
44	0.59535	0.06564	1115.063	546.50	3.777	0.368	1.390
45	0.59829	0.08281	1120.963	546.90	4.548	0.337	1.532
46	0.59733	0.04832	1119.363	547.10	7.555	0.257	1.939
47	0.59722	0.00000	1119.063	547.00	7.578	0.258	1.951
48	0.59728	0.00000	1119.163	547.00	5.197	0.311	1.617
49	0.63726	0.00000	1195.163	548.00	5.562	0.300	1.671
50	0.63572	0.00000	1192.163	547.90	8.567	0.241	2.066
51	0.63390	0.65379	1189.063	548.20	8.644	0.246	2.124
52	0.63611	0.05300	1193.863	548.80	5.032	0.317	1.597
53	0.63632	0.05457	1194.363	548.90	4.361	0.343	1.498
54	0.63754	0.02105	1196.863	549.10	8.576	0.240	2.060
55	0.63206	0.08452	1186.463	549.00	7.136	0.244	1.745
56	0.63231	0.06784	1187.463	549.50	5.350	0.294	1.575
57	0.63102	0.09854	1185.163	549.60	4.721	0.320	1.509
58	0.63389	0.04291	1190.763	549.80	7.128	0.244	1.740
59	0.63241	0.11000	1187.663	549.50	6.867	0.242	1.661
60	0.63325	0.09735	1189.563	549.80	4.108	0.346	1.421

DATE OF RUN 7/27/1983
ENGINE TESTED MODEL F404 WO/AFTER BURNER
DIFFUSER TESTED FULL SCALE
REFERENCE DATA FILES RUN14

RUN NO.	MASS FLOW PRI	MASS FLOW SEC	P STAGNATION	T STAGNATION	PT8/PS9	PS14/PT8	PT14/PS9
1	0.30259	0.00000	812.463	517.40	2.889	0.412	1.190
2	0.30291	0.00000	814.163	518.50	2.486	0.463	1.151
3	0.30288	0.03408	814.863	519.50	2.235	0.504	1.126
4	0.30323	0.04207	816.263	520.10	2.903	0.410	1.190
5	0.30153	0.01782	812.063	520.60	2.878	0.412	1.186
6	0.30146	0.02002	813.263	522.40	2.256	0.500	1.128
7	0.30016	0.05188	810.363	523.20	2.808	0.415	1.165
8	0.29960	0.06603	809.463	524.00	2.472	0.461	1.139
9	0.29946	0.05986	809.463	524.50	2.320	0.485	1.126
10	0.29969	0.04587	810.463	525.00	2.809	0.416	1.168
11	0.29939	0.08898	809.863	525.30	2.784	0.416	1.159
12	0.29902	0.07727	809.263	525.80	2.197	0.506	1.112
13	0.33584	0.09287	910.163	527.30	2.537	0.450	1.141
14	0.33623	0.07557	911.663	527.80	3.393	0.357	1.211
15	0.33703	0.08021	914.263	528.30	3.434	0.355	1.220
16	0.33678	0.05249	914.163	529.00	2.711	0.429	1.162
17	0.33442	0.06590	908.263	529.60	2.951	0.400	1.181
18	0.33491	0.06767	909.863	529.90	3.404	0.358	1.219
19	0.33581	0.06070	912.563	530.20	3.497	0.354	1.238
20	0.33544	0.03827	911.963	530.70	2.573	0.450	1.157
21	0.33593	0.02642	913.963	531.50	2.786	0.423	1.179
22	0.33564	0.04006	913.363	531.70	3.520	0.354	1.246
23	0.33565	0.00000	913.463	531.80	3.515	0.353	1.242
24	0.33584	0.00000	914.063	531.90	3.006	0.399	1.199
25	0.37150	0.00000	1012.163	533.00	3.440	0.360	1.237
26	0.37169	0.00000	1012.863	533.20	4.283	0.307	1.313
27	0.37166	0.03156	1013.063	533.50	4.261	0.306	1.306
28	0.37247	0.03149	1015.163	533.40	3.239	0.377	1.219
29	0.37189	0.00000	1013.963	533.80	2.951	0.404	1.193
30	0.37223	0.02261	1015.463	534.40	4.313	0.501	2.161

DATE OF RUN	7/27/1983
ENGINE TESTED	MODEL F404 WO/AFTER BURNER
DIFFUSER TESTED	FULL SCALE
REFERENCE DATA FILES	RUN14

RUN NO.	MASS FLOW PRI	MASS FLOW SEC	P STAGNATION	T STAGNATION	PT8/PS9	PS14/PT8	PT14/PS9
31	0.36957	0.03935	1008.563	534.80	4.062	0.311	1.265
32	0.36936	0.11588	1008.463	535.30	3.392	0.359	1.217
33	0.36967	0.05748	1009.663	535.70	3.099	0.385	1.192
34	0.36960	0.08313	1009.663	535.90	4.083	0.310	1.264
35	0.36735	0.10071	1004.263	536.70	4.006	0.315	1.261
36	0.36836	0.08726	1007.563	537.30	2.862	0.408	1.168
37	0.40440	0.10314	1106.763	537.90	3.253	0.370	1.202
38	0.40498	0.08252	1108.763	538.30	5.148	0.260	1.339
39	0.40568	0.07250	1111.063	538.70	5.314	0.263	1.397
40	0.40622	0.11192	1113.063	539.20	3.611	0.342	1.236
41	0.40625	0.06819	1113.663	539.70	3.989	0.316	1.262
42	0.40640	0.04825	1114.163	539.80	5.237	0.256	1.340
43	0.40709	0.03812	1116.263	540.00	5.274	0.255	1.346
44	0.40749	0.03217	1117.563	540.20	3.311	0.366	1.212
45	0.40928	0.04280	1122.063	539.80	3.685	0.342	1.262
46	0.40855	0.09436	1120.163	539.90	5.613	0.255	1.429
47	0.40829	0.00000	1119.863	540.30	5.507	0.257	1.414
48	0.40727	0.00000	1117.463	540.70	4.097	0.313	1.283
49	0.44256	0.00000	1215.163	541.50	4.692	0.287	1.346
50	0.44349	0.00000	1218.063	541.80	6.650	0.229	1.524
51	0.44403	0.01992	1219.663	541.90	6.605	0.230	1.521
52	0.44348	0.02491	1218.463	542.20	4.137	0.315	1.301
53	0.44361	0.03634	1219.063	542.40	3.788	0.335	1.268
54	0.44365	0.03641	1219.163	542.40	6.620	0.228	1.508
55	0.44183	0.04681	1214.263	542.50	6.048	0.235	1.422
56	0.44251	0.09731	1216.363	542.70	4.645	0.281	1.306
57	0.44198	0.08859	1215.463	543.20	4.090	0.310	1.267
58	0.44196	0.05462	1215.963	543.70	6.145	0.231	1.417
59	0.44146	0.10433	1214.563	543.70	6.008	0.233	1.398
60	0.44174	0.10591	1215.663	544.00	3.668	0.336	1.232

APPENDIX H

DATA ACQUISITION PROGRAM

A computer program which details the data acquisition process is included in this Appendix. VIBTEM was executed on a Hewlett Packard 9830 and is written in BASIC.

```
10 REM      FILE NAME: "VIBTEM"
20 REM
30 REM      DESCRIPTION:
40 REM      THIS PROGRAM PERFORMS SEQUENTIAL SCANNING
50 REM      OF SCANIVALVE '5' BETWEEN PORT ADDRESSES 1-42 IN STEPS OF ONE.
60 REM      IT ALSO PERFORMS TEMPERATURE MEASUREMENTS ON SRC '2' BETWEEN
70 REM      CHANNELS 1-19
80 REM
90 REM      VARIABLES FOR S/V SECTION.
100 REM        V  = DESIRED S/V
110 REM        A1 = LOW PORT
120 REM        A2 = HIGH PORT
130 REM        P  = PRESENT S/V PORT
140 REM        S  = STEP SIZE
150 REM      VARIABLES FOR TEMPERATURE SECTION.
160 REM        S$=SCANNER LISTEN CODE
170 REM        S=SCANNER #
180 REM        C1=LO CHANNEL
190 REM        C2=HI CHANNEL
200 REM        C=TRANSMITTED CHANNEL
210 REM        V=DVM READING
220 REM        R=RPM CHANNEL
230 PRINT
240 PRINT
250 PRINT
260 PRINT
270 PRINT
280 PRINT
290 DIM X[50],Y[20],Q[10],M[30],Z[50]
300 MAT X=ZER
310 MAT Y=ZER
320 MAT Q=ZER
330 MAT M=ZER
340 MAT Z=ZER
350 DISP "ENTER MONTH,DAY,YEAR OF RUN";
360 INPUT X[44],X[45],X[46]
```

```
370 WRITE (15,380)X[44],X[45],X[46]
380 FORMAT "DATE OF RUN:",F2.0,2X,F3.0,2X,F4.0
390 PRINT
400 PRINT
410 DISP "ENTER RUN #";
420 INPUT X[47]
430 X[49]=1
440 DISP "BAROMETER READING=?";
450 INPUT X[48]
460 PRINT "BAROMETER READING INCHES OF HG="X[48]
470 PRINT
480 PRINT
490 FORMAT B
500 FORMAT 2B
510 FORMAT 4B
520 FORMAT F3.0
530 GOTO 600
540 FOR I=1 TO 42
550 X[I]=0
560 NEXT I
570 FOR I=1 TO 19
580 Y[I]=0
590 NEXT I
600 WRITE (15,610)X[47],X[49]
610 FORMAT /,"RUN #",F3.0,4X,"PT #",F3.0
620 GOSUB 1320
625 PRINT "PRESSURES ? 1=YES 0=NO";
626 INPUT K1
627 IF K1=0 THEN 900
630 PRINT
640 PRINT
650 REM*****START OF PROGRAM SEGMENT TO RECORD PRESSURES************************
660 WRITE (13,510)256,20,768,512;
670 CMD "?D#","F1R7M3A1H1T3"
680 V=5
690 A1=1
```

```
700 A2=42
710 S=1
720 CMD "?D'"
730 WRITE (13,490)V;
740 WRITE (15,750)V
750 FORMAT "SCANIVALVE #",F3.0,/,/," PORT",8X,"IN H2O "
760 FOR A=A1 TO A2
770 GOSUB 1040
780 CMD "?D!"
790 WRITE (13,520)V+9
800 CMD "?D#","T3"
810 CMD "?C$"
820 ENTER (13,*)V0
830 X[A]=V0*100000
840 V0=V0*100000
850 WRITE (15,860)P,X[A]
860 FORMAT 1X,F3.0,4X,F8.2
870 CMD "?D!","C"
880 NEXT A
890 GOTO 900
900 DISP "ENTER TIP VOLTAGE ";
910 INPUT V9
920 P9=(V9-4.5839)/(-0.8248)-4.886
930 WRITE (15,940)P9
940 FORMAT 1X,"TIP POSITION ",F7.3,1X,"INCHES"
950 PRINT "----------------------------------"
960 DISP "ENTER 1 TO REPEAT";
980 INPUT R
990 X[49]=X[49]+1
1000 IF R=1 THEN 540
1010 STOP
1020 END
1030 REM  SUBROUTINE "POSIT"
1040 GOSUB 1220
1050 D=A-P
1060 CMD "?D!"
```

```
1070 IF D<0 THEN 1100
1080 IF D>0 THEN 1150
1090 RETURN
1100 REM    HOME S/V
1110 WRITE (13,520)V+4
1120 WRITE (13,*)"C"
1130 WAIT 4000
1140 GOTO 1040
1150 REM     ADVANCE S/V
1160 FOR I=1 TO D STEP S
1170 WRITE (13,520)V-1
1180 WRITE (13,*)"C"
1190 WAIT 200
1200 NEXT I
1210 GOTO 1040
1220 REM     READ S/V ADDRESS
1230 CMD "?G$"
1240 P0=RBYTE13
1250 L=BIAND(P0,15)
1260 T=ROT(P0,4)
1270 M=BIAND(T,7)
1280 P=10*M+L
1290 WRITE (13,500)256,95;
1300 RETURN
1310 REM*****SUBROUTINE TO RECORD TEMPS*******************************************
1320 DIM S$[3]
1330 FORMAT F3.0
1340 FORMAT 3B
1350 FORMAT 4B
1360 REM
1370 OUTPUT (13,1350)256,20,768,512;
1380 CMD "?D#","F1R7M3A1H1T3"
1390 S=2
1400 C1=60
1410 C2=78
1420 S$="?D("
```

```
1430 WRITE (15,1440)S
1440 FORMAT 5X,"SCANNER #",F2.0,/,/,2X,"CHAN",6X,"TEMP DEG. R"
1450 FOR C=C1 TO C2
1460 CMD S$
1470 OUTPUT (13,1330)C
1480 CMD "?D#"
1490 OUTPUT (13,1340)256,8,512;
1500 CMD "?C$"
1510 ENTER (13,*)V
1520 B=C-59
1530 Y[B]=V
1540 NEXT C
1550 Y1=Y[1]
1560 FOR I=1 TO 19
1570 Y[I]=Y1+Y[I]
1580 Y[1]=Y[1]/2
1590 Y[I]=FNT(Y[I]*1000)+460-0.42
1600 IF I<14 THEN 1610
1610 Y[I]=Y[I]+1.26
1620 IF I<8 THEN 1630
1630 Y[I]=Y[I]+0.42
1640 WRITE (15,1650)I,Y[I]
1650 FORMAT 2X,F3.0,3X,F14.6
1660 NEXT I
1670 WRITE (15,1680)
1680 FORMAT /,/
1690 CMD S$,"C"
1700 RETURN
1710 STOP
1720 DEF FNT(V)
1730 S1=32.0787+46.34*V-1.0515*V↑2
1740 S2=25.661297*V-0.61954869*V↑2+0.022181644*V↑3-0.000355009*V↑4
1750 S3=32.0787+9*S2/5
1760 RETURN S3
1770 STOP
```

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