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THE PRELIMINARY CHECKOUT, EVALUATION AND CALIBRATION OF A 3-COMPONENT FORCE MEASUREMENT SYSTEM FOR CALIBRATING PROPULSION SIMULATORS FOR WIND TUNNEL MODELS

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THE PRELIMINARY CHECKOUT, EVALUATION AND CALIBRATION OF A 3-COMPONENT FORCE MEASUREMENT SYSTEM FOR CALIBRATING PROPULSION SIMULATORS FOR WIND TUNNEL MODELS Final Report
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The propulsion simulator calibration laboratory (PSCL) in which calibrations can be performed to determine the gross thrust and airflow of propulsion simulators installed in wind tunnel models is described. The preliminary checkout, evaluation and calibration of the PSCL's 3 component force measurement system is reported. Methods and equipment were developed for the alignment and calibration of the force measurement system. The initial alignment of the system demonstrated the need for more efficient means of aligning system's components. The use of precision alignment jigs increases both the speed and accuracy with which the system is aligned. The calibration of the force measurement system shows that the methods and equipment for this procedure can be successful. E.A.K.

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Final Report
for

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No. NCC 2-100

"Calibration Laboratory Development for Propulsion Simulators"

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KU-FRL-510-1

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SUMMARY

Growing interest in close-coupled aircraft configurations, often using vectored thrust exhaust nozzles, has forced increasing emphasis on the accurate simulation of propulsive flows in aircraft wind tunnel models. NASA Ames Research Center is developing the Propulsion Simulator Calibration Laboratory(PSCL) in which calibrations can be performed to determine the gross thrust and airflow of propulsion simulators installed in wind tunnel models. This report describes the preliminary checkout, evaluation and calibration of the PSCL's 3-component force measurement system.

Methods and equipment were developed for the alignment and calibration of the force measurement system. The initial alignment of the system demonstrated the need for more efficient means of aligning system's components. The use of precision alignment jigs would increase both the speed and accuracy with which the system is aligned. The calibration of the force measurement system proved that the methods and equipment developed for this procedure could be used successfully.

The initial calibration of the force measurement system of the PSCL showed that calibrations of propulsion simulators can be performed with force accuracies of $\pm$0.826%full scale. This is lower than the $\pm$0.05%full scale accuracy required for these calibrations. The accuracy of the force measurement system is limited by the low accuracy of the force transducers being used. It is recommended that higher accuracy transducers be used to improve the system's performance. Further investigations that are required to validate the system's performance are outlined.

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LIST OF ACRONYMS

Acronym	Description
AEDC	Arnold Engineering and Development Center
A/D	Analog to Digital
ARC	Ames Research Center
CMAPS	Compact Multi-Mission Aircraft Propulsion Simulator
CRT	Cathode Ray Tube
DAS	Data Acquisition System
DEC	Digital Equipment Corporation
DG	Data General Corporation
D/A	Digital to Analog
NASA	National Aeronautics and Space Administration
PPAFU	Programmable Preamplifier Filter Unit
PSCL	Propulsion Simulator Calibration Laboratory
RMDU	Remote Multiplexer-Demultiplexer Unit
TCU	Temperature Control Unit
V/STOL	Vertical/Short Takeoff and Landing

Chapter 1

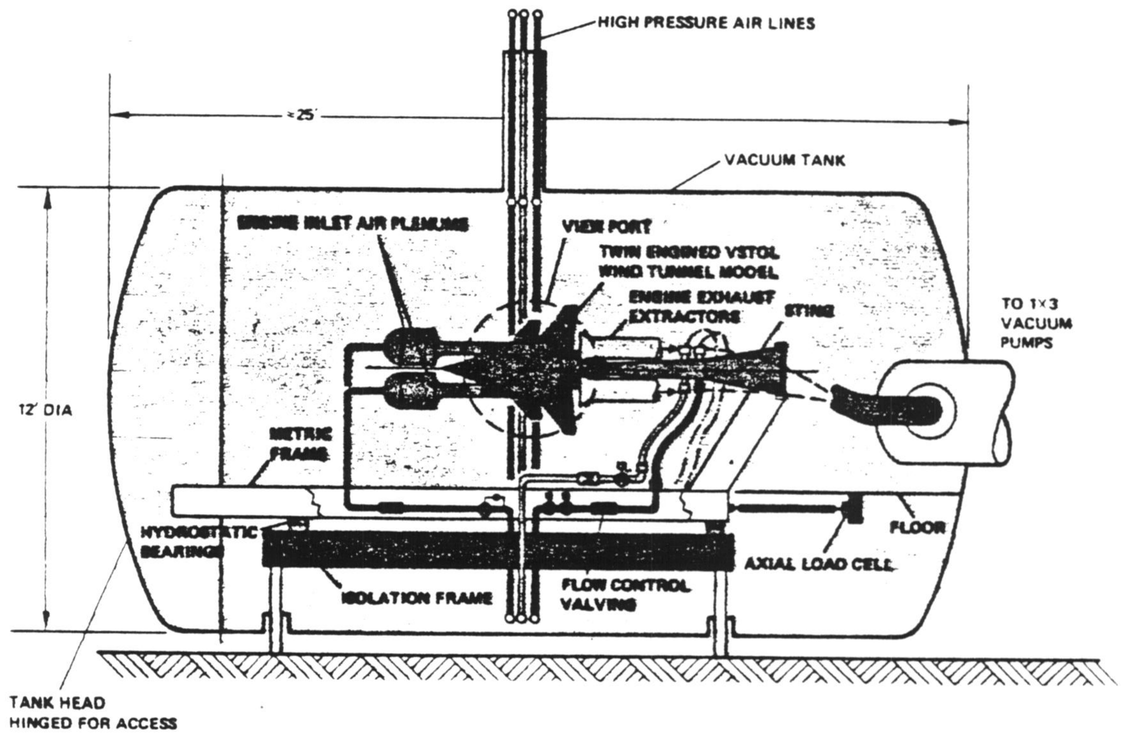
Introduction

The Aerodynamics Division at NASA's Ames Research Center is constructing a laboratory which will accurately calibrate propulsion simulators installed in wind tunnel models. This facility, called the Propulsion Simulator Calibration Laboratory(PSCL), provides the proper static pressure environment in which the gross thrust and airflow of the simulators are calibrated. It will be used for the calibration of turbo powered simulators, flow through and jet effects models, and for secondary calibrations of airflow meters.

The purpose of this project was to perform the operational checkout and initial calibration of the PSCL's force measurement system. This project was performed in conjunction with the construction and checkout of the other facility systems in the overall effort to make the PSCL an operational laboratory. Figure 1.1 shows a wind tunnel model installed in the PSCL's calibration tank.

The operational checkout of the force measurement system consisted of developing the methods and equipment used to level and align the various

Figure 1.1: PSCL Calibration Tank (ref. 1)



components of the force measurement system during their installation. Since the force measurement system is designed such that its configuration can be changed to calibrate a variety of simulators, this leveling and alignment procedure will be used repeatedly. The operational checkout also involved an evaluation of the ease and accuracy with which the system can be set up and used. Recommendations are made for improvements to the system's equipment and the set up procedures.

The initial calibration of the force measurement system investigated the operational characteristics of the system. After developing the equipment and methods that were required to perform the calibration, an evaluation of the overall accuracy of the system and of those elements likely to degrade performance of the system was made. Again, recommendations for improvements are made along with suggestions for future investigations.

The following paragraphs outline how the information about this project will be presented in this report.

Chapter 2 provides a description of the developments in aeronautics that spawned the need for the PSCL. A brief history is given on the work that has been done in the area of propulsion simulation.

In Chapter 3 the PSCL is described to familiarize the reader with the laboratory's various systems and capabilities.

Chapter 4 contains a detailed description of the force measurement system, of both its components and the theory of its operation. The parameters which are expected to effect the system's accuracy are discussed. Methods of correcting for these parameters are outlined. This chapter also details the procedures and equipment used to level and align the system during its initial installation.

An overview of the calibration is provided in Chapter 5. This includes a discussion of how the system's errors were investigated. The equipment and procedures used in the calibration and the results of the calibration are discussed.

The recommendations, developed as a result of this project, are contained in Chapter 6. Conclusions on the accuracy of the force measurement system, along with its operational characteristics are covered. Recommendations to improve the system's operation and its accuracy are presented along with recommendations of further work that is needed to be performed.

Chapter 2

History

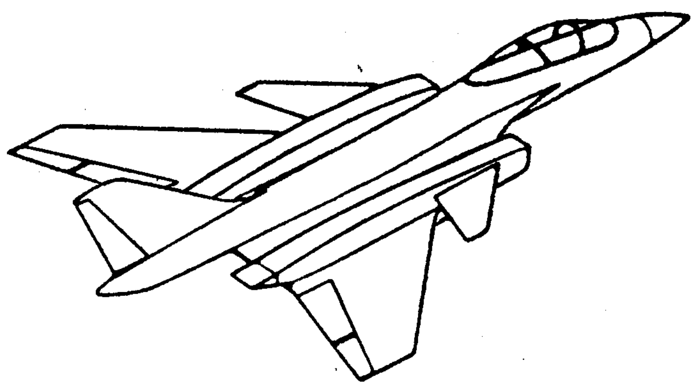
2.1. Introduction

The advent of close-coupled aircraft configurations(an example of which is shown in Figure 2.1) has forced increasing emphasis on the accurate simulation of propulsive flows in aircraft wind tunnel models. Compact placement of the inlet, canard, wing, and exhaust nozzle are characteristic of the V/STOL(Vertical Take Off and Landing) fighter aircraft that are currently being studied. These configurations exhibit a significant amount of airframe/propulsion system flow field interaction which is not adequately predicted by present wind tunnel test methods.

2.2. Compact Multi-Mission Aircraft Propulsion Simulator

The Aerodynamics Division at Ames Research Center is committed to two programs designed to advance the state-of-the-art of propulsive flow simulation

Figure 2.1: Close-Coupled Aircraft Configuration



FEATURES:

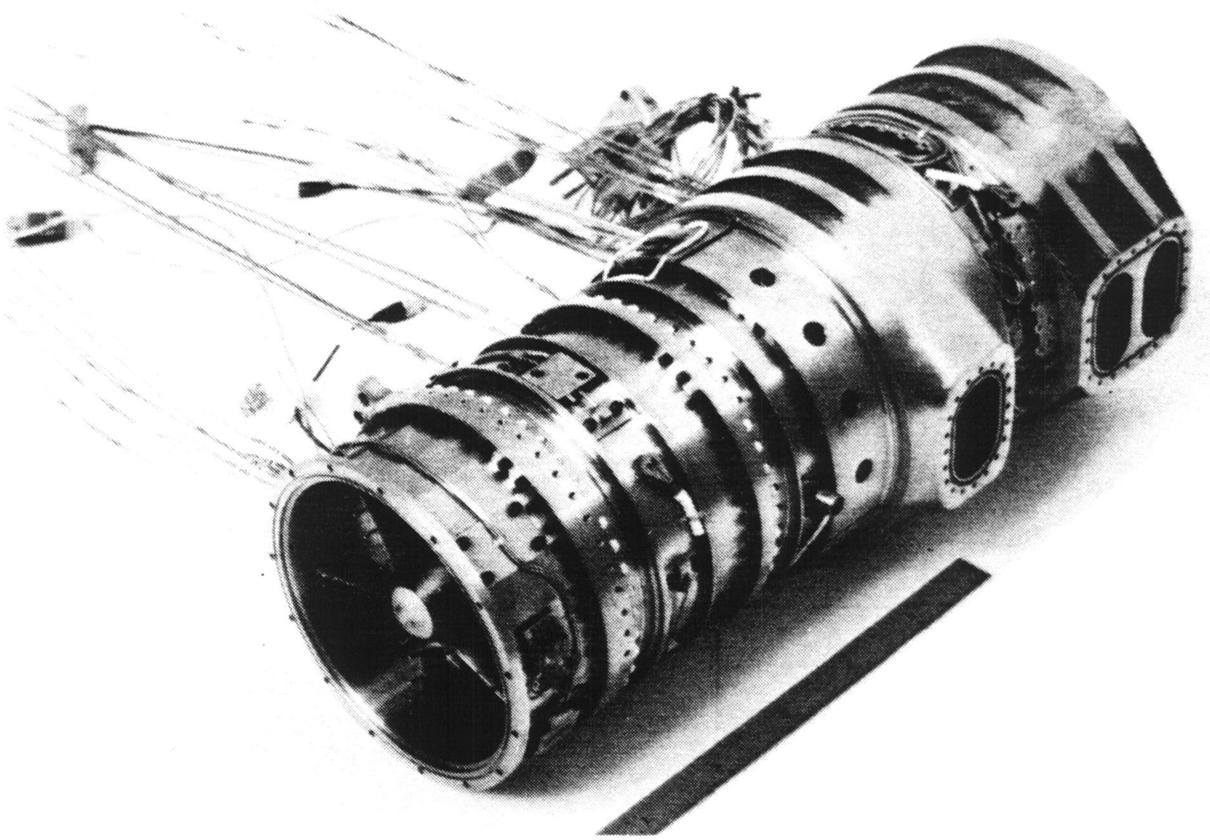
- Lift/cruise engine with non–axisymmetric thrust vectoring nozzles
- Forward lift fan or lift engine
- Close coupled inlets and nozzles
- Canards

in aircraft wind tunnel tests. The first program is the development of an air driven turbine engine called the Compact Multi-Mission Aircraft Propulsion Simulator(CMAPS). Conventional wind tunnel tests often employ two models to simulate the airframe/propulsion system interactions. A flow through model is used to obtain the inlet performance and a jet effects model is used to obtain the nozzle performance. The information from the tests of these two models is combined to determine the overall system performance. The CMAPS has the advantage over the two model technique by being able to simultaneously simulate the inlet and exhaust flows of supersonic fighter aircraft in wind tunnel models.

The CMAPS, seen in Figure 2.2, is a 0.085 scale version of a mixed flow turbine engine. The design is based on an engine with a fan pressure ratio of 2.9 and bypass ratio of 1.1. The engine employs a four stage compressor, a single stage turbine, and a single compressor/turbine rotor in its design. It has an overall length of 26.4 cm (10.4 in.), without an exhaust nozzle, and a compressor face diameter of 7.6 cm (3.0 in.). The turbine is driven by high pressure air which is supplied from an external source.

Since the program began in 1969, the simulators have gone through several phases of development and testing. Much of the work was performed under the sponsorship of the United States Air Force Aero Propulsion Laboratory by the General Electric Company, McDonnell Douglas Corporation, Tech Development Inc., and ARO Inc. at Arnold Engineering and Development Center(AEDC). This included the mechanical and operational checkout, control and performance testing, and the development of wind tunnel test techniques for these engines.

Figure 2.2: Compact Multi-Mission Propulsion Simulator (Courtesy of NASA ARC)



The ARC program is currently evaluating the simulators for their applications to wind tunnel tests of fighter aircraft. This has included conducting a wind tunnel test operating two simulators installed in an aircraft wind tunnel model.

2.3. Propulsion Simulator Calibration Laboratory

The construction of the Propulsion Simulator Calibration Laboratory(PSCL) is the second program in this effort to develop the hardware and techniques needed to better simulate propulsive flows. The PSCL is designed to fulfill the need for a facility in which the CMAPS and other simulators can be accurately calibrated.

The conceptual design of the PSCL, which began in 1979, showed that a facility was needed that could provide the proper static pressure environment so that simulators could be calibrated at the correct nozzle pressure ratios. To obtain installed performance(inlet and nozzle effects included in the calibration) the calibration chamber had to be large enough to accomodate an entire wind tunnel model with the simulators installed. The facility would need to supply heated, high pressure air to drive the CMAP'S turbines and as an inlet air supply. Accurate flow and force measurement systems would be required to calibrate simulator airflows and thrust. The conceptual design of the PSCL evolved from these requirements.

The detailed design of the laboratory has been completed along with the majority of the construction and fabrication work. The operational checkout of the laboratory's systems is now under way along with the facility safety review. As a part of the effort to make the PSCL operational, a project was begun in January 1981 to perform the operational checkout and calibration of the laboratory's force measurement system. This report discusses the work performed on this project.

Chapter 3

PSCL Facility Description

3.1. Introduction

The Propulsion Simulator Calibration Laboratory will furnish all the facilities necessary to perform the accurate calibration of gross thrust and airflow for propulsion simulators. In addition to the CMAPS, the PSCL will be used for the calibration of flow through and jet effects models, isolated ducts and nozzles, and secondary calibrations of airflow meters.

For the CMAPS to be used as an effective tool, the PSCL must provide calibration data accuracy on a level corresponding to ± 1 drag count in wind tunnel testing. To achieve this goal requires that PSCL have the following full scale(F.S.) measurement accuracies:

- ± 0.1 %for airflow measurements
- ± 0.05 %for force measurements

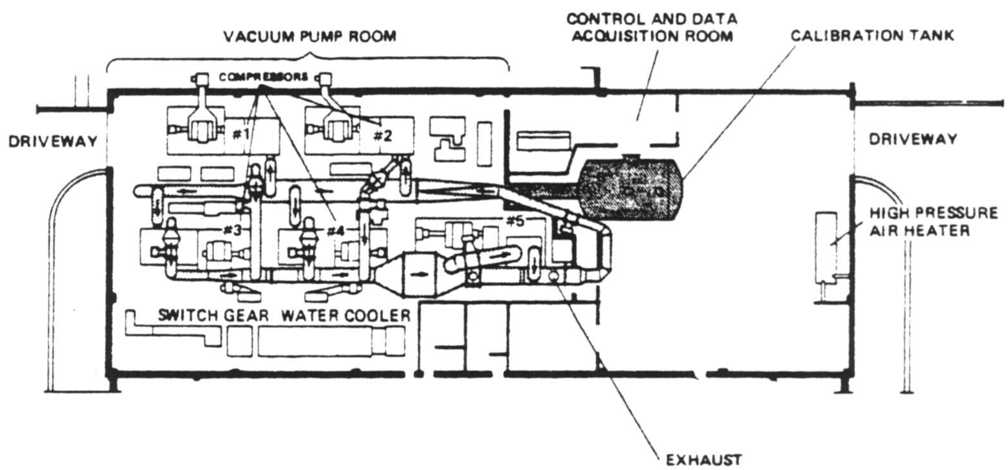
- $\pm$0.25 %for pressure measurements
- $\pm 1^\circ$F for temperature measurements

The PSCL occupies the area once used for a 0.3 x 0.9 m (1 x 3 ft) supersonic wind tunnel. The test section of the old tunnel circuit has been removed and a vacuum tank installed in its place. Figure 3.1 shows the floor plan of the PSCL. The major systems of the laboratory are (1) a vacuum tank and pumping plant, (2) a force balance assembly(located inside the vacuum tank), (3) a high pressure air supply and control system, and (4) a data acquisition system.

3.2. Vacuum Tank and Pumping Plant

The vacuum tank(Figure 1.1) provides the proper static pressure environment in which the propulsion simulators are calibrated. Since the static pressure of the wind tunnel test is matched in the vacuum tank, the simulators can be calibrated at the correct nozzle pressure ratio. The tank's large size, approximately 7.62 m (25 ft) in length and 3.66 m (12 ft) in diameter, permits an entire wind tunnel model(including its sting and the related test hardware) to be submerged in this pressure environment. This reduces the amount of time spent to disassemble and reassemble the model, and also increases the commonality between the static test and the wind tunnel test setup. The entire bell end of the tank is hinged, which allows access to the wind tunnel models and the various systems installed in the tank.

Figure 3.1: Floorplan of Propulsion Simulator Calibration Laboratory (ref. 1)



The PSCL will use the 0.3 x 0.9 m tunnel's pumping plant for the tank vacuum source. The pumping plant consists of four parallel connected Carrier Corporation compressors(#1-4 in Figure 3.1) in series with a Clark Corporation compressor(#5 in Figure 3.1). The Carrier centrifugal compressors are each rated at 228,120 kg-m/sec (3000 HP) and have a compression ratio of 2.38. The Clark centrifugal compressor is rated at 386,283 kg-m/sec (5080 HP) and has a compression ratio of 3.43. The pumping plant has a total compression ratio of 8.1 which allows the tank to be maintained at 12.4 kN/m^2 (1.8 psia) with the CMAPS being operated at their maximum flow of 8.16 kg/sec (18 lb/sec).

3.3. Force Measurement System

The force measurement system uses a metric frame supported on an isolation frame by hydrostatic bearings(see Figure 3.2.) The design allows three degrees of freedom in the horizontal plane(two forces and one moment). Connecting rods link the metric frame to the three load cells that are attached to the rails fixed at the sides and end of the vacuum tank(see Figure 3.3.) The three high-precision uniaxial load cells are used to measure the forces and moment. This will satisfy the force measurement requirements in the lift, thrust, and pitch degrees of freedom for V/STOL models equipped with vectored thrust nozzles and forward lift engines. Sets of load cells are available for load ranges up to 4448 N (1000lb). A detailed description of the force measurement system and its alignment is presented in the next chapter.

Figure 3.2: PSCL Floating Support System(ref. 1)

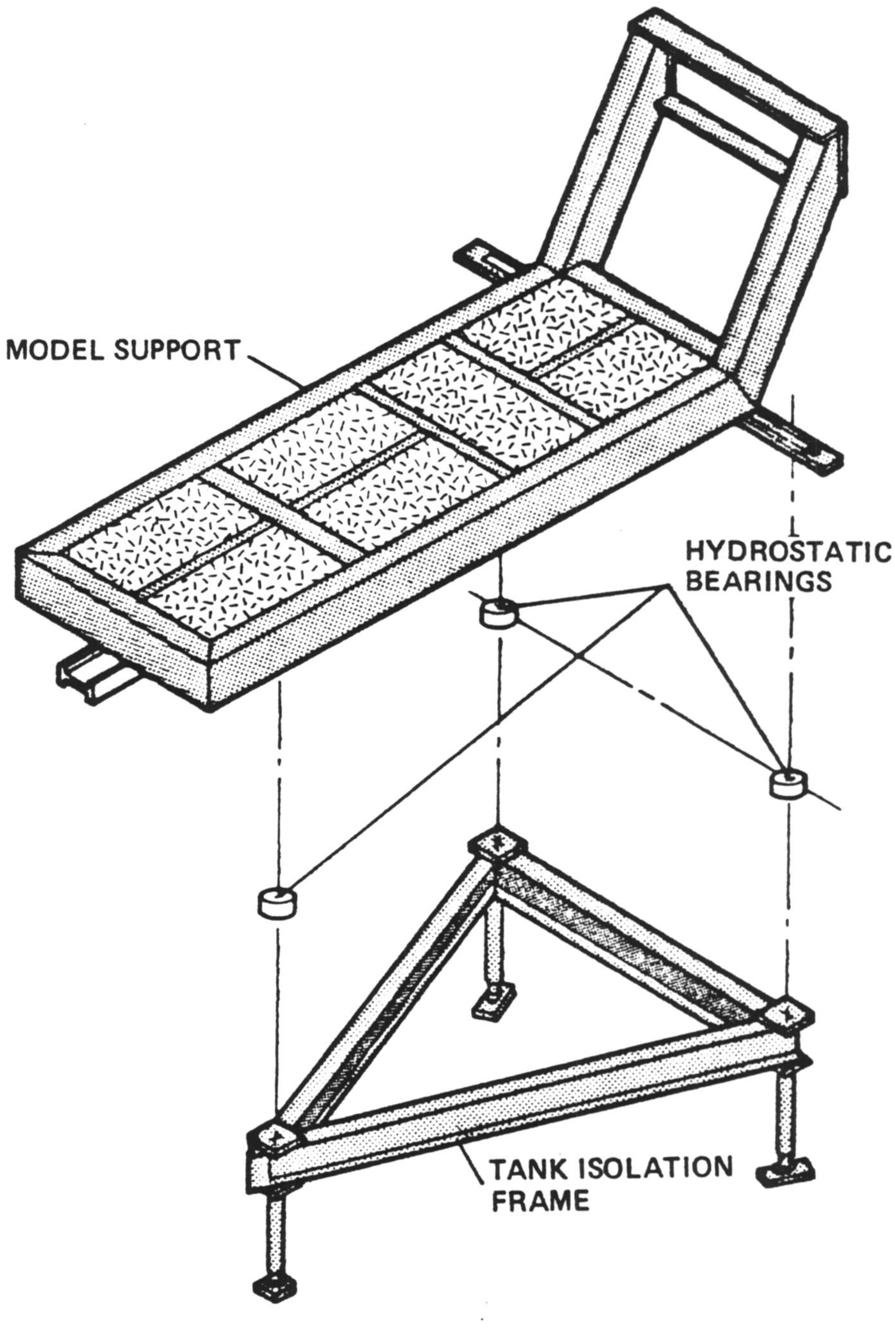
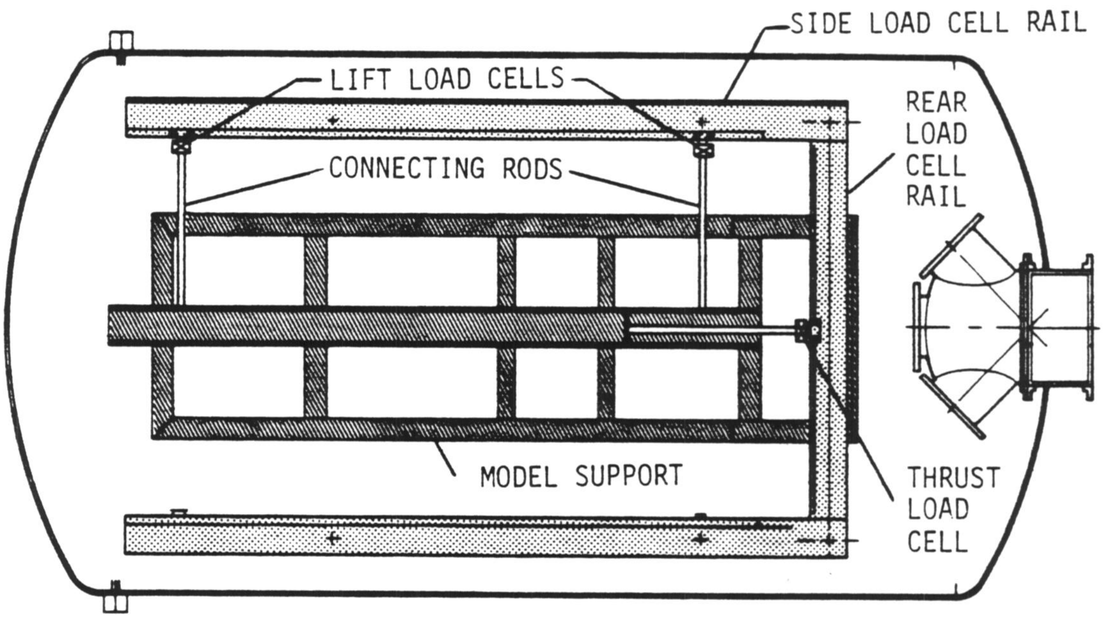


Figure 3.3: The PSCL's Force Measurement System



3.4. High Pressure Air System

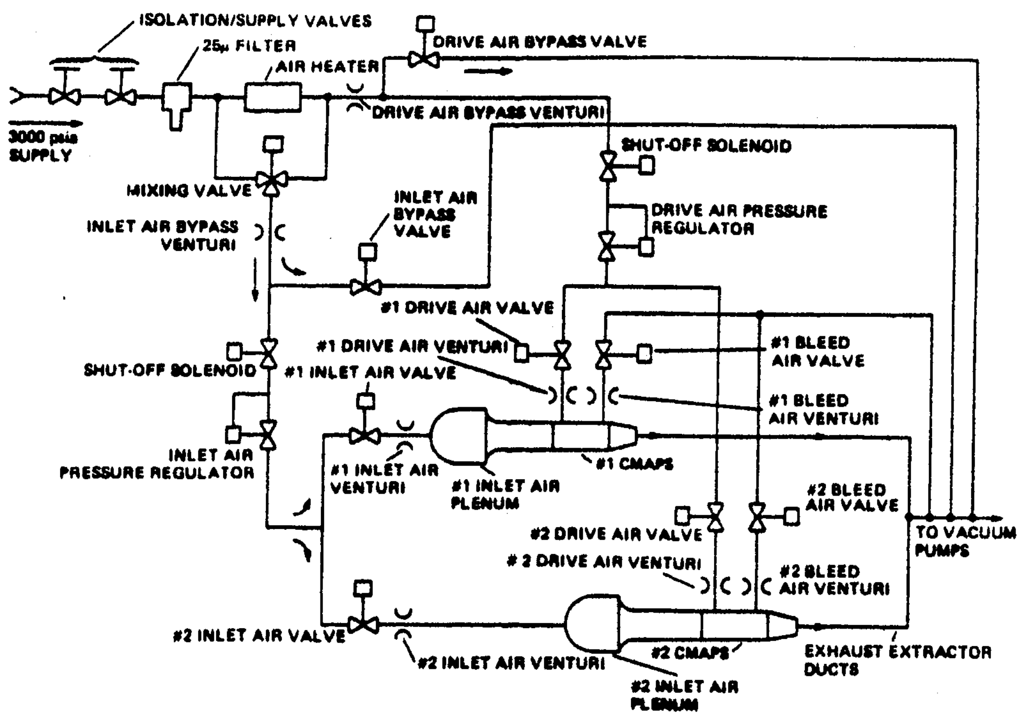
The PSCL's high pressure air supply and control system is designed to meet the airflow requirements of the wide variety of simulators to be calibrated in the laboratory. To accomplish this task, the laboratory must be able to provide correct airflow to the simulators controlled to the proper pressure and temperature. All the airflows must be accurately measured and must cross onto and off the metric frame with a minimal effect to force measurements. And finally, special hardware is required to supply air to simulator inlets and extract the exhaust flows.

3.4.1. Air System Heater and Control Valving.

For the CMAPS, heated, high pressure air is required for the inlet air supply and to drive the turbine. Figure 3.4 shows schematic of the PSCL's high pressure air system. High pressure air, 20.68 MN/m^2 (3000 psia) is supplied to the laboratory by the Ames High Pressure Air Distribution Network.

As the air enters the laboratory, it passes through a 25μ filter. Part of the air passes through a 1 MW air heater while the remaining air is bypassed. The heater can bring the air to a temperature of $93.3^{o}C$ ($200^{o}F$). Part of the air from the heater is supplied directly to the CMAPS turbine. Heating the air to drive the turbine prevents ice from forming in the CMAPS bleed air passages. The heated air that was not directed

Figure 3.4: PSCL High Pressure Air System(ref. 1)



to the turbines and that air which originally bypassed the heater is then used to supply the inlet air. This air is mixed by a valve to match the expected wind tunnel total temperature. As shown in the figure, each simulator will have its own set of control valves for the inlet, drive, and bleed airflows.

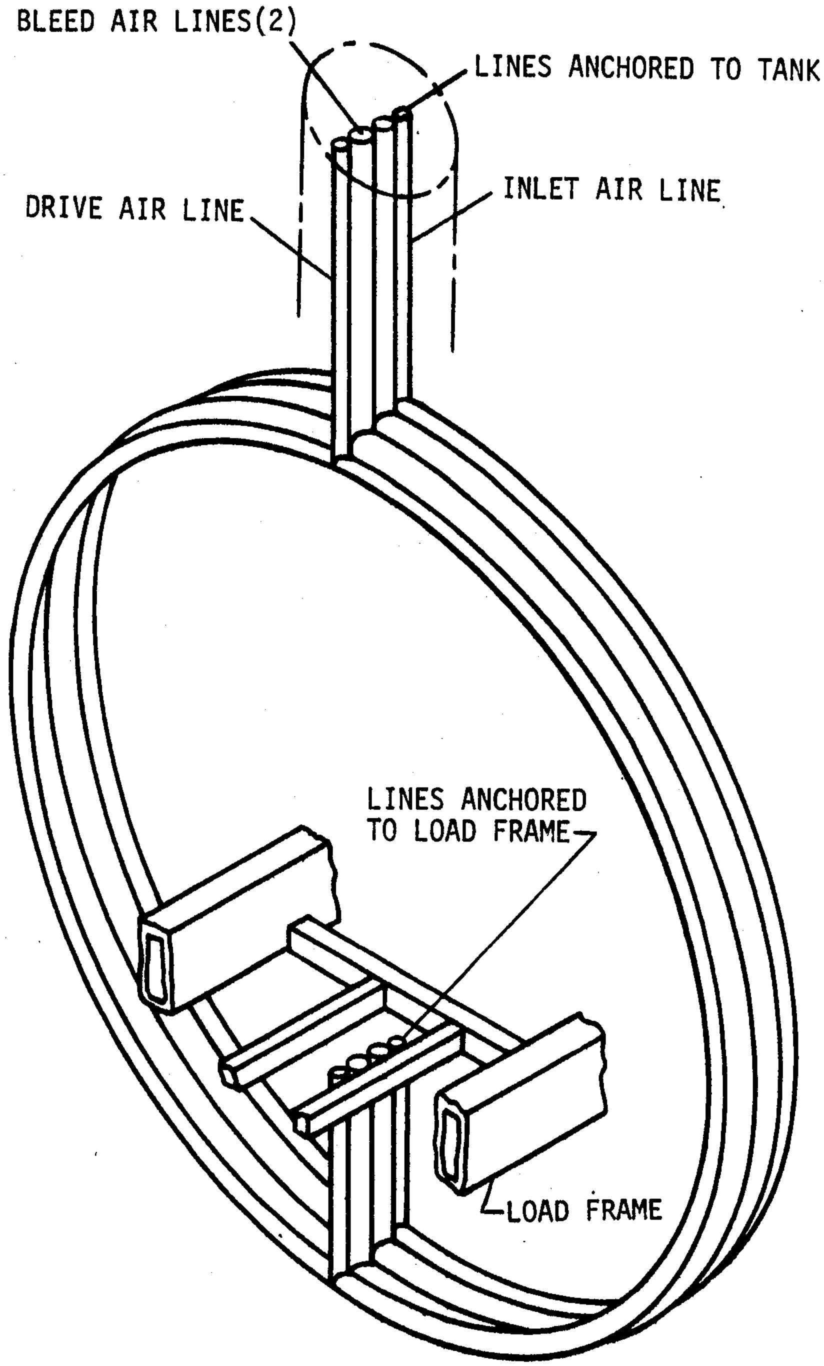
3.4.2. Airflow Measurement.

To accurately calibrate the simulators' airflow, all of the inlet, drive and bleed flows must be accurately measured. Critical flow venturis have been selected for this task because of their high level of accuracy. Figure 3.4 shows the placement of the venturis in the high pressure air system.

3.4.3. Air Line Bridge.

Airflows need to cross on and off the metric frame without effecting the force measurement accuracy. Figure 3.5 shows the air line bridge developed for this task. The bridge consists of one inlet air line, one drive air line, and two bleed air lines. The bridge attaches at the top of the vacuum tank and at the metric frame. It is designed with the large distance between the attachment points to provide a low stiffness, low hysteresis bridge across the load cells. The air lines are circular so that any effects of heating and pressurizing the lines will be canceled. The model airflows will cross the metric boundary at right angles to the plane of measurement. This will

Figure 3.5: High Pressure Air Line Bridge



minimize the effect of the momentum of these flows on the force measurements.

3.4.4. Inlet Air Supply Plenum and Ducting.

Because an inlet operating statistically experiences severe flow distortion, air will be supplied to the simulator inlet to match wind tunnel freestream stagnation conditions. The inlet air will be supplied through a settling plenum and duct work connected through a metric break to the inlet of the model. The inlet plenums will be designed to be adjustable so that a variety of simulator equipped models can be accommodated. An air supply pressure up to 110.3 kN/m^2 (16 psia), regulated to a temperature of 48.9°C (120°F), will be available at the inlets for simulator calibrations.

3.4.5. Engine Exhaust Air Scavenging Ducts.

The engine exhaust extractors will be designed to capture simulator exhaust to prevent exhaust recirculation or impingment on the metric frame. This system, like the inlet plenums, will be moveable so that a variety of flows can be captured. This will include flows from forward lift engines as well as deflected nozzles. The exhaust extractors duct the captured air to the vacuum pumps.

3.5. Data Acquisition System

The PSCL has a data acquisition system(DAS) compatible with the Ames Unitary Wind Tunnel Standard Data Acquisition System. There are 60 data channels presently available, with the capability to expand to 250 channels. All the instrumentation cabling required for a simulator calibration is provided. A termination panel is installed on the metric frame for convenient connection of the simulator instrumentation to the DAS. Excitation and signal conditioning will be done by a Teledyne Controls Programmable Preamplifier Filter Unit (PPAFU). Analog data will be collected at the calibration laboratory by a Teledyne Controls Remote Multiplexer-Demultiplexer Unit (RMDU). The RMDU will convert the analog signals to digital data and transmit the data offsite to the PSCL's central processor via a fiber optic link.

The data acquisition and storage is managed by a Digital Equipment Corporation PDP 11/34. The PDP 11/34 is equipped with 256k MOS memory and two 5.2 MB disk drives. Although plotting and the majority of the computation is done offsite, selected parameters will be computed on a real time basis and made available in the control room.

Figure 3.6 provides a summary of the PSCL's capabilities.

Figure 3.6: PSCL's Capabilities

CALIBRATION CAPABILITY
- Installed Simulator Performance in Complete Unitary Wind Tunnel Models
- Isolated Simulator Performance
- Flow Thru and Jet Effects Model Performance
- Isolated Ducts and Nozzles
- Flowmeters
- Installed Subsonic Simulator Performance
- Isolated Subsonic Simulator Performance

SYSTEM CAPACITY
- Force 0–4448 N (0–1000 lb)
- Airflow 0–11.8 kg/sec (0–26 lb/sec)
- Air Heating 1 megawatt
- Vacuum 12410N/m^2 @ 8.2 kg/sec (1.8 psia @18 lbm/sec)
- Engine Pressure Ratio/Nozzle Pressure Ratio Simulated to $M_\infty \approx 2.0$
- Chamber Size ~3.66 m (12 ft) dia x 7.62 m (25 ft) long

DATA ACQUISITION SYSTEM
- Unitary Wind Tunnel Standard Data Acquisition System
  Digital Equipment Corp. PDP 11/34 with 256 kW MOS Memory
  2 Each 5.2 MB Disk Drives
  Data Reduction Available On Site
  Plotting Available Off Site
- 45 Channels Analog(Expandable to 250 Channels)

ACCURACY GOALS (STATE-OF-THE-ART)
- Overall Force Resolution Equivalent to ±1 Drag Count (or better)

$$\left.\begin{array}{l}\text{-±0.1\% Airflow Accuracy}\\ \text{-±0.05\% Force Accuracy}\\ \text{-±0.25\% Pressure Accuracy}\\ \text{-±0.6°C (1°F) Temperature Accuracy}\end{array}\right\}\text{ Full Scale}$$

Chapter 4

PSCL Force Measurement System

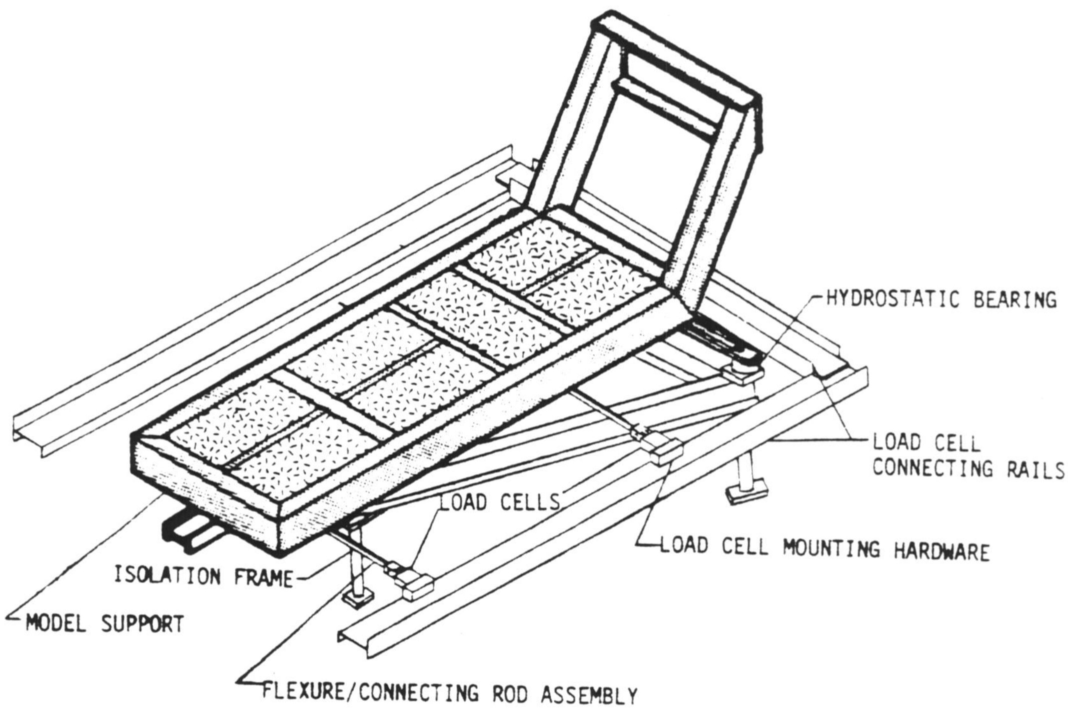
4.1. Introduction

The force measurement system of the PSCL is a three component balance which is designed to perform accurate force calibrations of propulsion simulators installed in wind tunnel models. The PSCL's force measurement system has three degrees of freedom in the horizontal plane, permitting measurement of two forces and one moment. This fulfills the calibration requirements for the thrust, lift, and pitching moment generated by simulator equipped V/STOL models.

Figure 4.1 shows the arrangement of the components of the force measurement system in the vacuum tank. The system consists of: 1)a wind tunnel model support system, 2)load cell connecting rails, 3)flexure/connecting rod assemblies, 4)load cells, 5)load cell mounting hardware, and 6)frame lock-out and frame travel stops(which are not shown.)

Simulator equipped wind tunnel models are mounted on the metric frame

Figure 4.1: PSCL Force Measurement System



which is floating on three hydrostatic oil bearings(see Figure 3.2.) This allows the frame free movement in the horizontal plane. Thrust loads produced by the simulators are transferred from the metric frame through a connecting rod to a load cell mounted on the rear load cell rail. Lift loads and pitching moments are transferred through connecting rods to the two load cells mounted on the side rails. All loads are in tension. Figure 4.2 shows the layout of the system's force sensing members and gives the basic equations used for determining the forces and moment. The nomenclature presented in the figure conforms to the standard used for wind tunnel model force balances.

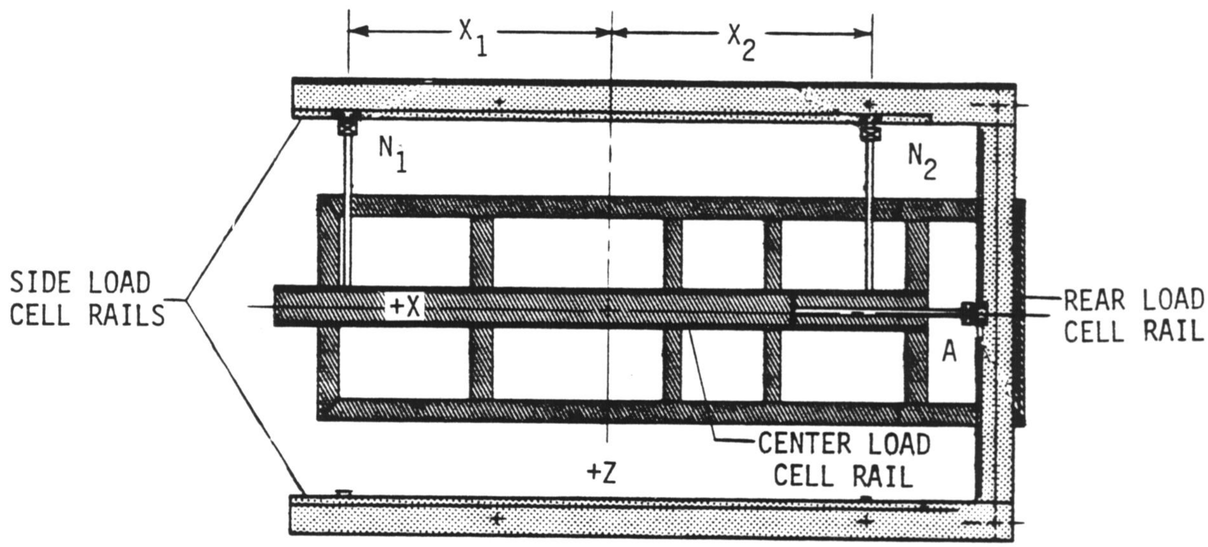
The force measurement system, like the rest of the PSCL, was designed to be as flexible as possible so that a wide variety of force calibrations can be performed. The configuration of the balance and the support systems can be changed to accomodate specific tests. The force balance capacity can be varied by simply changing load cells.

4.2. System Components

4.2.1. Wind Tunnel Model Support System.

The wind tunnel model support system, shown in Figure 4.3, consists of a metric frame, three hydrostatic bearings, and an isolation frame. The metric frame is designed to support a variety of simulator equipped wind

Figure 4.2: Force Balance Axis System and Nomenclature



$$F_x = A$$

$$F_z = N_1 + N_2$$

$$M_y = N_1X_1 - N_2X_2$$

where:

A = Axial Gauge

N_1 = Forward Normal Gauge

N_2 = Aft Normal Gauge

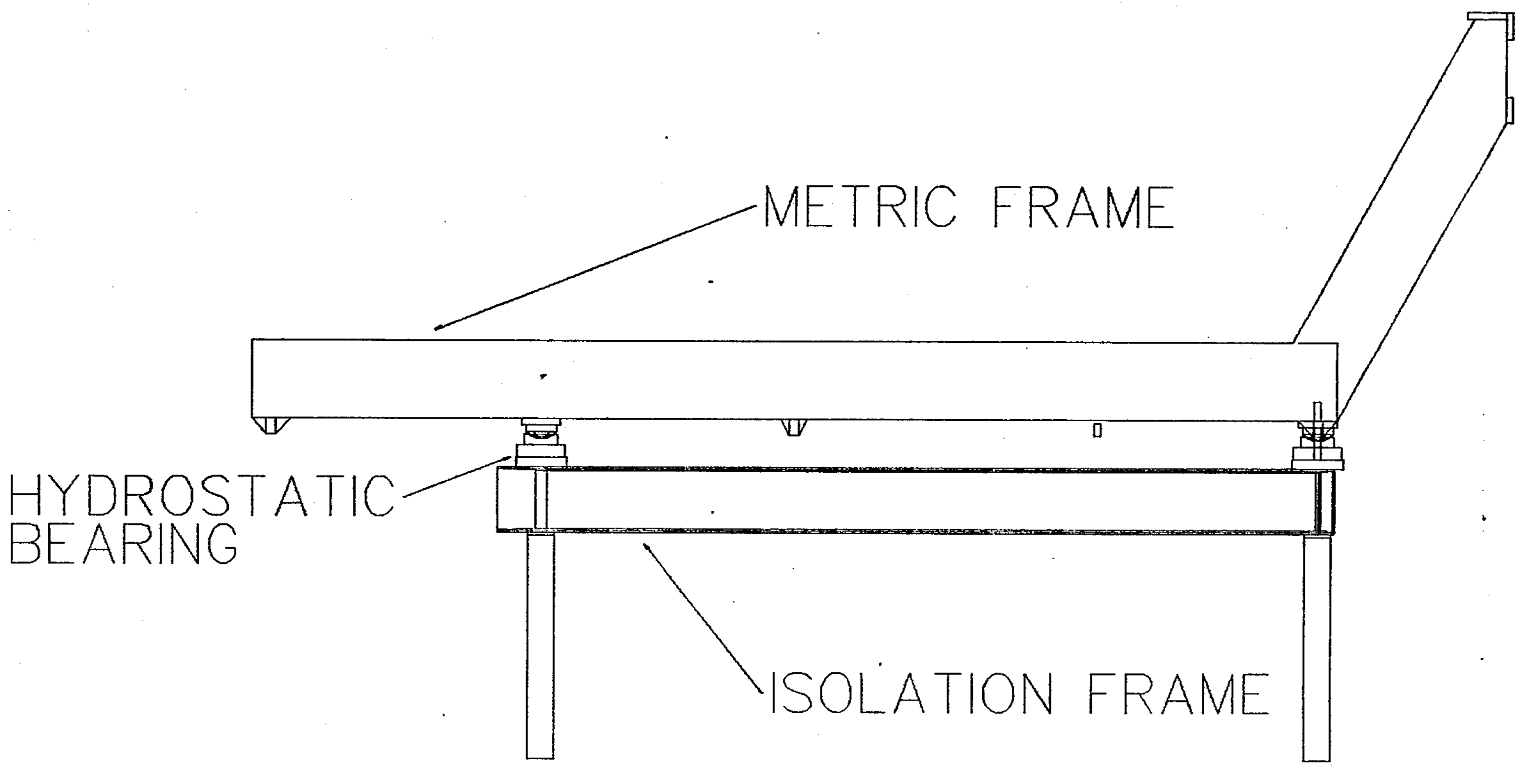


Figure 4.3: Wind Tunnel Model Support System

tunnel models. This includes sting mounted and floor mounted half-model types.

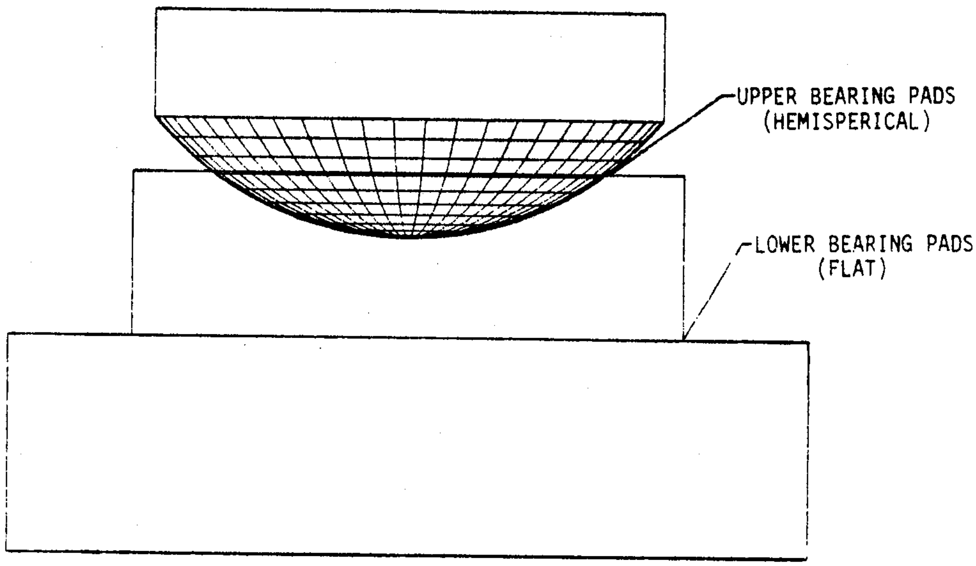
The metric frame is floated on three low-friction hydrostatic bearings. A representation of a bearing is shown in Figure 4.4. The bearings travel on a film of high pressure oil pumped between the pad surfaces. The lower set of pads(flat) allow horizontal travel of the bearings, while the upper set of pads(hemispherical) allows the bearings to adjust to a slight angular misalignment during setup. A hydraulic power supply is used to pump high pressure oil, 20.7 MN/m^2 (3000 psi) to the bearing pads at a rate of 7.2 l/min (1.9 gpm). A scavenge pump collects the oil at the bearings and returns it to the hydraulic power supply to be recirculated. The bearings have a horizontal travel of $\pm$0.64 cm ($\pm$0.25 in.) and an angular travel of $\pm$0.09 rad ($\pm 5^\circ$).

The hydrostatic bearings rest on the corners of the triangular isolation frame. The three legs of the isolation frame pass through the wall of the vacuum tank to the floor of the laboratory. This arrangement isolates the model support system from any physical distortion of the tank due to changes in the chamber temperature and pressure. There is a screw jack at the end of each of the isolation frame's legs to allow leveling and height adjustment of the frame.

4.2.2. Load Cell Rails.

An overhead view of the load cell rails is shown in Figure 4.2. The load cells are mounted on the non-metric rear and side rails which are bolted to

Figure 4.4: Hydrostatic Bearing



blocks that are welded to the vacuum tank. Rods connect the load cells to the metric center rail which is bolted to the metric frame. There are fifteen(15) stations, spaced 0.3 m (1 ft) apart, available for placement of the two lift load cells(N_1 and N_2.) This flexibility in placement will allow the system to be configured such that the load cells carry equal loads even as different models are calibrated.

4.2.3. Flexure/Connecting Rod Assemblies.

Flexure/connecting rod assemblies transfer the tension forces from the metric frame to the load cells. Figure 4.5 shows an assembly. Long connecting rods, approximately 0.9 m (36 in.), are used to minimize the effects of misalignment of the load cells due to deflections in the support hardware during loading. The jam nuts permit the orientation of the flexures to be adjusted by removing any slack in the connecting rod's threads. Low-stiffness flexures(Figure 4.6) have been placed at the end of the connecting rods to allow for a slight amount of misalignment during installation and operation. The flexures have an initial stiffness(K_i) of approximately 264 cm-kg/rad (4 in-lb/deg). The cut-out perpendicular to the flexural element is sized to prevent excessive deflections.

4.2.4. Load Cells.

Three high-precision uniaxial load cells are used to measure the forces generated by the simulators. Figure 4.7 shows the typical geometry of the

Figure 4.5: Flexure/Connecting Rod Assembly

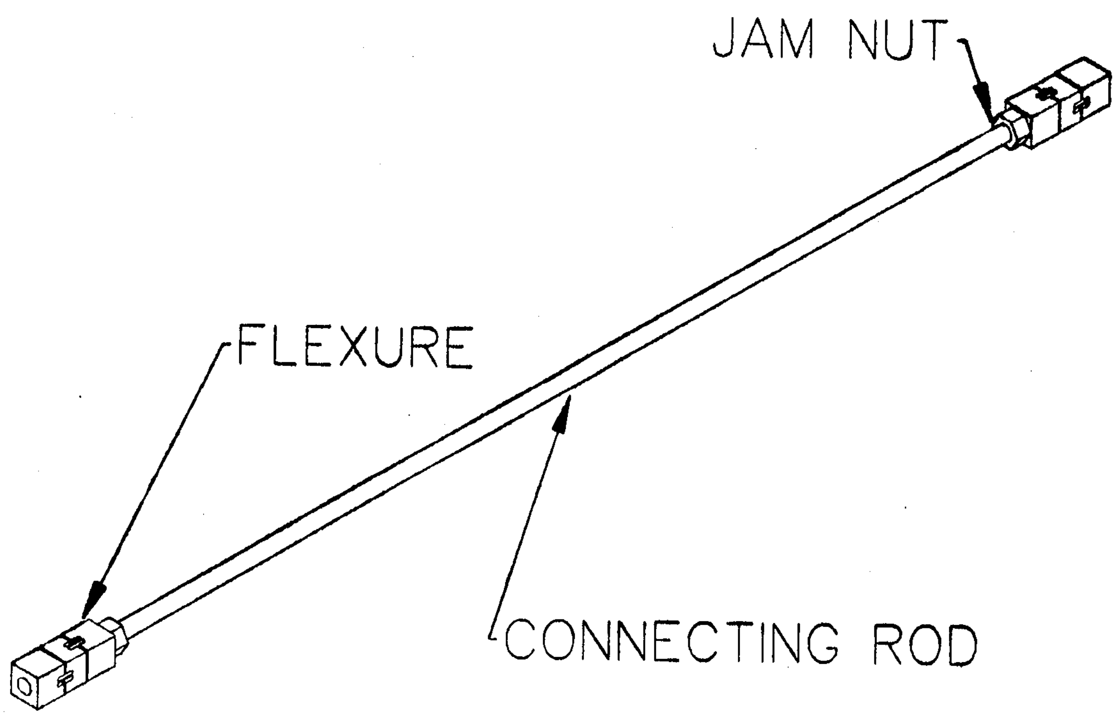


Figure 4.6: Low-Stiffness Flexure

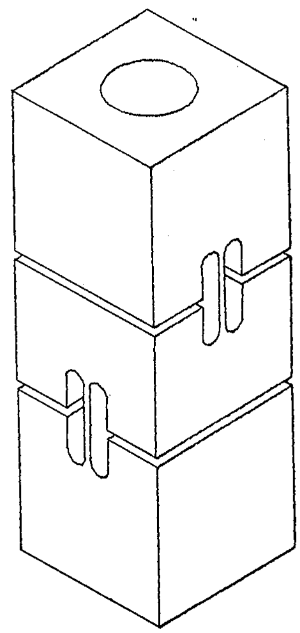
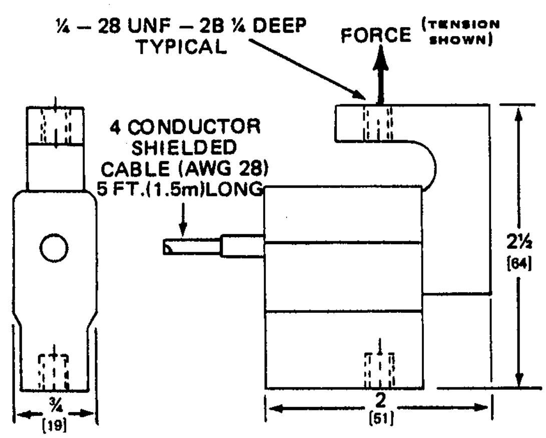


Figure 4.7: PSCL Load Cell Specifications

installation dimensions INCHES [mm]



Non-Linearity-% Full Scale		±0.03
Hysteresis-% Full Scale		±0.02
Non-Repeatability-% Full Scale		±0.01
Temperature Range, Compensated-°F	(-15 to 65°C)	0 to 150
Temperature Range, Operating-°F	(-50 to 90°C)	-65 to 200
Thermal Sensitivity-% of Reading °F	(±0.0015/°C)	±0.0008
Thermal Zero-% Full Scale/°F	(±0.0015/°C)	±0.0008
Thermal Zero-% Full Scale/°F For Moisture Resistant Models	(±0.0022/°C)	±0.0012
Creep, After 20 Min.-% of Load		±0.03
Overload Ratings-% Rated Capacity		
Safe		±150
Ultimate		±500
Nominal Output-mV/V		3
Zero Balance-% Full Scale		±1
Input Resistance-Ohms		350±3.5
Output Resistance-Ohms		350±3.5
Excitation Voltage		
Recommended-VDC		10
Maximum-VAC or VDC		15
Insulation Resistance, Bridge to Case-Megohms		5000
Side Load Effects		
1° **Load Offset-%** Full Scale		0.1
3° **Load Offset-%** Full Scale		0.3

load cells along with their performance specifications. The load cells are manufactured by Genisco Corp. Load cells with full scale ranges from 22 to 4448 N (5 to 1000 lb) are available for conducting calibrations. The capability to change the load capacity will allow the force measurement system to be tailored to the specific requirements of each calibration. This should provide the highest possible force resolution for each simulator calibration.

4.2.5. Load Cell Mounting Hardware.

The load cells are clamped to the load cell rails using the mounting hardware shown in Figure 4.8. The load cell is screwed onto the load cell mount which is clamped between the top and bottom pieces of the mounting bracket. The load cell mount has 2.54 cm (1.0 in.) of travel in the mounting brackets so that the flexure/connecting rod length can be adjusted.

4.2.6. Frame Lock-Out System and Travel Stop Blocks.

Two systems have been developed to protect the force measurement system. The first system, the metric frame lock-out, restrains the movement of the frame when the hydrostatic bearings are not operating. This prevents possible damage to the bearing surfaces. The system uses four hydraulically actuated pistons placed on the side rails near the four corners of the metric frame. When released, the pistons seat in cones, which are attached

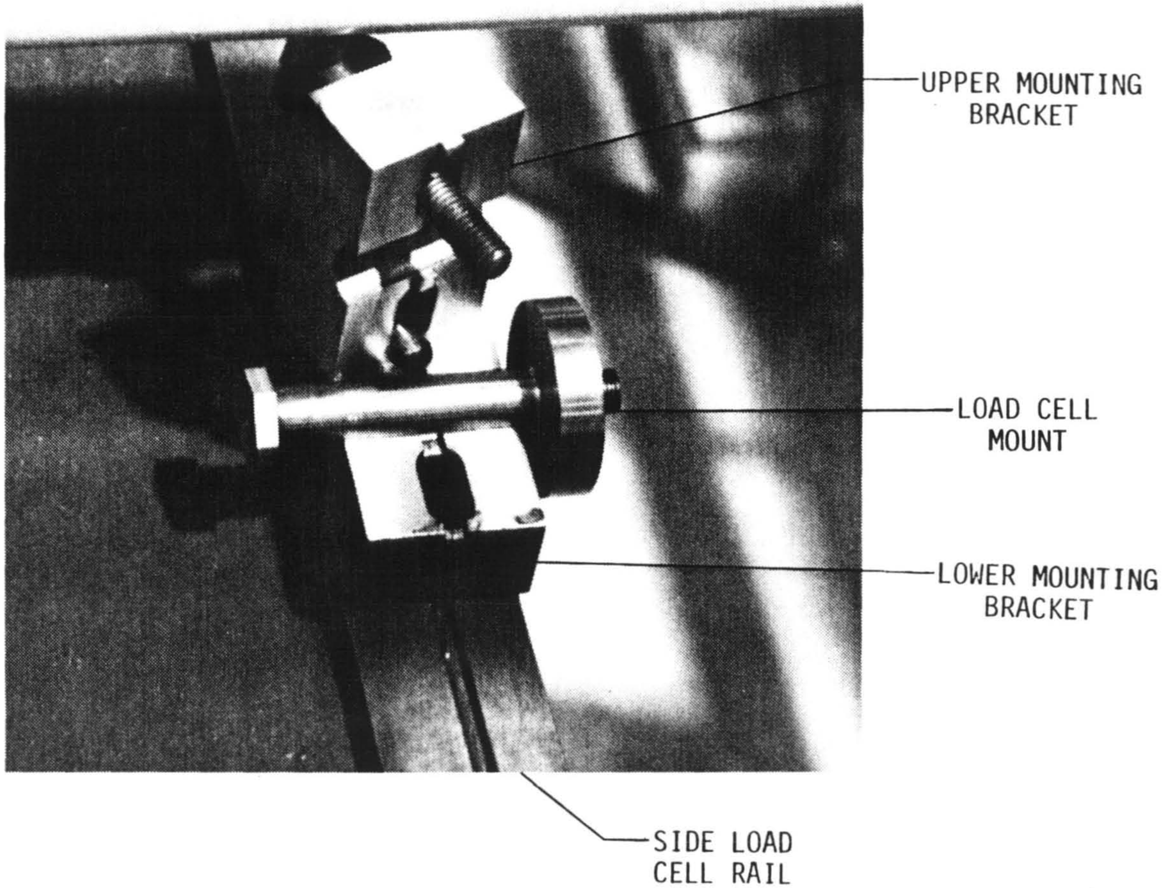


Figure 4.8: Load Cell Mounting Hardware

to the metric frame, to lock out any movement of the frame. This system also protects the load cells from damage while installing models or performing other work in the tank. Figure 4.9 shows one of the four lock-outs.

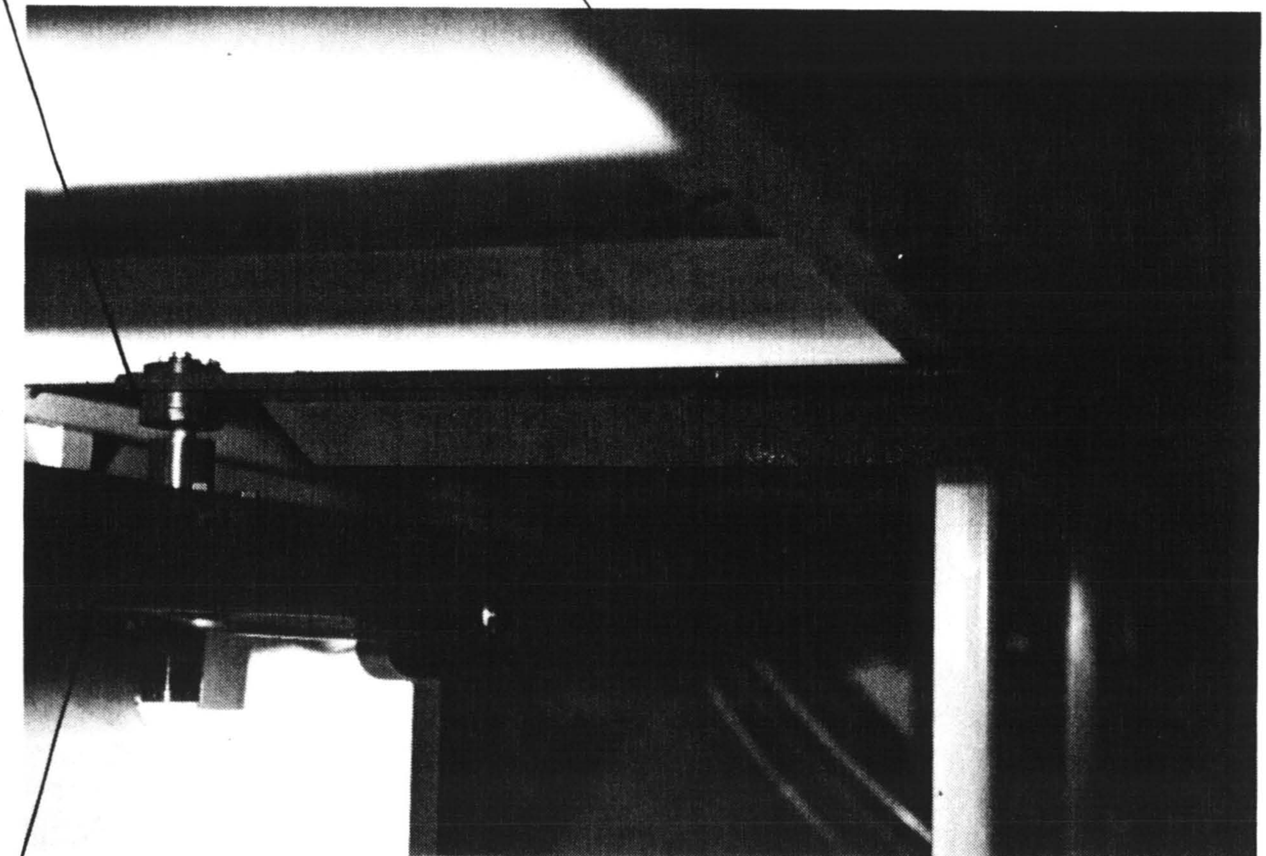
The second protection system is the frame travel stop blocks. The travel stop blocks, shown in Figure 4.10, limit the travel of the metric frame to prevent the load cells from being overloaded. The blocks consist of a square beam placed inside a larger square beam. One beam is bolted to the metric frame and the other to the non-metric supporting structure. By adjusting screws, the distance that one beam can move with respect to the other is limited. The gap for the screws is set using micrometers. There is one set of blocks at each end of the metric frame. There are future plans to develop a sensing system to be used in conjunction with the travel stops to warn if the travel stops are fouling.

4.3. Force Measurement System Error Parameters

From the general description of the PSCL and the detailed description of the force measurement system, it can be seen that the PSCL's force measurement system is influenced by a wide range of parameters which could cause errors in the force readings. If these errors are large enough to effect the accuracy of the system, $\pm 0.05\%$ full scale, they will either have to be eliminated or an analytical method will have to be developed to account for them. The following subsections describe the parameters expected to effect the force readings and suggest ways to either account for

METRIC FRAME LOCK-OUT

METRIC FRAME



SIDE LOAD CELL RAIL

Figure 4.9: Metric Frame Lock-Out

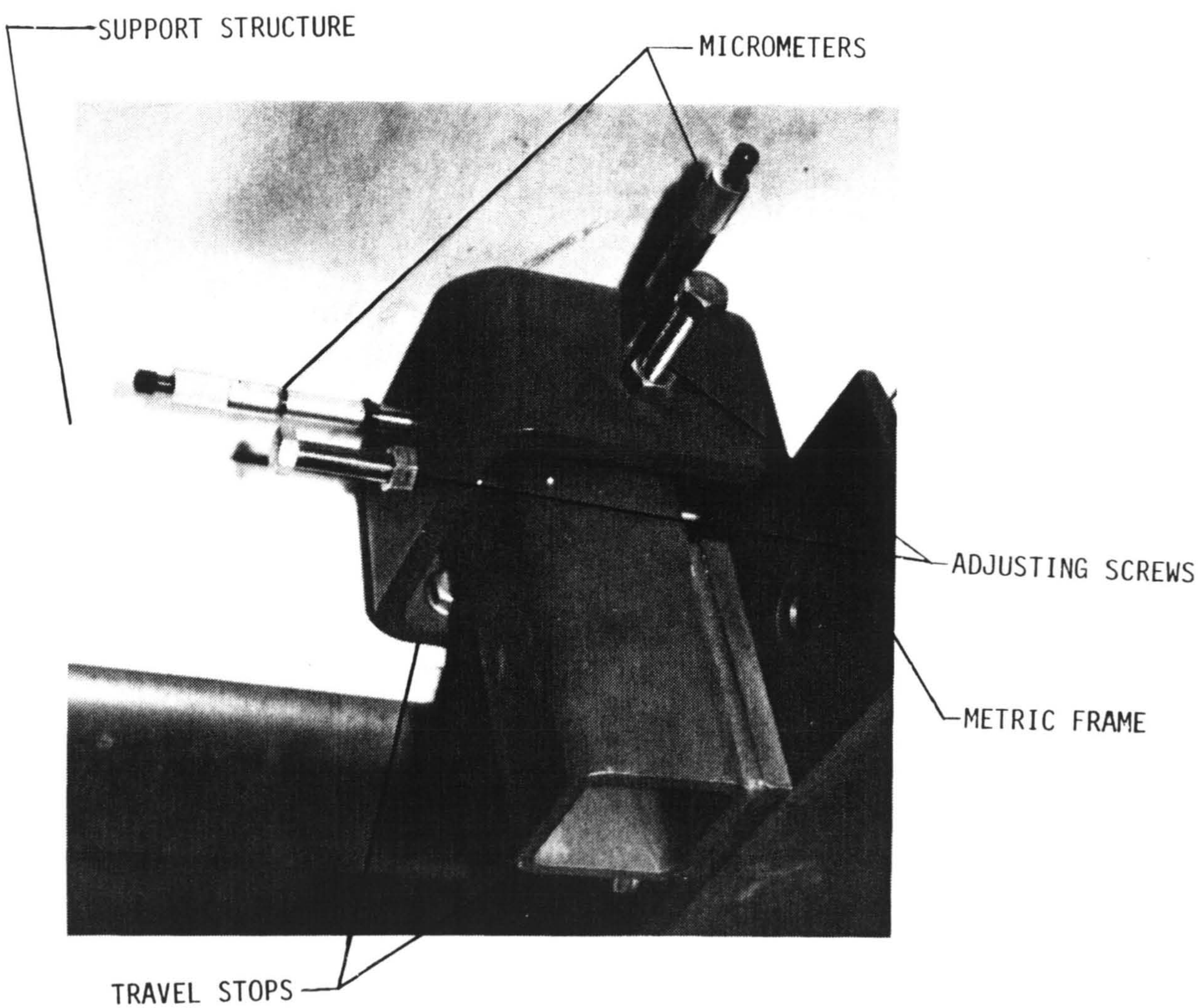


Figure 4.10: Travel Stop Blocks

these parameters in the data reduction equations or physically correct the errors.

4.3.1. Misalignment Errors.

Errors will be created due to the misalignment of the frame with respect to the load cells. This includes both the initial misalignment, introduced during the force measurement system installation, and the misalignment due to the structural deflection of the system under loading. Figure 4.11 shows the effects of an initial misalignment on a load reading. Instead of sensing the applied load, F_{app}, only the load $F_{app}\cos\alpha$ is measured. The percent of the error due to misalignment is given by

$$\begin{aligned}\%\text{Error} &= \frac{F_{app} - F_{app}\cos\alpha}{F_{app}} \\ &= 1 - \cos\alpha\end{aligned}$$

This relation also applies to any misalignment of the calibrating load with respect to the load cells. Applying the above relationship to the PSCL's force measurement system, the magnitude of the allowable misalignment was found to be $\pm$0.89cm ($\pm$0.35 in.) This is based on an allowable error of $\pm$0.005%F.S., which is one order of magnitude smaller than that required for the force measurement system.

Interactions(loads induced in one gauge by the loading of another gauge) due to the system deflecting under a thrust load is illustrated in Figure 4.12. Although no load is applied in the lift direction, the lift load cells are loaded due to the displacement of the frame caused by the thrust load.

Figure 4.11: Effects of Initial Misalignment

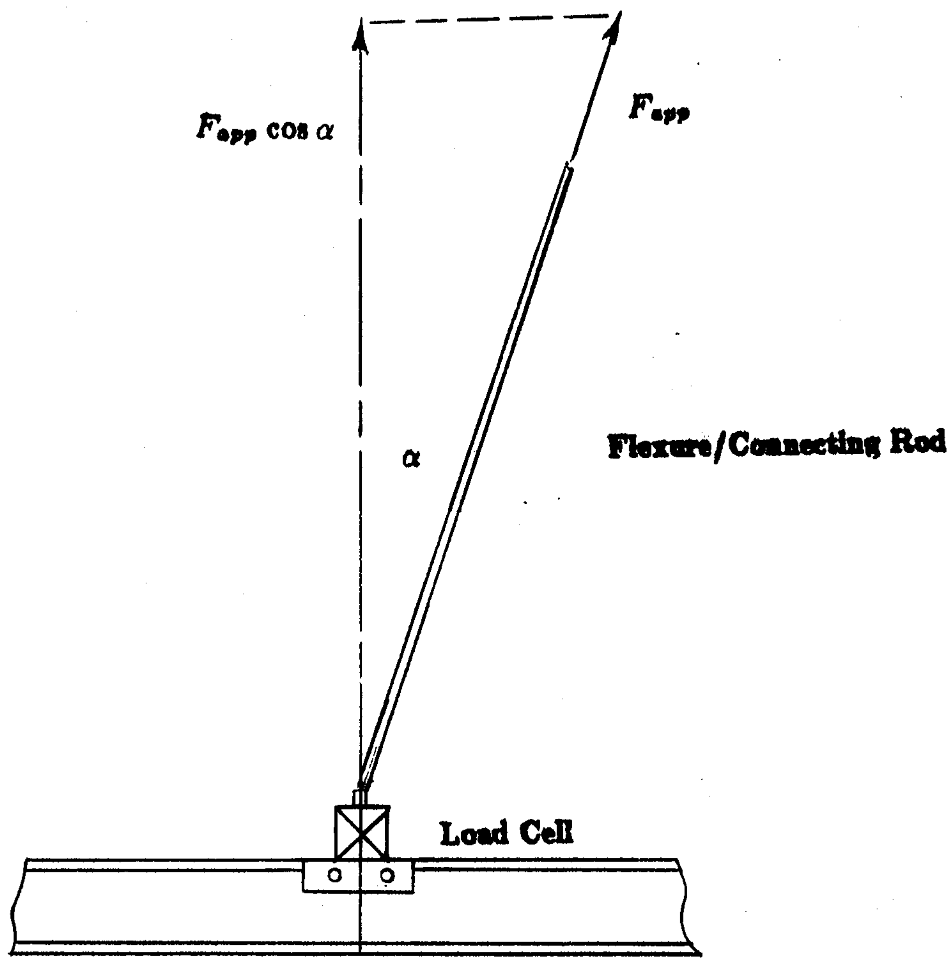
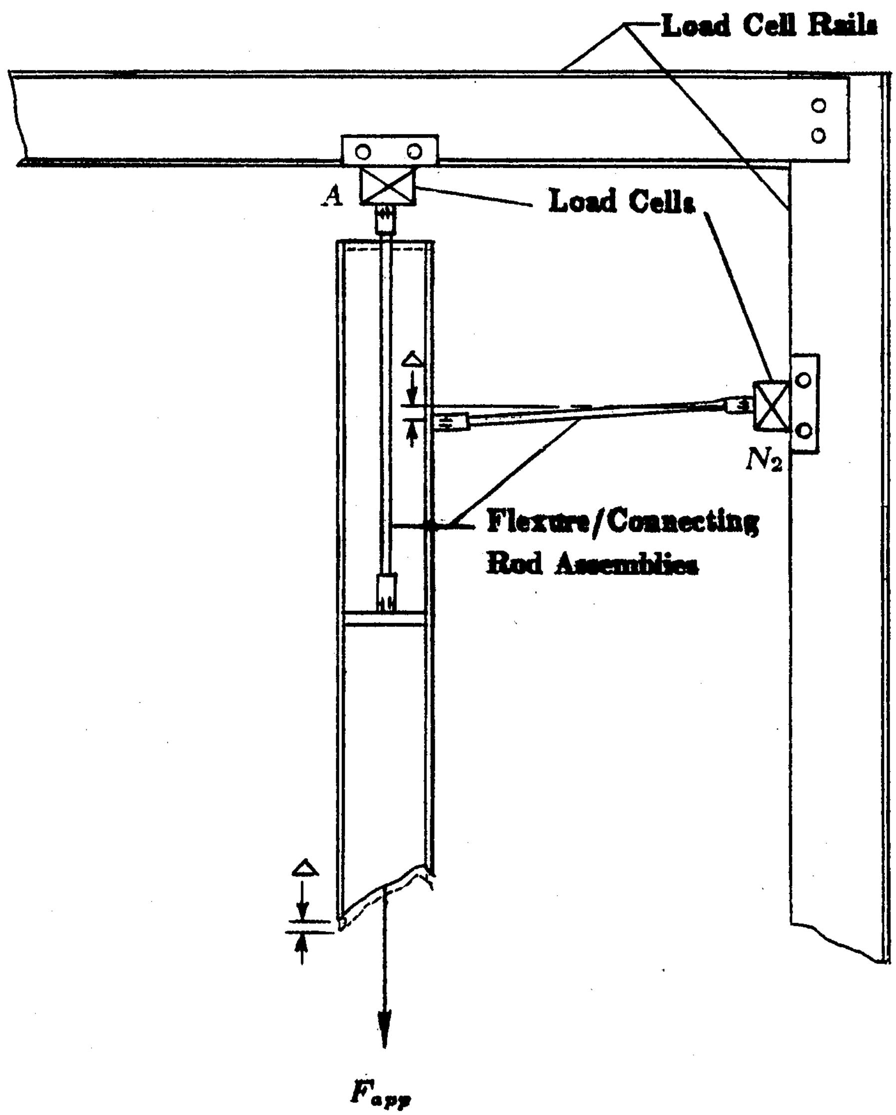


Figure 4.12: Effects of Structural Deflection



As mentioned in Section 4.2.5, the connecting rods were made as long as possible to minimize α and the resulting effects. If the interactions are large enough to effect the force measurement accuracy, they can be taken into account, because they should be repeatable. The procedure used to account for the interactions in the wind tunnel model balances at Ames should also apply to the PSCL's force measurement system. The loading schedule for the calibration of the force measurement system's interactions was developed with this procedure in mind. It is recommended that any interactions present in the system be corrected using this method, because the programming is already available.

A simplified version of the procedure used for the wind tunnel model balances, adapted from Reference 2, is presented here to familiarize the reader with these techniques. For a detailed description of this procedure, the reader is directed to References 2 and 3.

For this example, the interaction corrections to the thrust load cell(A) are outlined. This method, however, can be applied to any gauge. Using this procedure, the interactions that are present in the balance are determined experimentally. Once the interactions have been determined, they are described analytically. The balance readings can then be corrected by subtracting out the interactions calculated using these analytical descriptions. The load reading on gauge A, corrected for interactions is given by

$$F_A = P_A - I_A - CLD_A$$

where

F_A = force on gauge A corrected for interactions;[Newton (lb)]

P_A = force on gauge A uncorrected for interactions;[N (lb)]

I_A = total primary interaction correction for gauge A;[N (lb)]

CLD_A = total combined interaction correction for gauge A;[N (lb)]

In the above equation, P_A is the output of gauge A without any interactions taken into account. F_A is the gauge output corrected for primary interactions(I_A) and secondary, or combined, interactions(CLD_A.) The primary interactions on the gauge are created by loading another gauge(called the prime gauge) singularly. The secondary interactions are created by loading the prime gauge in combination with a secondary gauge.

For the initial calibration, loads are applied to only one load cell at a time. During this prime loading, each load cell is loaded from zero to full scale and back to zero. The change in load with millivolt output is described by a least squares polynomial curve that is fitted through the loading data for each load cell. The coefficients of these curve fits are considered the prime gauge coefficients(for gauge A, K_{Ai}). The load on gauge A(uncorrected for interactions), is given by the polynomial

$$P_A = \sum_{i=0}^{n} K_{Ai} R_A^i$$

where

$$
\begin{aligned}
P_A &= \text{force on gauge } A \text{ uncorrected for interactions;[Newton (lb)]} \\
K_{Ai} &= i^{th} \text{ prime gauge coefficient for gauge } A\text{;[N/mV (lb/mV)]} \\
R_A &= \text{millivolt output of gauge } A\text{;[mV]} \\
i &= \text{number of the polynomial term} \\
n &= \text{order of curve fit}
\end{aligned}
$$

The primary interaction loads, loads induced in the other load cells by loading the prime load cell, can now be determined. Figure 4.13 gives an example of the effect that loading gauge N_1 has on gauge A. Gauge A must be corrected for the primary interactions induced by loading gauges N_1 and N_2. The prime gauge coefficients determined above are used to convert the millivolt output of the load cells into interaction loads. The change in the interaction load with the load on the prime load cell is fitted with a least squares polynomial curve. These curve coefficients are called the primary interaction coefficients. The total primary interaction correction for load cell A, is given by

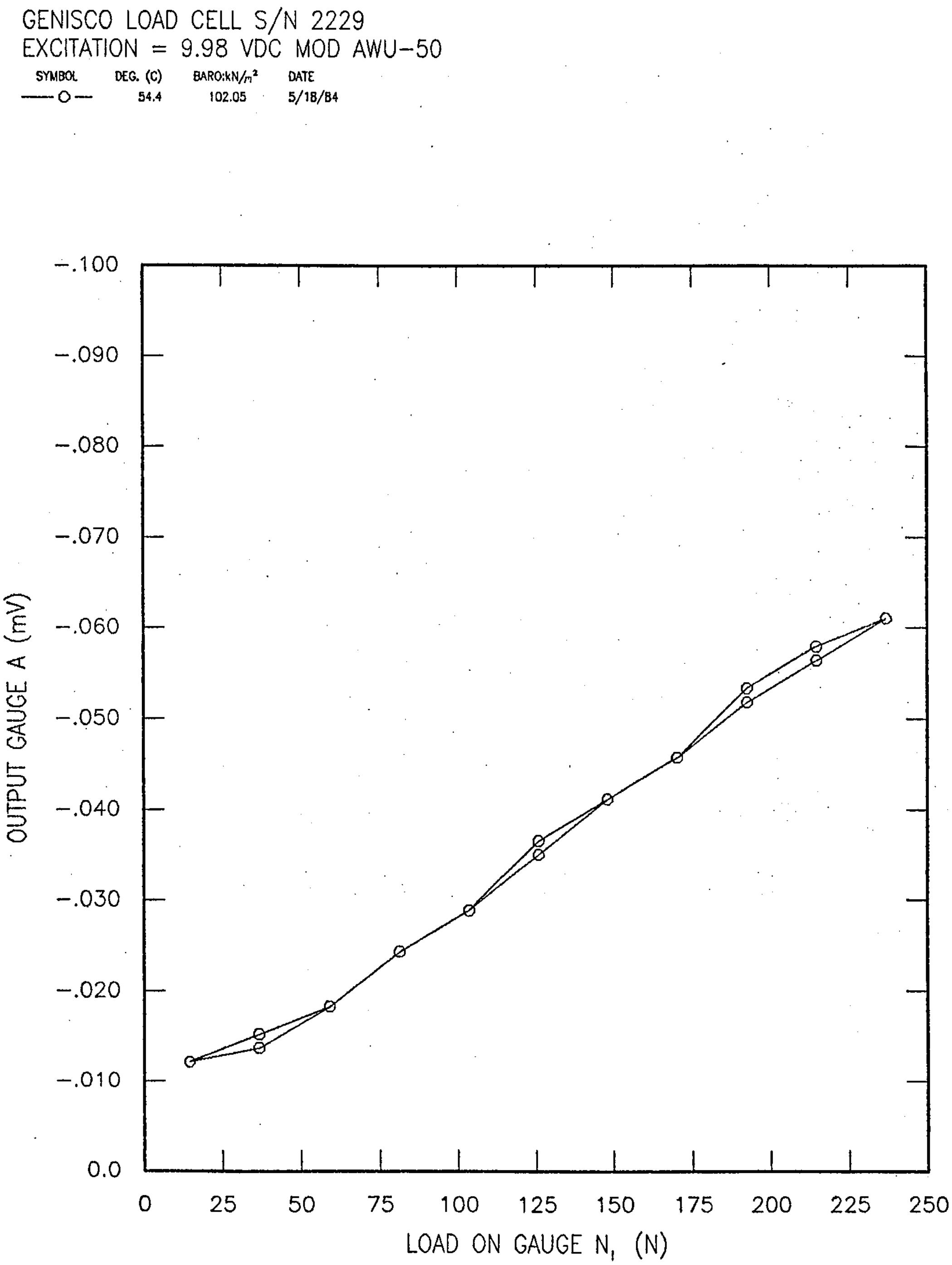
$$I_A = I_{AN_1} + I_{AN_2}$$

The primary interaction terms are given by the polynomials

$$
\begin{aligned}
I_{AN_1} &= \sum_{i=0}^{n} J_{iAN_1} P_{N_1}^{i} \\
I_{AN_2} &= \sum_{i=0}^{n} J_{iAN_2} P_{N_2}^{i}
\end{aligned}
$$

where

Figure 4.13: Primary interactions on gauge A due to load on gauge N_1



I_A = total primary interaction correction of gauge A;[Newton (lb)]

I_{AN_1} = primary interaction correction of gauge A due the load on gauge N_1;[N (lb)]

I_{AN_2} = primary interaction correction of gauge A due the load on gauge N_2;[N (lb)]

$P^i_{N_1}$ = load on gauge N_1 uncorrected for interactions;[N (lb)]

$P^i_{N_2}$ = load on gauge N_2 uncorrected for interactions;[N (lb)]

J_{iAN_1} = i^{th} primary interaction coefficient for gauge A due to P_{N_1}

J_{iAN_2} = i^{th} primary interaction coefficient for gauge A due to P_{N_2}

The combined interactions are found by repeating the prime loading cycles with a full scale load on a secondary load cell. For this example, gauge A must be corrected for the combined interactions where N_1 is the primary gauge and N_2 is the secondary gauge, and where N_2 is the primary gauge and N_1 is the secondary gauge. First, the difference is computed between the actual load applied and those calculated using the prime gauge and interaction coefficients. This difference is described as a function of the prime load with a least squares curve fit. This function is then ratioed by the secondary load. The coefficients of this polynomial are the combined interaction coefficients. The total combined interaction correction for load cell A, is given by

$$CLD_A = CLD_{AN_1N_2} + CLD_{AN_2N_1}$$

The combined interaction correction terms are given by the polynomials

$$CLD_{AN_1N_2} = \sum_{i=0}^{n} J_{iAN_1N_2} P_{N_1} P_{N_2}$$

$$CLD_{AN_2N_1} = \sum_{i=0}^{n} J_{iAN_2N_1} P_{N_2} P_{N_1}$$

where

$$CLD_A = \text{total combined interaction correction for gauge } A\text{;[Newton (lb)]}$$

$$CLD_{AN_1N_2} = \text{combined interaction correction of gauge } A \text{ due the primary load on gauge } N_1 \text{ and the secondary load on gauge } N_2\text{;[N (lb)]}$$

$$CLD_{AN_2N_1} = \text{combined interaction correction of gauge } A \text{ due the primary load on gauge } N_2 \text{ and the secondary load on gauge } N_1\text{;[N (lb)]}$$

$$J_{iAN_1N_2} = i^{th} \text{ combined interaction coefficient for gauge } A \text{ due the primary load on gauge } N_1 \text{ and the secondary load on gauge } N_2$$

$$J_{iAN_2N_1} = i^{th} \text{ combined interaction coefficient for gauge } A \text{ due the primary load on gauge } N_2 \text{ and the secondary load on gauge } N_1$$

The force on load cell A corrected for the primary and secondary interactions is F_A and is given by

$$F_A = P_A - I_A - CLD_A$$

The corrected load cell values can then be substituted for the uncorrected values in the above equations and the process begun again. This process is repeated until a specified tolerance for the difference in valves between iterations is met.

4.3.2. Resistive Forces.

This category includes any parameter that resists the free movement of the metric frame. This effect is seen as an increase in the hysteresis and a decrease in the sensitivity of the load cells. The hysteresis is defined as the difference in the force measurement depending on whether it is approached from a higher or lower value. The hydrostatic bearings, flexures, instrumentation wiring, and air lines will all contribute to the force measurement system's hysteresis. This effect occurs because all of the energy put into the system during the loading is not recoverable during unloading. If necessary, this effect can be ignored if readings are only taken while loading the system in increasing increments.

The spring resistance from the flexures, instrumentation wiring, and air lines will oppose the free movement of the metric frame. All of these elements should behave similar to spring connected to the frame. The resistive force for each of the elements can then be defined as:

$$F_{spring} = kx$$

where

F_{spring} = the resistive spring force;[Newton (lb)]

k = the spring constant;[N/cm (lb/in.)]

x = the metric frame's displacement;[cm (in.)]

Since x should be less than 0.025 cm (0.01 in.), these forces should be negligible if k is not too large. As discussed earlier, the flexures(section 4.2.3) and the air lines(Section 3.4.3) have been designed to make their spring constants as small as possible. This is also true of the instrumentation wiring, which was mentioned in Section 3.5. Instead of grouping the cables in large bundles, the wiring crosses the metric break in small, loosely arranged bundles. For the flexures and the instrumentation wiring, k will remain constant. These effects are a function of the frame's displacement due to loading. The air lines present a different problem in that their stiffness will change as they are heated and pressurized. These effects can be taken into account in a manner similar to the flexures and wiring, only in addition to the frame's displacement, the resisting force will be a function of the lines' pressure and temperature.

Another possible effect of the air lines is the chance that they may not expand symmetrically as they are heated and pressurized. If this is the case, some offset load will be placed on the frame. This effect too can be described as a function of the air lines' pressure and temperature. The effects of all of these resistive forces can be determined experimentally.

4.3.3. Flow Effects.

The design of the high pressure air system is such that flow crosses onto the metric frame perpendicular to the plane of measurement. This should prevent the momentum of the air traveling through the lines from being sensed by the load cells. A load will be sensed by the force measurement system for any flow crossing onto the frame at an angle. This load will be a function of the momentum of the flow in the pipes and their misalignment from perpendicular. This effect can be eliminated by adjusting the air lines, or can be corrected in the data reduction equations. The correction would be a function of the airflow in each line.

The quality of the force data may also be effected by simulator exhaust impingment on the metric frame. The frame should be very sensitive to any flow that is not captured by the exhaust extractors. Spillage from the exhaust extractors could create random fluctuations that either have to be eliminated by fine turning the extractor design or could be corrected by statistical methods.

4.3.4. Environmental Effects.

The calibration tank is a unique operating environment for the load cells. The reduced pressure and increased temperature could effect the load cell readings. Vibration from the pumping plant and the simulators could also produce reading errors.

If changes in the tank pressure and temperature do effect the load cells this will be seen as a change in sensitivity. This can be taken into account by calibrating the load cells over the expected operating range of pressure and temperature. The necessity for temperature corrections can be eliminated by placing the load cells in a temperature controlled environment. The effects of the vibration should be managed using statistical methods.

The PSCL was designed so that the misalignment errors, resistive forces, flow effects, and environmental effects would be negligible. A calibration was required, however, to verify that these parameters are inconsequential and that other sources of error have not been overlooked.

4.4. Force Measurement System Alignment and Installation

The purpose of aligning the force measurement system was to minimize the misalignment effects on the force readings(as discussed in subsection 4.3.1.) Misalignment of the force measurement system and/or the calibrating forces can degrade the desired performance($\pm$0.05%F.S.) of the force measurement system. The analytical analysis of a jet engine test stand in which the alignment had a critical effect on the stand's performance is discussed in Reference 4. Because the force measurement system has a flexible configuration, the system will need to be aligned as it is changed to adapt to various calibrations. The following subsections outline the procedures developed to perform the alignment of the system and the installation of the load cells and flexure/connecting rod assemblies. Also discussed are the problems encountered during the performance of these procedures and the changes made or those suggested to be made.

4.4.1. Horizontal Alignment.

The initial alignment was performed to level and the align the components of the force measurement system in the horizontal plane. The hydrostatic bearings were also leveled so that they would operate properly. This initial phase was performed using precision bench levels, a surveying transit, and stainless steel pointers(see Figure 4.14). The stainless steel pointers are designed to mount to the load cell rails at the load cell and flexures/connecting rod

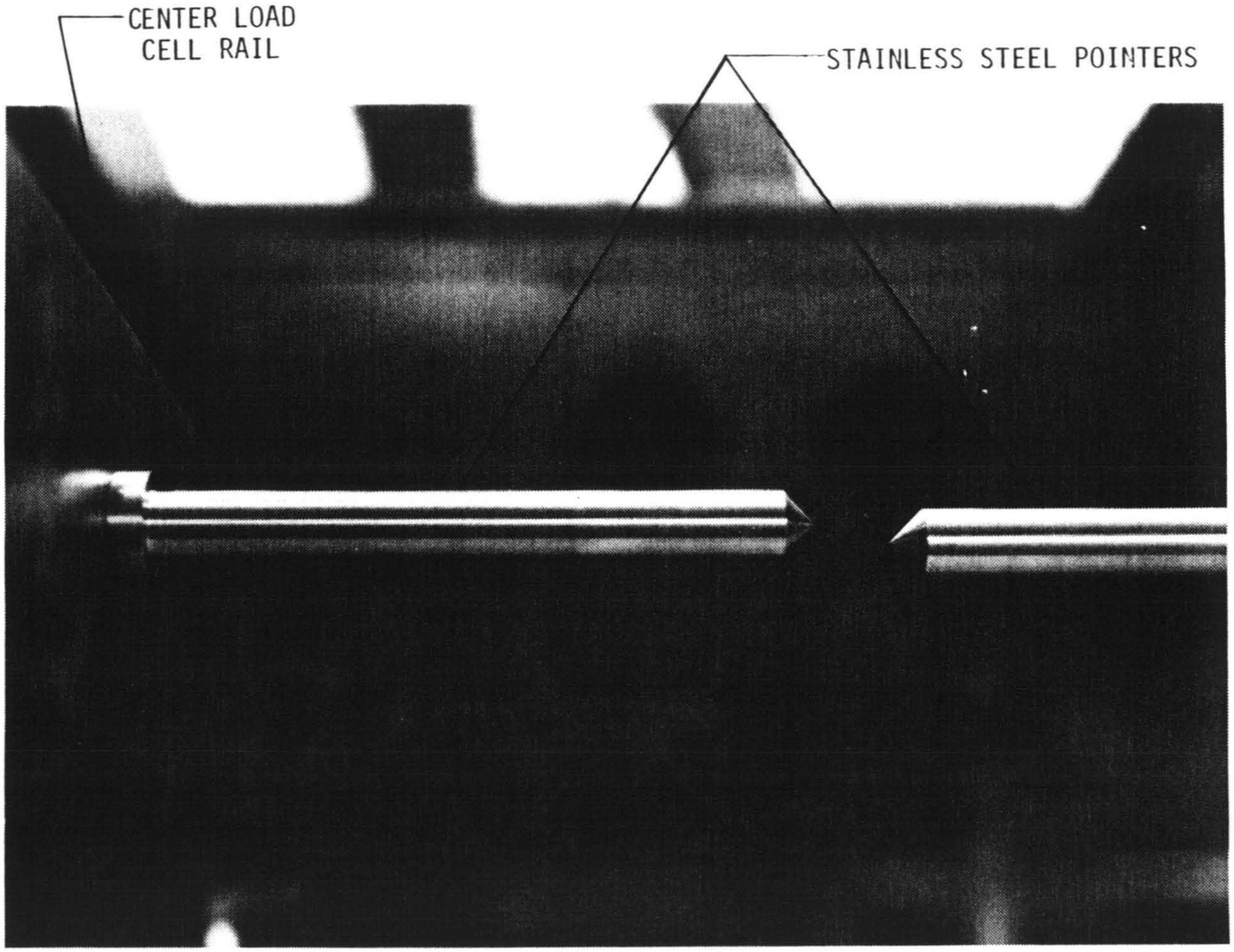


Figure 4.14: Stainless Steel Alignment Pointers

positions. They are used to determine if the rails are level and at the same height.

This phase began by leveling the hydrostatic bearings. This was accomplished by placing the levels on the bearing pads and then adjusting the legs of the isolation frame until the pads were level. The oil supply to the bearings was turned off during this phase. Because all the pads could not be brought to level at the same time(probably because of distortions in the isolation frame), the pads were brought to positions where the sum of their misalignment was a minimum. Each pad was brought to within $\pm 0.87 \times 10^{-3}$ rad ($\pm 0.05°$) of horizontal.

The pointers were installed at several positions on the load cell rails. The pointers screw directly into the center rail and mount onto the side and rear rails using the load cell mounting brackets. Using the surveying transit, the height and level of the pointers was determined at each position. This information was to be used to determine how the rails should be shimmed so that they would all be level and at equal heights. This would allow the flexure/connecting rod assemblies to be level when they were installed. However, the survey showed that the load cell rails were bowed enough that leveling all of the load cell positions at one time would be very difficult. For this reason only the three load cell positions used in the later calibration were leveled. Using a precision bench level, the center rail and the mounting brackets were shimmed until the pointers were level. Once the pointers were level, the height difference between the corresponding pointers was measured. Lower mounting brackets were then manufactured to compensate for the height difference.

While the lower mounts were being fabricated, two changes were made to the load cells' mounting hardware to allow the load cells' position to be adjusted. The horizontal alignment of the system demonstrated the need for greater flexibility in positioning the load cells. Slots were put in the mounting brackets so that the load cells' position could be adjusted from side to side. The load cell mounts were modified by placing the load cell position off the centerline of the mount to allow a height adjustment of $\pm$0.318 cm ($\pm$0.125 in.)

The horizontal leveling of the force measurement system, using the bench levels, steel pointers, and the surveying transit, was performed with an accuracy of $\pm$0.038 cm ($\pm$0.015 in.)

4.4.2. Component Alignment.

The purpose of this phase of the alignment was to position the load cells so that the lift gauge connecting rods were parallel to one another and perpendicular to the thrust gauge connecting rod. During this phase, dummy load cells(steel blocks of the same geometry as the live load cells) were installed in place of the load cells. This was done to protect the load cells from being overloaded. Figure 4.15 shows a dummy load cell installed on the side load cell rail. Live load cells were initially used during this phase, but a problem with the frame lock-outs caused a load cell to be destroyed. The lock-outs seated in a different position, which overloaded the load cell. To prevent this from occurring again, the dummy load cells were installed and the lock-outs left disengaged.

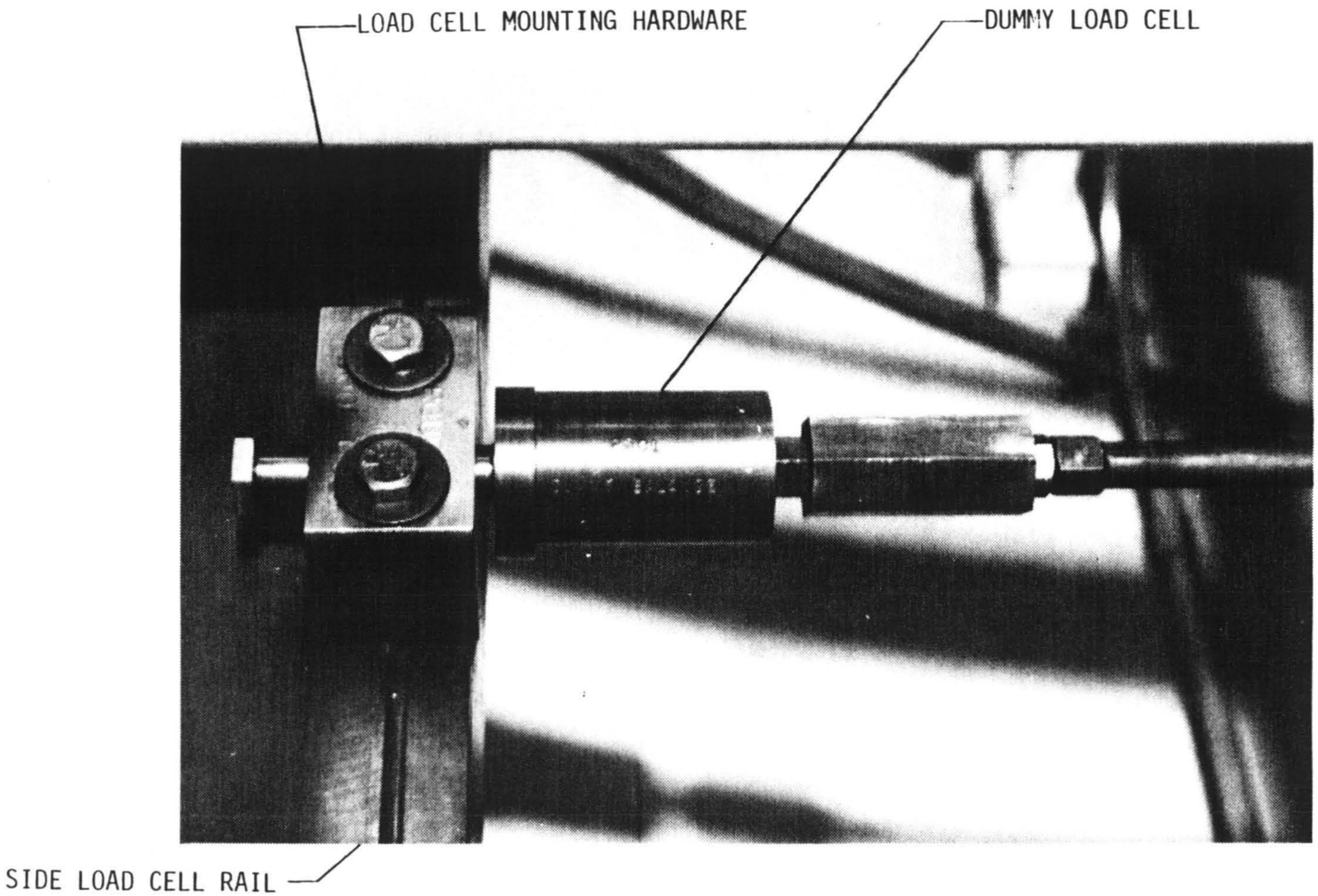


Figure 4:15: Dummy Load Cell Installed on Side Rail

This phase of the alignment was performed using precision bench levels, plum bobs, a steel tape, and a surveying transit. The hydrostatic bearings were operating. To begin this phase, the frame was centered(using the travel stops) such that the bearings were in the middle of their travel. This would help insure against their fouling later during the calibration. The flexures, connecting rods, dummy load cells, and load cell mounts were assembled prior to their installation. The jam nuts on the flexure/connecting rod assemblies were not tightened down. The assemblies were then installed on the rails and leveled. The jam nuts were then tightened down. The flexures were marked so that they could later be used as the assemblies' reference centerlines.

For the component alignment, the thrust load cell connecting rod was used as the reference from which the lift load cells were positioned. First, the thrust load cell was positioned such that its flexures were undeflected. This placed the entire assembly normal to the rear load cell rail and normal to its connecting point on the center load cell rail. To do this, the frame's position was adjusted using the travel stops, while the load cell's position was adjusted by moving the mounting bracket from side to side. A reference centerline for the force measurement system was then established through the thrust load cell's two flexures. This was done by sighting a line, using the surveying transit, through the plum bobs positioned over the assembly's centerline.

With the reference line established, plum bobs were located over the centerlines marked on the lift load cells' four flexures. The plum bobs over the two flexures nearest the center rail were set at an equal distance from force measurement system's reference centerline. The plum bobs positioned over the two flexures nearest the load cells were then set at an equal distance from the system's reference centerline. Observed from above, the plum bob lines formed a trapezoid. Measurements were then taken between the plum bob lines using a steel tape. With this information, the load cells' positions were adjusted until the lines over the flexures formed a rectangle which was parallel to the reference centerline. This placed the lift load cell connecting rods parallel to one another and perpendicular to the thrust load cell connecting rod.

After the component alignment was completed the frame's position was locked in place with the travel stops. All the load cell and mounting bracket positions were marked using tool makers die and a scribe. By marking these positions, the live gauges could to be installed in place of the dummy load cells without changing the force measurement system's alignment. A positioning accuracy of $\pm$0.1588 cm ($\pm$0.0625 in.) was attained using these methods.

The use of the plum bobs and surveying transit during this phase was both cumbersome and timing consuming. The positioning accuracy was also less than desired. One way to improve the alignment procedure would be to develop precision jigs to aid in the process. These jigs would be used to quickly and accurately position the connecting rod assemblies. Better control over the positioning would be obtained by incorporating adjustment screws into the design of the load cell mounting hardware.

4.4.3. Load Cell Installation.

Before installing the load cells, the hydrostatic bearing supply and scavenge pumps were turned on. The frame was held in position by the travel stop blocks. The load cells' output was carefully monitored during this phase to reduce the chance of their being overstressed. The flexures, connecting rods, load cells, and load cells were assembled, without tightening the jam nuts, prior to their installation on the rails. The assemblies were then installed on the rails, final positioning adjustments made, and the jam nuts locked down. Care was taken when installing the assemblies and tightening the jam nuts so that the load cells and flexures were not torqued. The mounting bracket bolts were finger tightened to hold the assemblies in position.

Prior to the final tightening of the mounting bracket bolts the travel stops were gapped to 0.015 cm (0.006 in.) Because the mounting brackets were shimmed, loads were introduced into the load cells as the bolts were tightened. Gapping the travel stops allowed the frame to move as the bolts were tightened which helped prevent overstressing the cells. As another precaution to protect the load cells during their installation, the bolts were always torqued such that the force was applied perpendicular to the load cells' sensitive axis.

The original intent was to perform the fine adjustment of the alignment of the force measurement system using the load cells as the alignment instrument. This would be accomplished by individually loading each cell and adjusting its position until a maximum load reading was obtained while minimizing any moments or off axis loads. Difficulties with the load cells, explained in Chapter 5, prevented this phase from being completed.

Chapter 5

Force Measurement System Calibration: Procedures and Results

5.1. Calibration Approach

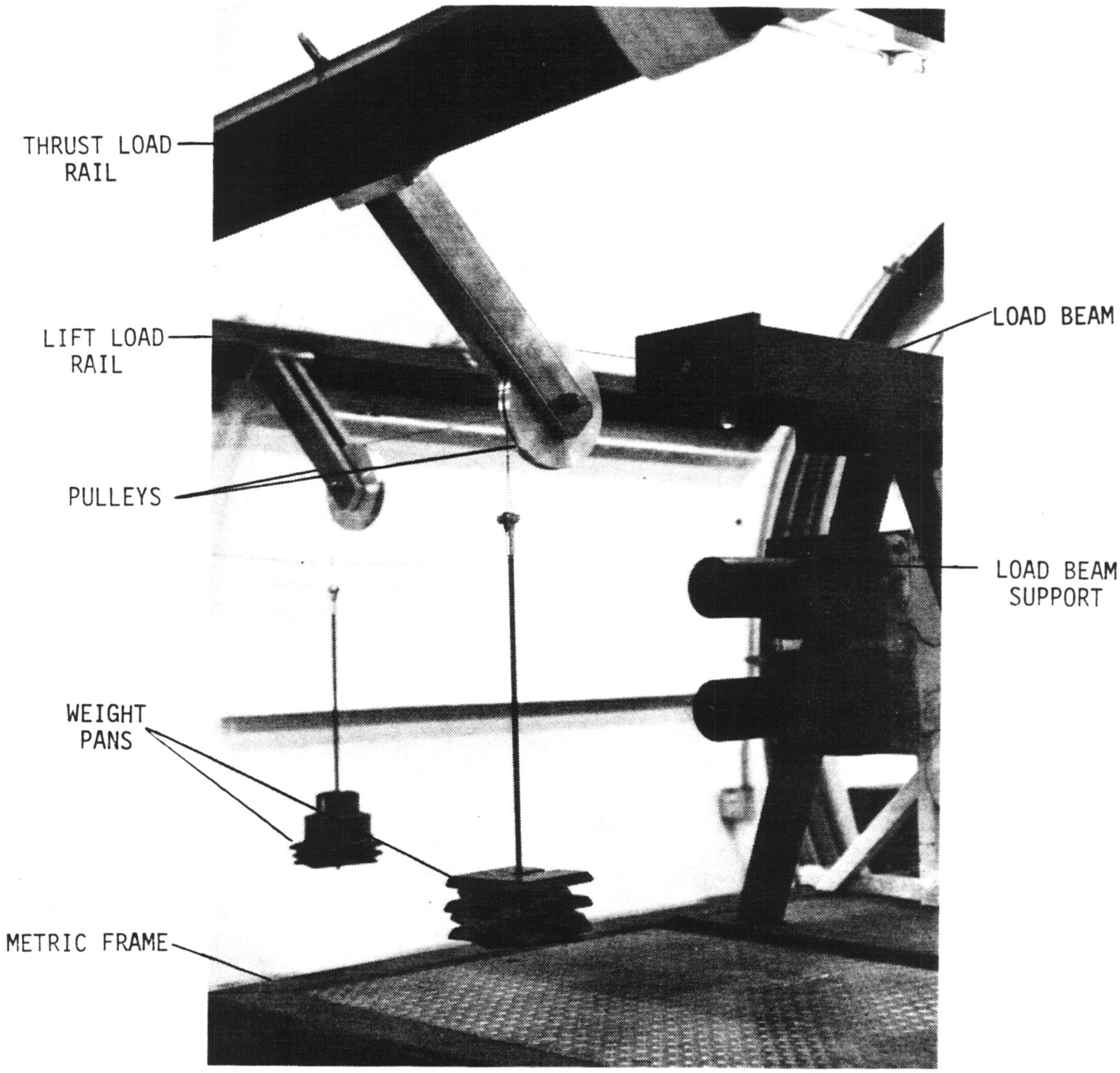
The purpose of calibrating the force measurement system was to determine the accuracy with which simulator calibrations can be performed. This was be done by placing known loads on the metric frame and comparing them with the resulting load cell output. This comparison between the forces applied and those sensed shows any basic tares or mechanical interactions inherent to the design of the force measurement system. This calibration was conducted to validate that the force measurement system could perform force calibrations within the required accuracy of $\pm 0.05\%$.

To evaluate the system's errors, a piecewise test plan was developed for the calibration of the PSCL's force measurement system. This was done in an effort to determine the individual contributions to the overall system error. This will help in later directing any efforts for improving the system to the areas where the most benefit will be realized. Also, by using this method, any unexpected increase or decrease in the error could be used to identify any problems with the calibration procedures or equipment.

Dead weight testing of the force measurement system was selected as the method of applying the known loads to the metric frame. Other methods of applying the loads, such as using hydraulic actuators, were considered but discarded. The overriding factors favoring the use of weights were their inherent simplicity, physical stability(their properties are not effected by time, temperature,etc.), availability, and accuracy.

Figure 5.1 shows the set up used for the calibration of the force measurement system. The basic concept is to place known loads on the metric frame using a dead weight/pulley/cable arrangement. To better simulate the conditions expected during a simulator calibration, the loads were applied in the same horizontal plane as the simulators will be mounted. This allowed any effects of the off axis loads produced by the simulators to be taken into account during the calibration. As mentioned in Section 4.2.5, there are fifteen(15) possible positions to place the two lift axis load cells. This will allow the setup of the force measurement system to be tailored to best fit the needs of each particular simulator calibration. For the initial calibration of the metric frame, the load cells were positioned as shown in Figure 5.2. The serial numbers of the load cells are shown in their respective positions in the figure. 222 N (50 lb) capacity load cells were used in all three load cell positions because of their ability to discern small forces.

Figure 5.1: Calibration Setup for the Force Measurement System



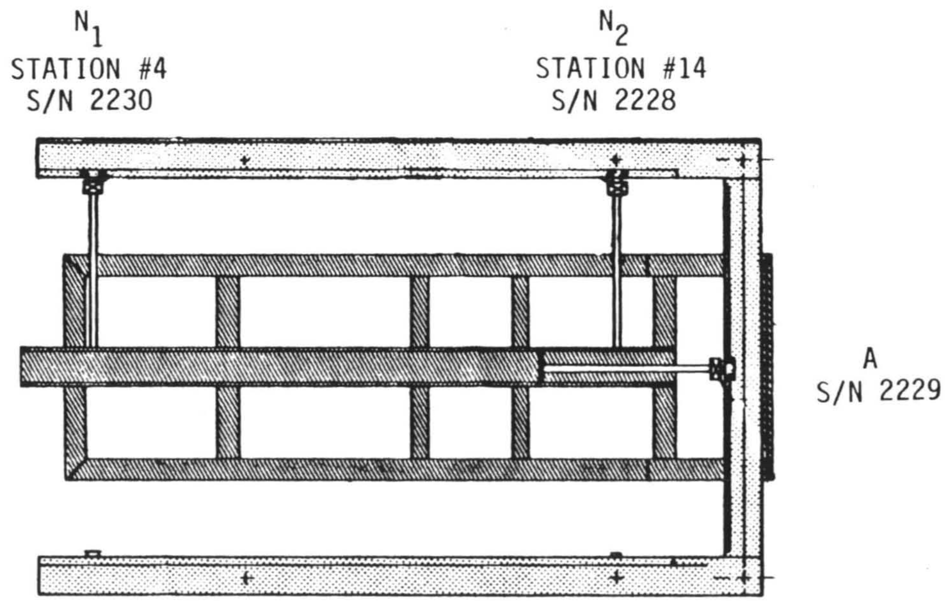


Figure 5.2: Load Cell Positions for the Initial Calibration

5.2. Calibration Equipment

5.2.1. Test Hardware.

Figure 5.1 shows the test hardware used to apply the calibration loads to the force measurement system. Cables are attached to the metric frame at the load beam and are run over the pulleys to the weight pans. As weight is placed on the pans, the load is transmitted through the cables to the force measurement system. The test hardware has been designed to provide a convenient setup to perform the calibration. Pulley positions are provided so that both forces and moments to can be applied to the metric frame during calibrations.

5.2.1.1. Weights

All weights used in the calibration of the force measurement system were first calibrated by the Materials and Test Engineering Branch(EEM) at ARC. Each weight was calibrated to an accuracy of ± 0.044 N (± 0.01 lb) using standards traceable to the National Bureau of Standards.

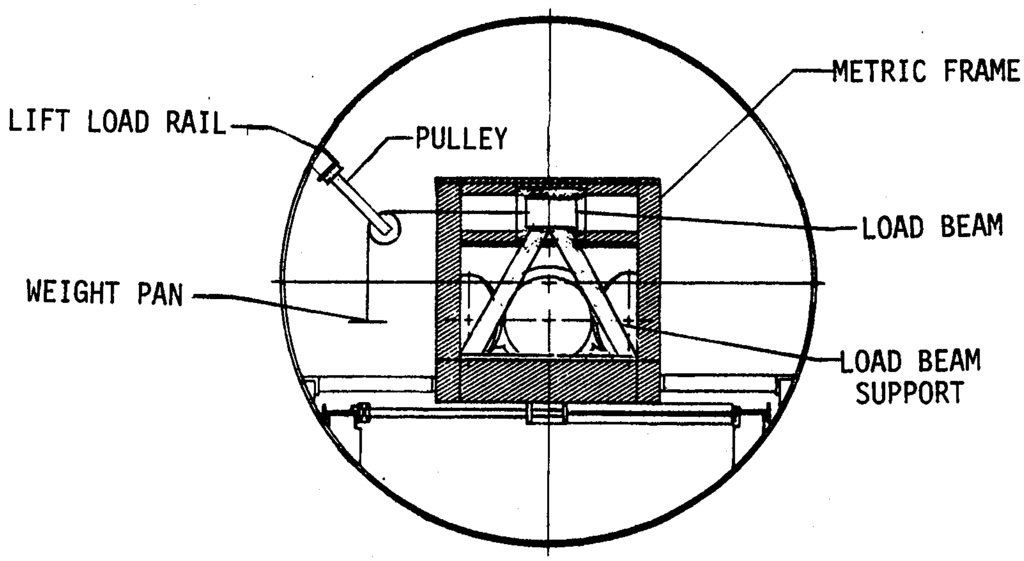
5.2.1.2. Load Rails(Thrust and Lift)

The load rails, shown in Figure 5.1, support the pulleys during the calibration. The rails are bolted to support blocks which are in turn welded to the vacuum tank.

The lift load rails(Figure 5.3), which are angle beams, have pulley stations at 0.3 m (1 ft) increments which correspond to the load cell positions. This allows the lift load cells to be loaded directly in line. The lift load rail design also allows off axis loads to be applied at 0.3 m (1 ft) increments. Horizontal slots in the beams permit the rails to be adjusted from side to side on the support bolts. Once the lift load rails are aligned with respect to the load cell rails, they can be locked down and subsequent alignment is unnecessary.

The thrust rail(see Figure 5.4) is an I beam positioned across the front of the vacuum tank. Because its position decreases access to the tank, the thrust rail is not a permanent tank fixture. The thrust load rail is brought into the tank using the vacuum tank's crane, placed on its support blocks, and aligned prior to each calibration. The thrust rail, like the side rails, has horizontal slots to allow it to be adjusted from side to side. The thrust rail has three pulley stations, one directly in line with the thrust load cell, and one on either side at a 0.3 m (1 ft) spacing. The offset stations can be used for placing moments on the frame.

Figure 5.3: Lift Load Rail



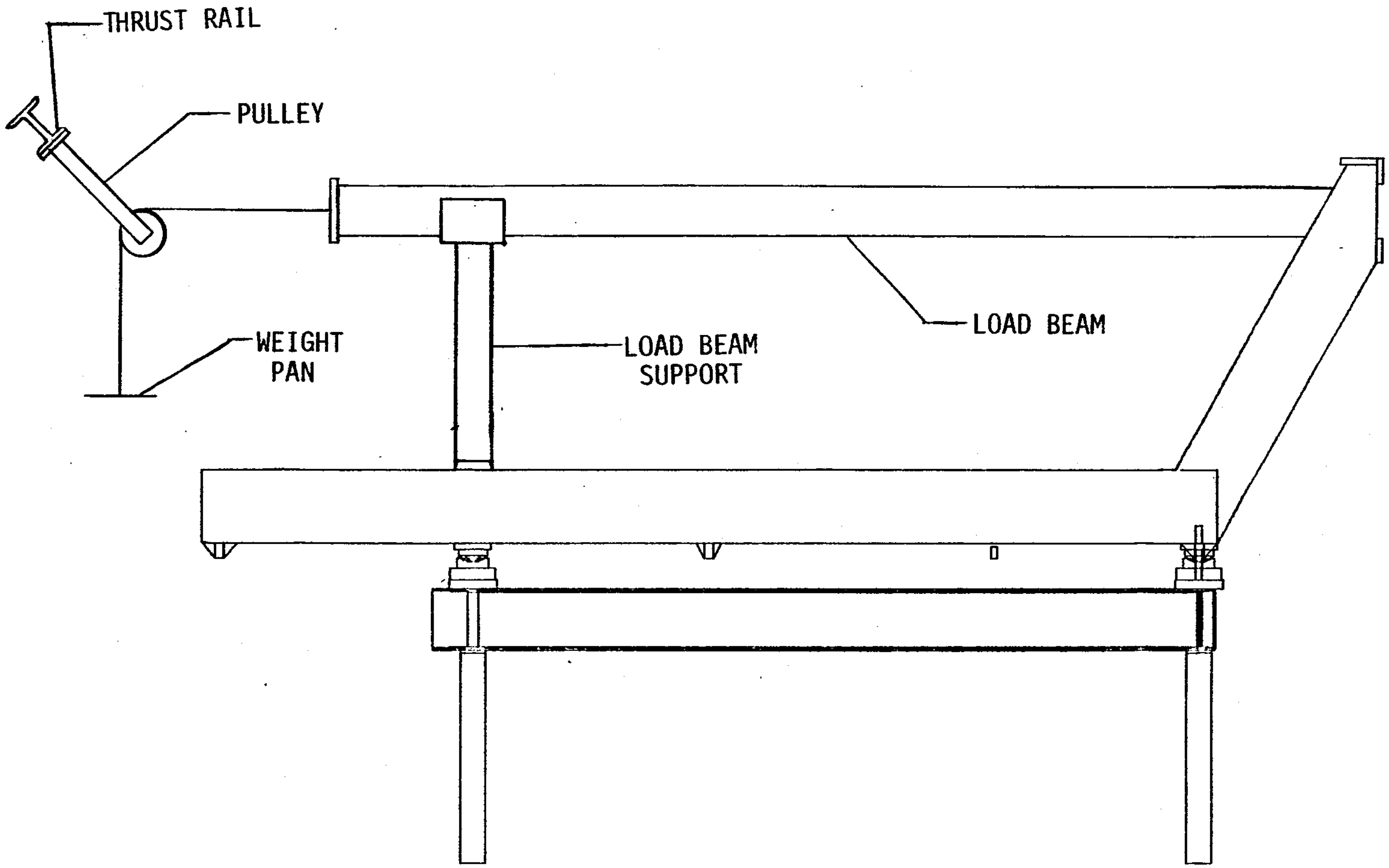


Figure 5.4: Thrust Load Rail

5.2.1.3. Load Beam and Support Frame

The calibration loads are applied to the force measurement system at the load beam. The beam is mounted on the metric frame in a manner similar to that used to mount the wind tunnel stings. The load beam has one centerline cable attachment point for loading the thrust load cell, and side attachment points spaced 0.3 m (1 ft) apart which correspond to the lift load cell stations. The support frame has screws in the bottom and sides of the load beam cradle so that the position of the beam can be adjusted. The frame also adds stiffness to the load beam for loading higher capacity lift load cells.

5.2.1.4. Pulleys

The pulleys used in the calibration were designed around precision machined double row bearings. These high quality bearings were employed to reduce the hysteresis introduced into the calibration by the test hardware. The base of each pulley has slots where the pulley is bolted to the load rail(see Figure 5.5) to allow vertical adjustment of the pulley's height.

5.2.2. Data Acquisition System.

Because the PSCL's data acquisition system was not yet operational, the signal conditioning, amplification, and data acquisition was performed by the control and data acquisition system used for the CMAPS. This system, seen in Figure 5.6,

Figure 5.5: Calibration Pulley

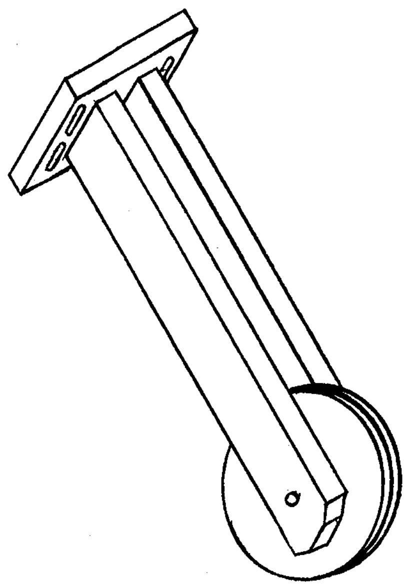
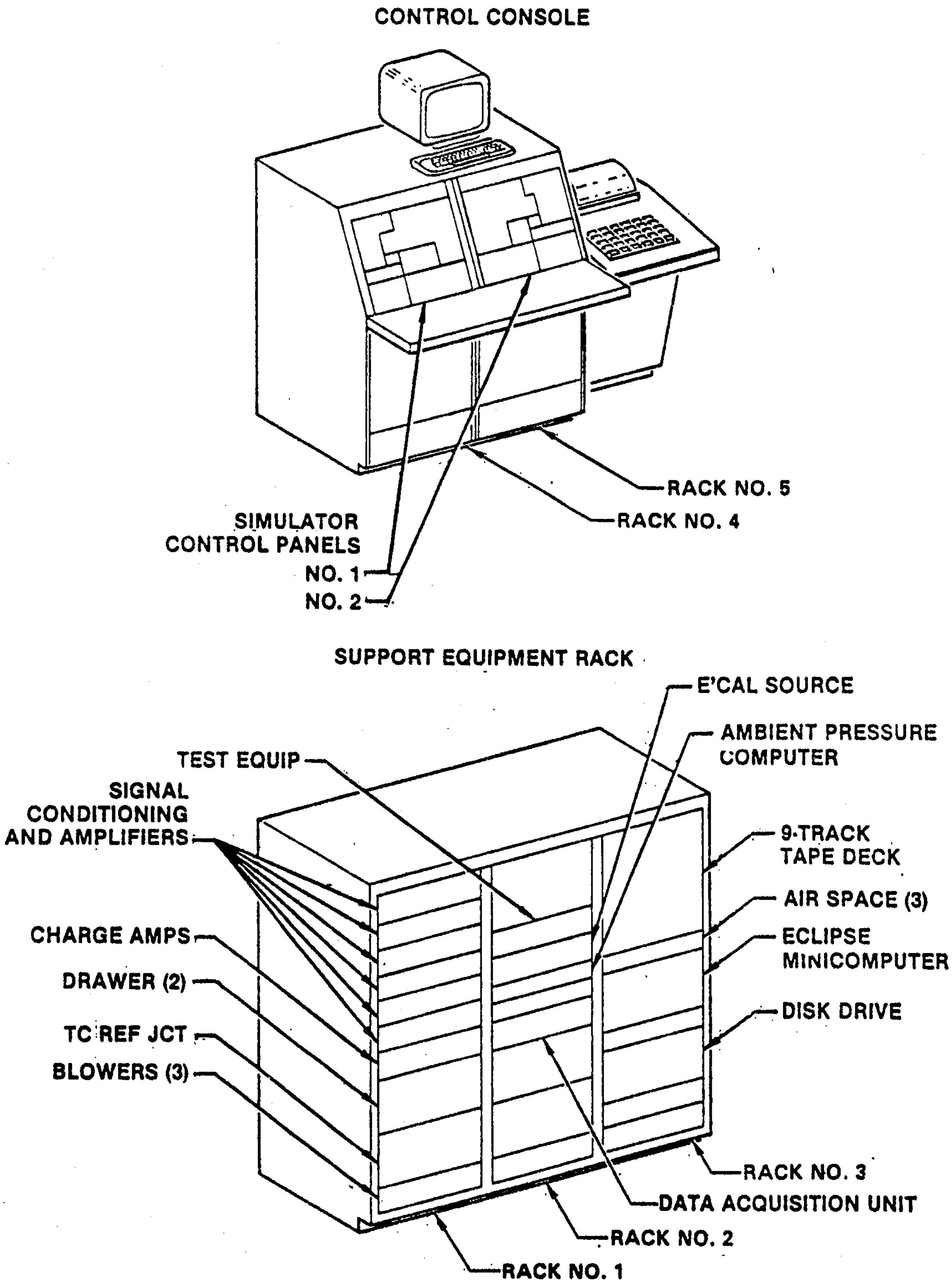


Figure 5.6: CMAPS Control System (ref. 5)



had all the hardware needed to perform the calibration, but required modifications to the system's software for it to be used as a stand alone data acquisition system.

The CMAPS Control System has 30 channels of signal conditioning and amplification. The transducer conditioners supply the excitation voltage for the load cells. The differential amplifiers furnish the amplification and filtering of the output signal. The analog to digital converter transforms the analog output signal to digital form so that the minicomputer can acquire and store the data. The following paragraphs describe the system's hardware and software.

5.2.2.1. Transducer Conditioner

Voltage excitation for the load cells was provided by Pacific Precision series 80A Transducer Conditioners. The transducer conditioners can be used to excite, balance, and calibrate 1, 2, and 4 active arm transducers needing constant current excitation and 4 active arm transducers needing constant voltage excitation. The load cells, which fall into the later category, had an excitation voltage of 10 VDC for the calibration. Each conditioner has a balancing potentiometer built in so that any bridge output offset can be zeroed. The conditioner also has two precision shunt resistors(10k Ohm and 75k Ohm) built in that can be used for calibrating the transducers.

5.2.2.2. Differential Amplifier

Signal amplification for the load cells was provided by Pacific Precision series 70A differential data amplifiers. The amplifiers have ten selectable power gain steps of 1, 2, 5, 10, 20, 50, 100, 200, 500, and 1000. A gain of 200 was used for the load cells. The amplifiers have nine selectable filter bandwidths of 1, 3, 10, 30, 300, 1k, 3k, and 10k. A 1 hertz filter was used on the load cell signal. A relay is built into the amplifiers which allows the channel inputs to be shorted to check the amplifiers for drift.

5.2.2.3. Analog-to-Digital Converter

The CMAPS Control System uses an Analogic ANDS5400 analog-to-digital(A/D) and digital-to-analog(D/A) converter to perform its data acquisition and engine control functions. For the force measurement system calibration, the A/D converter transformed the analog transducer signals to digital so that they could be acquired and stored by the minicomputer.

5.2.2.4. Minicomputer

The minicomputer used for the CMAPS Control System consists of a Data General(DG) Eclipse S/140 central processor, a fixed disc subsystem, a 9 track magnetic tape subsystem, a printer, and a CRT. The Eclipse S/140 central processor(which performs all the data acquisition, health monitoring, and control for the engines) has 64k words of MOS memory and floating point hardware. The 12.5 Mbyte fixed disc subsystem is used to store system software and data. The 9 track magnetic tape subsystem can be used to load software onto the system or dump data so that it can be stored or processed elsewhere. Data monitoring as well as system programing and other system input are performed with the printer and CRT display.

5.2.2.5. System Software

The CMAPS Control System is designed to provide the user control over two CMAPS, and furnish engine health monitoring and emergency shut-down. The system also has the capability to acquire CMAPS performance data and transfer this data to the computers of the NASA-ARC Wind Tunnel Data Acquisition System and output it to a printer. In acquiring the CMAPS data two scans of the 128 available data channels are taken. The first of these scans is discarded(it contains transients from the A/D converter), while the second scan is transferred to the ARC data acquisition system and/or sent to the line printer. No other provisions are made to store the data.

Modifications to the system software, initiated for this test, provide the user a much more flexible means of acquiring data. The new software, detailed in Reference 6, allows the user to specify at random which channels are to be acquired and stored on the hard disc. Multiple samples(from 1 to 9999) can be specified to be averaged for a given test condition. Multiple data points can also be specified. For example, the user can request that three(3) data points of 500 samples each be taken for a test condition of a 22 N (5 lb) load on the thrust load cell. The user can also input the value for the applied test condition to be stored in the raw data file. Figure 5.7 shows an example of a raw data file taken during the force measurement system calibration.

The data acquisition system also provides automatic control over the calibration features built into the signal conditioners and amplifiers. The system can be used to automatically switch in the shunt resistors in the conditioners or the input short relays on the amplifiers.

The raw data files were stored on the fixed disc subsystem during the data runs and then transferred to the magnetic tape using the 9 track magnetic tape subsystem. The raw data files were then transferred via the magnetic tape to a Digital Equipment Corporation(DEC) VAX 11/780 for data reduction and plotting.

5.3. Calibration Sequence and Results

The test sequence for this initial calibration was designed so that the effects of the individual contributions to the total system error could be determined. This is done by building up the elements piece by piece which are expected to effect the force data. The loading schedule for each sequence(the number and order in which the loads were placed on the gauges) is given.

Figure 5.7: Raw Calibration Data File

```
BAROMETER=14.698  NUMCHNL=   4  MSAMP=  50  MDATA=    3
         ANALOG DATA SCAN
         TIME   13:49:19
         DATE    4/27/84
         TEST CONDITION :    1
DATA POINT=    1
CHNL      RAW    SIGNAL ID  ENGR UNITS      CONV            APPLIED CONDITION
 13       1597   PP6        0.241911E  2    0.50000E  2   0.406000E  1  (POUNDS   )
 15         -4   PP8        0.335519E  0    0.50000E  2   0.000000E  0  (POUNDS   )
 18      -4455   PP11       0.731103E  2    0.19960E -2   0.000000E  0  (DEGREES  )
 34         -2   PP21       0.000000E  0    0.50000E  2   0.000000E  0  (POUNDS   )
DATA POINT=    2
CHNL      RAW    SIGNAL ID  ENGR UNITS      CONV            APPLIED CONDITION
 13       1597   PP6        0.241911E  2    0.50000E  2   0.406000E  1  (POUNDS   )
 15         -4   PP8        0.335519E  0    0.50000E  2   0.000000E  0  (POUNDS   )
 18      -4455   PP11       0.731103E  2    0.19960E -2   0.000000E  0  (DEGREES  )
 34         -2   PP21       0.000000E  0    0.50000E  2   0.000000E  0  (POUNDS   )
DATA POINT=    3
CHNL      RAW    SIGNAL ID  ENGR UNITS      CONV            APPLIED CONDITION
 13       1597   PP6        0.241911E  2    0.50000E  2   0.406000E  1  (POUNDS   )
 15         -4   PP8        0.335519E  0    0.50000E  2   0.000000E  0  (POUNDS   )
 18      -4455   PP11       0.731103E  2    0.19960E -2   0.000000E  0  (DEGREES  )
 34         -2   PP21       0.000000E  0    0.50000E  2   0.000000E  0  (POUNDS   )
```

The results of these calibrations are presented at the end of each subsection.

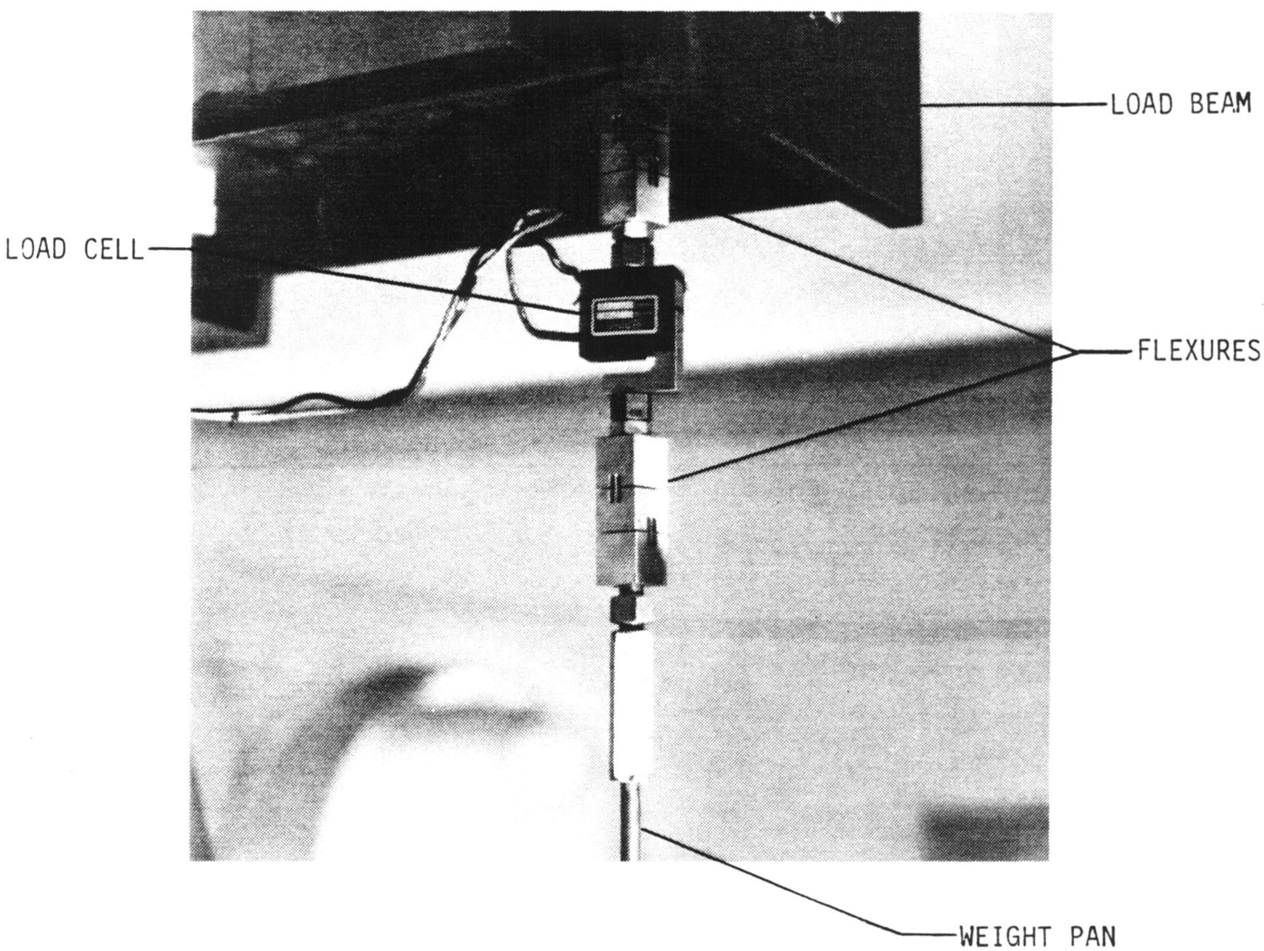
Prior to the calibration, all of the calibration fixtures were be aligned with the force measurement system using the surveying techniques described in Chapter 4. Misalignment of the calibration loads with respect to the load cells results in a lost of the load sensed by the load cells. This relation was discussed in section 4.3.1. It is important that the errors due to the misalignment of the calibrating loads not be attributed to the force measurement system. For this reason care was taken to align the calibration loads within ± 0.07938 cm (± 0.03125 in.)

5.3.1. Load Cell Calibration.

Before the calibration of the metric frame, each of the load cells was calibrated individually. This allowed the load cells' characteristics, free of errors associated with the force measurement system, to be determined. Calibrations were performed to determine the nonlinearity, hysteresis, nonrepeatability, and sensitivity of the load cells. Calibrations were conducted at different temperatures to determine the load cells' temperature sensitivity. A check was also made of the load cells' creep characteristics.

Figure 5.8 shows the arrangement used in these calibrations. Flexures were placed on either side of the load cell to insure that the load was directly in line with the load cell and that no side loads were being applied. The entire

Figure 5.8: Load Cell Calibration



assembly was hung from the load beam, which was installed on the metric frame.

A resistance calibration was performed prior to the load cell calibration. This is done by shunting across the negative excitation and negative signal leads of the load cell bridge with a precision resistor and monitoring how this simulated change in load effects the output. Later calibrations can then be referenced to this one by simply ratioing the resistance calibration results from the new test to the resistance calibrations for this test. A detailed explanation of the use of resistance calibrations can be found in references 2, 5, and 7.

The loading schedule for the load cell calibrations consisted of a series of 21 and 11 point calibrations. For a 21 point calibration, the load cell is loaded up and down scale in increments of 1/10th of the load cell's full scale capacity. For a 222 N (50 lb) load cell, this would mean that loading increments of 22 N (5 lb) would be used. An 11 point calibration simply uses loading increments of 1/5th of the cell's full scale capacity. 21 point and 11 point calibrations are the most commonly used by calibration laboratories at Ames. The 21 point loading is usually selected for the initial calibrations to build confidence that the gauge's behavior is being fully investigated. After the gauge is proved not to have any unexpected deviations, an 11 point calibration is used.

By loading both up and down scale the nonlinearity and hysteresis of the load cells is discovered. Nonlinearity is defined as the maximum deviation that the readings have from a linear fit placed through the load cell output.

The hysteresis is defined as the maximum deviation between readings for the same load, one being taken on the upscale loading and the other taken on the downscale loading. Figure 5.9 graphically illustrates these definitions.

One 21 point and four 11 point calibrations were performed at a constant temperature to determine each cell's nonrepeatability. The nonrepeatability is defined as the maximum variation of the load cell's output for the same load between the five calibrations. Five calibration cycles were performed to gain greater confidence in the calibration data. The total error is calculated by summing the load cell's nonrepeatability and nonlinearity. 11 point calibrations were performed at various temperatures to determine each load cell's change in sensitivity due to the change in temperature. A full scale load was placed on the load cells and the voltage output monitored over time to determine the cell's creep characteristics.

The individual performance characteristics of the load cells, as determined in the calibrations, are summarized in Figure 5.10. For reference, the required performance specifications are also listed in the figure. The average sensitivity is simply the average of the slopes of the least squares linear fits placed through the five calibration cycles performed on each of the load cells. Whenever a value is based on full scale(F.S.), this refers to the load cell's rated output as calculated using the average sensitivity. The creep value is based on the amount the load cell output varied under a constant full scale load 20 minutes after the load was applied.

Figure 5.9: Load Cell Calibration Curve; Error Description

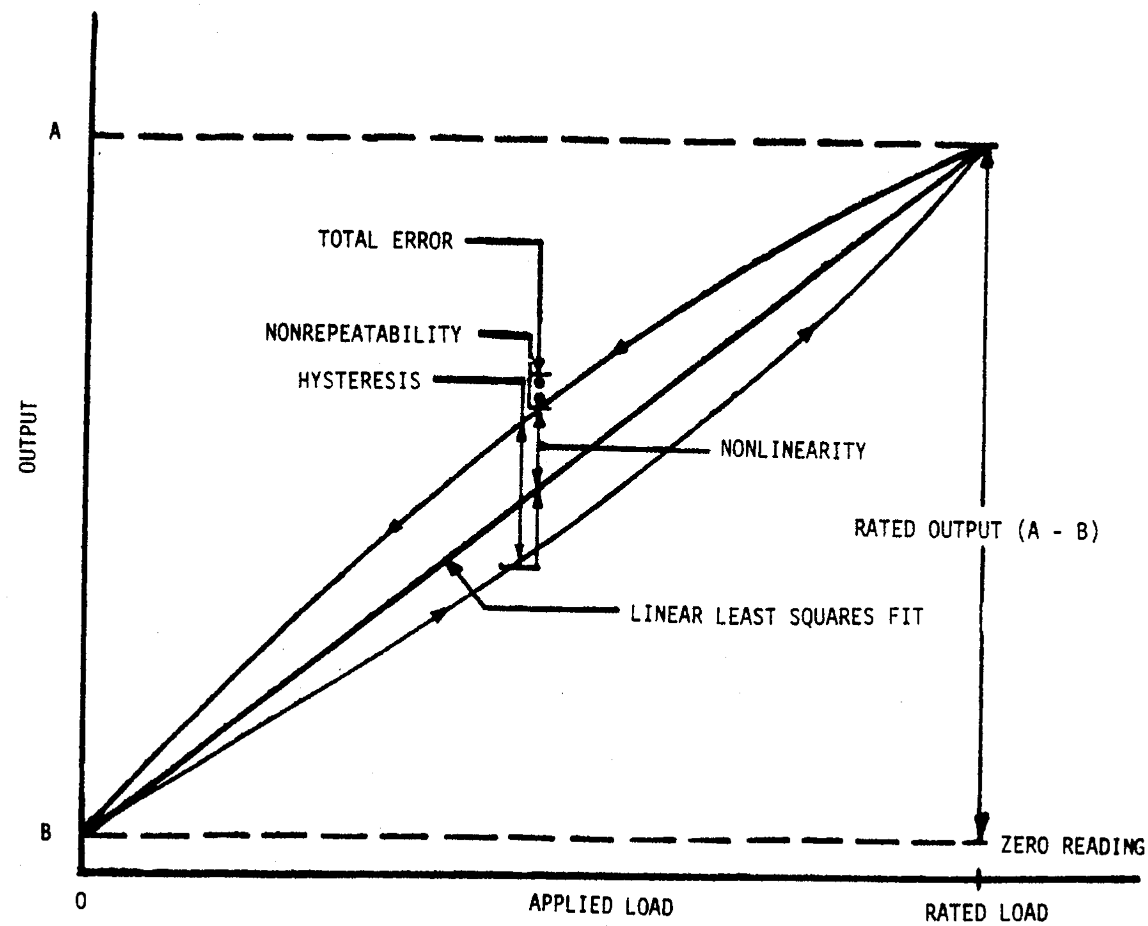


Figure 5.10: Results of Load Cell Calibrations

LOAD CELL	SPEC.	S/N 2228	S/N 2229	S/N 2230
AVERAGE SENSITIVITY(mV/N @ 54.4°C)		0.135309	0.135985	0.136082
NONREPEATABILITY(% F.S. @ 54.4° C)	±0.01	±0.200	±0.125	±0.248
CREEP(% F.S. @ 54.4°C, after 20 min)	0.06	0.253	0.214	0.236
TEMPERATURE SENSITIVITY(% F.S./°C)	0.0029	0.049	0.054	0.068
HYSTERESIS(F.S. @ 54.4°C)	0.04	0.028	0.084	0.051
NONLINEARITY(% F.S. @ 54.4°C)	±0.03	±0.016	±0.046	±0.026

The initial load cell calibrations revealed some unexpected problems. Although they met, or came close to meeting most of their performance specifications, the load cells performed badly in two areas. The load cells were very sensitive to temperature changes, and had a very high creep rate. Figure 5.11 shows S/N 2229's temperature behavior and Figure 5.12 shows its creep behavior.

Methods were developed in an attempt to eliminate these problems from the calibration data. "Hot boxes", like the one shown in Figure 5.13, were built to provide a stable temperature environment for the load cells. This allowed the temperature sensitivity problem to be controlled. The load cells were kept at a stable 54.4°C (130°F) during the calibrations.

Figure 5.12 demonstrates that if the load remains on the gauge long enough(approximately 40 min.), a stable value is reached. So, to eliminate the creep problem, a procedure was established to creep the load cells at full scale load before each calibration. Just before each calibration was begun, the load was cycled on and off the cells four times.

The data for these calibrations are presented in Appendix A in Tables 1.1-3.9. The data from the shunt calibrations can also be found in Table 4 of Appendix A. A sample size of 50 values was averaged for each data point.

Creeping the gauges before each calibration cycle improved the accuracy obtained during the individual load cell calibrations. Without creeping the load cells before each calibration cycle, higher levels of nonrepeatability would

Figure 5.11: Load Cell Temperature Sensitivity(S/N 2229)

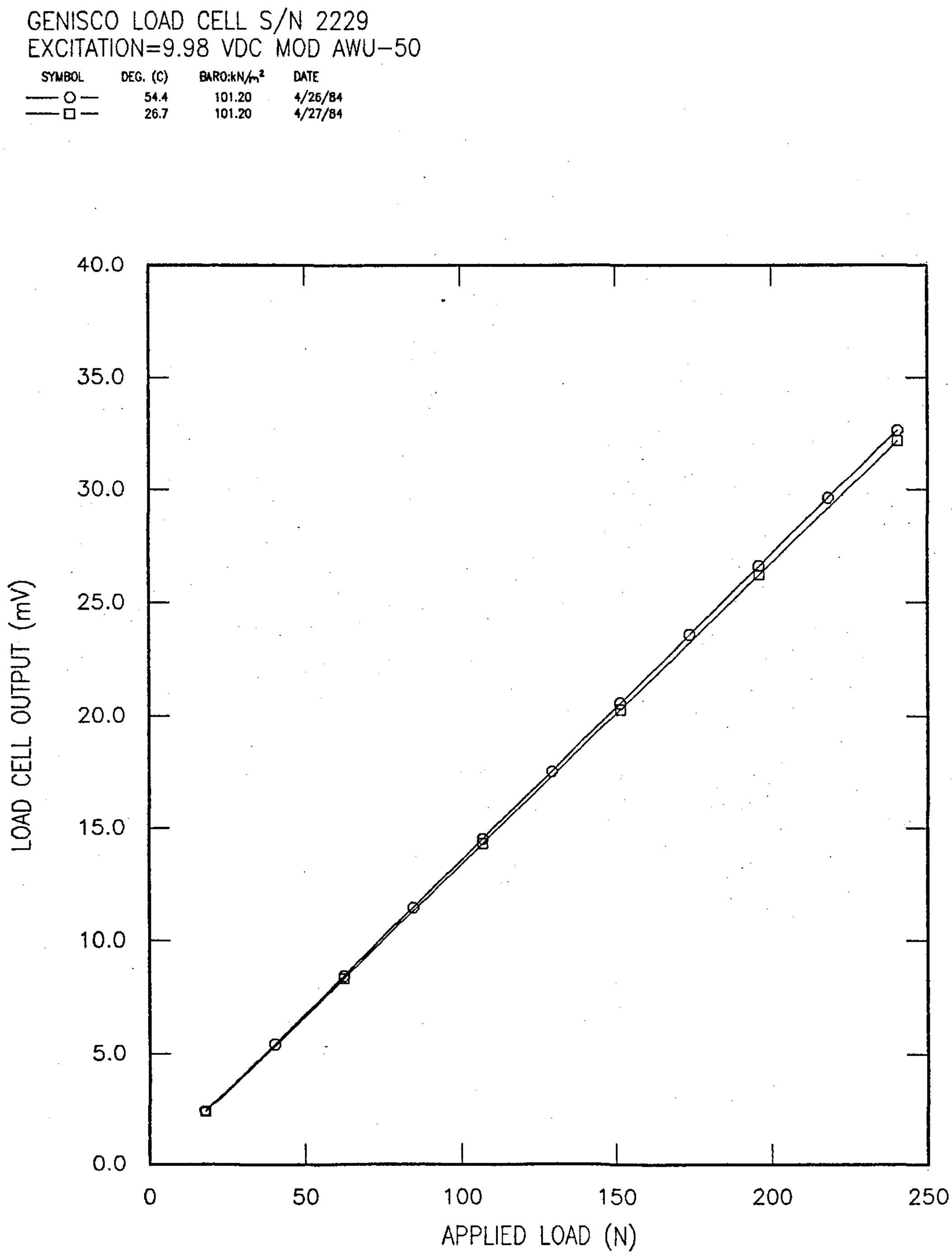


Figure 5.12: Load Cell Creep Behavior(S/N 2229)

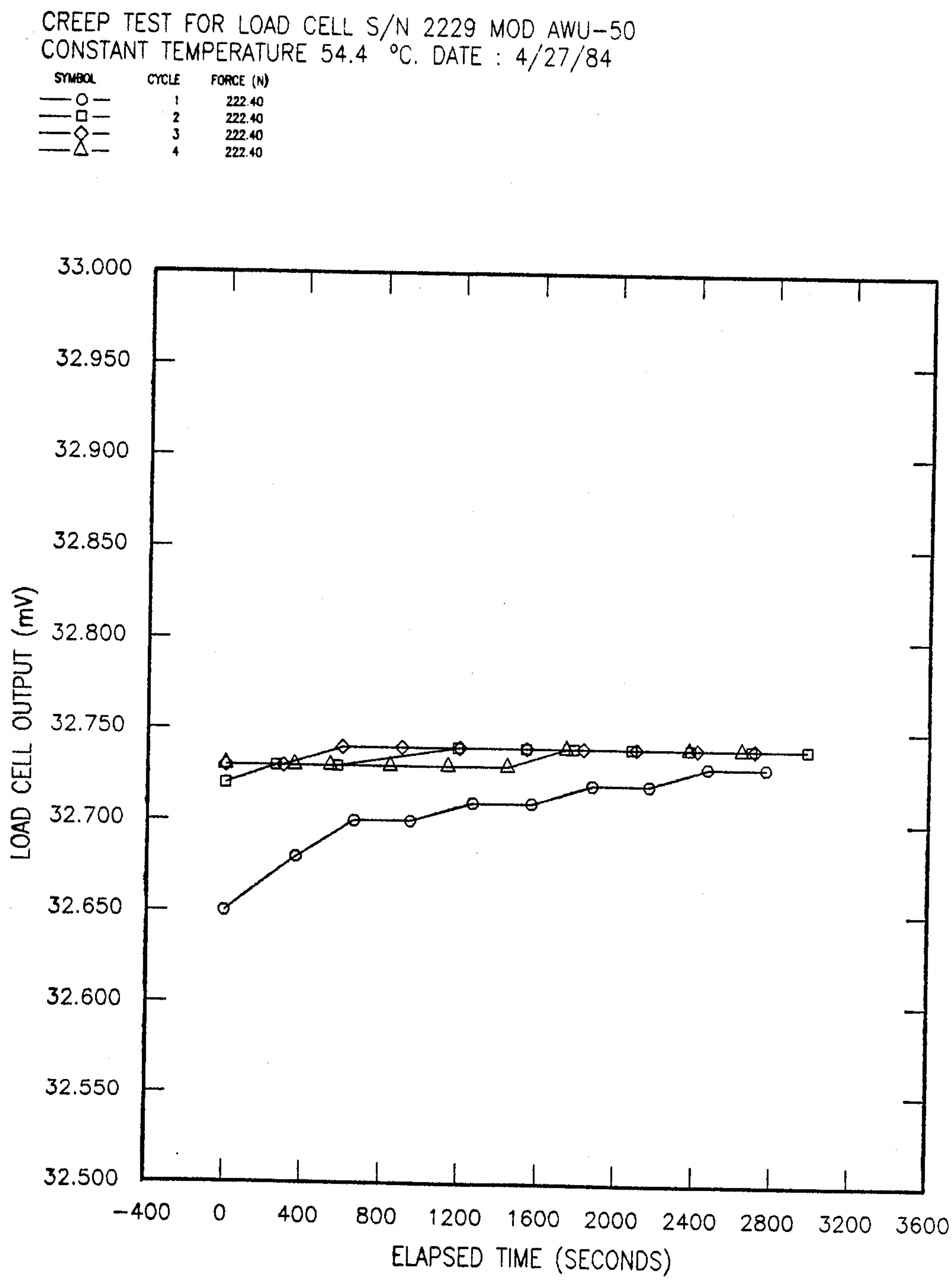
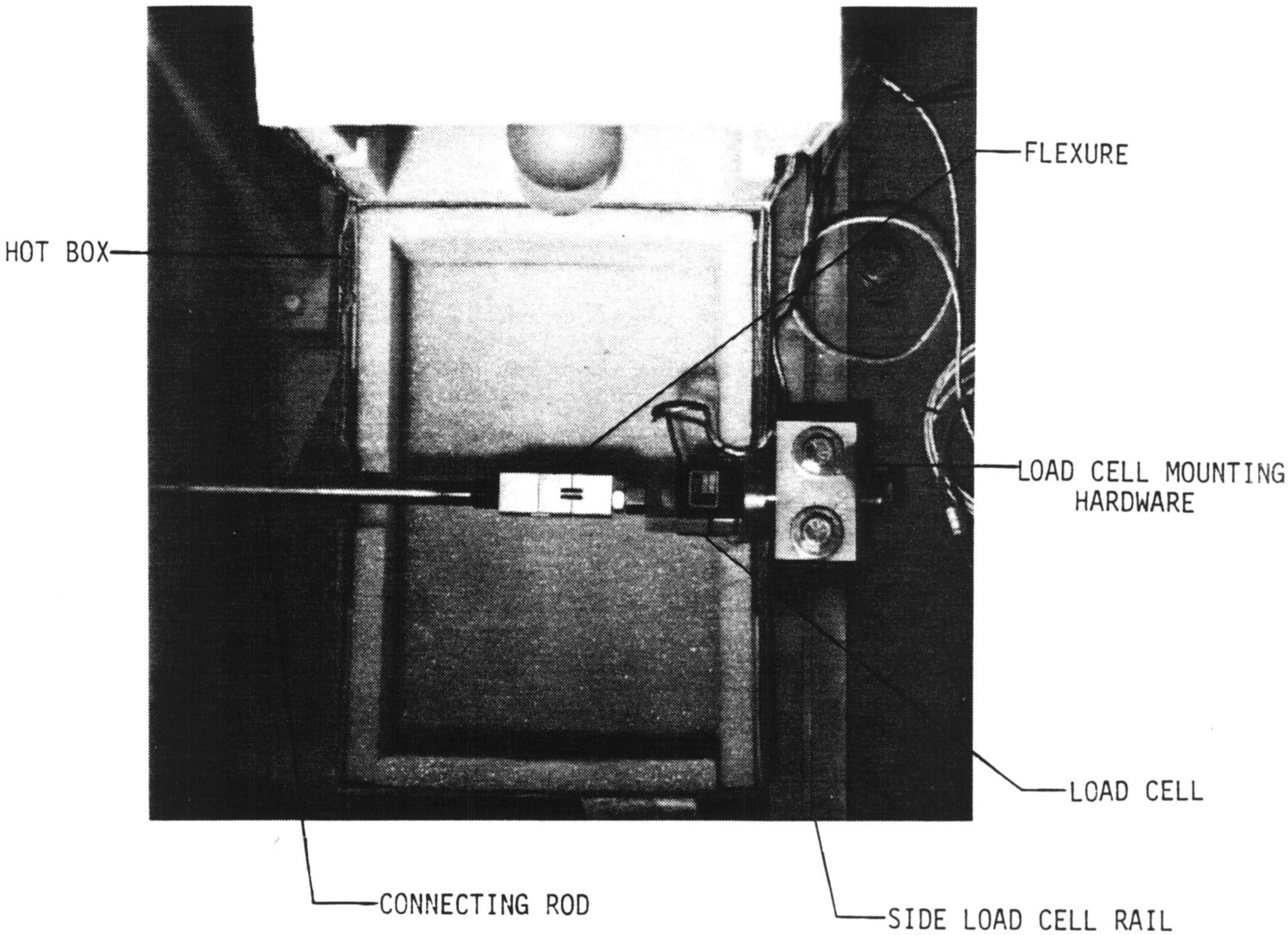


Figure 5.13: "Hot Boxes" Used to Control the Load Cells' Temperature



have been seen. The benefit of creeping the load cells is uncertain in the later calibrations. This is because of the longer time spans over which the data was taken for these calibrations. The load cells performed best immediately after they had finished their creep and loading cycles. For the following calibrations the creep problem appeared as higher levels of nonrepeatability.

Because the creep(seen as nonrepeatability) is so large, the maximum accuracy of the force measurement system is limited by the accuracy of the load cells and not the errors associated with the system's design. The load cells' low accuracy levels made it difficult to detect the small contributions of the force measurement system's error parameters.

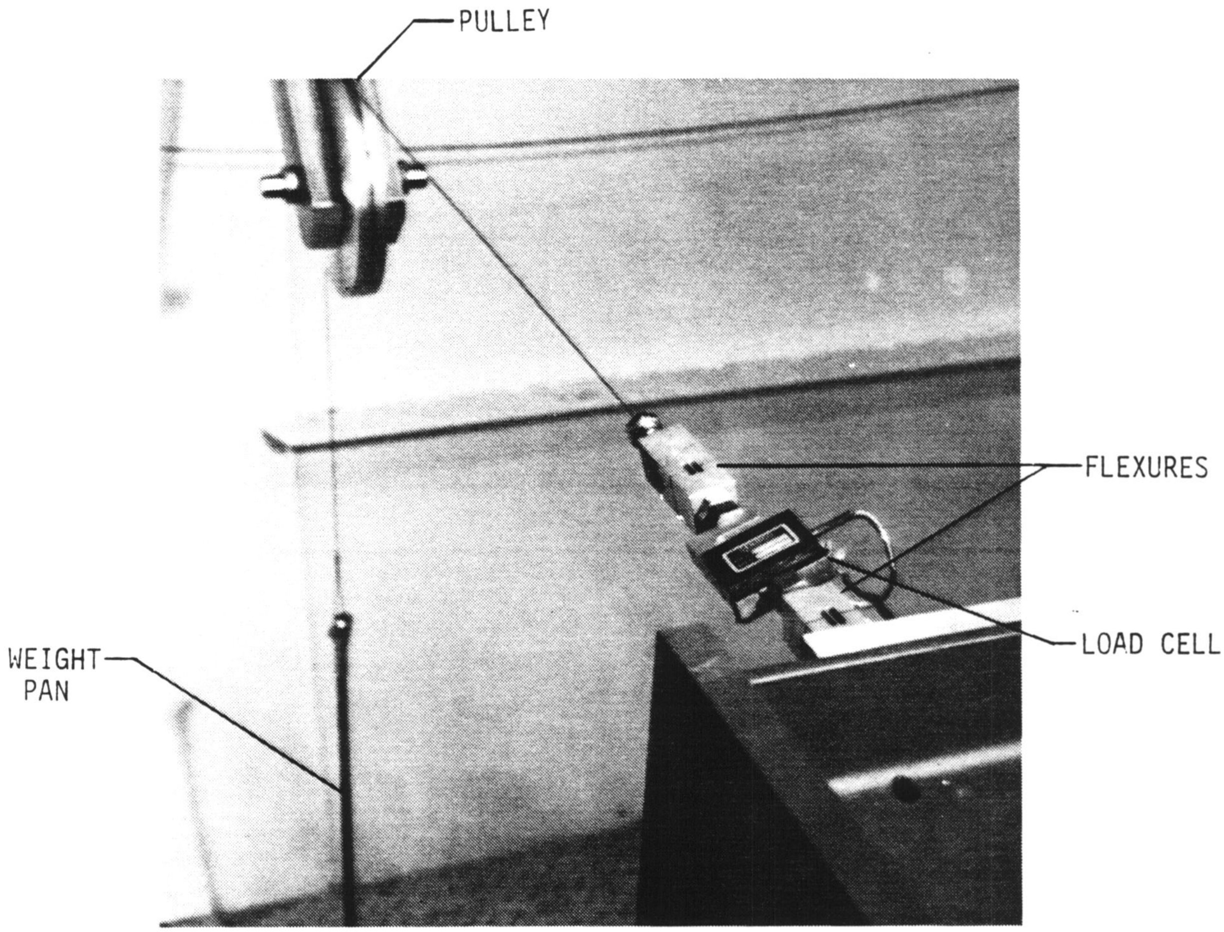
The positions of the load cells in the force measurement system for the following calibrations were:

$$A = \text{S/N } 2229$$
$$N_1 = \text{S/N } 2230$$
$$N_2 = \text{S/N } 2228$$

5.3.2. Pulley Calibration.

The pulley system was checked for hysteresis before it was used in the force measurement system calibration. This was done by taking one of the load cells that was calibrated as described above, and loading it through the pulley(see Figure 5.10). Flexures were placed on either side of the load cell and the assembly attached to the load beam. A cable was run from the load cell over the pulley to the weight pan. The difference

Figure 5.14: Pulley Calibration Setup



between the in line calibration of the load cell(Subsection 5.3.1) and this calibration was the hysteresis due to the friction in the pulley's ball bearings.

The loading schedule for this calibration consisted of four 11 point calibrations performed for each of the two pulleys. Performing the 11 point calibration several times gave a higher confidence that the pulley hysteresis was repeatable.

The pulley calibration was conducted using load cell S/N 2229. Because the sensitivity was not of concern, only the hysteresis and nonlinearity, the calibration was performed at room temperature. The results of the calibrations are presented in Tables 5.1 and 5.2 of Appendix A.

Interestingly, loading the load cell through the pulleys does not increase the hysteresis. In fact, the output from the upscale and downscale loadings are scattered fairly randomly about the least squares fit through the data. The load cell's nonlinearity is at at approximately the same level as in the individual load cell calibration. For pulley #1 it's $\pm$0.038%F.S. and for pulley #2 it's $\pm$0.031%F.S as compared with the $\pm$0.046%F.S. found during the individual calibration of S/N 2229. These data indicate that the level of friction present in the pulleys is less than can be discerned by load cells. The pulley system therefore did not effect the calibration data.

5.3.3. Bearing Friction.

For the first stage of the force measurement system calibration, all the wiring and air lines were disconnected from the metric frame. Only the thrust gauge was installed in the force measurement system. With the frame free of all wiring, the air lines, and the lift load flexures, the only thing effecting the load readings was the hydrostatic bearing friction. The thrust cell was then loaded through a pulley positioned on the thrust load rail.

Three 11 point calibrations were performed for the bearing friction calibration. For the calibration of the hydrostatic bearing friction, the load cell was kept at a constant 54.4° C (130°F). A comparison of the results of this calibration with the individual load cell calibration gives the magnitude of the hysteresis due to the bearing friction. The results of this calibration are shown in Appendix A in Table 6.

The hysteresis again was not a definite effect. The data is randomly scattered about the linear fit for the upscale and downscale loadings. The reduction in hysteresis might be attributed to the vibration of the metric frame caused by the hydrostatic bearings. The vibration from the bearings increased the data scatter enough that the data sample size had to be increased. The sample size for this and the following checks had to be increased from 50 to 500 to get the data to converge.

The nonlinearity measured during the bearing calibration was $\pm 0.042\%$F.S.

This is of the same order of magnitude as experienced during the individual load cell calibrations. The sensitivity of load cell increased slightly above that exhibited in the individual load cell calibration. Although this could be due to a high point on one of the bearings, it is more likely due to the characteristics of the load cell. However, because the hysteresis is lower and the nonlinearity is the same(compared to the individual calibration of the load cell), the effects of the bearing friction must be below the accuracy level of the load cell.

5.3.4. Resistance Due to Flexures.

For this check, the test setup was the same as for the bearing friction, except that the N_2 gauge was installed. In this case, the thrust gauge was effected by both the bearing friction and the resistive stiffness of the flexures. The difference between this calibration and the bearing friction calibration was the contribution of the flexures to the force measurement system error.

The loading schedule for this check consisted of three 11 point loadings. The effects of the flexure stiffness was also below the level of accuracy of the load cell. For this calibration, the nonlinearity was $\pm$0.027%F.S. and the average sensitivity was 0.136460mV/N (0.606976 mV/lb). No hysteresis is displayed. The data taken during this calibration, conducted at 54.4°C (130°F), are presented in Table 7 of Appendix A.

5.3.5. Mechanical Interactions.

The mechanical interactions were determined in a manner similar to that used to calibrate the wind tunnel model balances at Ames. All three gauges were installed in the force measurement system. To determine the primary interactions, each gauge was loaded individually through a 21 point, followed by an 11 point calibration. By recording the output of all three gauges, the interactions between the loaded primary gauge and the other gauges was seen.

Next, each gauge was again loaded through an 11 point calibration, but this time one of the other two gauges had a constant full scale load applied. This was repeated for all the possible load cell combinations(six total.) This gave the combined, or secondary, loading effects.

For this and the remaining calibrations, all the load cells were kept at 130^{o}F. Although mechanical interactions are present in the force measurement system(see data in Tables 1.1-1.9 of Appendix B), their order of magnitude was less than the nonrepeatability of the load cells. A definitive calibration of these interactions was thus impossible. As in the earlier calibrations the low accuracy of the load cells masks the effects of the mechanical interactions.

The sensitivity of gauges N_1 and N_2 increased(Tables 7.1-7.9 of Appendix A), with no change in the hysteresis or nonlinearity. A large decrease in sensitivity of gauge A, - 0.608%F.S. based on the uninstalled average, was seen during this calibration. The output at maximum load for gauge A falls considerably short of that predicted by the linear fit, indicating that the frame may have been fouling on the thrust travel stop. This was confirmed in later tests. The fouling was not detected because the data reduction was not performed until after the test setup was changed.

5.3.6. Instrumentation Wiring Resistance.

Following the check for mechanical interactions, all the instrumentation wiring was installed on the metric frame. The loading schedule consisted of two 11 point calibrations for each of the three gauges. Two calibrations were made to check the repeatability of the results. The difference between these calibrations and the calibrations conducted to find the primary mechanical interactions was the effects of the wiring.

The rather large drop in sensitivity in the A gauge during the previous calibration was recovered during this loading. The sensitivity of the N_1 gauge remained the same while the N_2 gauge saw another increase(see Tables 8.1-8.3 of Appendix A.) The nonlinearity and hysteresis for all the gauges remained at or below those levels experienced in the bare calibration of the frame. The addition of the instrumentation wiring therefore does not effect the force data. The calibration of the wiring resistance was limited by the accuracy of the load cells. The data for this calibration are presented in Appendix B, Tables 2.1-2.3.

5.3.7. Air Line Resistance.

This check is similar to the wiring resistance check. The air lines were connected to the metric frame. Each gauge was again loaded individually through two 11 point calibrations. The results from this test are compared with the wiring resistance check to determine the incremental effects the air lines have.

The results from the air line calibration are very similar to the results of the check of the instrumentation wiring resistance. The air lines do not effect the force data(see Appendix A, Tables 9.1-9.3, and Appendix B, Tables 3.1-3.3.)

NOTE: Because the safety review of the high pressure air system has not been completed and the pumping plant is not operational, the following calibrations could not be performed. They are outlined here, however, so that as these systems become available, the force measurement system calibration can be completed. To save time and energy, it is suggested that these checks be performed in conjunction with the checkout of the high pressure air system and the pumping plant.

5.3.8. Air Line Resistance(Pressurized and Heated).

This test checks the results of heating and pressurizing the high pressure air lines. For safety reasons, no one can be allowed in the vacuum tank while the air lines are pressurized. All test runs will be made with the tank door shut and clamped. This will mean that the pressure in the lines will have to be bled off before a loading change can be made, which will making the testing very time consuming. For this reason, it is suggested that only a limited number of conditions be investigated. This is done to determine if the contribution to the system error is large enough to warrant further study.

For the first step, the air lines should be heated and pressurized to their maximum expected operating conditions. This is done with no flow in the lines and no load applied to the gauges. Any load sensed by the load cells will be due to the unsymmetrical expansion of the air lines. The next step will be to place a full scale load on the load cells and again bring the air lines up to their maximum operating temperature and pressure. From the zero and full scale points the sensitivity of the load cells under these operating conditions can be determined. By comparing these sensitivities with those obtained in the previous sequence, the magnitude of the heating and pressurization effects can be determined.

If the error is large enough to effect the accuracy of the system, correction maps that are a function of the air line pressures and temperatures will have to be developed for the force readings.

5.3.9. Flow Effects(Momentum and Impingment Tares).

Because the size of the momentum tares will be a function of the airflow through the air lines, this effect should be initially checked with the maximum expected airflow passing through the lines. This will indicate whether the momentum tares are large enough to require further investigation. One method of performing this check is to simply route the airflow from the inlet and drive air lines back out of the vacuum tank through bleed air lines. Any force sensed by the load cells would be a consequence of the air momentum not crossing the metric break at a right angle. If the tares are large enough to degrade the force measurement system's accuracy, the piping will either have to be adjusted to eliminate the tares or the tares will need to be documented as a function of the line airflow.

An operational check of the exhaust extractors will have to be made to determine if there is any impingment of the exhaust flow on the metric frame. To perform this check, a nozzle should be installed in the tank just as it would during a calibration. Tufts should be put on the nozzle, the exhaust extractors, and the rear portion of the metric frame so that any flow disturbances can be seen. The nozzle should be run from zero to its maximum operating airflow to check the extractor's efficiency over the nozzle's entire operating range. The load cell signals should also be monitored to determine the magnitude of the signal perturbations caused by the exhaust.

5.3.10. Vacuum Effects.

The effects of ambient pressure variations on the load cell output can be determined during the pumping plant checkout. This is done with a no load condition on the force measurement system. The load cell output is recorded and checked for variations over the pressure operating range of the vacuum tank.

5.3.11. Standard Nozzle Calibration.

Ultimately, the quality of the PSCL will be judged by its ability to reproduce the performance characteristics of known reference nozzles. This must be done over the ranges of thrust, mass flow, and pressure ratio at which the PSCL is expected to operate. For the proof test of the PSCL as a calibration facility, several standard nozzles should be calibrated. The calibration of these reference nozzles(such as the ASME standards) will demonstrate the accuracy of the laboratory. They should be calibrated again periodically to check for changes in PSCL's performance.

5.4. Calibration Summary

Because the accuracy of the load cells' was so low, the performance limits of the calibration equipment and methods, and the force measurement system could not be defined. However, some conclusions about their performance can be made.

The equipment and methods developed for the calibration of the PSCL's force measurement system were convenient and easy to use. The equipment did not add any detectable hysteresis or misalignment error to the calibration data.

The effects of the hydrostatic bearings, flexures, instrumentation wiring, and the air lines are below the level of accuracy obtainable with the laboratory's present load cells. This is indicated by the comparable or lower levels of non-linearity and hysteresis shown by the load cells, between their installed and uninstalled performance. In fact, the vibration of the hydrostatic bearings seems to have eliminated the gauges' hysteresis. The increases in the sensitivity of gauges between the uninstalled and installed calibrations have no physical meaning. The increases can more than likely be attributed to the non-repeatability of the load cells and not to the design of the force measurement system.

Mechanical interactions are present, but their order of magnitude is quite small. Using load cells with higher accuracies, these interactions could be calibrated, allowing them to be taken into account.

While the fact that the system errors are too small to be detected by the load cells is good, it does not validate the force measurement system's design. The system errors could still be above the $\pm 0.05\%$F.S. accuracy required for the force calibrations of propulsion simulators. To obtain a realistic idea of the accuracy of the force measurement system will require that these calibrations be repeated using higher accuracy load cells. The calibrations described in Subsections 5.3.8 through 5.3.11 will also have to be performed. The equipment and procedures validated in this project should be used to perform these calibrations.

An accuracy level can be stated for the force measurement system from the data taken during these calibrations. The accuracy is, however, mainly a function of the load cells' characteristics and not those of the force measurement system. The accuracy obtainable with the present system is the sum of the nonrepeatability and nonlinearity for the individual gauges over all the calibrations. The worst case is for gauge N_1. It limits the system accuracy to $\pm 0.826\%$F.S.

Chapter 6

Recommendations

6.1. Introduction

Having completed the operational checkout and initial calibration of the force measurement system, recommendations for improvements and future investigations can be made. The system improvements are broken into two groups. The first, operational improvements, contains recommendations to make the alignment and calibration process safer and more efficient. The second, accuracy improvements, has suggestions for hardware and methods that will improve the accuracy of the force measurement system.

6.2. Operational Improvements

Overall, the force measurement system and the calibration equipment operated well. However, several improvements can be made which will increase the accuracy and decrease the time spent aligning the force measurement system and the calibration equipment. Improvements can be made to protect the load cells from being overstressed. Additional equipment is also needed to make the individual load cell calibrations more efficient.

It is recommended that fine controls for adjusting the position of the load cell mounts and pulleys be developed. Better control over the horizontal and vertical position of the load cell mounts and the pulleys would improve the accuracy with which the force measurement system and the calibration equipment is aligned. Eliminating the cumbersome methods presently used could reduce the time required for setup and alignment by up to 25%.

The fouling of gauge A during the calibration of the force measurement system's mechanical interactions demonstrated the need for a warning system(mentioned in Subsection 4.26) to be developed. The mechanisms for warning that the travel stops are fouling will alert operators to problems such as overload conditions. They will also help prevent data from being taken while the frame is fouling.

Changes should be made to improve the operation of the frame lockout system. To prevent damage to any more load cells(see Subsection 4.4.2), two of the four lockouts have been removed from the system. Using only two lockouts, the frame will still be secured and there is a better chance that the frame will always lock out in the same position. To test this theory, high capacity load cells should be installed in the force measurement system, and the lockouts released and engaged several times. If the output from the load cells remains constant, the frame is locking out in a consistent position.

Additional equipment is needed to support the ongoing load cell calibrations. During the individual calibrations the equipment available could support only two simultaneous load cell calibrations. It is recommended that a calibration stand be developed that can be used outside the vacuum tank, so that the tank can be freed for more important tasks. The stand should accomodate four or more load cells, so that the time consuming creep checks can conducted on several load cells at one time. Each load cell station would have all the electrical hookups needed. Additional weights will also be required to perform several load cell calibrations at one time. These equipment improvements could reduce the time required for the individual load cell calibrations by 33%to 50%.

6.3. Accuracy Improvements

The accuracy of the force measurement system will be improved most by replacing the present load cells. The desired accuracy of $\pm 0.05\%$F.S. for force measurements is not obtainable with the present load cells. It is recommended that several manufacturers be contacted in the effort to select the new load cells. Suggested sources include Interface Inc., Ormond Inc., and Saber Corp. A competitive calibration program should be set up using demonstrator load cells from each manufacturer. The replacement load cells will be those which perform best during the demonstration calibrations. Identical procedures should be used for each calibration.

Precision alignment jigs should be developed for installing the load cell hardware. These jigs would insure that the lift force connecting rods are parallel to one another and that they are perpendicular to that thrust force connecting rod. This would greatly simplify the the installation of the load cell hardware. These jigs would have to be adjustable to accomodate various force measurement system configurations. Using the jigs to align the force measurement system could provide a time saving of at least 50%. The accuracy with which the alignment is performed could be improved by 33%to 50%.

After the new load cells have been installed using the precision alignment jigs, the system should be checked for interactions. The interactions should be zeroed out using the fine position controls on the load cell mounts to adjust the positions of the load cells.

Even with new load cells the temperature effects will still need to be taken into account. One solution is to calibrate the gauges at various temperatures and then correct the force measurement system data using these calibrations. An easier approach is to develop a Temperature Control Unit(TCU) to keep the cells at a constant temperature. The TCU temperature should be set higher than the maximum tank temperature(about 48.9° C (120° F.))

The TCU is similar in concept to the "hot boxes" mentioned in Chapter 5, but would be much more compact. Once the load cell is installed in the

TCU, they could be moved as a unit. This would simplify the individual calibrations of the gauges and their installation in the force measurement system. Each TCU should have provisions for electrical hook-up to the power for its heating element, load cell excitation and signal, and the load cell temperature instrumentation.

6.4. Future Investigations

Because the low accuracy of the load cells masked the characteristics of the force measurement system, the calibrations performed during this project must be repeated. These should be done after higher accuracy load cells have been purchased for the laboratory. The tares due to the bearings, flexures, instrumentation wiring, and air lines and the mechanical interactions should then be determined using the methods outlined in Chapter 5.

To complete the calibration of the force measurement system, the following calibrations(as outlined in Chapter 5) must also be performed:

- Air Line Resistance(Pressurized and Heated)
- Flow Effects(Momentum Tares and Exhaust Impingment)
- Vacuum Effects
- Standard Nozzle Calibration

It is recommended that these calibrations be performed in conjunction with the checkout of the facility's high pressure air system and pumping plant.

This will reduce the manhours and equipment run times required for the calibrations.

After the first three of these calibrations are completed, the methods for correcting any errors in the force data need to be developed. Various check forces and moments should be placed on the frame to verify that these correction routines properly calculate the loads. Once the loads are adequately predicted, the standard nozzle calibration can begin.

The results from the standard nozzle calibration are very important. The quality of the laboratory as a whole will be judged by this calibration. The information from this calibration will be used to document the accuracy levels that can be obtained in the PSCL. The nozzles should be calibrated again periodically to check for any changes in the laboratory's characteristics.

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APPENDIX A

TABLE 1.1
GENISCO LOAD CELL
MOD AWU-50
S/N 2228
EXCITATION=9.98 VDC
DATE: 4/17/84
TIME: 15:23:29
TEMP: 130 F
BARO: 14.71 PSI

FIRST & SECOND CYCLE

Coefficients C(1).....C(0): 6.0153963E-01 6.6670459E-04

Point	lb	mV	Calculated mV	Deviation mV)
1	4.090000	2.458500	2.460964	0.002464
2	9.090000	5.467100	5.468662	0.001562
3	14.090000	8.472800	8.476360	0.003560
4	19.090000	11.479900	11.484058	0.004158
5	24.090000	14.488600	14.491756	0.003156
6	29.090000	17.497300	17.499455	0.002155
7	34.090000	20.506000	20.507153	0.001153
8	39.090000	23.516200	23.514851	-0.001349
9	44.090000	26.520300	26.522549	0.002249
10	49.090000	29.529000	29.530247	0.001247
11	54.090000	32.536200	32.537945	0.001745
12	49.090000	29.530500	29.530247	-0.000253
13	44.090000	26.523300	26.522549	-0.000751
14	39.090000	23.517700	23.514851	-0.002849
15	34.090000	20.507500	20.507153	-0.000347
16	29.090000	17.501900	17.499455	-0.002445
17	24.090000	14.491700	14.491756	0.000056
18	19.090000	11.484500	11.484058	-0.000442
19	14.090000	8.477400	8.476360	-0.001040
20	9.090000	5.470200	5.468662	-0.001538
21	4.090000	2.463000	2.460964	-0.002036
22	14.090000	8.477400	8.476360	-0.001040
23	24.090000	14.491700	14.491756	0.000056
24	34.090000	20.509000	20.507153	-0.001847
25	44.090000	26.523300	26.522549	-0.000751
26	54.090000	32.537700	32.537945	0.000245
27	44.090000	26.523300	26.522549	-0.000751
28	34.090000	20.509000	20.507153	-0.001847
29	24.090000	14.493200	14.491756	-0.001444
30	14.090000	8.477400	8.476360	-0.001040
31	4.090000	2.463000	2.460964	-0.002036

RMS Deviation: 0.00033045 mV

TABLE 1.2
GENISCO LOAD CELL
MOD AWU-50
S/N 2228
EXCITATION=9.98 VDC
DATE: 4/17/84
TIME: 15:23:29
TEMP: 130 F
BARO: 14.71 PSI

FIRST CYCLE

Coefficients C(1).....C(0): 6.0154824E-01 -7.1371155E-05

Point	lbs	mV	Calculated mV	Deviation mV)
1	4.090000	2.458500	2.460261	0.001761
2	9.090000	5.467100	5.468002	0.000902
3	14.090000	8.472800	8.475743	0.002943
4	19.090000	11.479900	11.483485	0.003585
5	24.090000	14.488600	14.491226	0.002626
6	29.090000	17.497300	17.498967	0.001667
7	34.090000	20.506000	20.506708	0.000708
8	39.090000	23.516200	23.514449	-0.001751
9	44.090000	26.520300	26.522191	0.001891
10	49.090000	29.529000	29.529932	0.000932
11	54.090000	32.536200	32.537673	0.001473
12	49.090000	29.530500	29.529932	-0.000568
13	44.090000	26.523300	26.522191	-0.001109
14	39.090000	23.517700	23.514449	-0.003251
15	34.090000	20.507500	20.506708	-0.000792
16	29.090000	17.501900	17.498967	-0.002933
17	24.090000	14.491700	14.491226	-0.000474
18	19.090000	11.484500	11.483485	-0.001015
19	14.090000	8.477400	8.475743	-0.001657
20	9.090000	5.470200	5.468002	-0.002198
21	4.090000	2.463000	2.460261	-0.002739

RMS Deviation: 0.00043373 mV

TABLE 1.3
GENISCO LOAD CELL
MOD AWU-50
S/N 2228
EXCITATION=9.98 VDC
DATE: 4/17/84
TIME: 15:39:28
TEMP: 130 F
BARO: 14.71 PSI

SECOND CYCLE

Coefficients C(1).....C(0): 6.0151242E-01 2.5319468E-03

Point	lb	mV	Calculated mV	Deviation mV)
1	4.090000	2.463000	2.462718	-0.000282
2	14.090000	8.477400	8.477842	0.000442
3	24.090000	14.491700	14.492966	0.001266
4	34.090000	20.509000	20.508090	-0.000910
5	44.090000	26.523300	26.523215	-0.000085
6	54.090000	32.537700	32.538339	0.000639
7	44.090000	26.523300	26.523215	-0.000085
8	34.090000	20.509000	20.508090	-0.000910
9	24.090000	14.493200	14.492966	-0.000234
10	14.090000	8.477400	8.477842	0.000442
11	4.090000	2.463000	2.462718	-0.000282

RMS Deviation: 0.00018819 mV

TABLE 1.4
GENISCO LOAD CELL
MOD AWU-50
S/N 2228
EXCITATION=9.98 VDC
DATE: 4/17/84
TIME: 16:47:02
TEMP: 130 F
BARO: 14.70 PSI

Coefficients C(1),....C(0): 6.0108381E-01 2.2548981E-01

Point	lb	mV	Calculated mV	Deviation mV)
1	4.090000	2.682900	2.683923	0.001023
2	14.090000	8.695000	8.694761	-0.000239
3	24.090000	14.705700	14.705599	-0.000101
4	34.090000	20.716300	20.716437	0.000137
5	44.090000	26.726900	26.727275	0.000375
6	54.090000	32.737500	32.738113	0.000613
7	44.090000	26.728400	26.727275	-0.001125
8	34.090000	20.716300	20.716437	0.000137
9	24.090000	14.705700	14.705599	-0.000101
10	14.090000	8.695000	8.694761	-0.000239
11	4.090000	2.684400	2.683923	-0.000477

RMS Deviation: 0.00016334 mV

TABLE 1.5
GENISCO LOAD CELL
MOD AWU-50
S/N 2228
EXCITATION=9.98 VDC
DATE: 4/18/84
TIME: 10:41:46
TEMP: 130 F
BARO: 14.69 PSI

Coefficients C(1),....C(0): 6.0163329E-01 -6.5765610E-04

Point	lb	mV	Calculated mV	Deviation mV)
1	4.090000	2.459080	2.460022	0.000942
2	14.090000	8.472530	8.476355	0.003825
3	24.090000	14.487500	14.492688	0.005188
4	34.090000	20.507100	20.509021	0.001921
5	44.090000	26.522000	26.525354	0.003354
6	54.090000	32.541599	32.541687	0.000088
7	44.090000	26.528101	26.525354	-0.002747
8	34.090000	20.513200	20.509021	-0.004179
9	24.090000	14.496700	14.492688	-0.004012
10	14.090000	8.478630	8.476355	-0.002275
11	4.090000	2.462130	2.460022	-0.002108

RMS Deviation: 0.00094522 mV

TABLE 1.6
GENISCO LOAD CELL
MOD AWU-50
S/N 2228
EXCITATION=9.98 VDC
DATE: 4/19/84
TIME: 10:03:36
TEMP: 130 F
BARO: 14.76 PSI

Coefficients C(1).....C(0): 6.0349724E-01 -7.7644996E-03

Point	lbs	mV	Calculated mV	Deviation mV)
1	4.090000	2.457860	2.460539	0.002679
2	14.090000	8.494700	8.495512	0.000812
3	24.090000	14.530000	14.530484	0.000484
4	34.090000	20.565300	20.565456	0.000156
5	44.090000	26.599000	26.600429	0.001429
6	54.090000	32.634300	32.635401	0.001101
7	44.090000	26.602100	26.600429	-0.001671
8	34.090000	20.566800	20.565456	-0.001344
9	24.090000	14.531500	14.530484	-0.001016
10	14.090000	8.496230	8.495512	-0.000718
11	4.090000	2.462450	2.460539	-0.001911

RMS Deviation: 0.00041806 mV

TABLE 1.7
GENISCO LOAD CELL
MOD AWU-50
S/N 2228
EXCITATION=9.98 VDC
DATE: 4/19/84
TIME: 12:45:43
TEMP: 85 F
BARO: 14.76 PSI

Coefficients C(1).....C(0): 5.9450490E-01 -1.6593764E-02

Point	lbs	mV	Calculated mV	Deviation mV)
1	4.090000	2.414560	2.414931	0.000371
2	14.090000	8.360690	8.359980	-0.000710
3	24.090000	14.306800	14.305029	-0.001771
4	34.090000	20.251400	20.250078	-0.001322
5	44.090000	26.196000	26.195127	-0.000873
6	54.090000	32.139100	32.140176	0.001076
7	44.090000	26.194500	26.195127	0.000627
8	34.090000	20.249900	20.250078	0.000178
9	24.090000	14.303800	14.305029	0.001229
10	14.090000	8.359160	8.359980	0.000820
11	4.090000	2.414560	2.414931	0.000371

RMS Deviation: 0.00029021 mV

TABLE 1.8
GENISCO LOAD CELL
MOD AWU-50
S/N 2228
EXCITATION=9.98 VDC
DATE: 4/17/84
TIME: 9:09:13
TEMP: 130 F
BARO: 14.73 PSI
APPLIED LOAD = 54.09 LB

	ELAPSED TIME(SEC)	OUTPUT mV
FIRST CYCLE		
	0	0.324900E+02
	92	0.325068E+02
	401	0.325373E+02
	690	0.325526E+02
	988	0.325587E+02
	1289	0.325663E+02
	1591	0.325663E+02
	1890	0.325693E+02
	2191	0.325693E+02
	2488	0.325724E+02
	2811	0.325709E+02
	3089	0.325709E+02
	3388	0.325724E+02
	3690	0.325693E+02
SECOND CYCLE		
	0	0.327250E+02
	272	0.327250E+02
	576	0.327265E+02
	874	0.327280E+02
	1235	0.327280E+02
	1474	0.327280E+02
	1781	0.327280E+02
	2074	0.327265E+02
	2372	0.327265E+02
	2672	0.327265E+02
	2972	0.327250E+02
	3271	0.327250E+02
	3572	0.327235E+02
THIRD CYCLE		
	0	0.327219E+02
	368	0.327235E+02
	692	0.327265E+02
	969	0.327235E+02
	1266	0.327265E+02
	1566	0.327265E+02
	1866	0.327265E+02
	2165	0.327250E+02
	2466	0.327265E+02
	2764	0.327250E+02
	3066	0.327265E+02
	3365	0.327250E+02
	3656	0.327265E+02

TABLE 2.1
GENISCO LOAD CELL
MOD AWU-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 4/26/84
TIME: 13:23:56
TEMP: 130 F
BARO: 14.68 PSI

FIRST & SECOND CYCLES

Coefficients C(1).....C(0): 6.0471717E-01 -1.1066373E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	4.060000	2.445380	2.444085	-0.001295
2	9.060000	5.452140	5.467671	0.015531
3	14.060000	8.474160	8.491257	0.017097
4	19.060000	11.494600	11.514843	0.020243
5	24.060000	14.518200	14.538429	0.020229
6	29.060000	17.543300	17.562014	0.018714
7	34.060000	20.568300	20.585600	0.017300
8	39.060000	23.593400	23.609186	0.015786
9	44.060000	26.615400	26.632772	0.017372
10	49.060000	29.642000	29.656358	0.014358
11	54.060000	32.662500	32.679944	0.017444
12	49.060000	29.649600	29.656358	0.006758
13	44.060000	26.632200	26.632772	0.000572
14	39.060000	23.614800	23.609186	-0.005614
15	34.060000	20.591200	20.585600	-0.005600
16	29.060000	17.569200	17.562014	-0.007186
17	24.060000	14.545700	14.538429	-0.007271
18	19.060000	11.519100	11.514843	-0.004257
19	14.060000	8.495510	8.491257	-0.004253
20	9.060000	5.470450	5.467671	-0.002779
21	4.060000	2.443850	2.444085	0.000235
22	14.060000	8.497040	8.491257	-0.005783
23	24.060000	14.548700	14.538429	-0.010271
24	34.060000	20.601900	20.585600	-0.016300
25	44.060000	26.652000	26.632772	-0.019228
26	54.060000	32.696000	32.679944	-0.016056
27	44.060000	26.653500	26.632772	-0.020728
28	34.060000	20.606500	20.585600	-0.020900
29	24.060000	14.554800	14.538429	-0.016371
30	14.060000	8.503140	8.491257	-0.011883
31	4.060000	2.449950	2.444085	-0.005865

RMS Deviation: 0.00242788 mV

TABLE 2.2
GENISCO LOAD CELL
MOD AWU-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 4/26/84
TIME: 13:23:56
TEMP: 130 F
BARO: 14.68 PSI

FIRST CYCLE

Coefficients C(1).....C(0): 6.0454945E-01 -1.3220084E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	4.060000	2.445380	2.441251	-0.004129
2	9.060000	5.452140	5.463998	0.011858
3	14.060000	8.474160	8.486745	0.012585
4	19.060000	11.494600	11.509492	0.014892
5	24.060000	14.518200	14.532240	0.014040
6	29.060000	17.543300	17.554987	0.011687
7	34.060000	20.568300	20.577734	0.009434
8	39.060000	23.593400	23.600481	0.007081
9	44.060000	26.615400	26.623229	0.007829
10	49.060000	29.642000	29.645976	0.003976
11	54.060000	32.662500	32.668723	0.006223
12	49.060000	29.649600	29.645976	-0.003624
13	44.060000	26.632200	26.623229	-0.008971
14	39.060000	23.614800	23.600481	-0.014319
15	34.060000	20.591200	20.577734	-0.013466
16	29.060000	17.569200	17.554987	-0.014213
17	24.060000	14.545700	14.532240	-0.013460
18	19.060000	11.519100	11.509492	-0.009608
19	14.060000	8.495510	8.486745	-0.008765
20	9.060000	5.470450	5.463998	-0.006452
21	4.060000	2.443850	2.441251	-0.002599

RMS Deviation: 0.00223717 mV

TABLE 2.3
GENISCO LOAD CELL
MOD AWU-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 4/26/84
TIME: 13:33:46
TEMP: 130 F
BARO: 14.68 PSI

SECOND CYCLE

Coefficients C(1),....C(0):   6.0506248E-01   -7.3026906E-03

Point	lbs	mV	Calculated mV	Deviation mV
1	4.060000	2.443850	2.449251	0.005401
2	14.060000	8.497040	8.499876	0.002836
3	24.060000	14.548700	14.550501	0.001801
4	34.060000	20.601900	20.601125	-0.000775
5	44.060000	26.652000	26.651750	-0.000250
6	54.060000	32.696000	32.702375	0.006375
7	44.060000	26.653500	26.651750	-0.001750
8	34.060000	20.606500	20.601125	-0.005375
9	24.060000	14.554800	14.550501	-0.004299
10	14.060000	8.503140	8.499876	-0.003264
11	4.060000	2.449950	2.449251	-0.000699

RMS Deviation: 0.00108838 mV

TABLE 2.4
GENISCO LOAD CELL
MOD AWU-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 4/26/84
TIME: 14:30:17
TEMP: 130 F
BARO: 14.67 PSI

Coefficients C(1).....C(0): 6.0396382E-01 -2.8255365E-02

Point	lbs	mV	Calculated mV	Deviation mV)
1	4.060000	2.418280	2.423838	0.005558
2	14.060000	8.458660	8.463476	0.004816
3	24.060000	14.496000	14.503114	0.007114
4	34.060000	20.537900	20.542752	0.004852
5	44.060000	26.579800	26.582391	0.002591
6	54.060000	32.617100	32.622029	0.004929
7	44.060000	26.587400	26.582391	-0.005009
8	34.060000	20.551600	20.542752	-0.008848
9	24.060000	14.511200	14.503114	-0.008086
10	14.060000	8.469330	8.463476	-0.005854
11	4.060000	2.425900	2.423838	-0.002062

RMS Deviation: 0.00174043 mV

TABLE 2.5
GENISCO LOAD CELL
MOD AWU-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 4/27/84
TIME: 12:45:52
TEMP: 130 F
BARO:14.70 PSI

Coefficients C(1).....C(0): 6.0548634E-01 -2.3860329E-02

Point	lbs	mV	Calculated mV	Deviation mV)
1	4.060000	2.432320	2.434414	0.002094
2	14.060000	8.484140	8.489278	0.005138
3	24.060000	14.539000	14.544141	0.005141
4	34.060000	20.593900	20.599004	0.005104
5	44.060000	26.648700	26.653868	0.005168
6	54.060000	32.706700	32.708731	0.002031
7	44.060000	26.659400	26.653868	-0.005532
8	34.060000	20.606100	20.599004	-0.007096
9	24.060000	14.551200	14.544141	-0.007059
10	14.060000	8.493300	8.489278	-0.004022
11	4.060000	2.435380	2.434414	-0.000966

RMS Deviation: 0.00147147 mV

TABLE 2.6
GENISCO LOAD CELL
MOD AWU-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 4/27/84
TIME: 13:49:19
TEMP: 130 F
BARO: 14.70 PSI

Coefficients C(1).....C(0): 6.0519459E-01 -3.4852630E-02

Point	lbs	mV	Calculated mV	Deviation mV)
1	4.060000	2.419110	2.422237	0.003127
2	14.060000	8.465360	8.474183	0.008823
3	24.060000	14.519200	14.526129	0.006929
4	34.060000	20.571600	20.578075	0.006475
5	44.060000	26.625400	26.630021	0.004621
6	54.060000	32.679300	32.681967	0.002667
7	44.060000	26.634600	26.630021	-0.004579
8	34.060000	20.588400	20.578075	-0.010325
9	24.060000	14.536000	14.526129	-0.009871
10	14.060000	8.479080	8.474183	-0.004897
11	4.060000	2.425210	2.422237	-0.002973

RMS Deviation: 0.00195794 mV

TABLE 2.7
GENISCO LOAD CELL
MOD AWU-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 4/27/84
TIME: 15:52:24
TEMP: 80 F
BARO: 14.68 PSI

Coefficients C(1),....C(0): 5.9580204E-01 -2.2630793E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	4.060000	2.397700	2.396325	-0.001375
2	14.060000	8.355290	8.354346	-0.000944
3	24.060000	14.317500	14.312366	-0.005134
4	34.060000	20.275100	20.270387	-0.004713
5	44.060000	26.229600	26.228407	-0.001193
6	54.060000	32.181100	32.186427	0.005327
7	44.060000	26.228100	26.228407	0.000307
8	34.060000	20.272000	20.270387	-0.001613
9	24.060000	14.311400	14.312366	0.000966
10	14.060000	8.349180	8.354346	0.005166
11	4.060000	2.393120	2.396325	0.003205

RMS Deviation: 0.00100309 mV

TABLE 2.8
GENISCO LOAD CELL
MOD AWU-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 4/27/84
TIME: 8:08:30
TEMP: 130 F
BARO: 14.71 PSI

APPLIED LOAD = 54.06 LB

	ELAPSED TIME(SEC)	OUTPUT mV
FIRST CYCLE		
	0	0.326549E+02
	366	0.326839E+02
	661	0.326961E+02
	945	0.327022E+02
	1265	0.327083E+02
	1562	0.327144E+02
	1874	0.327175E+02
	2166	0.327190E+02
	2464	0.327251E+02
	2760	0.327251E+02
SECOND CYCLE		
	0	0.327236E+02
	260	0.327312E+02
	575	0.327342E+02
	1185	0.327388E+02
	1532	0.327388E+02
	1775	0.327403E+02
	2072	0.327418E+02
	2374	0.327449E+02
	2683	0.327434E+02
	2975	0.327449E+02
THIRD CYCLE		
	0	0.327251E+02
	300	0.327327E+02
	600	0.327358E+02
	901	0.327418E+02
	1197	0.327418E+02
	1536	0.327418E+02
	1824	0.327418E+02
	2099	0.327403E+02
	2410	0.327403E+02
	2701	0.327434E+02

TABLE 3.1
GENISCO LOAD CELL
MOD AWU-50
S/N 2230
EXCITATION=9.98 VDC
DATE: 4/17/84
TIME: 16:00:54
TEMP: 130 F
BARO: 14.70 PSI

FIRST & SECOND CYCLES

Coefficients C(1).....C(0): 6.0642715E-01 9.6522319E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	4.090000	2.565300	2.576809	0.011509
2	9.090000	5.597900	5.608945	0.011045
3	14.090000	8.630400	8.641081	0.010681
4	19.090000	11.663000	11.673217	0.010217
5	29.090000	17.731200	17.737488	0.006288
6	34.090000	20.763800	20.769624	0.005824
7	39.090000	23.799400	23.801760	0.002360
8	44.090000	26.828900	26.833895	0.004995
9	49.090000	29.859900	29.866031	0.006131
10	54.090000	32.895500	32.898167	0.002667
11	49.090000	29.867600	29.866031	-0.001569
12	44.090000	26.836500	26.833895	-0.002605
13	39.090000	23.807000	23.801760	-0.005240
14	34.090000	20.772900	20.769624	-0.003276
15	29.090000	17.740300	17.737488	-0.002812
16	24.090000	14.707800	14.705352	-0.002448
17	19.090000	11.676700	11.673217	-0.003483
18	14.090000	8.644200	8.641081	-0.003119
19	9.090000	5.613100	5.608945	-0.004155
20	4.090000	2.582100	2.576809	-0.005291
21	14.090000	8.642700	8.641081	-0.001619
22	24.090000	14.707800	14.705352	-0.002448
23	34.090000	20.772900	20.769624	-0.003276
24	44.090000	26.836500	26.833895	-0.002605
25	54.090000	32.897000	32.898167	0.001167
26	44.090000	26.836500	26.833895	-0.002605
27	34.090000	20.774400	20.769624	-0.004776
28	24.090000	14.712400	14.705352	-0.007048
29	14.090000	8.647200	8.641081	-0.006119
30	4.090000	2.585200	2.576809	-0.008391

RMS Deviation: 0.00103530 mV

TABLE 3.2
GENISCO LOAD CELL
MOD AWU-50
S/N 2230
EXCITATION=9.98 VDC
DATE: 4/17/84
TIME: 16:00:54
TEMP: 130 F
BARO: 14.70 PSI

FIRST CYCLE

Coefficients C(1).....C(0): 6.0647816E-01 9.3203560E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	4.090000	2.565300	2.573699	0.008399
2	9.090000	5.597900	5.606090	0.008190
3	14.090000	8.630400	8.638481	0.008081
4	19.090000	11.663000	11.670872	0.007872
5	29.090000	17.731200	17.735653	0.004453
6	34.090000	20.763800	20.768044	0.004244
7	39.090000	23.799400	23.800435	0.001035
8	44.090000	26.828900	26.832826	0.003926
9	49.090000	29.859900	29.865216	0.005316
10	54.090000	32.895500	32.897607	0.002107
11	49.090000	29.867600	29.865216	-0.002384
12	44.090000	26.836500	26.832826	-0.003674
13	39.090000	23.807000	23.800435	-0.006565
14	34.090000	20.772900	20.768044	-0.004856
15	29.090000	17.740300	17.735653	-0.004647
16	24.090000	14.707800	14.703262	-0.004538
17	19.090000	11.676700	11.670872	-0.005828
18	14.090000	8.644200	8.638481	-0.005719
19	9.090000	5.613100	5.606090	-0.007010
20	4.090000	2.582100	2.573699	-0.008401

RMS Deviation: 0.00129069 mV

TABLE 3.3
GENISCO LOAD CELL
MOD AWU-50
S/N 2230
EXCITATION=9.98 VDC
DATE: 4/17/84
TIME: 16:20:28
TEMP: 130 F
BARO: 14.70 PSI

SECOND CYCLE

Coefficients C(1).....C(0): 6.0631410E-01 1.0346405E-01

Point	lb	mV	Calculated mV	Deviation mV)
1	4.090000	2.582100	2.583289	0.001189
2	14.090000	8.642700	8.646430	0.003730
3	24.090000	14.707800	14.709571	0.001771
4	34.090000	20.772900	20.772712	-0.000188
5	44.090000	26.836500	26.835853	-0.000647
6	54.090000	32.897000	32.898994	0.001994
7	44.090000	26.836500	26.835853	-0.000647
8	34.090000	20.774400	20.772712	-0.001688
9	24.090000	14.712400	14.709571	-0.002829
10	14.090000	8.647200	8.646430	-0.000770
11	4.090000	2.585200	2.583289	-0.001911

RMS Deviation: 0.00056341 mV

TABLE 3.4
GENISCO LOAD CELL
MOD AWU-50
S/N 2230
EXCITATION=9.98 VDC
DATE: 4/18/84
TIME: 10:23:25
TEMP: 130 F
BARO: 14.70 PSI

Coefficients C(1).....C(0): 6.0494270E-01 1.8445517E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	4.090000	2.489280	2.492661	0.003381
2	14.090000	8.534040	8.542088	0.008048
3	24.090000	14.583400	14.591515	0.008115
4	34.090000	20.634200	20.640942	0.006742
5	44.090000	26.688101	26.690369	0.002268
6	54.090000	32.740500	32.739796	-0.000704
7	44.090000	26.694199	26.690369	-0.003830
8	34.090000	20.646400	20.640942	-0.005458
9	24.090000	14.597099	14.591515	-0.005584
10	14.090000	8.549290	8.542088	-0.007202
11	4.090000	2.498440	2.492661	-0.005779

RMS Deviation: 0.00171057 mV

TABLE 3.5
GENISCO LOAD CELL
MOD AWU-50
S/N 2230
EXCITATION=9.98 VDC
DATE: 4/18/84
TIME: 11:17:15
TEMP: 130 F
BARO: 14.68 PSI

Coefficients C(1).....C(0): 6.0524955E-01 2.5498585E-02

Point	lb	mV	Calculated mV	Deviation mV
1	4.090000	2.499800	2.500969	0.001169
2	14.090000	8.552450	8.553465	0.001015
3	24.090000	14.605099	14.605960	0.000861
4	34.090000	20.656200	20.658456	0.002256
5	44.090000	26.707300	26.710951	0.003651
6	54.090000	32.763000	32.763447	0.000447
7	44.090000	26.713400	26.710951	-0.002449
8	34.090000	20.660800	20.658456	-0.002344
9	24.090000	14.609700	14.605960	-0.003740
10	14.090000	8.555500	8.553465	-0.002035
11	4.090000	2.499800	2.500969	0.001169

RMS Deviation: 0.00066024 mV

TABLE 3.6
GENISCO LOAD CELL
MOD AWU-50
S/N 2230
EXCITATION=9.98 VDC
DATE: 4/19/84
TIME: 11:05:25
TEMP: 130 F
BARO: 14.76 PSI

Coefficients C(1).....C(0): 6.0346855E-01 2.4019269E-02

Point	lb	mV	Calculated mV	Deviation mV
1	4.090000	2.489810	2.492206	0.002396
2	14.090000	8.525790	8.526891	0.001101
3	24.090000	14.561800	14.561577	-0.000223
4	34.090000	20.593200	20.596262	0.003062
5	44.090000	26.629200	26.630948	0.001748
6	54.090000	32.665100	32.665633	0.000533
7	44.090000	26.633700	26.630948	-0.002752
8	34.090000	20.597800	20.596262	-0.001538
9	24.090000	14.563300	14.561577	-0.001723
10	14.090000	8.527320	8.526891	-0.000429
11	4.090000	2.494380	2.492206	-0.002174

RMS Deviation: 0.00055699 mV

TABLE 3.7
GENISCO LOAD CELL
MOD AWU-50
S/N 2230
EXCITATION=9.98 VDC
DATE: 4/30/84
TIME: 8:57:43
TEMP: 80 F
BARO: 14.82 PSI

Coefficients C(1).....C(0): 5.9368628E-01 2.2094097E-02

Point	lbs	mV	Calculated mV	Deviation mV)
1	4.060000	2.440100	2.432460	-0.007640
2	14.060000	8.373900	8.369323	-0.004577
3	24.060000	14.310750	14.306186	-0.004564
4	34.060000	20.244550	20.243049	-0.001501
5	44.060000	26.181450	26.179912	-0.001538
6	54.060000	32.118300	32.116775	-0.001525
7	44.060000	26.178400	26.179912	0.001512
8	34.060000	20.240000	20.243049	0.003049
9	24.060000	14.301600	14.306186	0.004586
10	14.060000	8.361700	8.369323	0.007623
11	4.060000	2.427885	2.432460	0.004575

RMS Deviation: 0.00134456 mV

TABLE 3.8
GENISCO LOAD CELL
MOD AWU-50
S/N 2230
EXCITATION=9.98 VDC
DATE: 4/17/84
TIME: 9:09:13
TEMP: 130 F
BARO: 14.73 PSI
APPLIED LOAD = 54.29 LB

	ELAPSED TIME(SEC)	OUTPUT mV
FIRST CYCLE		
	0	0.328822E+02
	92	0.329005E+02
	401	0.329218E+02
	690	0.329401E+02
	988	0.329447E+02
	1289	0.329539E+02
	1591	0.329554E+02
	1890	0.329584E+02
	2191	0.329600E+02
	2488	0.329600E+02
	2811	0.329630E+02
	3089	0.329630E+02
	3388	0.329630E+02
	3690	0.329630E+02
SECOND CYCLE		
	0	0.329386E+02
	272	0.329508E+02
	576	0.329554E+02
	874	0.329569E+02
	1235	0.329569E+02
	1474	0.329584E+02
	1781	0.329569E+02
	2074	0.329584E+02
	2372	0.329569E+02
	2672	0.329569E+02
	2972	0.329569E+02
	3271	0.329554E+02
	3572	0.329569E+02
THIRD CYCLE		
	0	0.329355E+02
	368	0.329462E+02
	692	0.329493E+02
	969	0.329508E+02
	1266	0.329523E+02
	1566	0.329523E+02
	1866	0.329539E+02
	2165	0.329523E+02
	2466	0.329554E+02
	2764	0.329539E+02
	3066	0.329539E+02
	3365	0.329539E+02
	3656	0.329539E+02

TABLE 4
GENISCO LOAD CELLS
MODEL AWU-50
EXCITATION=9.96 VDC
DATE: 5/17/84
TIME: 15:42:26
TEMP: 130 F
BARO: 14.76 PSI

LOAD CELL	RAW CTS.	MV CHANGE
S/N 2229	7201	10.99818
S/N 2230	7293	11.12857
S/N 2228	6893	10.51820

NOTE: A 10K OHM PRECISION RESISTOR WAS PLACED ACROSS THE NEGATIVE SIGNAL AND NEGATIVE EXCITATION LEADS TO OBTAIN THE MV CHANGE. THE RESISTOR WAS PLACED ON THE LEADS AT THE DATA SYSTEM.

TABLE 5.1
GENISCO LOAD CELL
MOD AWU-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 4/20/84
TIME: 10:02:01
TEMP: Room Temp.
BARO: 14.83 PSI

PULLEY #1 CALIBRATION

FIRST CYCLE

Coefficients C(1),....C(0): 5.9214124E-01 -4.9105984E-03

Point	lb	mV	Calculated mV	Deviation mV)
1	0.000000	0.003052	-0.004911	-0.007962
2	10.000000	5.912960	5.916502	0.003542
3	20.000000	11.835100	11.837914	0.002814
4	30.000000	17.761800	17.759327	-0.002473
5	40.000000	23.682400	23.680739	-0.001661
6	50.000000	29.609100	29.602151	-0.006949
7	40.000000	23.682400	23.680739	-0.001661
8	30.000000	17.752600	17.759327	0.006727
9	20.000000	11.827400	11.837914	0.010514
10	10.000000	5.911430	5.916502	0.005072
11	0.000000	0.003052	-0.004911	-0.007962

RMS Deviation: 0.00179232 mV

SECOND CYCLE

Coefficients C(1),....C(0): 5.9201192E-01 -6.6970500E-03

Point	lb	mV	Calculated mV	Deviation mV)
1	0.000000	0.003052	-0.006697	-0.009749
2	10.000000	5.902280	5.913422	0.011142
3	20.000000	11.832000	11.833541	0.001541
4	30.000000	17.749600	17.753661	0.004061
5	40.000000	23.673200	23.673780	0.000580
6	50.000000	29.601400	29.593899	-0.007501
7	40.000000	23.676300	23.673780	-0.002520
8	30.000000	17.751100	17.753661	0.002561
9	20.000000	11.832000	11.833541	0.001541
10	10.000000	5.905330	5.913422	0.008092
11	0.000000	0.003052	-0.006697	-0.009749

RMS Deviation: 0.00197183 mV

THIRD CYCLE

Coefficients C(1).....C(0): 5.9207646E-01 -7.6128565E-03

Point	lb	mV	Calculated mV	Deviation mV)
1	0.000000	0.003052	-0.007613	-0.010665
2	10.000000	5.906860	5.913152	0.006292
3	20.000000	11.827400	11.833916	0.006516
4	30.000000	17.755700	17.754681	-0.001019
5	40.000000	23.676300	23.675446	-0.000854
6	50.000000	29.606000	29.596210	-0.009790
7	40.000000	23.674700	23.675446	0.000746
8	30.000000	17.751100	17.754681	0.003581
9	20.000000	11.827400	11.833916	0.006516
10	10.000000	5.903810	5.913152	0.009342
11	0.000000	0.003052	-0.007613	-0.010665

RMS Deviation: 0.00213247 mV

FOURTH CYCLE

Coefficients C(1).....C(0): 5.9181037E-01 -4.0589855E-03

Point	lb	mV	Calculated mV	Deviation mV)
1	0.000000	0.003052	-0.004059	-0.007111
2	10.000000	5.903810	5.914045	0.010235
3	20.000000	11.829000	11.832148	0.003148
4	30.000000	17.743500	17.750252	0.006752
5	40.000000	23.671700	23.668356	-0.003344
6	50.000000	29.589200	29.586460	-0.002740
7	40.000000	23.668600	23.668356	-0.000244
8	30.000000	17.757200	17.750252	-0.006946
9	20.000000	11.827400	11.832148	0.004748
10	10.000000	5.911430	5.914045	0.002615
11	0.000000	0.003052	-0.004059	-0.007111

RMS Deviation: 0.00171958 mV

TABLE 5.2
GENISCO LOAD CELL
MOD AWU-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 4/20/84
TIME: 11:10:34
TEMP: Room Temp.
BARO: 14.83 PSI

PULLEY #2 CALIBRATION

FIRST CYCLE

Coefficients C(1).....C(0): 5.9226422E-01 -1.9398745E-03

Point	lb	mV	Calculated mV	Deviation mV)
1	0.000000	0.000000	-0.001940	-0.001940
2	10.000000	5.919160	5.920702	0.001542
3	20.000000	11.847500	11.843345	-0.004155
4	30.000000	17.771200	17.765987	-0.005213
5	40.000000	23.690400	23.688629	-0.001771
6	50.000000	29.608000	29.611271	0.003271
7	40.000000	23.688900	23.688629	-0.000271
8	30.000000	17.766600	17.765987	-0.000613
9	20.000000	11.839900	11.843345	0.003445
10	10.000000	5.911530	5.920702	0.009172
11	0.000000	0.001526	-0.001940	-0.003466

RMS Deviation: 0.00119533 mV

SECOND CYCLE

Coefficients C(1).....C(0): 5.9230265E-01 -3.3671684E-03

Point	lb	mV	Calculated mV	Deviation mV)
1	0.000000	0.001526	-0.003367	-0.004894
2	10.000000	5.916110	5.919659	0.003549
3	20.000000	11.847500	11.842686	-0.004814
4	30.000000	17.768200	17.765712	-0.002488
5	40.000000	23.696500	23.688739	-0.007761
6	50.000000	29.614100	29.611765	-0.002335
7	40.000000	23.684300	23.688739	0.004439
8	30.000000	17.759000	17.765712	0.006712
9	20.000000	11.836800	11.842686	0.005886
10	10.000000	5.913060	5.919659	0.006599
11	0.000000	0.001526	-0.003367	-0.004894

RMS Deviation: 0.00157064 mV

THIRD CYCLE

Coefficients C(1).....C(0): 5.9190478E-01 -7.1555548E-04

Point	lb	mV	Calculated mV	Deviation mV)
1	0.000000	0.001526	-0.000716	-0.002242
2	10.000000	5.917640	5.918332	0.000692
3	20.000000	11.833700	11.837380	0.003680
4	30.000000	17.763600	17.756428	-0.007172
5	40.000000	23.672100	23.675475	0.003375
6	50.000000	29.592700	29.594523	0.001823
7	40.000000	23.676700	23.675475	-0.001225
8	30.000000	17.760500	17.756428	-0.004072
9	20.000000	11.836800	11.837380	0.000580
10	10.000000	5.911530	5.918332	0.006802
11	0.000000	0.001526	-0.000716	-0.002242

RMS Deviation: 0.00113153 mV

FOURTH CYCLE

Coefficients C(1).....C(0): 5.9190556E-01 -7.1329742E-04

Point	lb	mV	Calculated mV	Deviation mV)
1	0.000000	0.001526	-0.000713	-0.002240
2	10.000000	5.914580	5.918342	0.003762
3	20.000000	11.839900	11.837398	-0.002502
4	30.000000	17.762100	17.756453	-0.005647
5	40.000000	23.682800	23.675509	-0.007291
6	50.000000	29.588200	29.594564	0.006364
7	40.000000	23.678200	23.675509	-0.002691
8	30.000000	17.752900	17.756453	0.003553
9	20.000000	11.830700	11.837398	0.006698
10	10.000000	5.916110	5.918342	0.002232
11	0.000000	0.001526	-0.000713	-0.002240

RMS Deviation: 0.00136579 mV

TABLE 6
GENISCO LOAD CELL
MOD A4U-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 5/14/84
TIME: 10:42:58
TEMP: 130 F
BARO: 14.73 PSI

HYDROSTATIC BEARING CALIBRATION

FIRST CYCLE

Coefficients C(1).....C(0): 6.0578843E-01 -4.7253399E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.480000	2.055890	2.060890	0.005000
2	13.480000	8.105960	8.118775	0.012815
3	23.480000	14.172800	14.176659	0.003859
4	33.480000	20.236600	20.234543	-0.002057
5	43.480000	26.297400	26.292427	-0.004973
6	53.480000	32.342900	32.350312	0.007412
7	43.480000	26.298900	26.292427	-0.006473
8	33.480000	20.236600	20.234543	-0.002057
9	23.480000	14.174400	14.176659	0.002259
10	13.480000	8.122760	8.118775	-0.003985
11	3.480000	2.072690	2.060890	-0.011800

RMS Deviation: 0.00202125 mV

SECOND CYCLE

Coefficients C(1).....C(0): 6.0554770E-01 -4.2744717E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.480000	2.072690	2.064561	-0.008129
2	13.480000	8.105960	8.120038	0.014078
3	23.480000	14.172800	14.175515	0.002715
4	33.480000	20.230500	20.230992	0.000492
5	43.480000	26.288200	26.286469	-0.001731
6	53.480000	32.341400	32.341946	0.000546
7	43.480000	26.288200	26.286469	-0.001731
8	33.480000	20.232100	20.230992	-0.001108
9	23.480000	14.175900	14.175515	-0.000385
10	13.480000	8.125820	8.120038	-0.005782
11	3.480000	2.063530	2.064561	0.001031

RMS Deviation: 0.00161103 mV

THIRD CYCLE

Coefficients C(1).....C(0): 6.0565898E-01 -4.4970995E-02

Point	lb	mV	Calculated mV	Deviation mV
1	3.480000	2.063530	2.062722	-0.000808
2	13.480000	8.107490	8.119312	0.011822
3	23.480000	14.163700	14.175902	0.012202
4	33.480000	20.229000	20.232492	0.003492
5	43.480000	26.298900	26.289081	-0.009819
6	53.480000	32.339800	32.345671	0.005871
7	43.480000	26.286700	26.289081	0.002381
8	33.480000	20.235100	20.232492	-0.002608
9	23.480000	14.189600	14.175902	-0.013698
10	13.480000	8.130400	8.119312	-0.011088
11	3.480000	2.060470	2.062722	0.002252

RMS Deviation: 0.00250701 mV

TABLE 7
GENISCO LOAD CELL
MOD AWU-50
S/N 2229
EXCITATION=9.98 VDC
DATE: 5/14/84
TIME: 13:24:47
TEMP: 130 F
BARO: 14.73 PSI

FLEXURE CALIBRATION

FIRST CYCLE

Coefficients C(1).....C(0): 6.0704180E-01 -4.0909185E-02

Point	lb	mV	Calculated mV	Deviation mV
1	3.480000	2.070130	2.071596	0.001466
2	13.480000	8.136790	8.142014	0.005224
3	23.480000	14.209600	14.212432	0.002832
4	33.480000	20.279300	20.282850	0.003550
5	43.480000	26.349000	26.353268	0.004268
6	53.480000	32.420200	32.423686	0.003486
7	43.480000	26.359700	26.353268	-0.006432
8	33.480000	20.291500	20.282850	-0.008650
9	23.480000	14.215700	14.212432	-0.003268
10	13.480000	8.139850	8.142014	0.002164
11	3.480000	2.076240	2.071596	-0.004644

RMS Deviation: 0.00138931 mV

SECOND CYCLE

Coefficients C(1).....C(0): 6.0680945E-01 -3.3846246E-02

Point	lb	mV	Calculated mV	Deviation mV
1	3.480000	2.076240	2.077851	0.001611
2	13.480000	8.142900	8.145945	0.003045
3	23.480000	14.217200	14.214040	-0.003160
4	33.480000	20.296100	20.282134	-0.013966
5	43.480000	26.347500	26.350229	0.002729
6	53.480000	32.409500	32.418323	0.008823
7	43.480000	26.349000	26.350229	0.001229
8	33.480000	20.283900	20.282134	-0.001766
9	23.480000	14.220300	14.214040	-0.006260
10	13.480000	8.142900	8.145945	0.003045
11	3.480000	2.073180	2.077851	0.004671

RMS Deviation: 0.00176537 mV

THIRD CYCLE

Coefficients C(1),....,C(0): 6.0707631E-01 -4.0987966E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.480000	2.073180	2.071638	-0.001542
2	13.480000	8.139850	8.142401	0.002551
3	23.480000	14.211100	14.213164	0.002064
4	33.480000	20.283900	20.283927	0.000027
5	43.480000	26.353600	26.354690	0.001090
6	53.480000	32.424800	32.425453	0.000653
7	43.480000	26.356600	26.354690	-0.001910
8	33.480000	20.288400	20.283927	-0.004473
9	23.480000	14.211100	14.213164	0.002064
10	13.480000	8.139850	8.142401	0.002551
11	3.480000	2.074710	2.071638	-0.003072

RMS Deviation: 0.00069604 mV

TABLE 7.1
GENISCO LOAD CELL
MOD AWU-50
GAUGE: A/#2229
EXCITATION=9.98 VDC
DATE: 5/17/84
TIME: 13:39:43
TEMP: 130 F
BARO: 14.76 PSI

MECHANICAL INTERACTIONS - BARE FRAME
PRIMARY GAUGE OUTPUT

FIRST & SECOND CYCLE

Coefficients C(1).....C(0): 6.0118300E-01 8.1366862E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	1.982320	2.059259	0.076939
2	8.290000	5.022910	5.065174	0.042264
3	13.290000	8.052820	8.071089	0.018269
4	18.290000	11.087300	11.077004	-0.010296
5	23.290000	14.129400	14.082919	-0.046481
6	28.290000	17.154700	17.088834	-0.065866
7	33.290000	20.152600	20.094749	-0.057851
8	38.290000	23.139800	23.100664	-0.039136
9	43.290000	26.102600	26.106579	0.003979
10	48.290000	29.047200	29.112494	0.065294
11	53.290000	31.965800	32.118409	0.152609
12	48.290000	29.057800	29.112494	0.054694
13	43.290000	26.113300	26.106579	-0.006721
14	38.290000	23.152000	23.100664	-0.051336
15	33.290000	20.166300	20.094749	-0.071551
16	28.290000	17.163900	17.088834	-0.075066
17	23.290000	14.135500	14.082919	-0.052581
18	18.290000	11.090400	11.077004	-0.013396
19	13.290000	8.054340	8.071089	0.016749
20	8.290000	5.025960	5.065174	0.039214
21	3.290000	1.983850	2.059259	0.075409
22	13.290000	8.057390	8.071089	0.013699
23	23.290000	14.130900	14.082919	-0.047981
24	33.290000	20.164800	20.094749	-0.070051
25	43.290000	26.122500	26.106579	-0.015921
26	53.290000	31.981000	32.118409	0.137409
27	43.290000	26.125500	26.106579	-0.018921
28	33.290000	20.169400	20.094749	-0.074651
29	23.290000	14.141600	14.082919	-0.058681
30	13.290000	8.061970	8.071089	0.009119
31	3.290000	1.988420	2.059259	0.070839

RMS Deviation: 0.01093801 mV

TABLE 7.2
GENISCO LOAD CELL
MOD AWU-50
GAUGE: A/#2229
EXCITATION=9.98 VDC
DATE: 5/17/84
TIME: 13:39:43
TEMP: 130 F
BARO: 14.76 PSI

MECHANICAL INTERACTIONS - BARE FRAME
PRIMARY GAUGE OUTPUT

FIRST CYCLE

Coefficients C(1).....C(0): 6.0129518E-01 7.5701269E-02

Point	lb	mV	Calculated mV	Deviation mV
1	3.290000	1.982320	2.053962	0.071642
2	8.290000	5.022910	5.060438	0.037528
3	13.290000	8.052820	8.066914	0.014094
4	18.290000	11.087300	11.073390	-0.013910
5	23.290000	14.129400	14.079866	-0.049534
6	28.290000	17.154700	17.086342	-0.068358
7	33.290000	20.152600	20.092818	-0.059782
8	38.290000	23.139800	23.099294	-0.040506
9	43.290000	26.102600	26.105770	0.003170
10	48.290000	29.047200	29.112245	0.065045
11	53.290000	31.965800	32.118721	0.152921
12	48.290000	29.057800	29.112245	0.054445
13	43.290000	26.113300	26.105770	-0.007530
14	38.290000	23.152000	23.099294	-0.052706
15	33.290000	20.166300	20.092818	-0.073482
16	28.290000	17.163900	17.086342	-0.077558
17	23.290000	14.135500	14.079866	-0.055634
18	18.290000	11.090400	11.073390	-0.017010
19	13.290000	8.054340	8.066914	0.012574
20	8.290000	5.025960	5.060438	0.034478
21	3.290000	1.983850	2.053962	0.070112

RMS Deviation: 0.01293286 mV

TABLE 7.3
GENISCO LOAD CELL
MOD AWU-50
GAUGE: A/#2229
EXCITATION=9.98 VDC
DATE: 5/17/84
TIME: 14:01:43
TEMP: 130 F
BARO: 14.76 PSI

MECHANICAL INTERACTIONS - BARE FRAME
PRIMARY GAUGE OUTPUT

SECOND CYCLE

Coefficients C(1).....C(0): 6.0161945E-01 6.8168929E-02

Point	lb	mV	Calculated mV	Deviation mV
1	3.290000	1.983850	2.047497	0.063647
2	13.290000	8.057390	8.063691	0.006301
3	23.290000	14.130900	14.079886	-0.051014
4	33.290000	20.164800	20.096081	-0.068719
5	43.290000	26.122500	26.112275	-0.010225
6	53.290000	31.981000	32.128470	0.147470
7	43.290000	26.125500	26.112275	-0.013225
8	33.290000	20.169400	20.096081	-0.073319
9	23.290000	14.141600	14.079886	-0.061714
10	13.290000	8.061970	8.063691	0.001721
11	3.290000	1.988420	2.047497	0.059077

RMS Deviation: 0.01952315 mV

TABLE 7.4
GENISCO LOAD CELL
MOD AMU-50
GAUGE: N1/#2230
EXCITATION=9.98 VDC
DATE: 5/18/84
TIME: 11:23:08
TEMP: 130 F
BARO: 14.80 PSI

MECHANICAL INTERACTIONS - BARE FRAME
PRIMARY GAUGE OUTPUT

FIRST & SECOND CYCLE

Coefficients C(1),....C(0): 6.1099894E-01 1.0376488E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	2.016450	2.020563	0.004113
2	8.290000	5.071620	5.075558	0.003938
3	13.290000	8.126800	8.130552	0.003752
4	18.290000	11.180400	11.185547	0.005147
5	23.290000	14.234100	14.240542	0.006442
6	28.290000	17.289300	17.295537	0.006237
7	33.290000	20.344400	20.350531	0.006131
8	38.290000	23.402700	23.405526	0.002826
9	43.290000	26.457800	26.460521	0.002721
10	48.290000	29.514500	29.515515	0.001015
11	53.290000	32.566700	32.570510	0.003810
12	48.290000	29.519100	29.515515	-0.003585
13	43.290000	26.465500	26.460521	-0.004979
14	38.290000	23.413300	23.405526	-0.007774
15	33.290000	20.356600	20.350531	-0.006069
16	28.290000	17.301500	17.295537	-0.005963
17	23.290000	14.244800	14.240542	-0.004258
18	18.290000	11.188100	11.185547	-0.002553
19	13.290000	8.131370	8.130552	-0.000818
20	8.290000	5.079250	5.075558	-0.003692
21	3.290000	2.025600	2.020563	-0.005037
22	13.290000	8.126800	8.130552	0.003752
23	23.290000	14.234100	14.240542	0.006442
24	33.290000	20.349000	20.350531	0.001531
25	43.290000	26.459400	26.460521	0.001121
26	53.290000	32.566700	32.570510	0.003810
27	43.290000	26.463900	26.460521	-0.003379
28	33.290000	20.355100	20.350531	-0.004569
29	23.290000	14.244800	14.240542	-0.004258
30	13.290000	8.132900	8.130552	-0.002348
31	3.290000	2.024070	2.020563	-0.003507

RMS Deviation: 0.00078926 mV

TABLE 7.5
GENISCO LOAD CELL
MOD AWU-50
GAUGE: N1/#2230
EXCITATION=9.98 VDC
DATE: 5/18/84
TIME: 11:23:08
TEMP: 130 F
BARO: 14.80 PSI

MECHANICAL INTERACTIONS - BARE FRAME
PRIMARY GAUGE OUTPUT

FIRST CYCLE

Coefficients C(1),....C(0): 6.1101962E-01 9.7492025E-03

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	2.016450	2.020004	0.003554
2	8.290000	5.071620	5.075102	0.003482
3	13.290000	8.126800	8.130200	0.003400
4	18.290000	11.180400	11.185298	0.004898
5	23.290000	14.234100	14.240396	0.006296
6	28.290000	17.289300	17.295494	0.006194
7	33.290000	20.344400	20.350592	0.006192
8	38.290000	23.402700	23.405691	0.002991
9	43.290000	26.457800	26.460789	0.002989
10	48.290000	29.514500	29.515887	0.001387
11	53.290000	32.566700	32.570985	0.004285
12	48.290000	29.519100	29.515887	-0.003213
13	43.290000	26.465500	26.460789	-0.004711
14	38.290000	23.413300	23.405691	-0.007609
15	33.290000	20.356600	20.350592	-0.006008
16	28.290000	17.301500	17.295494	-0.006006
17	23.290000	14.244800	14.240396	-0.004404
18	18.290000	11.188100	11.185298	-0.002802
19	13.290000	8.131370	8.130200	-0.001170
20	8.290000	5.079250	5.075102	-0.004148
21	3.290000	2.025600	2.020004	-0.005596

RMS Deviation: 0.00101524 mV

TABLE 7.6
GENISCO LOAD CELL
MOD AWU-50
GAUGE: N1/#2230
EXCITATION=9.98 VDC
DATE: 5/18/84
TIME: 11:36:40
TEMP: 130 F
BARO: 14.80 PSI

MECHANICAL INTERACTIONS - BARE FRAME
PRIMARY GAUGE OUTPUT

SECOND CYCLE

Coefficients C(1).....C(0): 6.1092331E-01 1.2929902E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	2.025600	2.022868	-0.002732
2	13.290000	8.126800	8.132101	0.005301
3	23.290000	14.234100	14.241334	0.007234
4	33.290000	20.349000	20.350567	0.001567
5	43.290000	26.459400	26.459800	0.000400
6	53.290000	32.566700	32.569033	0.002333
7	43.290000	26.463900	26.459800	-0.004100
8	33.290000	20.355100	20.350567	-0.004533
9	23.290000	14.244800	14.241334	-0.003466
10	13.290000	8.132900	8.132101	-0.000799
11	3.290000	2.024070	2.022868	-0.001202

RMS Deviation: 0.00110374 mV

TABLE 7.7
GENISCO LOAD CELL
MOD AWU-50
GAUGE: N2/#2228
EXCITATION=9.98 VDC
DATE: 5/17/84
TIME: 15:05:36
TEMP: 130 F
BARO: 14.76 PSI

MECHANICAL INTERACTIONS - BARE FRAME
PRIMARY GAUGE OUTPUT

FIRST & SECOND CYCLE

Coefficients C(1),....C(0): 6.0366124E-01 2.8193976E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	1.995040	2.014239	0.019199
2	8.290000	5.024210	5.032546	0.008336
3	13.290000	8.048800	8.050852	0.002052
4	18.290000	11.071900	11.069158	-0.002742
5	23.290000	14.096500	14.087464	-0.009036
6	28.290000	17.116500	17.105770	-0.010730
7	33.290000	20.135000	20.124077	-0.010923
8	38.290000	23.151900	23.142383	-0.009517
9	43.290000	26.162800	26.160689	-0.002111
10	48.290000	29.169100	29.178995	0.009895
11	53.290000	32.181500	32.197301	0.015801
12	48.290000	29.170600	29.178995	0.008395
13	43.290000	26.159700	26.160689	0.000989
14	38.290000	23.151900	23.142383	-0.009517
15	33.290000	20.138000	20.124077	-0.013923
16	28.290000	17.122600	17.105770	-0.016830
17	23.290000	14.102600	14.087464	-0.015136
18	18.290000	11.078000	11.069158	-0.008842
19	13.290000	8.051850	8.050852	-0.000998
20	8.290000	5.028790	5.032546	0.003756
21	3.290000	1.998090	2.014239	0.016149
22	13.290000	8.050330	8.050852	0.000522
23	23.290000	14.096500	14.087464	-0.009036
24	33.290000	20.133400	20.124077	-0.009323
25	43.290000	26.150600	26.160689	0.010089
26	53.290000	32.173800	32.197301	0.023501
27	43.290000	26.152100	26.160689	0.008589
28	33.290000	20.130400	20.124077	-0.006323
29	23.290000	14.094900	14.087464	-0.007436
30	13.290000	8.051850	8.050852	-0.000998
31	3.290000	1.998090	2.014239	0.016149

RMS Deviation: 0.00195811 mV

TABLE 7.8
GENISCO LOAD CELL
MOD A4U-50
GAUGE: N2/#2228
EXCITATION=9.98 VDC
DATE: 5/17/84
TIME: 15:05:36
TEMP: 130 F
BARO: 14.76 PSI

MECHANICAL INTERACTIONS - BARE FRAME
PRIMARY GAUGE OUTPUT

FIRST CYCLE

Coefficients C(1).....C(0): 6.0376564E-01 2.6590057E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	1.995040	2.012979	0.017939
2	8.290000	5.024210	5.031807	0.007597
3	13.290000	8.048800	8.050635	0.001835
4	18.290000	11.071900	11.069464	-0.002436
5	23.290000	14.096500	14.088292	-0.008208
6	28.290000	17.116500	17.107120	-0.009380
7	33.290000	20.135000	20.125948	-0.009052
8	38.290000	23.151900	23.144776	-0.007124
9	43.290000	26.162800	26.163605	0.000805
10	48.290000	29.169100	29.182433	0.013333
11	53.290000	32.181500	32.201261	0.019761
12	48.290000	29.170600	29.182433	0.011833
13	43.290000	26.159700	26.163605	0.003905
14	38.290000	23.151900	23.144776	-0.007124
15	33.290000	20.138000	20.125948	-0.012052
16	28.290000	17.122600	17.107120	-0.015480
17	23.290000	14.102600	14.088292	-0.014308
18	18.290000	11.078000	11.069464	-0.008536
19	13.290000	8.051850	8.050635	-0.001215
20	8.290000	5.028790	5.031807	0.003017
21	3.290000	1.998090	2.012979	0.014889

RMS Deviation: 0.00230671 mV

TABLE 7.9
GENISCO LOAD CELL
MOD AWU-50
GAUGE: N2/#2228
EXCITATION=9.98 VDC
DATE: 5/17/84
TIME: 15:21:05
TEMP: 130 F
BARO: 14.76 PSI

MECHANICAL INTERACTIONS - BARE FRAME
PRIMARY GAUGE OUTPUT

SECOND CYCLE

Coefficients C(1),....C(0): 6.0360209E-01 2.5925252E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	1.998090	2.011776	0.013686
2	13.290000	8.050330	8.047797	-0.002533
3	23.290000	14.096500	14.083818	-0.012682
4	33.290000	20.133400	20.119839	-0.013561
5	43.290000	26.150600	26.155860	0.005260
6	53.290000	32.173800	32.191881	0.018081
7	43.290000	26.152100	26.155860	0.003760
8	33.290000	20.130400	20.119839	-0.010561
9	23.290000	14.094900	14.083818	-0.011082
10	13.290000	8.051850	8.047797	-0.004053
11	3.290000	1.998090	2.011776	0.013686

RMS Deviation: 0.00333435 mV

TABLE 8.1
GENISCO LOAD CELL
MOD AWU-50
GAUGE: A/#2229
EXCITATION=9.98 VDC
DATE: 5/21/84
TIME: 13:12:39
TEMP: 130 F
BARO: 14.71 PSI

MECHANICAL INTERACTIONS - INSTRUMENTATION WIRING INSTALLED
PRIMARY GAUGE OUTPUT

FIRST CYCLE

Coefficients C(1).....C(0): 6.0594461E-01 -1.1972615E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	1.974820	1.981585	0.006765
2	13.290000	8.041210	8.041031	-0.000179
3	23.290000	14.098400	14.100477	0.002077
4	33.290000	20.163300	20.159924	-0.003376
5	43.290000	26.217500	26.219370	0.001870
6	53.290000	32.271700	32.278816	0.007116
7	43.290000	26.220500	26.219370	-0.001130
8	33.290000	20.166400	20.159924	-0.006476
9	23.290000	14.106100	14.100477	-0.005623
10	13.290000	8.042740	8.041031	-0.001709
11	3.290000	1.980920	1.981585	0.000665

RMS Deviation: 0.00126571 mV

SECOND CYCLE

Coefficients C(1).....C(0): 6.0593294E-01 -8.6288845E-03

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	1.980920	1.984890	0.003970
2	13.290000	8.042740	8.044220	0.001480
3	23.290000	14.103000	14.103549	0.000549
4	33.290000	20.166400	20.162879	-0.003521
5	43.290000	26.220500	26.222208	0.001708
6	53.290000	32.276200	32.281537	0.005337
7	43.290000	26.223600	26.222208	-0.001392
8	33.290000	20.164800	20.162879	-0.001921
9	23.290000	14.109100	14.103549	-0.005551
10	13.290000	8.047320	8.044220	-0.003100
11	3.290000	1.982450	1.984890	0.002440

RMS Deviation: 0.00097093 mV

TABLE A.2
GENISCO LOAD CELL
MOD AWU-50
GAUGE: N1/#2230
EXCITATION=9.98 VDC
DATE: 5/21/84
TIME: 12:08:17
TEMP: 130 F
BARO: 14.71 PSI

MECHANICAL INTERACTIONS - INSTRUMENTATION WIRING INSTALLED
PRIMARY GAUGE OUTPUT

FIRST CYCLE

Coefficients C(1).....C(0): 6.1130219E-01 7.8369229E-03

Point	lb	mV	Calculated mV	Deviation mV
1	3.290000	2.015470	2.019021	0.003551
2	13.290000	8.130540	8.132043	0.001503
3	23.290000	14.242600	14.245065	0.002465
4	33.290000	20.354600	20.358087	0.003487
5	43.290000	26.466600	26.471109	0.004509
6	53.290000	32.581700	32.584131	0.002431
7	43.290000	26.475700	26.471109	-0.004591
8	33.290000	20.363700	20.358087	-0.005613
9	23.290000	14.248700	14.245065	-0.003635
10	13.290000	8.136650	8.132043	-0.004607
11	3.290000	2.018520	2.019021	0.000501

RMS Deviation: 0.00110078 mV

SECOND CYCLE

Coefficients C(1).....C(0): 6.1119785E-01 1.1649713E-02

Point	lb	mV	Calculated mV	Deviation mV
1	3.290000	2.018520	2.022491	0.003971
2	13.290000	8.135120	8.134469	-0.000651
3	23.290000	14.244100	14.246448	0.002348
4	33.290000	20.356100	20.358426	0.002326
5	43.290000	26.468100	26.470405	0.002305
6	53.290000	32.577100	32.582383	0.005283
7	43.290000	26.475700	26.470405	-0.005295
8	33.290000	20.365200	20.358426	-0.006774
9	23.290000	14.248700	14.246448	-0.002252
10	13.290000	8.135120	8.134469	-0.000651
11	3.290000	2.023100	2.022491	-0.000609

RMS Deviation: 0.00107615 mV

TABLE 8.3
GENISCO LOAD CELL
MOD AWU-50
GAUGE: N2/#2228
EXCITATION=9.98 VDC
DATE: 5/21/84
TIME: 12:30:21
TEMP: 130 F
BARO: 14.71 PSI

MECHANICAL INTERACTIONS - INSTRUMENTATION WIRING INSTALLED
PRIMARY GAUGE OUTPUT

FIRST CYCLE

Coefficients C(1).....C(0): 6.0618189E-01 -2.3185698E-03

Point	lb	mV	Calculated mV	Deviation mV
1	3.290000	1.990960	1.992020	0.001060
2	13.290000	8.052400	8.053839	0.001439
3	23.290000	14.119900	14.115658	-0.004242
4	33.290000	20.184400	20.177476	-0.006924
5	43.290000	26.239700	26.239295	-0.000405
6	53.290000	32.296600	32.301114	0.004514
7	43.290000	26.236700	26.239295	0.002595
8	33.290000	20.178300	20.177476	-0.000824
9	23.290000	14.116900	14.115658	-0.001242
10	13.290000	8.052400	8.053839	0.001439
11	3.290000	1.989430	1.992020	0.002590

RMS Deviation: 0.00094214 mV

SECOND CYCLE

Coefficients C(1).....C(0): 6.0608280E-01 -5.7024120E-03

Point	lb	mV	Calculated mV	Deviation mV
1	3.290000	1.989430	1.988310	-0.001120
2	13.290000	8.046290	8.049138	0.002848
3	23.290000	14.112300	14.109966	-0.002334
4	33.290000	20.173700	20.170794	-0.002906
5	43.290000	26.233600	26.231622	-0.001978
6	53.290000	32.285900	32.292450	0.006550
7	43.290000	26.232100	26.231622	-0.000478
8	33.290000	20.175300	20.170794	-0.004506
9	23.290000	14.109300	14.109966	0.000666
10	13.290000	8.049340	8.049138	-0.000202
11	3.290000	1.984850	1.988310	0.003460

RMS Deviation: 0.00092290 mV

TABLE 9.1
GENISCO LOAD CELL
MOD AWU-50
GAUGE: A/#2229
EXCITATION=9.98 VDC
DATE: 5/22/84
TIME: 08:09:13
TEMP: 130 F
BARO: 14.73 PSI

MECHANICAL INTERACTIONS
AIR LINES & INSTRUMENTATION WIRING INSTALLED
PRIMARY GAUGE OUTPUT

FIRST CYCLE

Coefficients C(1).....C(0): 6.0493623E-01 -1.9379860E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	1.964680	1.970860	0.006180
2	13.290000	8.012920	8.020223	0.007303
3	23.290000	14.067300	14.069585	0.002285
4	33.290000	20.121600	20.118947	-0.002653
5	43.290000	26.166800	26.168309	0.001509
6	53.290000	32.208900	32.217672	0.008772
7	43.290000	26.172900	26.168309	-0.004591
8	33.290000	20.124600	20.118947	-0.005653
9	23.290000	14.077900	14.069585	-0.008315
10	13.290000	8.022080	8.020223	-0.001857
11	3.290000	1.973840	1.970860	-0.002980

RMS Deviation: 0.00161987 mV

SECOND CYCLE

Coefficients C(1).....C(0): 6.0482541E-01 -1.1230447E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	1.973840	1.978645	0.004805
2	13.290000	8.020550	8.026899	0.006349
3	23.290000	14.076400	14.075153	-0.001247
4	33.290000	20.124600	20.123408	-0.001192
5	43.290000	26.169800	26.171662	0.001862
6	53.290000	32.215000	32.219916	0.004916
7	43.290000	26.172900	26.171662	-0.001238
8	33.290000	20.129200	20.123408	-0.005792
9	23.290000	14.079500	14.075153	-0.004347
10	13.290000	8.028180	8.026899	-0.001281
11	3.290000	1.981480	1.978645	-0.002835

RMS Deviation: 0.00114150 mV

TABLE 9.2
GENISCO LOAD CELL
MOD AWU-50
GAUGE: N1/#2230
EXCITATION=9.98 VDC
DATE: 5/22/84
TIME: 09:01:30
TEMP: 130 F
BARO: 14.73 PSI

MECHANICAL INTERACTIONS
AIR LINES & INSTRUMENTATION WIRING INSTALLED
PRIMARY GAUGE OUTPUT

FIRST CYCLE

Coefficients C(1).....C(0): 6.1057643E-01 1.7750161E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	2.017420	2.026547	0.009127
2	13.290000	8.132200	8.132311	0.000111
3	23.290000	14.237800	14.238075	0.000275
4	33.290000	20.346500	20.343839	-0.002661
5	43.290000	26.447600	26.449604	0.002004
6	53.290000	32.547100	32.555368	0.008268
7	43.290000	26.450600	26.449604	-0.000996
8	33.290000	20.351100	20.343839	-0.007261
9	23.290000	14.245500	14.238075	-0.007425
10	13.290000	8.133730	8.132311	-0.001419
11	3.290000	2.026570	2.026547	-0.000023

RMS Deviation: 0.00150395 mV

SECOND CYCLE

Coefficients C(1).....C(0): 6.1024040E-01 2.3442804E-02

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	2.026570	2.031134	0.004564
2	13.290000	8.133730	8.133538	-0.000192
3	23.290000	14.236300	14.235942	-0.000358
4	33.290000	20.338900	20.338346	-0.000554
5	43.290000	26.436900	26.440750	0.003850
6	53.290000	32.537900	32.543154	0.005254
7	43.290000	26.444500	26.440750	-0.003750
8	33.290000	20.343500	20.338346	-0.005154
9	23.290000	14.239400	14.235942	-0.003458
10	13.290000	8.135250	8.133538	-0.001712
11	3.290000	2.029620	2.031134	0.001514

RMS Deviation: 0.00100221 mV

TABLE 9.3
GENISCO LOAD CELL
MOD AWU-50
GAUGE: N2/#2228
EXCITATION=9.98 VDC
DATE: 5/22/84
TIME: 09:30:48
TEMP: 130 F
BARO: 14.73 PSI

MECHANICAL INTERACTIONS
AIR LINES & INSTRUMENTATION WIRING INSTALLED
PRIMARY GAUGE OUTPUT

FIRST CYCLE

Coefficients C(1).....C(0): 6.0622868E-01 1.0611785E-03

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	1.990380	1.995554	0.005174
2	13.290000	8.057700	8.057840	0.000140
3	23.290000	14.125000	14.120127	-0.004873
4	33.290000	20.184700	20.182414	-0.002286
5	43.290000	26.248900	26.244701	-0.004199
6	53.290000	32.301000	32.306988	0.005988
7	43.290000	26.242800	26.244701	0.001901
8	33.290000	20.183200	20.182414	-0.000786
9	23.290000	14.120400	14.120127	-0.000273
10	13.290000	8.059220	8.057840	-0.001380
11	3.290000	1.994960	1.995554	0.000594

RMS Deviation: 0.00097829 mV

SECOND CYCLE

Coefficients C(1).....C(0): 6.0606307E-01 8.7163323E-05

Point	lb	mV	Calculated mV	Deviation mV)
1	3.290000	1.994960	1.994035	-0.000925
2	13.290000	8.054640	8.054665	0.000025
3	23.290000	14.115800	14.115296	-0.000504
4	33.290000	20.177000	20.175927	-0.001073
5	43.290000	26.236700	26.236558	-0.000142
6	53.290000	32.294900	32.297188	0.002288
7	43.290000	26.238300	26.236558	-0.001742
8	33.290000	20.175500	20.175927	0.000427
9	23.290000	14.115800	14.115296	-0.000504
10	13.290000	8.054640	8.054665	0.000025
11	3.290000	1.991910	1.994035	0.002125

RMS Deviation: 0.00035798 mV

APPENDIX B

TABLE 1.1
MECHANICAL INTERACTIONS - BARE FRAME
EXCITATION=9.98 VDC
DATE: 5/17/84
TIME: 13:39:43
TEMP: 130 F
BARO: 14.76 PSI
PRIMARY GAUGE: A/#2229
SECONDRY GAUGE:

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.329000E+01	0.000000E+00	0.000000E+00	0.198232E+01	0.427025E-01	0.106768E-01
0.829000E+01	0.000000E+00	0.000000E+00	0.502291E+01	0.350770E-01	0.915156E-02
0.132900E+02	0.000000E+00	0.000000E+00	0.805282E+01	0.305018E-01	0.762630E-02
0.182900E+02	0.000000E+00	0.000000E+00	0.110873E+02	0.244014E-01	0.457578E-02
0.232900E+02	0.000000E+00	0.000000E+00	0.141294E+02	0.213512E-01	0.000000E+00
0.282900E+02	0.000000E+00	0.000000E+00	0.171547E+02	0.183011E-01	-0.152526E-02
0.332900E+02	0.000000E+00	0.000000E+00	0.201526E+02	0.137258E-01	-0.610105E-02
0.382900E+02	0.000000E+00	0.000000E+00	0.231398E+02	0.915053E-02	-0.915157E-02
0.432900E+02	0.000000E+00	0.000000E+00	0.261026E+02	0.610036E-02	-0.122021E-01
0.482900E+02	0.000000E+00	0.000000E+00	0.290472E+02	0.152509E-02	-0.137274E-01
0.532900E+02	0.000000E+00	0.000000E+00	0.319658E+02	-0.457526E-02	-0.167779E-01
0.482900E+02	0.000000E+00	0.000000E+00	0.290578E+02	0.305018E-02	-0.137274E-01
0.432900E+02	0.000000E+00	0.000000E+00	0.261133E+02	0.305018E-02	-0.106768E-01
0.382900E+02	0.000000E+00	0.000000E+00	0.231520E+02	0.610036E-02	-0.106768E-01
0.332900E+02	0.000000E+00	0.000000E+00	0.201663E+02	0.106756E-01	-0.610105E-02
0.282900E+02	0.000000E+00	0.000000E+00	0.171639E+02	0.137258E-01	-0.305052E-02
0.232900E+02	0.000000E+00	0.000000E+00	0.141355E+02	0.167760E-01	0.000000E+00
0.182900E+02	0.000000E+00	0.000000E+00	0.110904E+02	0.213512E-01	0.152526E-02
0.132900E+02	0.000000E+00	0.000000E+00	0.805434E+01	0.183011E-01	0.000000E+00
0.829000E+01	0.000000E+00	0.000000E+00	0.502596E+01	0.228763E-01	0.305052E-02
0.329000E+01	0.000000E+00	0.000000E+00	0.198385E+01	0.289767E-01	0.762630E-02
SECOND CYCLE					
0.329000E+01	0.000000E+00	0.000000E+00	0.198385E+01	0.289767E-01	0.762630E-02
0.132900E+02	0.000000E+00	0.000000E+00	0.805739E+01	0.213512E-01	0.457578E-02
0.232900E+02	0.000000E+00	0.000000E+00	0.141309E+02	0.198262E-01	0.000000E+00
0.332900E+02	0.000000E+00	0.000000E+00	0.201648E+02	0.457527E-02	-0.762631E-02
0.432900E+02	0.000000E+00	0.000000E+00	0.261225E+02	-0.152509E-02	-0.122021E-01
0.532900E+02	0.000000E+00	0.000000E+00	0.319810E+02	-0.762544E-02	-0.183031E-01
0.432900E+02	0.000000E+00	0.000000E+00	0.261255E+02	-0.152509E-02	-0.122021E-01
0.332900E+02	0.000000E+00	0.000000E+00	0.201694E+02	0.915053E-02	-0.610105E-02
0.232900E+02	0.000000E+00	0.000000E+00	0.141416E+02	0.122007E-01	-0.152526E-02
0.132900E+02	0.000000E+00	0.000000E+00	0.806197E+01	0.244014E-01	0.610105E-02
0.329000E+01	0.000000E+00	0.000000E+00	0.198842E+01	0.274516E-01	0.915156E-02

TABLE 1.2
MECHANICAL INTERACTIONS - BARE FRAME
EXCITATION=9.98 VDC
DATE: 5/17/84
TIME: 11:01:23
TEMP: 130 F
BARO: 14.80 PSI
PRIMARY GAUGE: A/#2229
SECONDRY GAUGE: N1/#2230

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.329000E+01	0.532900E+02	0.000000E+00	0.192186E+01	0.325720E+02	0.122074E-01
0.132900E+02	0.532900E+02	0.000000E+00	0.797421E+01	0.325613E+02	0.762963E-02
0.232900E+02	0.532900E+02	0.000000E+00	0.140266E+02	0.325491E+02	0.152593E-02
0.332900E+02	0.532900E+02	0.000000E+00	0.200804E+02	0.325369E+02	0.152593E-02
0.432900E+02	0.532900E+02	0.000000E+00	0.261282E+02	0.325201E+02	0.000000E+00
0.532900E+02	0.532900E+02	0.000000E+00	0.321760E+02	0.325094E+02	-0.457777E-02
0.432900E+02	0.532900E+02	0.000000E+00	0.261328E+02	0.325232E+02	0.000000E+00
0.332900E+02	0.532900E+02	0.000000E+00	0.200819E+02	0.325399E+02	0.152593E-02
0.232900E+02	0.532900E+02	0.000000E+00	0.140311E+02	0.325537E+02	0.152593E-02
0.132900E+02	0.532900E+02	0.000000E+00	0.797573E+01	0.325690E+02	0.610370E-02
0.329000E+01	0.532900E+02	0.000000E+00	0.192644E+01	0.325842E+02	0.122074E-01

TABLE 1.3

MECHANICAL INTERACTIONS - BARE FRAME

EXCITATION=9.98 VDC
DATE: 5/17/84
TIME: 14:11:13
TEMP: 130 F
BARO: 14.76 PSI
PRIMARY GAUGE: A/#2229
SECONDRY GAUGE: N2/#2228

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.329000E+01	0.000000E+00	0.532900E+02	0.200672E+01	0.183011E-01	0.321754E+02
0.132900E+02	0.000000E+00	0.532900E+02	0.807569E+01	0.106756E-01	0.321677E+02
0.232900E+02	0.000000E+00	0.532900E+02	0.141492E+02	0.152509E-02	0.321632E+02
0.332900E+02	0.000000E+00	0.532900E+02	0.201862E+02	-0.610035E-02	0.321555E+02
0.432900E+02	0.000000E+00	0.532900E+02	0.261438E+02	-0.106756E-01	0.321525E+02
0.532900E+02	0.000000E+00	0.532900E+02	0.319932E+02	-0.198261E-01	0.321464E+02
0.432900E+02	0.000000E+00	0.532900E+02	0.261423E+02	-0.122007E-01	0.321510E+02
0.332900E+02	0.000000E+00	0.532900E+02	0.201862E+02	-0.457526E-02	0.321586E+02
0.232900E+02	0.000000E+00	0.532900E+02	0.141584E+02	0.152509E-02	0.321647E+02
0.132900E+02	0.000000E+00	0.532900E+02	0.808331E+01	0.915053E-02	0.321723E+02
0.329000E+01	0.000000E+00	0.532900E+02	0.201282E+01	0.152509E-01	0.321799E+02

TABLE 1.4
MECHANICAL INTERACTIONS - BARE FRAME
EXCITATION=9.98 VDC
DATE: 5/18/84
TIME: 11:23:08
TEMP: 130 F
BARO: 14.80 PSI
PRIMARY GAUGE: N1/#2230
SECONDRY GAUGE:

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.000000E+00	0.329000E+01	0.000000E+00	-0.122040E-01	0.201645E+01	0.000000E+00
0.000000E+00	0.829000E+01	0.000000E+00	-0.137295E-01	0.507162E+01	0.152615E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.183060E-01	0.812680E+01	0.152615E-02
0.000000E+00	0.182900E+02	0.000000E+00	-0.244080E-01	0.111804E+02	0.152615E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.289845E-01	0.142341E+02	0.152615E-02
0.000000E+00	0.282900E+02	0.000000E+00	-0.350865E-01	0.172893E+02	0.152615E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.411885E-01	0.203444E+02	0.152615E-02
0.000000E+00	0.382900E+02	0.000000E+00	-0.457650E-01	0.234027E+02	0.152615E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.533925E-01	0.264578E+02	0.457844E-02
0.000000E+00	0.482900E+02	0.000000E+00	-0.579690E-01	0.295145E+02	0.457844E-02
0.000000E+00	0.532900E+02	0.000000E+00	-0.610200E-01	0.325667E+02	0.610458E-02
0.000000E+00	0.482900E+02	0.000000E+00	-0.564435E-01	0.295191E+02	0.610458E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.518670E-01	0.264655E+02	0.305229E-02
0.000000E+00	0.382900E+02	0.000000E+00	-0.457650E-01	0.234133E+02	0.305229E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.411885E-01	0.203566E+02	0.152615E-02
0.000000E+00	0.282900E+02	0.000000E+00	-0.366120E-01	0.173015E+02	0.152615E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.289845E-01	0.142448E+02	0.152615E-02
0.000000E+00	0.182900E+02	0.000000E+00	-0.244080E-01	0.111881E+02	0.152615E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.183060E-01	0.813137E+01	0.152615E-02
0.000000E+00	0.829000E+01	0.000000E+00	-0.152550E-01	0.507925E+01	0.152615E-02
0.000000E+00	0.329000E+01	0.000000E+00	-0.122040E-01	0.202560E+01	0.152615E-02
		SECOND CYCLE			
0.000000E+00	0.329000E+01	0.000000E+00	-0.122040E-01	0.202560E+01	0.152615E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.183060E-01	0.812680E+01	0.152615E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.289845E-01	0.142341E+02	0.152615E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.396630E-01	0.203490E+02	0.305229E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.518670E-01	0.264594E+02	0.457844E-02
0.000000E+00	0.532900E+02	0.000000E+00	-0.610200E-01	0.325667E+02	0.610458E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.518670E-01	0.264639E+02	0.457844E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.396630E-01	0.203551E+02	0.152615E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.289845E-01	0.142448E+02	0.152615E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.183060E-01	0.813290E+01	0.152615E-02
0.000000E+00	0.329000E+01	0.000000E+00	-0.106785E-01	0.202407E+01	0.000000E+00

TABLE 1.5
MECHANICAL INTERACTIONS - BARE FRAME
EXCITATION=9.98 VDC
DATE: 5/18/84
TIME: 11:46:59
TEMP: 130 F
BARO: 14.80 PSI
PRIMARY GAUGE: N1/#2230
SECONDRY GAUGE: A/#2229

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.532900E+02	0.329000E+01	0.000000E+00	0.322552E+02	0.199204E+01	-0.289968E-01
0.532900E+02	0.132900E+02	0.000000E+00	0.322445E+02	0.809171E+01	-0.259445E-01
0.532900E+02	0.232900E+02	0.000000E+00	0.322308E+02	0.141960E+02	-0.213661E-01
0.532900E+02	0.332900E+02	0.000000E+00	0.322186E+02	0.203017E+02	-0.198399E-01
0.532900E+02	0.432900E+02	0.000000E+00	0.322064E+02	0.264060E+02	-0.167876E-01
0.532900E+02	0.532900E+02	0.000000E+00	0.321942E+02	0.325066E+02	-0.137353E-01
0.532900E+02	0.432900E+02	0.000000E+00	0.322079E+02	0.264121E+02	-0.167876E-01
0.532900E+02	0.332900E+02	0.000000E+00	0.322201E+02	0.203139E+02	-0.198399E-01
0.532900E+02	0.232900E+02	0.000000E+00	0.322354E+02	0.142082E+02	-0.228922E-01
0.532900E+02	0.132900E+02	0.000000E+00	0.322506E+02	0.809934E+01	-0.259445E-01
0.532900E+02	0.329000E+01	0.000000E+00	0.322628E+02	0.199967E+01	-0.274706E-01

TABLE 1.6

MECHANICAL INTERACTIONS - BARE FRAME

EXCITATION=9.98 VDC

DATE: 5/18/84

TIME: 14:27:03

TEMP: 130 F

BARO: 14.77 PSI

PRIMARY GAUGE: N1/#2230

SECONDRY GAUGE: N2/#2228

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.000000E+00	0.329000E+01	0.532900E+02	-0.915936E-02	0.202324E+01	0.323196E+02
0.000000E+00	0.132900E+02	0.532900E+02	-0.152656E-01	0.812652E+01	0.323196E+02
0.000000E+00	0.232900E+02	0.532900E+02	-0.259515E-01	0.142313E+02	0.323227E+02
0.000000E+00	0.332900E+02	0.532900E+02	-0.366375E-01	0.203407E+02	0.323242E+02
0.000000E+00	0.432900E+02	0.532900E+02	-0.457968E-01	0.264501E+02	0.323272E+02
0.000000E+00	0.532900E+02	0.532900E+02	-0.564928E-01	0.325518E+02	0.323288E+02
0.000000E+00	0.432900E+02	0.532900E+02	-0.457968E-01	0.264607E+02	0.323288E+02
0.000000E+00	0.332900E+02	0.532900E+02	-0.366375E-01	0.203529E+02	0.323257E+02
0.000000E+00	0.232900E+02	0.532900E+02	-0.274781E-01	0.142435E+02	0.323242E+02
0.000000E+00	0.132900E+02	0.532900E+02	-0.152656E-01	0.813719E+01	0.323211E+02
0.000000E+00	0.329000E+01	0.532900E+02	-0.915936E-02	0.203087E+01	0.323181E+02
SECOND CYCLE					
0.000000E+00	0.329000E+01	0.532900E+02	-0.915936E-02	0.203087E+01	0.323181E+02
0.000000E+00	0.132900E+02	0.532900E+02	-0.152656E-01	0.813109E+01	0.323211E+02
0.000000E+00	0.232900E+02	0.532900E+02	-0.259515E-01	0.142374E+02	0.323242E+02
0.000000E+00	0.332900E+02	0.532900E+02	-0.366375E-01	0.203468E+02	0.323257E+02
0.000000E+00	0.432900E+02	0.532900E+02	-0.457968E-01	0.264561E+02	0.323288E+02
0.000000E+00	0.532900E+02	0.532900E+02	-0.580093E-01	0.325609E+02	0.323318E+02
0.000000E+00	0.432900E+02	0.532900E+02	-0.488500E-01	0.264638E+02	0.323303E+02
0.000000E+00	0.332900E+02	0.532900E+02	-0.366375E-01	0.203544E+02	0.323257E+02
0.000000E+00	0.232900E+02	0.532900E+02	-0.259515E-01	0.142466E+02	0.323227E+02
0.000000E+00	0.132900E+02	0.532900E+02	-0.152656E-01	0.813871E+01	0.323211E+02
0.000000E+00	0.329000E+01	0.532900E+02	-0.915936E-02	0.203239E+01	0.323181E+02

TABLE 1.7
MECHANICAL INTERACTIONS - BARE FRAME
EXCITATION=9.98 VDC
DATE: 5/17/84
TIME: 15:05:36
TEMP: 130 F
BARO: 14.76 PSI
PRIMARY GAUGE: N2/#2228
SECONDRY GAUGE:

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.000000E+00	0.000000E+00	0.329000E+01	-0.137238E-01	0.533781E-01	0.199504E+01
0.000000E+00	0.000000E+00	0.829000E+01	-0.137238E-01	0.564283E-01	0.502421E+01
0.000000E+00	0.000000E+00	0.132900E+02	-0.137238E-01	0.549032E-01	0.804880E+01
0.000000E+00	0.000000E+00	0.182900E+02	-0.121989E-01	0.533781E-01	0.110719E+02
0.000000E+00	0.000000E+00	0.232900E+02	-0.762433E-02	0.549032E-01	0.140965E+02
0.000000E+00	0.000000E+00	0.282900E+02	-0.914920E-02	0.533781E-01	0.171165E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.914920E-02	0.533781E-01	0.201350E+02
0.000000E+00	0.000000E+00	0.382900E+02	-0.457460E-02	0.533781E-01	0.231519E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.457460E-02	0.533781E-01	0.261628E+02
0.000000E+00	0.000000E+00	0.482900E+02	-0.304973E-02	0.533781E-01	0.291691E+02
0.000000E+00	0.000000E+00	0.532900E+02	0.000000E+00	0.518530E-01	0.321815E+02
0.000000E+00	0.000000E+00	0.482900E+02	-0.304973E-02	0.518530E-01	0.291706E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.457460E-02	0.549032E-01	0.261597E+02
0.000000E+00	0.000000E+00	0.382900E+02	-0.609947E-02	0.549032E-01	0.231519E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.762433E-02	0.564283E-01	0.201380E+02
0.000000E+00	0.000000E+00	0.282900E+02	-0.762433E-02	0.564283E-01	0.171226E+02
0.000000E+00	0.000000E+00	0.232900E+02	-0.121989E-01	0.579534E-01	0.141026E+02
0.000000E+00	0.000000E+00	0.182900E+02	-0.152487E-01	0.594785E-01	0.110780E+02
0.000000E+00	0.000000E+00	0.132900E+02	-0.152487E-01	0.610036E-01	0.805185E+01
0.000000E+00	0.000000E+00	0.829000E+01	-0.167735E-01	0.610036E-01	0.502879E+01
0.000000E+00	0.000000E+00	0.329000E+01	-0.167735E-01	0.625286E-01	0.199809E+01
SECOND CYCLE					
0.000000E+00	0.000000E+00	0.329000E+01	-0.167735E-01	0.625286E-01	0.199809E+01
0.000000E+00	0.000000E+00	0.132900E+02	-0.182984E-01	0.640537E-01	0.805033E+01
0.000000E+00	0.000000E+00	0.232900E+02	-0.137238E-01	0.610036E-01	0.140965E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.106741E-01	0.610036E-01	0.201334E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.106741E-01	0.594785E-01	0.261506E+02
0.000000E+00	0.000000E+00	0.532900E+02	-0.914920E-02	0.579534E-01	0.321738E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.106741E-01	0.594785E-01	0.261521E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.121989E-01	0.610036E-01	0.201304E+02
0.000000E+00	0.000000E+00	0.232900E+02	-0.152487E-01	0.610036E-01	0.140949E+02
0.000000E+00	0.000000E+00	0.132900E+02	-0.167735E-01	0.625286E-01	0.805185E+01
0.000000E+00	0.000000E+00	0.329000E+01	-0.182984E-01	0.625286E-01	0.199809E+01

TABLE 1.8

MECHANICAL INTERACTIONS - BARE FRAME

EXCITATION=9.98 VDC
DATE: 5/17/84
TIME: 15:31:25
TEMP: 130 F
BARO: 14.76 PSI
PRIMARY GAUGE: N2/#2228
SECONDRY GAUGE: A/#2229

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.532900E+02	0.000000E+00	0.329000E+01	0.319627E+02	0.350770E-01	0.196606E+01
0.532900E+02	0.000000E+00	0.132900E+02	0.319673E+02	0.320269E-01	0.801677E+01
0.532900E+02	0.000000E+00	0.232900E+02	0.319688E+02	0.320269E-01	0.140644E+02
0.532900E+02	0.000000E+00	0.332900E+02	0.319688E+02	0.289767E-01	0.200968E+02
0.532900E+02	0.000000E+00	0.432900E+02	0.319581E+02	0.305018E-01	0.261170E+02
0.532900E+02	0.000000E+00	0.532900E+02	0.319658E+02	0.274516E-01	0.321388E+02
0.532900E+02	0.000000E+00	0.432900E+02	0.319718E+02	0.274516E-01	0.261201E+02
0.532900E+02	0.000000E+00	0.332900E+02	0.319764E+02	0.289767E-01	0.200968E+02
0.532900E+02	0.000000E+00	0.232900E+02	0.319810E+02	0.305018E-01	0.140644E+02
0.532900E+02	0.000000E+00	0.132900E+02	0.319764E+02	0.335520E-01	0.802135E+01
0.532900E+02	0.000000E+00	0.329000E+01	0.319856E+02	0.335520E-01	0.196911E+01

TABLE 1.9

MECHANICAL INTERACTIONS - BARE FRAME

EXCITATION=9.98 VDC

DATE: 5/17/84

TIME: 15:05:36

TEMP: 130 F

BARO: 14.76 PSI

PRIMARY GAUGE: N2/#2228

SECONDRY GAUGE: N1/#2230

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.000000E+00	0.532900E+02	0.329000E+01	-0.717782E-01	0.325679E+02	0.200230E+01
0.000000E+00	0.532900E+02	0.132900E+02	-0.702511E-01	0.325740E+02	0.806568E+01
0.000000E+00	0.532900E+02	0.232900E+02	-0.687239E-01	0.325771E+02	0.141306E+02
0.000000E+00	0.532900E+02	0.332900E+02	-0.671967E-01	0.325771E+02	0.201924E+02
0.000000E+00	0.532900E+02	0.432900E+02	-0.656695E-01	0.325771E+02	0.262467E+02
0.000000E+00	0.532900E+02	0.532900E+02	-0.641423E-01	0.325801E+02	0.323039E+02
0.000000E+00	0.532900E+02	0.432900E+02	-0.656695E-01	0.325786E+02	0.262512E+02
0.000000E+00	0.532900E+02	0.332900E+02	-0.671967E-01	0.325817E+02	0.201924E+02
0.000000E+00	0.532900E+02	0.232900E+02	-0.687239E-01	0.325817E+02	0.141336E+02
0.000000E+00	0.532900E+02	0.132900E+02	-0.717782E-01	0.325832E+02	0.807026E+01
0.000000E+00	0.532900E+02	0.329000E+01	-0.733055E-01	0.325832E+02	0.200688E+01
		SECOND CYCLE			
0.000000E+00	0.532900E+02	0.329000E+01	-0.733055E-01	0.325832E+02	0.200688E+01
0.000000E+00	0.532900E+02	0.132900E+02	-0.702511E-01	0.325832E+02	0.806568E+01
0.000000E+00	0.532900E+02	0.232900E+02	-0.687239E-01	0.325817E+02	0.141291E+02
0.000000E+00	0.532900E+02	0.332900E+02	-0.656695E-01	0.325832E+02	0.201879E+02
0.000000E+00	0.532900E+02	0.432900E+02	-0.671967E-01	0.325817E+02	0.262436E+02
0.000000E+00	0.532900E+02	0.532900E+02	-0.656695E-01	0.325817E+02	0.322963E+02
0.000000E+00	0.532900E+02	0.432900E+02	-0.671967E-01	0.325832E+02	0.262451E+02
0.000000E+00	0.532900E+02	0.332900E+02	-0.671967E-01	0.325878E+02	0.201924E+02
0.000000E+00	0.532900E+02	0.232900E+02	-0.702511E-01	0.325847E+02	0.141321E+02
0.000000E+00	0.532900E+02	0.132900E+02	-0.717782E-01	0.325847E+02	0.806874E+01
0.000000E+00	0.532900E+02	0.329000E+01	-0.733055E-01	0.325847E+02	0.188021E+01

TABLE 2.1

MECHANICAL INTERACTIONS - INSTRUMENTATION WIRING INSTALLED

EXCITATION=9.98 VDC

DATE: 5/21/84

TIME: 13:12:39

TEMP: 130 F

BARO: 14.71 PSI

PRIMARY GAUGE: A/#2229

SECONDRY GAUGE:

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.329000E+01	0.000000E+00	0.000000E+00	0.197482E+01	0.167783E-01	0.152637E-02
0.132900E+02	0.000000E+00	0.000000E+00	0.804121E+01	0.213542E-01	-0.305274E-02
0.232900E+02	0.000000E+00	0.000000E+00	0.140984E+02	0.305060E-01	-0.106846E-01
0.332900E+02	0.000000E+00	0.000000E+00	0.201633E+02	0.381325E-01	-0.198428E-01
0.432900E+02	0.000000E+00	0.000000E+00	0.262175E+02	0.503349E-01	-0.213691E-01
0.532900E+02	0.000000E+00	0.000000E+00	0.322717E+02	0.594867E-01	-0.274746E-01
0.432900E+02	0.000000E+00	0.000000E+00	0.262205E+02	0.518602E-01	-0.198428E-01
0.332900E+02	0.000000E+00	0.000000E+00	0.201664E+02	0.411831E-01	-0.122109E-01
0.232900E+02	0.000000E+00	0.000000E+00	0.141061E+02	0.305060E-01	-0.915821E-02
0.132900E+02	0.000000E+00	0.000000E+00	0.804274E+01	0.198289E-01	-0.305274E-02
0.329000E+01	0.000000E+00	0.000000E+00	0.198092E+01	0.167783E-01	0.152637E-02
		SECOND CYCLE			
0.329000E+01	0.000000E+00	0.000000E+00	0.198092E+01	0.167783E-01	0.152637E-02
0.132900E+02	0.000000E+00	0.000000E+00	0.804274E+01	0.213542E-01	-0.305274E-02
0.232900E+02	0.000000E+00	0.000000E+00	0.141030E+02	0.289807E-01	-0.915821E-02
0.332900E+02	0.000000E+00	0.000000E+00	0.201664E+02	0.366072E-01	-0.152637E-01
0.432900E+02	0.000000E+00	0.000000E+00	0.262205E+02	0.472843E-01	-0.213691E-01
0.532900E+02	0.000000E+00	0.000000E+00	0.322762E+02	0.579614E-01	-0.274746E-01
0.432900E+02	0.000000E+00	0.000000E+00	0.262236E+02	0.472843E-01	-0.198428E-01
0.332900E+02	0.000000E+00	0.000000E+00	0.201648E+02	0.381325E-01	-0.152637E-01
0.232900E+02	0.000000E+00	0.000000E+00	0.141091E+02	0.305060E-01	-0.610547E-02
0.132900E+02	0.000000E+00	0.000000E+00	0.804732E+01	0.198289E-01	-0.152637E-02
0.329000E+01	0.000000E+00	0.000000E+00	0.198245E+01	0.183036E-01	0.152637E-02

TABLE 2.2

MECHANICAL INTERACTIONS - INSTRUMENTATION WIRING INSTALLED

EXCITATION=9.98 VDC
DATE: 5/21/84
TIME: 12:08:17
TEMP: 130 F
BARO: 14.71 PSI
PRIMARY GAUGE: N1/#2230
SECONDRY GAUGE:

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.000000E+00	0.329000E+01	0.000000E+00	-0.106844E-01	0.201547E+01	0.305362E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.198425E-01	0.813054E+01	0.305362E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.305270E-01	0.142426E+02	0.305362E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.366324E-01	0.203546E+02	0.305362E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.503695E-01	0.264666E+02	0.458043E-02
0.000000E+00	0.532900E+02	0.000000E+00	-0.610539E-01	0.325817E+02	0.916086E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.518959E-01	0.264757E+02	0.458043E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.412114E-01	0.203637E+02	0.305362E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.290006E-01	0.142487E+02	0.305362E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.198425E-01	0.813665E+01	0.305362E-02
0.000000E+00	0.329000E+01	0.000000E+00	-0.122108E-01	0.201852E+01	0.152681E-02
SECOND CYCLE					
0.000000E+00	0.329000E+01	0.000000E+00	-0.122108E-01	0.201852E+01	0.152681E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.198425E-01	0.813512E+01	0.305362E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.305270E-01	0.142441E+02	0.305362E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.412114E-01	0.203561E+02	0.305362E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.488432E-01	0.264681E+02	0.305362E-02
0.000000E+00	0.532900E+02	0.000000E+00	-0.610539E-01	0.325771E+02	0.610724E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.534222E-01	0.264757E+02	0.458043E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.412114E-01	0.203652E+02	0.305362E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.335797E-01	0.142487E+02	0.305362E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.228952E-01	0.813512E+01	0.305362E-02
0.000000E+00	0.329000E+01	0.000000E+00	-0.137371E-01	0.202310E+01	0.305362E-02

TABLE 2.3

MECHANICAL INTERACTIONS - INSTRUMENTATION WIRING INSTALLED

EXCITATION=9.98 VDC
DATE: 5/21/84
TIME: 12:30:21
TEMP: 130 F
BARO: 14.71 PSI
PRIMARY GAUGE: N2/#2228
SECONDRY GAUGE:

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.000000E+00	0.000000E+00	0.329000E+01	-0.106904E-01	0.167646E-01	0.199096E+01
0.000000E+00	0.000000E+00	0.132900E+02	-0.916319E-02	0.167646E-01	0.805240E+01
0.000000E+00	0.000000E+00	0.232900E+02	-0.916319E-02	0.167646E-01	0.141199E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.916319E-02	0.167646E-01	0.201844E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.916319E-02	0.167646E-01	0.262397E+02
0.000000E+00	0.000000E+00	0.532900E+02	-0.916319E-02	0.167646E-01	0.322966E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.916319E-02	0.167646E-01	0.262367E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.916319E-02	0.167646E-01	0.201783E+02
0.000000E+00	0.000000E+00	0.232900E+02	-0.106904E-01	0.152405E-01	0.141169E+02
0.000000E+00	0.000000E+00	0.132900E+02	-0.106904E-01	0.167646E-01	0.805240E+01
0.000000E+00	0.000000E+00	0.329000E+01	-0.106904E-01	0.152405E-01	0.198943E+01
SECOND CYCLE					
0.000000E+00	0.000000E+00	0.329000E+01	-0.106904E-01	0.152405E-01	0.198943E+01
0.000000E+00	0.000000E+00	0.132900E+02	-0.106904E-01	0.167646E-01	0.804629E+01
0.000000E+00	0.000000E+00	0.232900E+02	-0.106904E-01	0.167646E-01	0.141123E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.106904E-01	0.152405E-01	0.201737E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.916319E-02	0.152405E-01	0.262336E+02
0.000000E+00	0.000000E+00	0.532900E+02	-0.916319E-02	0.137165E-01	0.322859E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.106904E-01	0.152405E-01	0.262321E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.106904E-01	0.152405E-01	0.201753E+02
0.000000E+00	0.000000E+00	0.232900E+02	-0.106904E-01	0.137165E-01	0.141093E+02
0.000000E+00	0.000000E+00	0.132900E+02	-0.137448E-01	0.152405E-01	0.804934E+01
0.000000E+00	0.000000E+00	0.329000E+01	-0.137448E-01	0.152405E-01	0.198485E+01

TABLE 3.1
MECHANICAL INTERACTIONS
AIR LINES & INSTRUMENTATION WIRING INSTALLED
EXCITATION=9.98 VDC
DATE: 5/22/84
TIME: 08:09:13
TEMP: 130 F
BARO: 14.73 PSI
PRIMARY GAUGE: A/#2229
SECONDRY GAUGE:

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.329000E+01	0.000000E+00	0.000000E+00	0.196468E+01	0.137090E-01	0.000000E+00
0.132900E+02	0.000000E+00	0.000000E+00	0.801292E+01	0.167554E-01	0.305495E-02
0.232900E+02	0.000000E+00	0.000000E+00	0.140673E+02	0.182786E-01	0.122198E-01
0.332900E+02	0.000000E+00	0.000000E+00	0.201216E+02	0.213251E-01	0.213847E-01
0.432900E+02	0.000000E+00	0.000000E+00	0.261668E+02	0.243715E-01	0.320770E-01
0.532900E+02	0.000000E+00	0.000000E+00	0.322089E+02	0.289412E-01	0.412418E-01
0.432900E+02	0.000000E+00	0.000000E+00	0.261729E+02	0.228483E-01	0.320770E-01
0.332900E+02	0.000000E+00	0.000000E+00	0.201246E+02	0.167554E-01	0.213847E-01
0.232900E+02	0.000000E+00	0.000000E+00	0.140779E+02	0.137090E-01	0.122198E-01
0.132900E+02	0.000000E+00	0.000000E+00	0.802208E+01	0.137090E-01	0.305495E-02
0.329000E+01	0.000000E+00	0.000000E+00	0.197384E+01	0.121857E-01	0.152748E-02
SECOND CYCLE					
0.329000E+01	0.000000E+00	0.000000E+00	0.197384E+01	0.121857E-01	0.152748E-02
0.132900E+02	0.000000E+00	0.000000E+00	0.802055E+01	0.121857E-01	0.305495E-02
0.232900E+02	0.000000E+00	0.000000E+00	0.140764E+02	0.137090E-01	0.106923E-01
0.332900E+02	0.000000E+00	0.000000E+00	0.201246E+02	0.137090E-01	0.213847E-01
0.432900E+02	0.000000E+00	0.000000E+00	0.261698E+02	0.182786E-01	0.305495E-01
0.532900E+02	0.000000E+00	0.000000E+00	0.322150E+02	0.243715E-01	0.397144E-01
0.432900E+02	0.000000E+00	0.000000E+00	0.261729E+02	0.198018E-01	0.290220E-01
0.332900E+02	0.000000E+00	0.000000E+00	0.201292E+02	0.152322E-01	0.213847E-01
0.232900E+02	0.000000E+00	0.000000E+00	0.140795E+02	0.137090E-01	0.122198E-01
0.132900E+02	0.000000E+00	0.000000E+00	0.802818E+01	0.106625E-01	0.305495E-02
0.329000E+01	0.000000E+00	0.000000E+00	0.198148E+01	0.913931E-02	0.152748E-02

TABLE 3.2
MECHANICAL INTERACTIONS
AIR LINES & INSTRUMENTATION WIRING INSTALLED
EXCITATION=9.98 VDC
DATE: 5/22/84
TIME: 09:01:30
TEMP: 130 F
BARO: 14.73 PSI
PRIMARY GAUGE: N1/#2230
SECONDRY GAUGE:

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.000000E+00	0.329000E+01	0.000000E+00	-0.168062E-01	0.201742E+01	0.305185E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.320846E-01	0.813220E+01	0.305185E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.412516E-01	0.142378E+02	0.305185E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.504186E-01	0.203465E+02	0.305185E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.580578E-01	0.264476E+02	0.457777E-02
0.000000E+00	0.532900E+02	0.000000E+00	-0.702805E-01	0.325471E+02	0.457777E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.611135E-01	0.264506E+02	0.457777E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.488908E-01	0.203511E+02	0.305185E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.381959E-01	0.142455E+02	0.305185E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.259732E-01	0.813373E+01	0.305185E-02
0.000000E+00	0.329000E+01	0.000000E+00	-0.168062E-01	0.202657E+01	0.305185E-02
		SECOND CYCLE			
0.000000E+00	0.329000E+01	0.000000E+00	-0.168062E-01	0.202657E+01	0.305185E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.229176E-01	0.813373E+01	0.305185E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.336124E-01	0.142363E+02	0.305185E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.427794E-01	0.203389E+02	0.305185E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.534743E-01	0.264369E+02	0.305185E-02
0.000000E+00	0.532900E+02	0.000000E+00	-0.626413E-01	0.325379E+02	0.305185E-02
0.000000E+00	0.432900E+02	0.000000E+00	-0.534743E-01	0.264445E+02	0.305185E-02
0.000000E+00	0.332900E+02	0.000000E+00	-0.458351E-01	0.203435E+02	0.305185E-02
0.000000E+00	0.232900E+02	0.000000E+00	-0.366681E-01	0.142394E+02	0.152593E-02
0.000000E+00	0.132900E+02	0.000000E+00	-0.336124E-01	0.813525E+01	0.152593E-02
0.000000E+00	0.329000E+01	0.000000E+00	-0.213897E-01	0.202962E+01	0.152593E-02

TABLE 3.3
MECHANICAL INTERACTIONS
AIR LINES & INSTRUMENTATION WIRING INSTALLED
EXCITATION=9.98 VDC
DATE: 5/22/84
TIME: 09:30:48
TEMP: 130 F
BARO: 14.73 PSI
PRIMARY GAUGE: N2/#2228
SECONDRY GAUGE:

APPLIED GAUGE LOAD(LB)			GAUGE OUTPUT(mV)		
A	N1	N2	A	N1	N2
0.000000E+00	0.000000E+00	0.329000E+01	-0.915682E-02	0.167623E-01	0.199038E+01
0.000000E+00	0.000000E+00	0.132900E+02	-0.915682E-02	0.167623E-01	0.805770E+01
0.000000E+00	0.000000E+00	0.232900E+02	-0.106830E-01	0.167623E-01	0.141250E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.106830E-01	0.167623E-01	0.201847E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.915682E-02	0.182861E-01	0.262489E+02
0.000000E+00	0.000000E+00	0.532900E+02	-0.915682E-02	0.167623E-01	0.323010E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.915682E-02	0.167623E-01	0.262428E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.106830E-01	0.167623E-01	0.201832E+02
0.000000E+00	0.000000E+00	0.232900E+02	-0.915682E-02	0.167623E-01	0.141204E+02
0.000000E+00	0.000000E+00	0.132900E+02	-0.915682E-02	0.167623E-01	0.805922E+01
0.000000E+00	0.000000E+00	0.329000E+01	-0.915682E-02	0.167623E-01	0.199496E+01
		SECOND CYCLE			
0.000000E+00	0.000000E+00	0.329000E+01	-0.915682E-02	0.167623E-01	0.199496E+01
0.000000E+00	0.000000E+00	0.132900E+02	-0.915682E-02	0.167623E-01	0.805464E+01
0.000000E+00	0.000000E+00	0.232900E+02	-0.915682E-02	0.167623E-01	0.141158E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.763068E-02	0.167623E-01	0.201770E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.763068E-02	0.167623E-01	0.262367E+02
0.000000E+00	0.000000E+00	0.532900E+02	-0.763068E-02	0.167623E-01	0.322949E+02
0.000000E+00	0.000000E+00	0.432900E+02	-0.763068E-02	0.167623E-01	0.262383E+02
0.000000E+00	0.000000E+00	0.332900E+02	-0.763068E-02	0.167623E-01	0.201755E+02
0.000000E+00	0.000000E+00	0.232900E+02	-0.763068E-02	0.167623E-01	0.141158E+02
0.000000E+00	0.000000E+00	0.132900E+02	-0.763068E-02	0.167623E-01	0.805464E+01
0.000000E+00	0.000000E+00	0.329000E+01	-0.915682E-02	0.167623E-01	0.199191E+01