Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) Fixture: Capabilities Description and User Manual

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16. Abstract

This technical note describes the current configuration and capabilities of the Full-Scale Aircraft Structural Test Evaluations and Research (FASTER) fixture. The FASTER fixture was originally designed and fabricated through a cost-share arrangement with The Boeing Company in 1998. The fixture is capable of testing full-scale fuselage panels under conditions representative of those seen by an aircraft in actual operation. Several major modifications and upgrades have been made working with The Boeing Company, which include implementing capabilities to test larger radius panels and integrating an environmental system to provide the unique capability of applying synchronous mechanical-temperature-humidity load profiles. The most recent control and data acquisition (DAQ) upgrade provides a new 2-station, 40-channel FlexTest® 200 control system, 128-channel FlexDAC for strain gauges from MTS®, 48 channels for DAQ from Agilent EX1629, 24 channels for thermocouples, and 24 channels for strain gauges from HBM MGCplus for the use on FASTER fixture.

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FASTER, full-scale, load, fuselage panel, control, data acquisition

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CSZ	Cincinnati Sub-Zero
DAQ	Data acquisition
DUC	Digital universal conditioner
E/P	Electro/pneumatic
ESMT	Emerging Structures Technologies
FASTER	Full-Scale Aircraft Structural Test Evaluation and Research
HPU	Hydraulic pressure unit
HSM	Hydrologic service manifold
I/O	Input/output
LVDT	Linear Variable Differential Transformer
MUD	Multiple universal driver
PID	Proportional integral derivative
SCFM	Standard cubic feet per minute
VME	Versa Module Europa

EXECUTIVE SUMMARY

This technical note describes the current configuration and capabilities of the Full-Scale Aircraft Structural Test Evaluations and Research (FASTER) fixture. The FASTER fixture was originally designed and fabricated through a cost-share arrangement with The Boeing Company in 1998. The fixture is capable of testing full-scale fuselage panels under conditions representative of those seen by an aircraft in actual operation. Several major modifications and upgrades have been made working with The Boeing Company, which include implementing capabilities to test larger radius panels and integrating an environmental system to provide the unique capability of applying synchronous mechanical-temperature-humidity load profiles. The most recent control and data acquisition upgrade provides a new 2-station, 40-channel FlexTest® 200 control system, 128-channel FlexDAC for strain gauges from MTS®, 48 channels for data acquisition from Agilent EX1629 and 24 channels for thermocouples, and 24 channels for strain gauges from HBM MGCplus for the use on FASTER fixture.

CHAPTER I: INTRODUCTION AND BACKGROUND

The Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) fixture is a state-of-the-art core capability developed at the FAA William J. Hughes Technical Center to perform structural testing of legacy and next-generation fuselage structure. The FASTER lab was established December 1998 through a cost-share arrangement with The Boeing Company (which paid a third of the cost). The fixture is capable of testing full-scale fuselage panels under conditions representative of those seen by an aircraft in actual operation and features a unique adaptation of mechanical, fluid, hydraulic, and electronic components capable of applying pressurization, longitudinal, and hoop loads to a curved fuselage test panel, and controlled temperature and humidity environments (see figure 1).

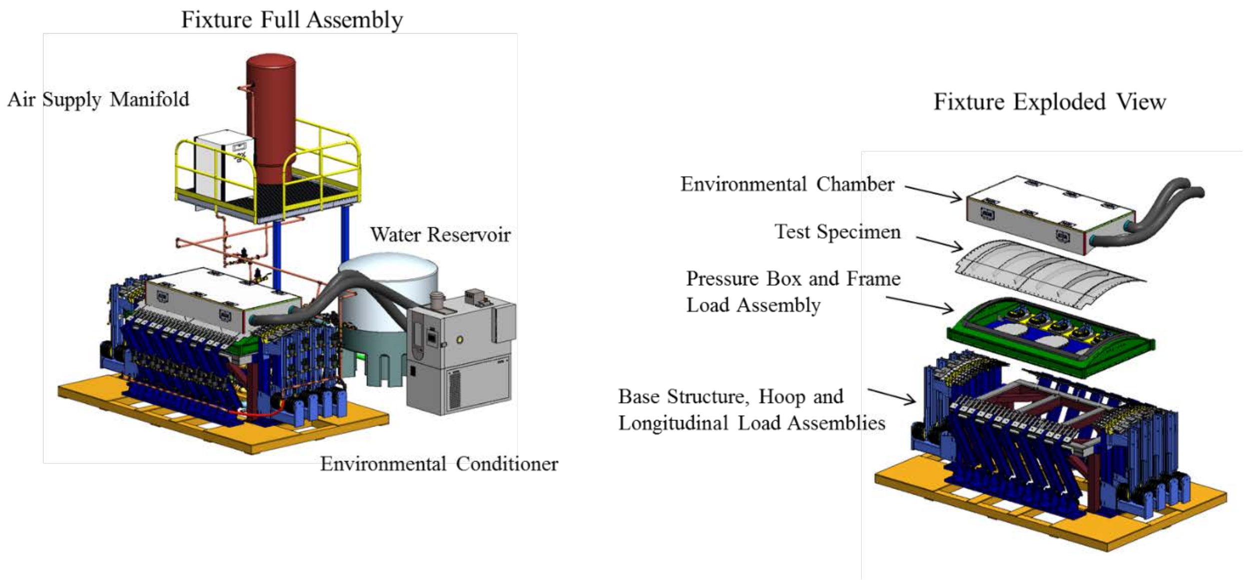


Figure 1. FASTER test fixture

In general, the FASTER fixture can accommodate fuselage panels containing up to six frames with typical dimensions of 125 inches in length, 73 inches in chord length (76-inch arc length), and radii ranging from 60 to 130 inches. The internal pressure is applied using water or air media. The system is capable of dynamically cycling the internal pressure at a rate of two pressurization cycles per minute and performing a static pressurization to levels above flight gradients up to 20 psi. The hoop and longitudinal stresses are simulated by the controlled application of distributed loads around the perimeter of the test panel. A description of the original FASTER fixture configuration is provided in [1]. Recent modifications integrated an environmental system with the FASTER fixture to apply synchronous mechanical-temperature-humidity load profiles. The environmental system consists of a remote conditioner to control temperature and humidity, and a chamber on the test panel to contain the environment. With this enhancement, fuselage panels can be tested under a variety of operating environments ranging from hot-wet (165°F and 85–95% humidity) to extreme cold (-50°F) conditions.

This facility is being effectively used to leverage resources through partnerships with other government agencies, industry, and academia to provide critical data needed by both industry and the FAA to safely allow new technologies to be introduced into commercial applications. Numerous test programs have been completed through partnerships with other government agencies, industry, and academia (see table 1). The data obtained from the tests are used to calibrate and validate methodologies used for fatigue and damage-tolerance assessments. Several issues related to the structural integrity of fuselage applications have been and continue to be examined using this lab, including the phenomena of widespread fatigue damage, the fatigue and damage tolerance characteristics of current and emerging metallic and composite designs, performance of bonded repair technologies, assessment of conventional and emerging non-destructive inspection, and the application of structural health monitoring methods.

Table 1. FASTER test programs

	Program Name	Objective	Dates	Partner
Completed	Crack Initiation Test	Study evolution of multiple site damage; 1 panel tested	December 2000 to October 2001	Boeing
	Multiple Site Damage Tests	Determine effects of multiple cracks on fatigue crack growth and residual strength; 4 panels tested	January 1999 to November 2000	NASA, USAF, and Boeing
	Fatigue Enhancement Test	Assess polyisocyanurate foam on fuselage response; 1 panel tested	January 2000 to June 2000	Florida International University
	Composite Fuselage Structure	Study damage tolerance capabilities of composite fuselage structure; 6 panels tested	April 2006 to September 2007	Wichita State University and Adams Aircraft
	Extended Fatigue Testing	Study fatigue crack initiation and formation in retired B727 fuselage structure; 2 panels tested	December 2002 to March 2008	Delta Air Lines and Sandia Labs
	Advanced Material/Integral Structure	Study damage tolerance capabilities and damage containment features of advanced material—integral structures; 1 panel tested	February 2011 to October 2011	Boeing, NASA
	Bonded Repair Technology	Study damage tolerance capabilities and the effects of environment in the durability and structural integrity of adhesive bonded repairs of metallic fuselage; 4 panels tested	April 2008 to December 2016	Boeing
Ongoing	Advanced Material/Integral Structure	Study damage tolerance capabilities of emerging metallic structures technology for fuselage application; 7 panels planned to be tested	January 2017 to January 2021	ARCONIC

The FASTER fixture has evolved over the past two decades to provide a variety of structural-loading and data-acquisition capabilities. Several major modifications have been made through cost-share arrangements mainly with The Boeing Company for the different test programs, as shown in table 1, and include:

- Modification to test fuselage panels for Boeing 727 aircraft, which had a fuselage radius of 74 inches in 2003
- Upgrade from UNIX® to Windows®-based operating system in 2003
- Modification to add axial tension-compression capability in 2010 [2]
- Modification to increase axial load capacity and to accommodate large radius PRSEUS test panel in 2011 [3]
- Modification to add environmental system to provide the capability of applying synchronous mechanical-temperature-humidity load profiles and convert pressurization media from water to air for pressure box in 2013
- Upgrade control and data acquisition (DAQ) system and convert pressurization media for the axial, hoop, and frame loaders from water to air in 2015
- Modification to increase axial load capacity for Arconic panel residual strength test in 2017

A general description is provided in the subsequent sections of the main body of this technical note whereas details are provided in the supporting appendices: appendix A details the environmental system; appendix B summarizes the acceptance testing done to demonstrate full functionality of the current system; appendix C describes the user interface and general operation; and appendix D details the most recent axial load modification for increased load capacity.

CHAPTER II: DESCRIPTION OF FASTER FIXTURE

OVERVIEW

The FASTER fixture, located at the FAA William J. Hughes Technical Center, was developed for full-scale testing of fuselage structures under simulated flight conditions, as shown in figure 1. The test fixture features a unique adaptation of mechanical, fluid, and electronic components and is capable of applying combined internal pressure and axial load with appropriate hoop reactions to fuselage panels. As shown in the exploded view in figure 1, the fixture consists of a base structure, hoop load assembly, longitudinal load assembly, fuselage pressure box, frame load assembly, and shear fixture assembly.

The test fixture is capable of dynamically cycling the internal pressure and of performing a static pressurization. The hoop and axial stresses are simulated by the controlled application of distributed loads around the perimeter of the test panel. Forces are distributed by individual loading linkages using a two-tier coaxial whiffle tree assembly, which generates four equal forces from each controlled load point. Seven load points are used on each side of the specimen, creating 28 attachment points. Axial forces are applied using similar loading devices on each end of the panel, consisting of four load control points and 16 attachment points. Similar devices are available to apply hoop tension loads at each end of a frame.

An innovative shear-load application system was developed that uses two load-distribution points in the longitudinal direction at the edges of the specimen. The force is applied as a couple and is reacted by a couple in the hoop direction. A unique feature of the shear loading system is the elastomeric coupling between the loading mechanisms and the test specimen. The elastomer, which has a soft shear modulus, creates a close approximation to uniform shear distribution in both the applied and reacted couples.

All forces are generated using water and air as the fluid medium. The external loads are generated by applying pressure to bladder-type actuators, which are controlled by electro/pneumatic (E/P) control valves. The E/P valves are driven by a computer control system in a closed-loop configuration. The operator can control the loads, speed, and type of test. Data from strain transducers, load transducers, and pressure transducers are displayed on color monitors in real time and stored for off-line analysis.

MECHANICAL LOADING MECHANISMS

In general, the hoop, axial, and shear stresses are simulated by the controlled application of distributed loads around the perimeter of the test panel. Actuators with a lever arm construction are used to apply loads as described in the subsequent sections.

HOOP LOAD: Hoop forces are distributed by individual loading linkages using a two-tier coaxial whiffle tree assembly, which generates four equal forces from each controlled load device up to 25,000 lb. Hoop tensile forces are distributed by seven individual loading mechanisms/whiffletree assemblies on each side of the specimen via 28 attachment points. The hoop tensile load assembly consists of one actuator, a lever arm, a fulcrum pivot point, a load cell, and a whiffle tree assembly, as shown in figure 2. The lever arm is connected to the actuator at one end and to the load cell at the other, and rotates about the fulcrum pivot point. The distance from the water actuator to the fulcrum is l_1, and the distance from the top of the lever arm to the fulcrum is l_2. As the actuator inflates, the bottom of the lever arm will displace amount u_1, causing the top of the level arm to displace an amount u_2 ($u_1 = 4 \times u_2$) in tension. The actuators used are air-water springs, a product by Firestone. An air-water spring is an elastomeric rubber fabric bellow with metal end closures, which contains a column of compressed air or water.

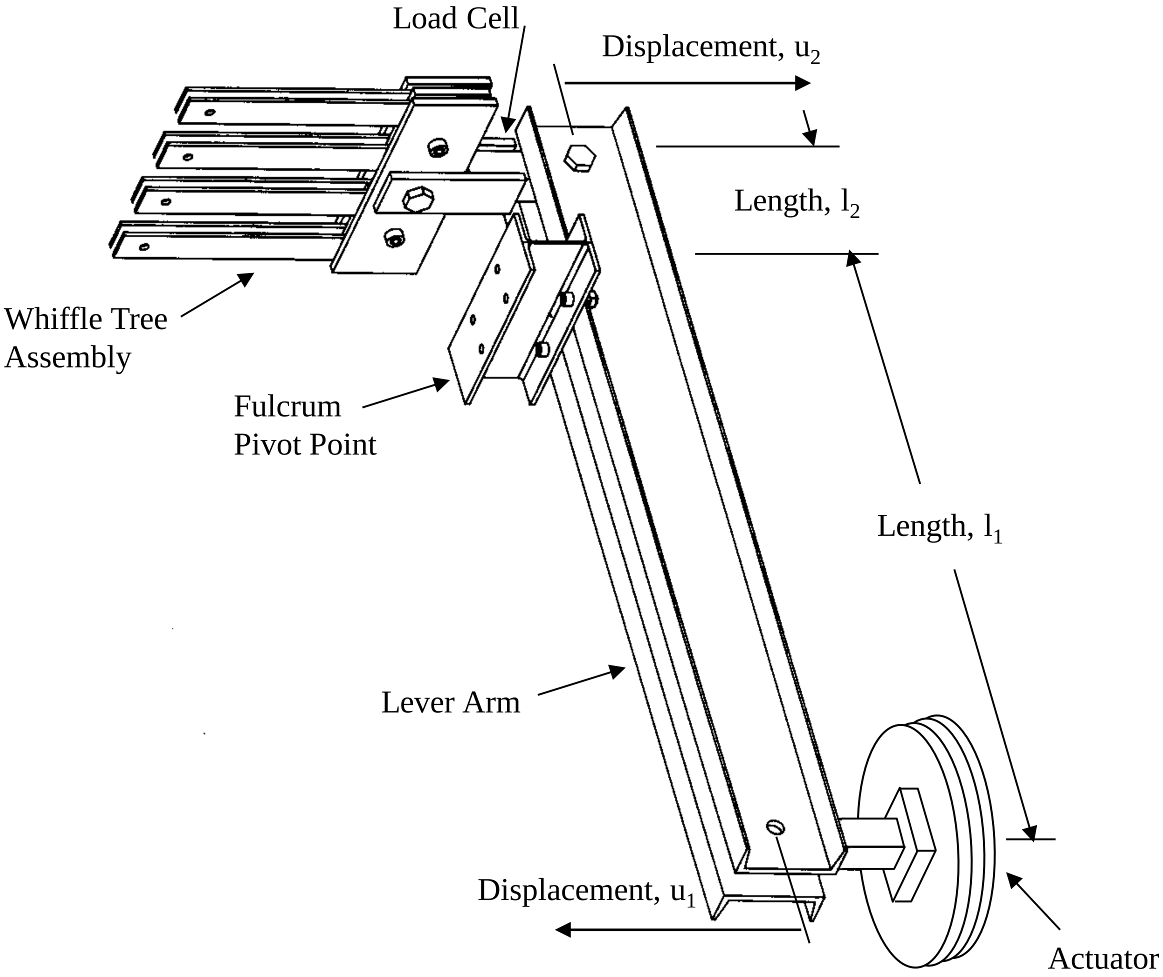


Figure 2. Schematic of the hoop tensile load mechanism

AXIAL LOAD: Similarly, four load devices on each end apply axial tension and compression at loads up to ±20,000 lb to simulated fuselage bending at 16 load application points. The axial tension-compression load assembly consists of two actuators, a lever arm, a fulcrum pivot point, a load cell, a whiffle tree, and a push rod assembly, as shown in figure 3. It was designed to apply both tension and compression. Tension-compression FUTEK load cells are used (item no. FSH00712), having a maximum measurement capability up to ±50,000 lb.

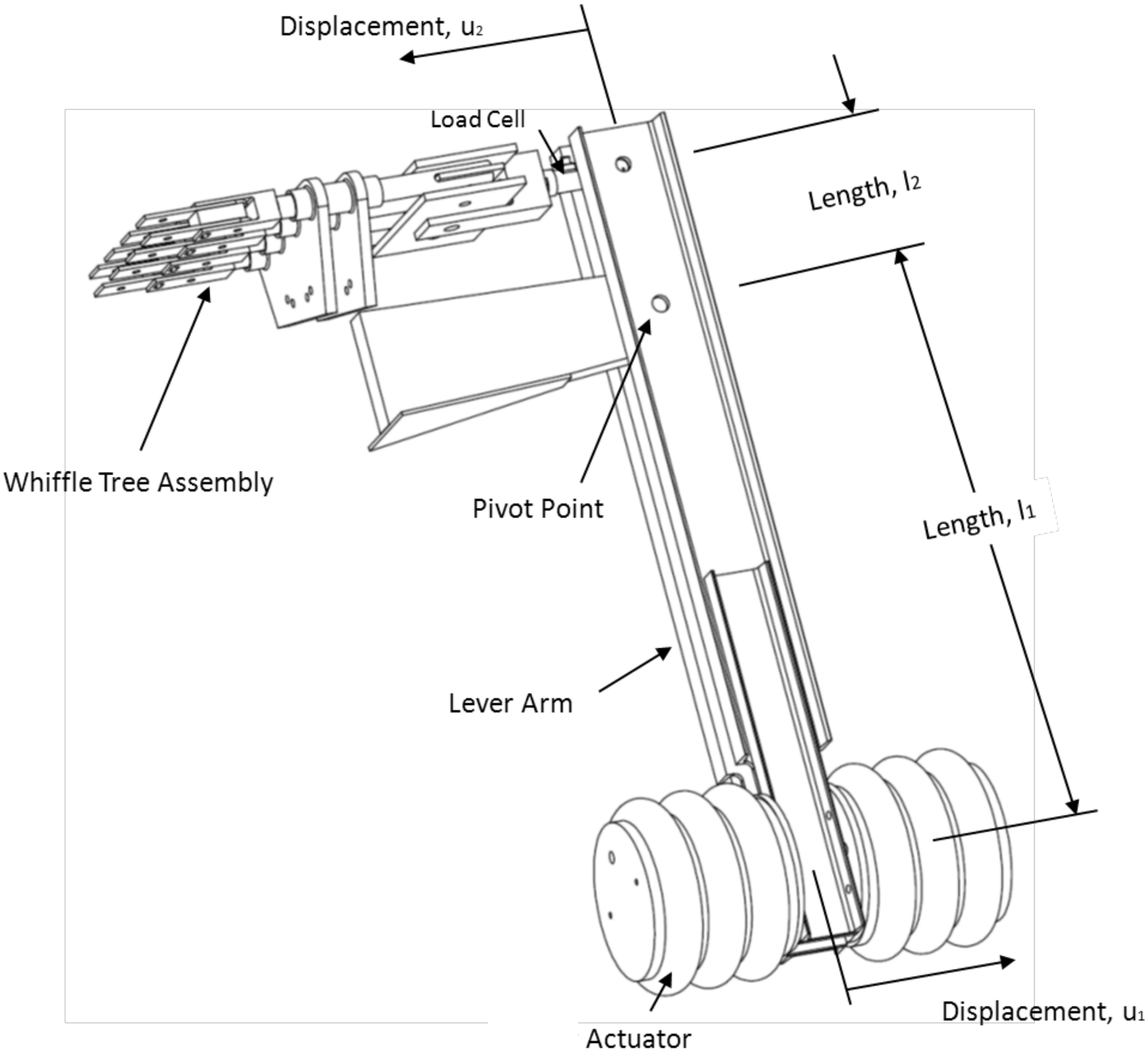


Figure 3. Schematic of the axial tension-compression load mechanism

SHEAR LOAD: The shear load assembly consists of the shear fixture and four counter-balance poles and baskets, as shown in figure 3. The shear fixture consists of a rigid reaction structure, a pair of actuators, shear lever arms, pivot points, longitudinal skis, and hoop skis. The longitudinal and hoop skis are attached to the curved panel using an elastic 1-inch-thick by 4-inch-wide polyurethane strip with a Shore A hardness rating of 90. As the actuator inflates, the shear lever arm will displace downward, u_1, and will rotate about the shear arm pivot point. As a result, the lever arm keyway, which is attached to a longitudinal ski, will displace amount u_2 as shown in figure 4. The displacement u_2 will deform the polyurethane strip, which will distribute the point force at the keyway into a uniform shear force distributed along the entire length of the longitudinal ski. By inflating the two actuators, which are located at diagonal corners of the reaction structure, the shear loads are applied through the longitudinal skis in equal magnitude but opposite direction. The shear couple is reacted by the rigid support structure, which is attached to the hoop skis. The entire shear load fixture weighs approximately 3800 lb. To ensure this weight is not applied to the panel, the fixture is counterbalanced using four weights attached to the fixture through four cable support columns, as shown in figure 4.

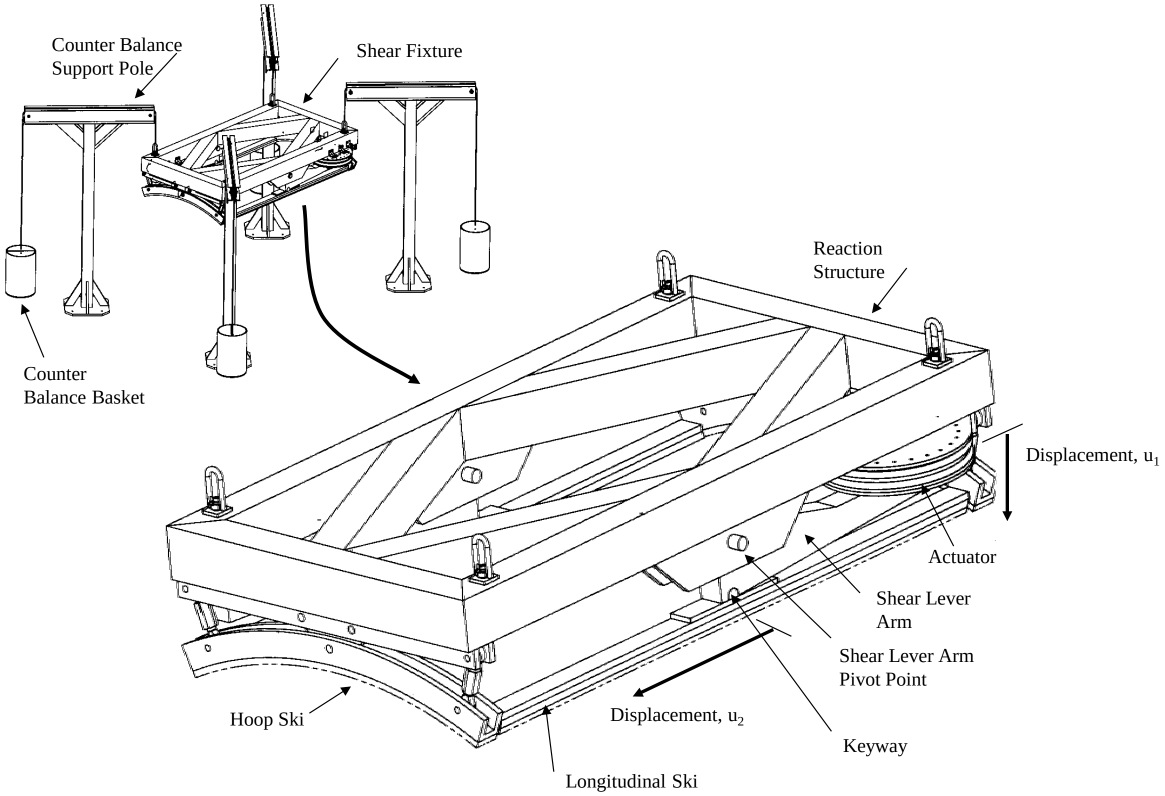


Figure 4. Schematic of shear loading mechanism

FRAME LOAD: The frame load assembly loading mechanism is shown in figure 5. The figure shows a cut-away view through a frame loader. The frame loading mechanism consists of an actuator, a frame lever arm, a fulcrum pivot point, a radial reaction link, and a frame load link. As the actuator inflates, the end of the frame lever arm will displace an amount u_1 and will cause a displacement of the frame load link in the hoop direction u_2. The radial reaction link ensures that the frame attachment point is displaced only in the hoop direction. Twelve load mechanisms are used to apply hoop forces to frame ends of up to 6900 lb.

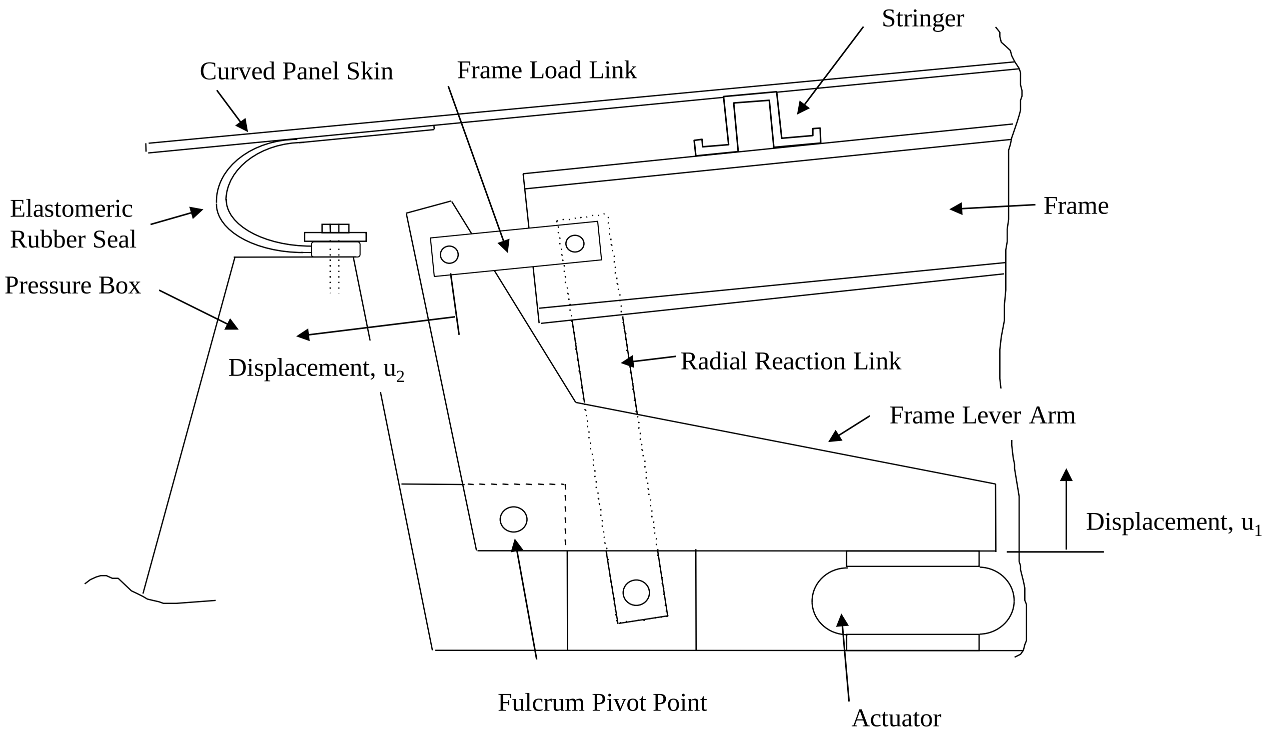


Figure 5. Schematic of frame loading mechanism

The curved panel can be pressurized using either air, water, or a combination of both. The panel skin is attached to the pressure box using an elastomeric rubber seal, as shown in figure 5. The seal is bonded to the panel skin and bolted to the pressure box.

SERVO LOOP CONTROL

Servo loop controls are used for each of the loading mechanisms: fuselage pressure, hoop frame, hoop, axial, and shear. The command signal for all servo channels is a voltage driver signal.

FUSELAGE PRESSURIZATION

The control features for fuselage pressurization using water is shown in figure 6. Dome valve FU1 controls the flow of water from the supply manifold into the fuselage. The command signal to the E/P valve is CTRL-FU1. The fuselage pressure is read back using a pressure transducer. The E/P valve response is routed back to CTRL-FU1 channel.

Dome valve FU2 controls the flow of water from the fuselage back to the return line. It is a controlled command signal CTRL-FU2 to the E/P valve. In addition, the feedback signal from the E/P valve is routed back via the same channel.

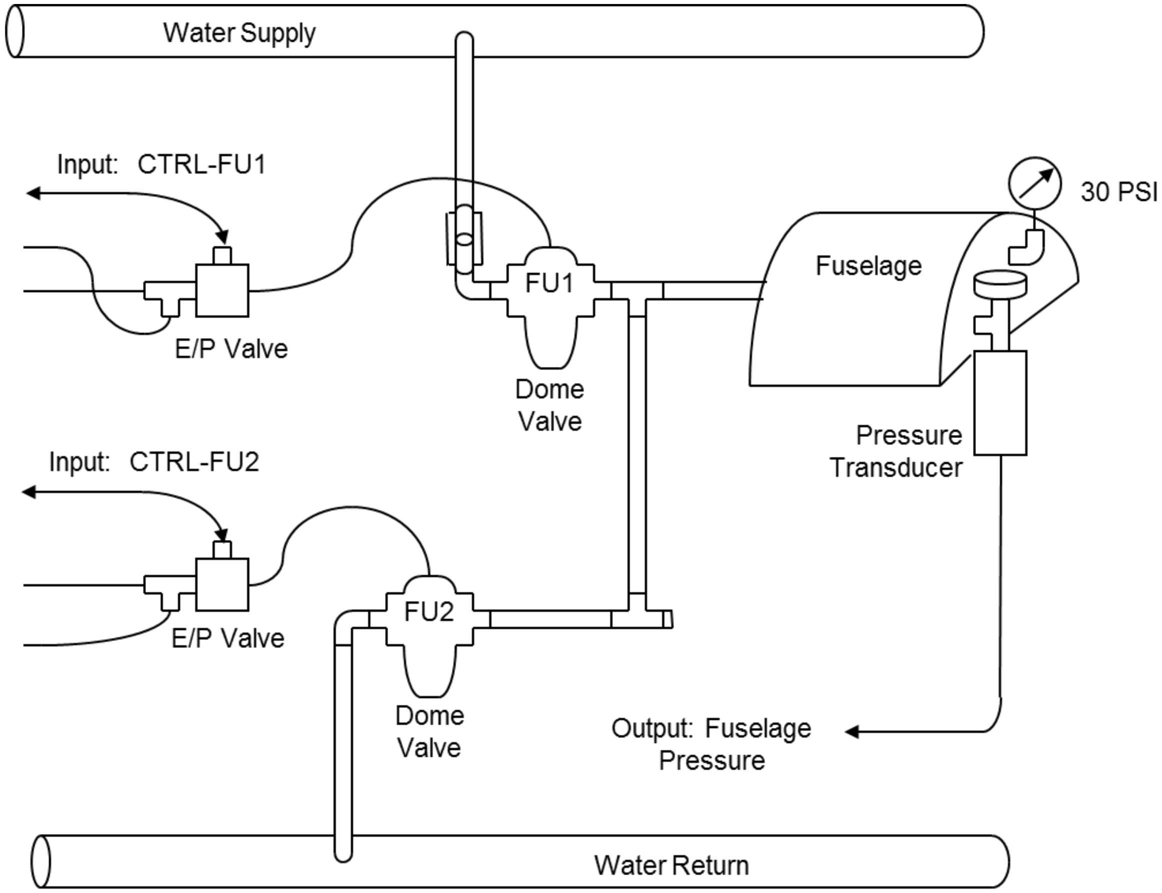


Figure 6. Fuselage pressure servo loop using water

The control features for fuselage pressurization using air is much more simplified compared to using water, as shown in figure 7. A single high air-volume E/P valve with an air booster is used to control air flow to the fuselage panel. The command signal is CTRL-FU1. The fuselage pressure is read back using a pressure transducer. The E/P valve response is routed back via the same channel CTRL-FU1.

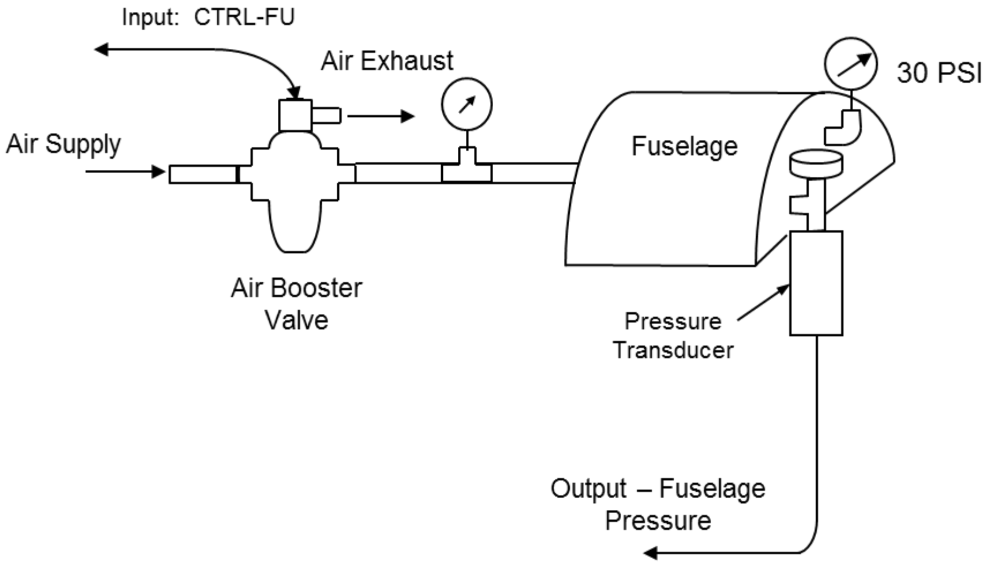


Figure 7. Fuselage pressure servo loop using air

HOOP LOAD: Figure 8 shows a typical example of a servo control loop for the hoop loaders using air in which the input, output, and channel number designations are specific to AD7-14. The relative position of all 14 hoop load mechanisms is shown in the figure. High air-volume E/P pressure controller AD7-14 controls the flow of air from the supply to the actuator. The servo channel command signal is AD7-14CTH to the E/P valve. In addition, the feedback signal from the E/P valve is routed back via the same channel. The feedback and output from the 25,000-lb load cell is routed back to finish the control loop.

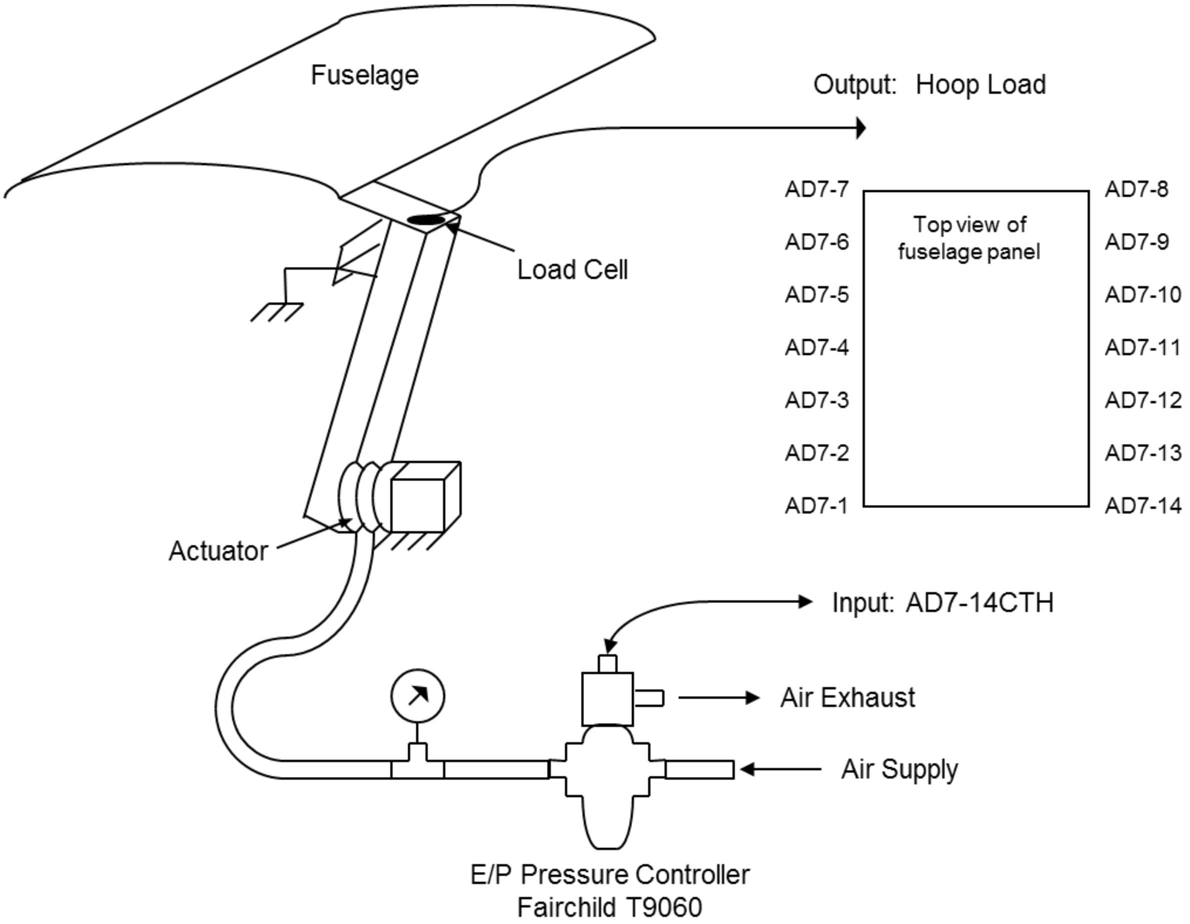


Figure 8. Hoop load servo loop using air

AXIAL LOAD: Figure 9 shows a typical example of a servo loop control for an axial load mechanism, using air, in which the input, output, and channel number designations are specific to AD8-1. For each axial load mechanism, there are two dome valves: one to apply tension load, AD8-1T, and the other for compressive loads, AD8-1C. These dome valves control the flow of water from the supply manifold into the actuators.

The servo channel command signal AD8-1CTL is sent to a signal splitter used to direct the command to either a tension or a compression E/P valve to control the associated dome valves. The feedback and output from the tension-compression FUTEK load cell (Model FSH00712, ±20,000 lb) is routed back to finish the control loop.

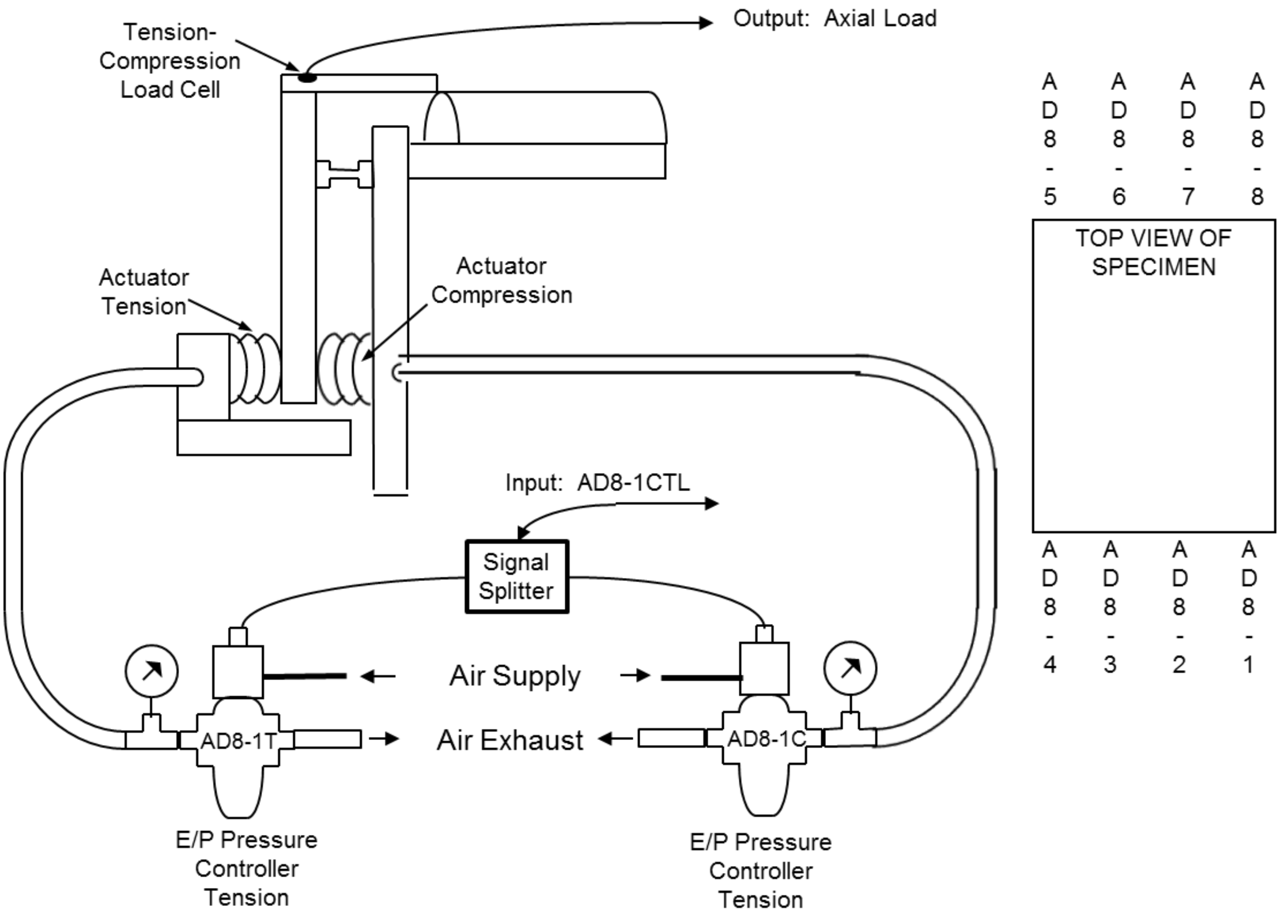


Figure 9. Axial load servo loop using air

A signal splitter box is used to control the tension or compression load direction using a single control channel (see figure 10). If the signal is positive, the splitter circuit outputs a voltage equal to the input on the tension E/P valve. If the signal is negative, the splitter circuit outputs voltage equal to the inverse of the negative voltage on the compression E/P valve, as shown in figure 11. The signal splitter box combines the feedback from both E/P valves into a single signal, which is checked and verified using the feedback from the load cells. More details about this modification are given in [2].

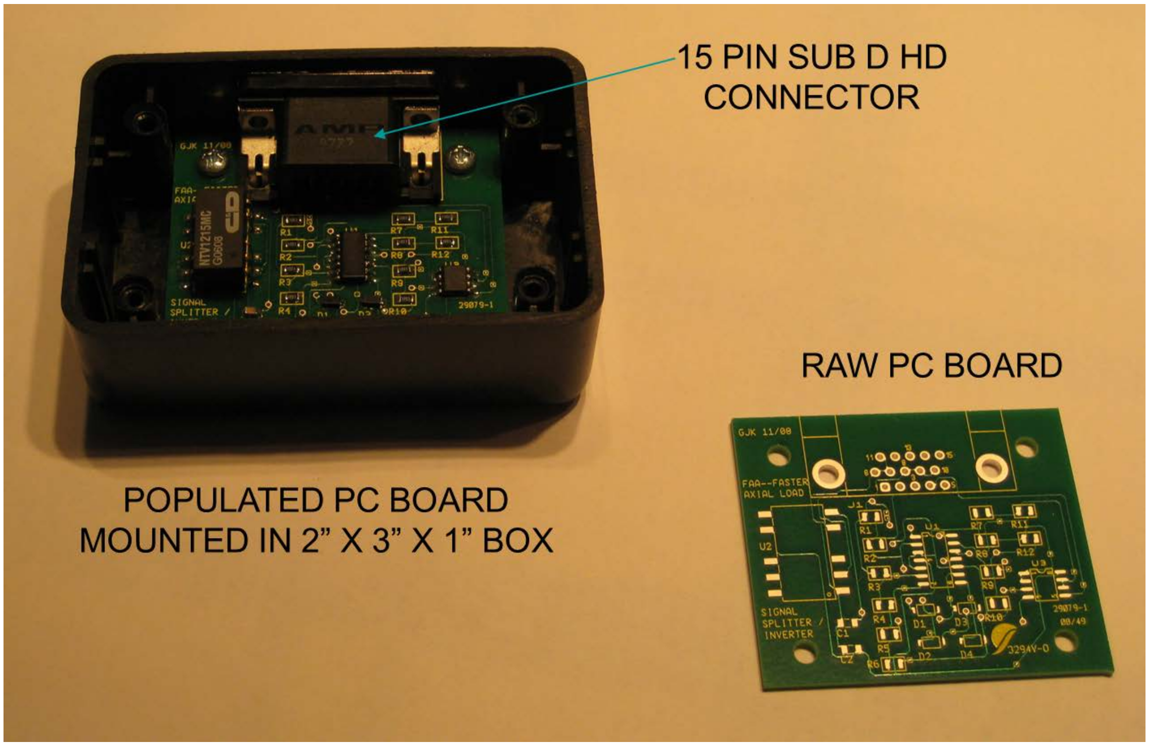


Figure 10. Signal splitter box for axial load assembly

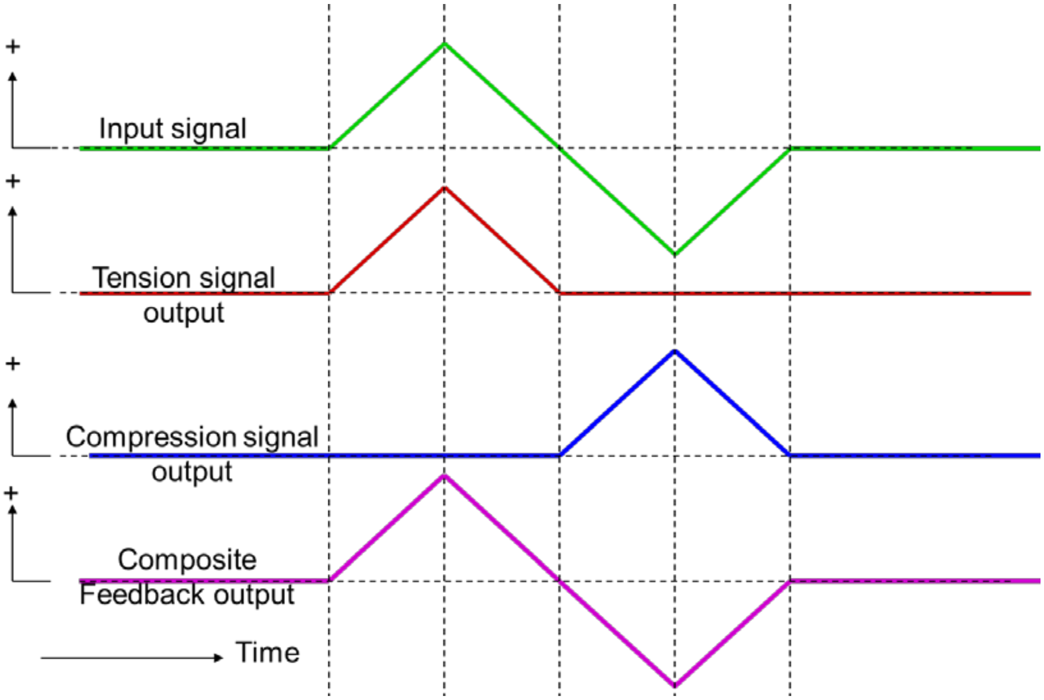


Figure 11. Schematic of signal splitter box processing mechanism

SHEAR LOAD: Figure 12 shows the shear load link servo loop, which controls the application of shear loads to the test specimen. High air-volume E/P pressure controller, SH1, controls the flow of air from the supply to the two actuators. One completion bridge for the strain gauges is fixed to the shear arm. The completion bridge signal is returned to the controller.

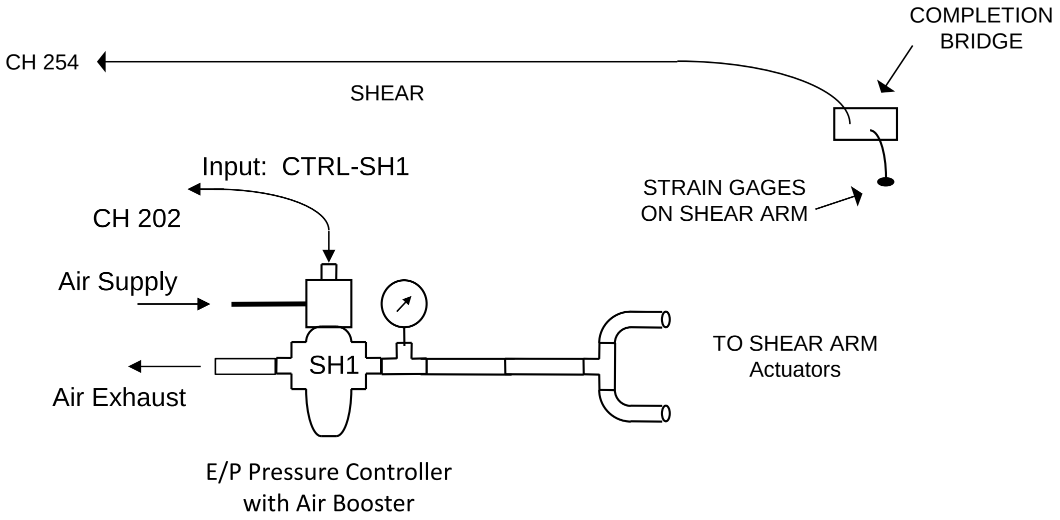


Figure 12. Shear load servo loop using air

FRAME LOAD: Figure 13 shows a typical example of a servo loop control for a hoop load mechanism using air, in which the input, output, and channel number designations are specific to AD4-1. The relative position of all 12-frame load mechanisms is shown in the figure. Radial and frame links apply loads to the specimen frame in proportion to the displacement of the actuator. The servo channel command signal AD4-1CTH is directed to the E/P valve. High air-volume E/P pressure controller, AD4-1, controls the flow of air from the supply to the actuator. In addition, the feedback signal from the E/P valve is routed back where pressure from the transducer AD-4-1F is calibrated to the frame hoop load measured using frame load cell AD4-1H.

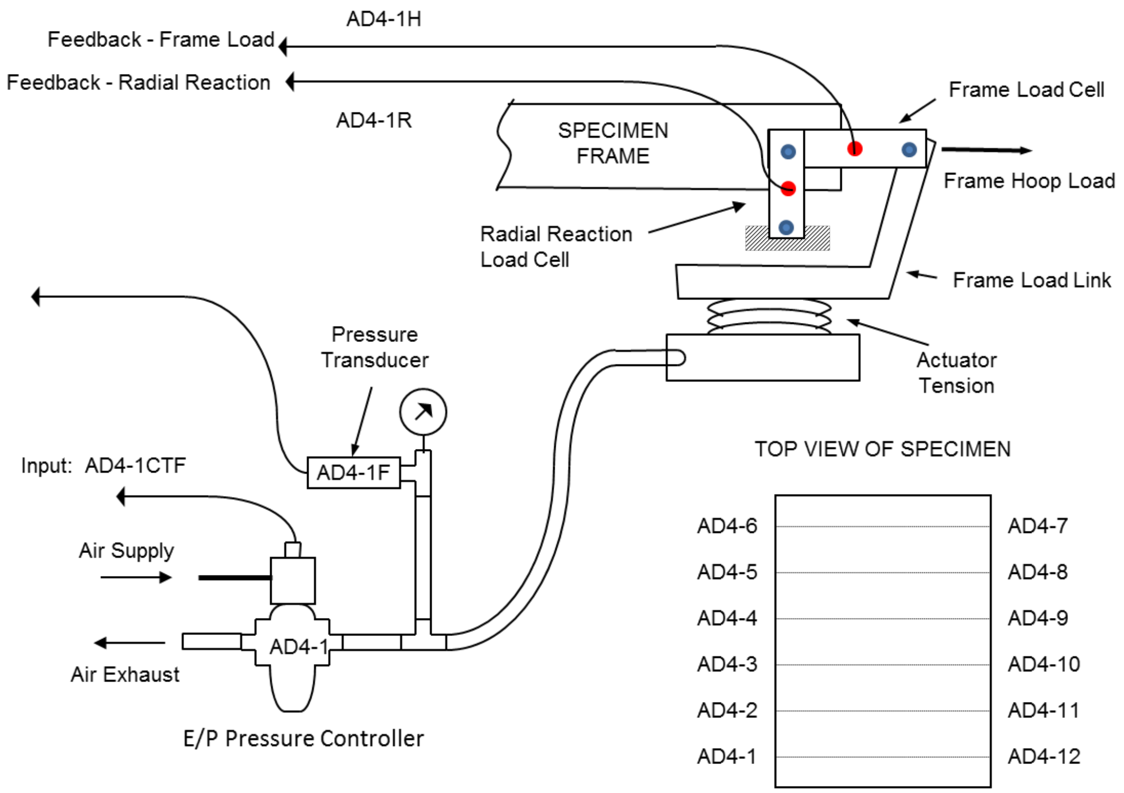


Figure 13. Frame load servo loop using air

CHAPTER III: SUPPORTING SYSTEMS FOR FASTER FIXTURE

HYDRAULIC SYSTEM

The system is designed to use both water and air as the hydraulic fluid, as described in the following two sections.

WATER SUPPLY SYSTEM

A stand-alone closed-loop water supply system is used to apply fuselage panel pressures up to 20 psi, as shown in figure 14. It consists of a 1050-gallon reservoir, a 40-HP pump capable of discharging water at 140-psi pressure into a supply manifold, and a radiator on the water return line that acts as a heat exchanger to keep the water temperature below 105ºF.

The water supply manifold consists of a 3-inch diameter pressure supply line, and a 4-inch diameter return line fabricate using CPVC and PVC tubing. The system is designed to have a maximum working pressure of 125 psig and a maximum flow rate of 250 gallons per minute using a 3-inch diameter type-III pressure regulated dome valve in the supply line. A return line scavenge pump maintains a vacuum to control depressurization rates and to control loads to zero applied pressure.

Two dome valves, SU1 and SU2, regulate the water flow of the system. The dome valves use air pressure applied above the valve diaphragm controlled by E/P valves to accurately regulate water outlet pressure. The water outlet pressure from the dome valve is identical to the air inlet pressure applied above the diaphragm by the E/P valve. The water pressure at the outlet of the dome valve SU1 is varied through the input control of the E/P valve, CTRL-SU1. The water flow path back from the return manifold to the reservoir through dome valve SU2 is controlled by E/P valve, CTRL-SU2.

AIR SUPPLY SYSTEM

The air supply system shown in figure 15 consists of an air compressor, a 400-gallon storage tank, and a compressed air dryer supplying dry filtered air with a minimum flow of 250 standard cubic feet per minute (SCFM). The system is designed to have a maximum working pressure of 125 psig to provide the pressure to drive all the load mechanisms: fuselage pressure, hoop, axial, frame, and shear loads. The air supply manifold consists of 1.5-inch diameter copper tubing and fittings welded together to provide the pressure to the axial, hoop, and frame load actuators connected using flex hoses. A volume booster value controls the applied fuselage panel pressure. The flow of air into the manifold and volume booster valve is controlled by inlet and exhaust solenoid valves.

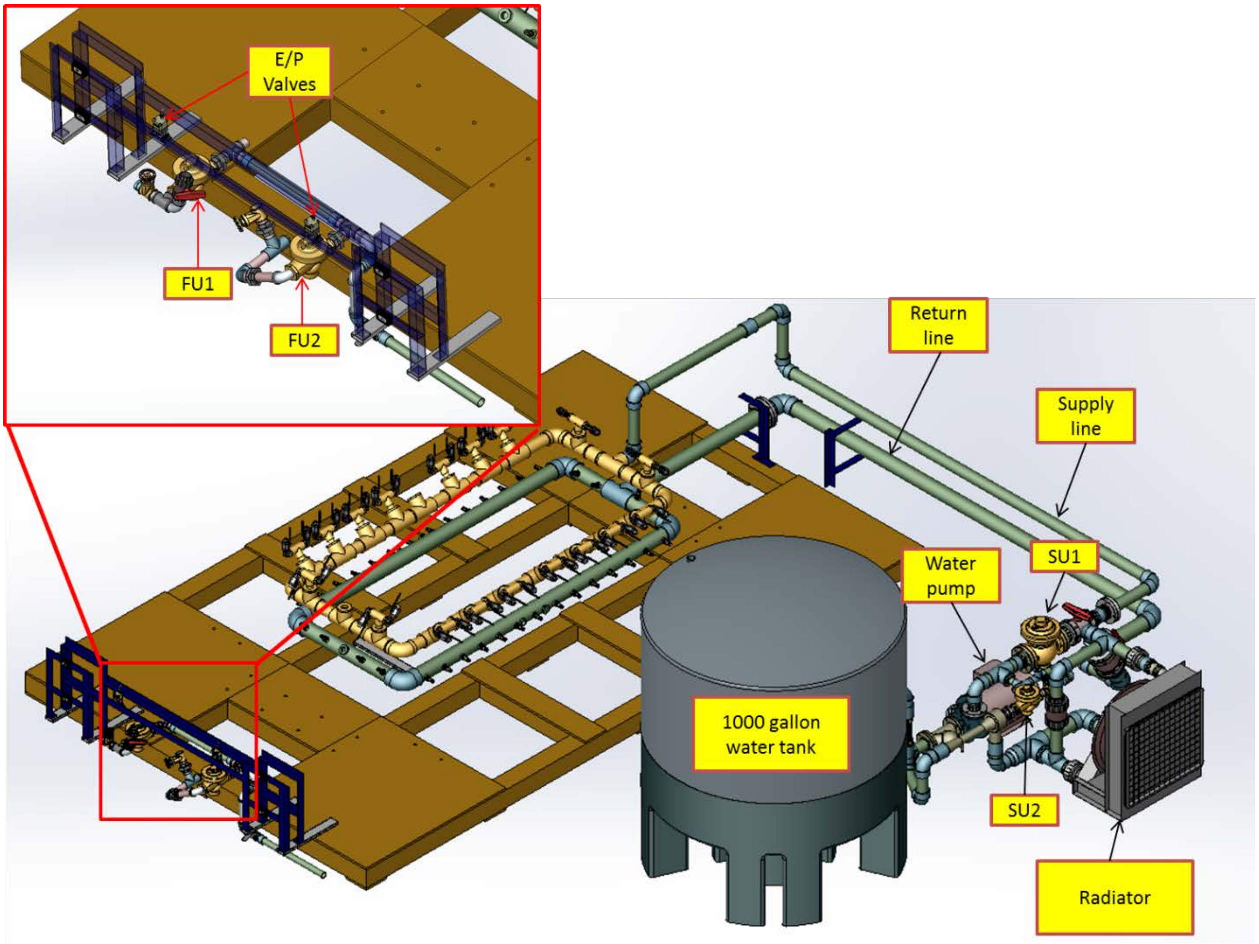


Figure 14. Water-supply system

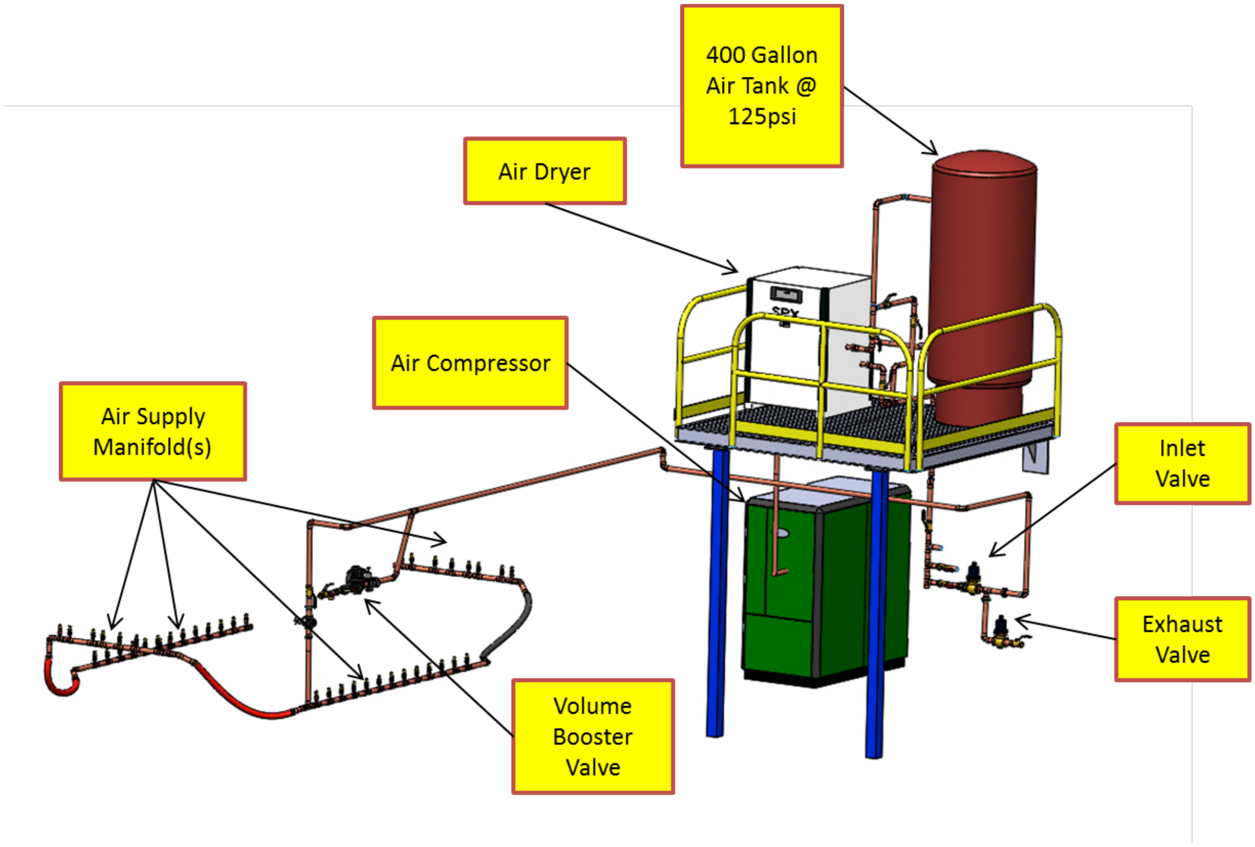


Figure 15. Air-supply system

ELECTRICAL SYSTEM

The general electrical power setup is as follows:

The 40-HP electric motor used in the water supply system requires a 460 VAC 3 phase at 60-Hz power supply.

1. The 1.5-HP motor for the heat-exchanger radiator of the water-supply system also requires 460 VAC 3 phase at 60-Hz power supply.
2. Remote environmental conditioner from Cincinnati Sub Zero (CSZ) requires a 208-Volt, 3-phase 60-Hz power supply. The full load rating of this unit is 86 amps.
3. Both the compressor and air-dryer of the air-supply system require a 460-VAC/3-phase/60-Hz power supply.
4. All supporting computer equipment requires common house power at 115 VAC, single phase at 60 Hz. An uninterruptible power source provides at least 30 minutes of full operation in the event of an unscheduled power shutdown.
5. MTS FlexTest® 200 control provides the powers to all instrumentation: 1) all strain gauge instrumentation (strain gauges, load links, and fuselage and rover pressure transducers) is powered by a 5-Volt DC supply, 2) frame loader pressure transducers is powered by a 12-Volt DC supply, and 3) Fairchild E/P valves are powered by a 24-Volt DC supply.

PNEUMATIC SYSTEM

The pneumatic system consists of an array of E/P servo valves interfaced with the air supply system described earlier, which provides an uninterrupted supply of compressed dry air. A schematic of the pneumatic system for a single loading mechanism using air is shown in figure 16. A high air-volume E/P pressure controller is directly connected to the air supply, which can provide an air inlet flow of 220 SCFM. The E/P valves convert a 0 to 10 Volt control input signal to a proportional 0 to 75 or 150 psi pressure output to inflate the actuator and apply load. On unloading, the actuator deflates, and the air pressure is exhausted through the valve back to ambient.

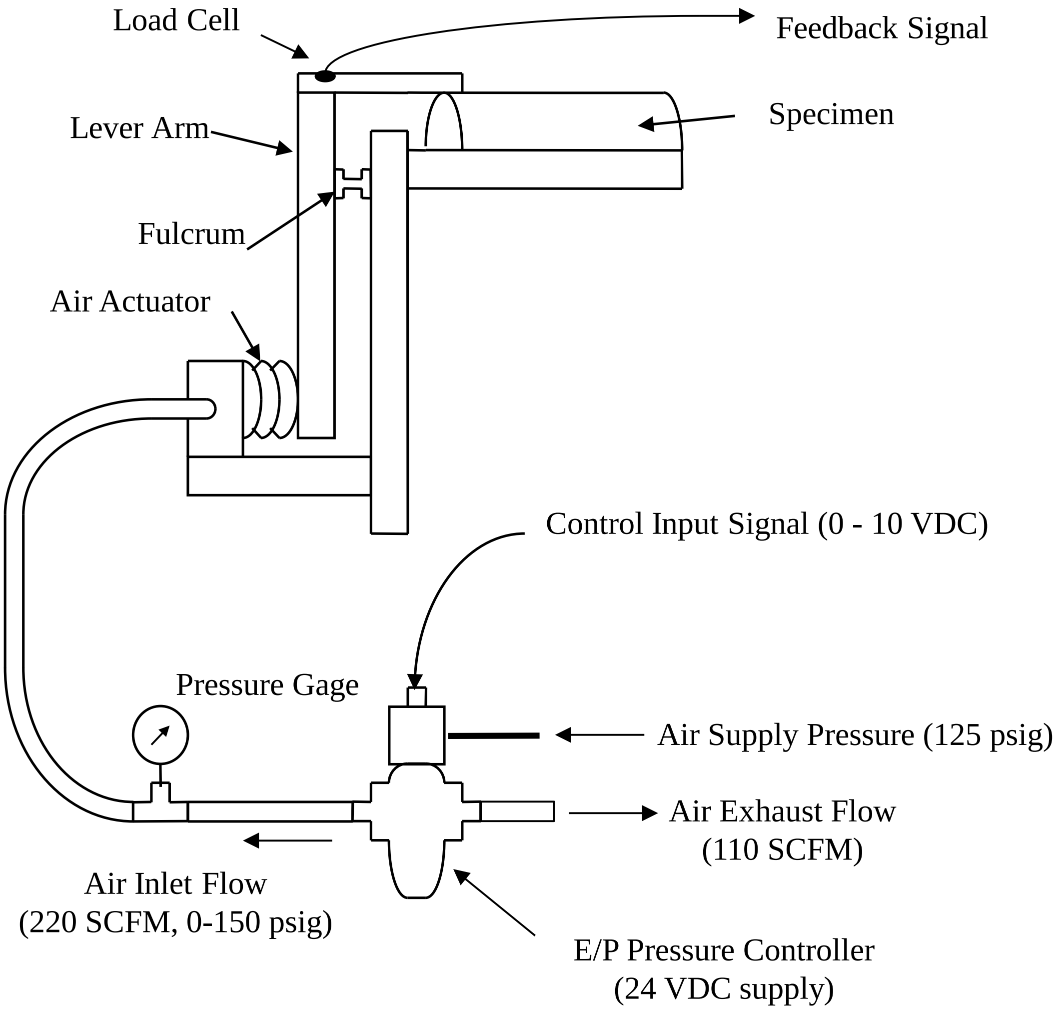


Figure 16. Schematic of pneumatic system

CHAPTER IV: CONTROL AND DATA-ACQUISITION SYSTEM

OVERVIEW

The original control and DAQ system was a customized hardware and software system programmed by Boeing circa 1998. In its original configuration, the HP E1421B 6-slot VXI mainframe used a VXI-743 controller card in its zero slot, four (4) HP/Agilent E1419 modules situated on the mainframe process the required data and control channels, and one (1) slot open for future expansion. The control and data-acquisition application programs and the graphical user interface were developed on an Agilent VEE (Visual Engineering Environment).

Although the system was proven to be robust and reliable, several concerns developed over time:

- Reliance: Highly complex, closed architecture systems that rely on Boeing engineers for changes or fixes. Dome valve failures, resulting in testing downtime for repairs.
- Obsolescence: System was designed and built using 1990s technology and became a problem. Drivers for several VXI Boards are and were not supported. Windows XP was the latest operating system that can be used with test boards. New replacement parts and boards are no longer available. Must rely on “used” parts market
- Performance: Load frequency was limited
- Maintenance: Dome valve needed rebuilding and parts replaced on annul basis

Consequently, there was an increased operational risk using the original hydraulic, control, and DAQ system, which necessitated an upgraded to current standards for structural testing as outlined in this chapter.

Table 2 lists all current control and DAQ channels. A photograph of the current system in the facility control room is shown in figure 17 and consists of the following major items::

1. Controller
2. DAQ System
3. Server PC, Client PCs, and Cables

Table 2. FASTER control and DAQ channel requirements

Parameter	Number	Device/Signal
Load Control	40:	
System Pressure	2	Electro-Pneumatic Valve: 0-10 VDC control, 12-32 VDC supply
Applied Fuselage Pressure	2	Electro-Pneumatic Valve: 0-10 VDC control, 12-32 VDC supply
Hoop Load	14	Electro-Pneumatic Valve: 0-10 VDC control, 12-32 VDC supply
Axial Load	8*	Electro-Pneumatic Valve: 0-10 VDC control, 12-32 VDC supply
Frame Load	12	Electro-Pneumatic Valve: 0-10 VDC control, 12-32 VDC supply
Shear Load	2	Electro-Pneumatic Valve: 0-10 VDC control, 12-32 VDC supply
Temperature and Humidity Control	6:	See Appendix B
On/Off	2	
Set-Point	2	
Processing Values	2	
Pressure Monitoring Transducers	15:	
System Pressure	1	Pressure Transducer: 0–10 VDC feedback, 0–120 PSI measure, 12–32 VDC supply
Fuselage Pressure (Box and Rover)	2	Pressure Transducer: 0–10 VDCfeedback, 0–30 PSI measure, 12–32 VDC supply
Frame Load	12	Pressure Transducer: 0–5 VDC feedback, 0- 120 PSI measure, 12–32 VDC supply
Load Cells	47:	
Hoop Load (Tension)	14	Load Cells: 0-2 mV/V feedback, 0–25000 lb, 5 VDC Supply
Axial Load at center (Tension-Compression)	4	Load Cells: 0–2 mV/V feedback, -20,000 to +-20000 lb, 5 VDC Supply
Axial Load at corners(Tension – Compression)	4	Load Cells: 0–2 mV/V feedback, -50,000 to +-50000 lbs, 5 VDC Supply
Applied Frame Load (Tension)	12	Load Cells: 0–1 mV/Vfeedback, 0–6900 lb, 5 VDC Supply

Table 2. FASTER control and DAQ channel requirements (continued)

Parameter	Number	Device/Signal
Frame Radial Reaction Load (T-C)	12	Load Cells: 0–1 mV/Vfeedback, 0–5000 lb, 5 VDC Supply
Shear Load	1	Load Cells: 0–?? VDC feedback, ?? lb, 5 VDC Supply
Strain Gauge Channels	200	Strain gauges: 5 VDC Supply
FlexDAC 20	128	
Agilent EX1629	48	
HBM MGCplus	24	
Temperature Sensors	8	0-1 VDC feedback, 5 VDC power supply
Humidity Sensors	8	0-1 VDC feedback, 5 VDC power supply
Thermocouples	24	
LVDT	12	± 2.2 VDC feedback, 5 VDC power supply
D/A Output	8	
A/D Input	8	
Digital I/O	24	

LVDT = Linear Variable Differential Transformer
I/O = Input/Output

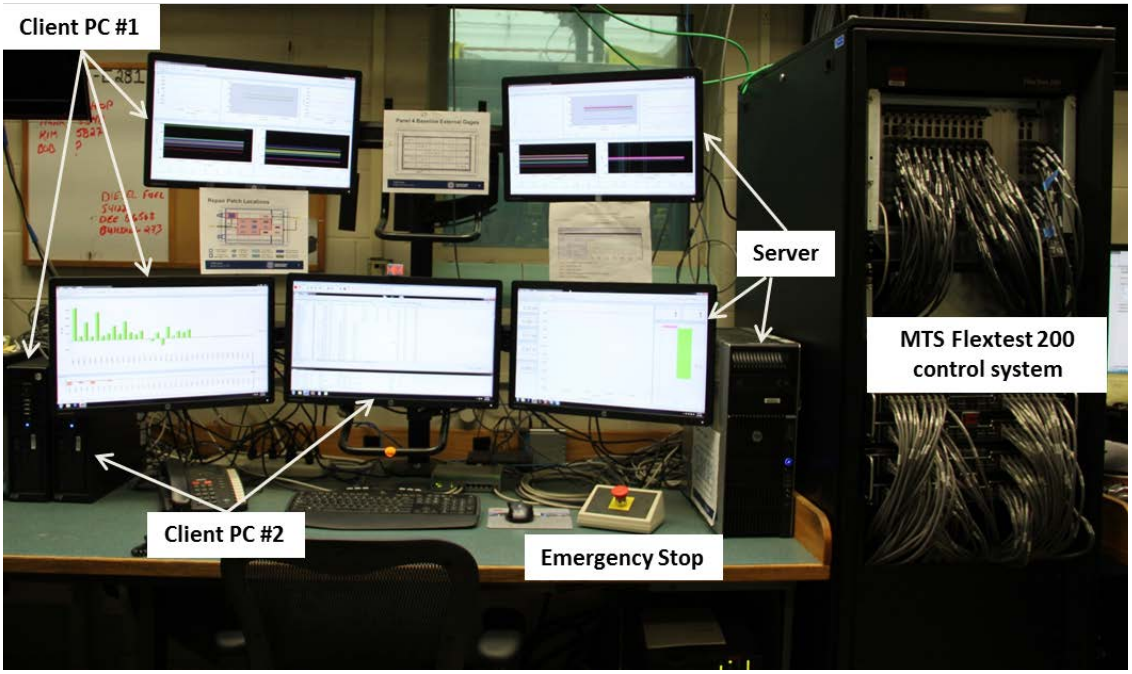


Figure 17. Picture of current control and DAQ system

The schematic of the complete control and DAQ system is shown in figure 18. Figure 19 shows the complete hardware configuration and components within the AeroPro™ software tree structure and includes a FlexTest 200 controller, two 64-channel FlexDAC 20 strain gauge consoles, a HBM MGCplus chassis including three eight-channel strain gauge boards and three eight-channel thermocouple boards, and a 48-channel Agilent VTI 1629 strain gauge conditioner.

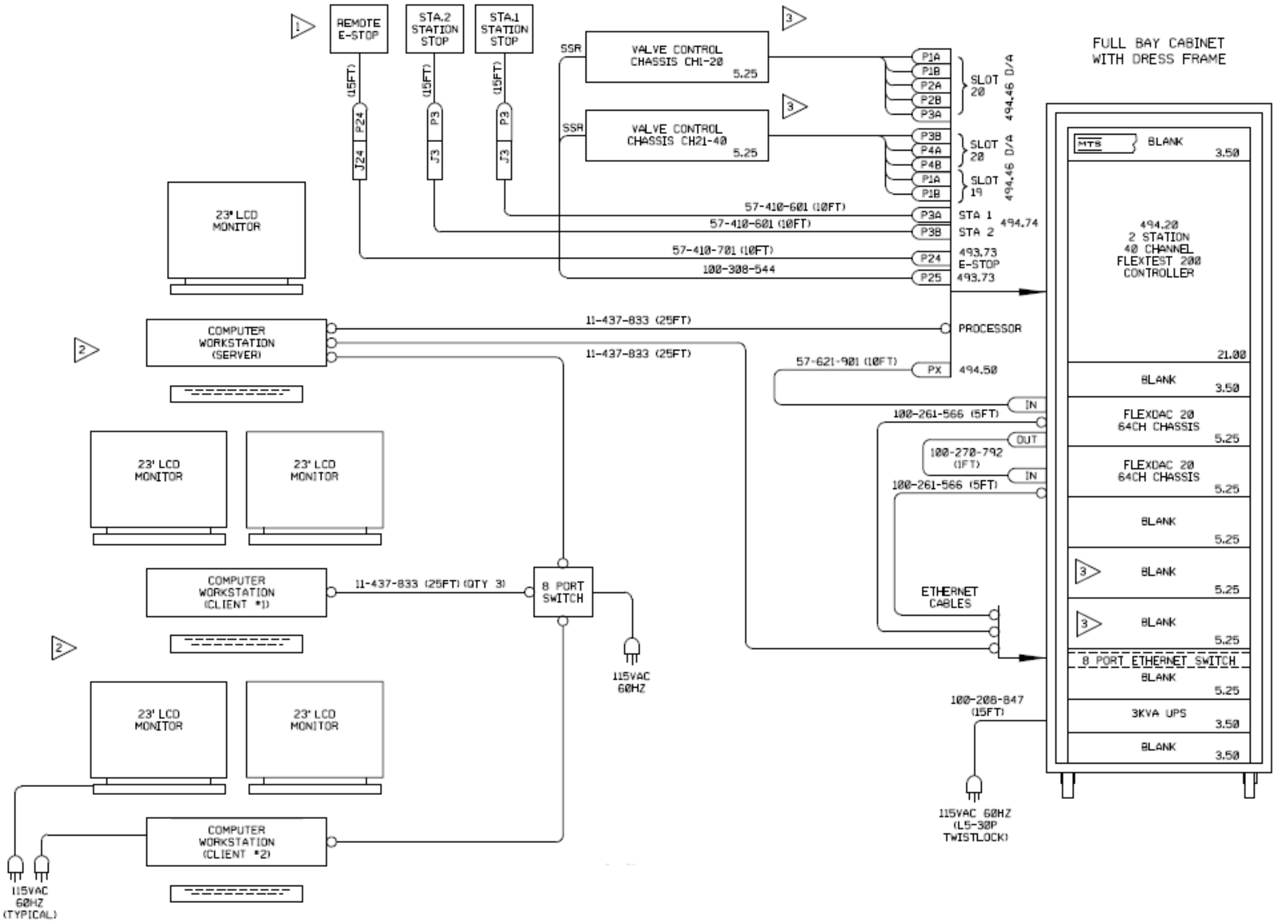


Figure 18. Schematic of complete control and DAQ system

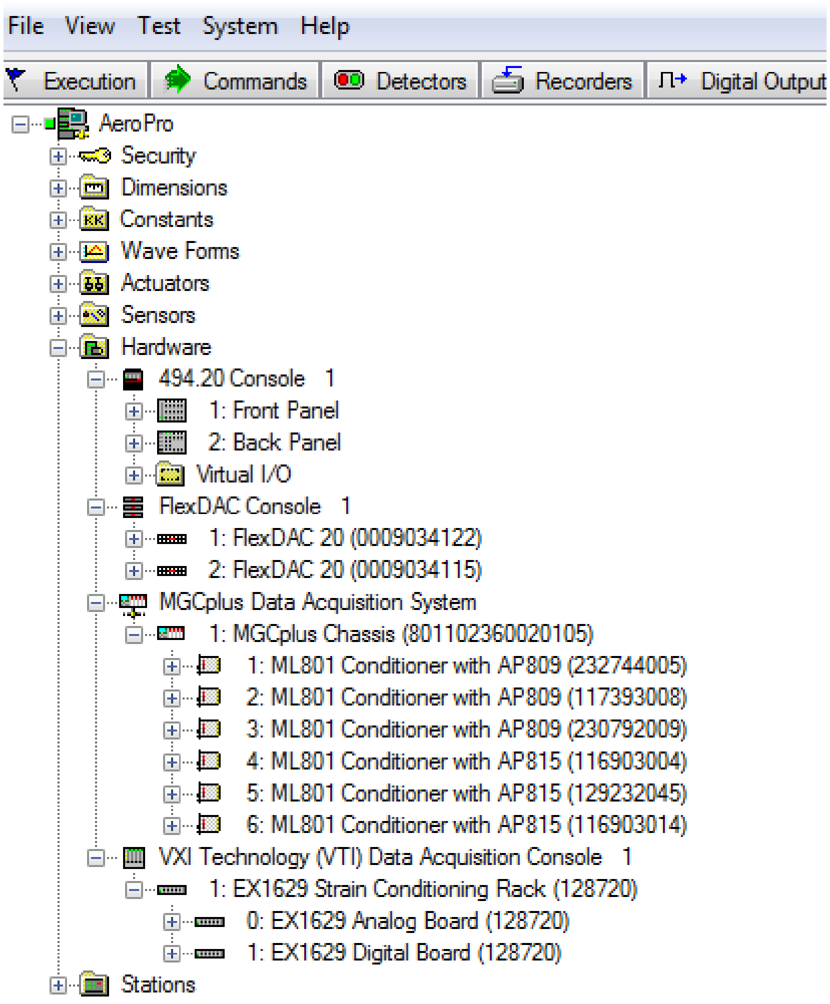


Figure 19. Hardware configuration in AeroPro software

CONTROL SYSTEM

CONTROLLER HARDWARE

The controller consists of a two-station MTS FlexTest 200 control system with 40 control channels [4]. The control instrumentation uses MTS model 494.20 mounted in full-height console, which houses all of the FlexTest 200 electronic components. The console contains a Universal Power Supply (UPS) to ensure that the tests shutdown in a fail-safe manner in the event of a main power failure. The cooling fan on the top ensures that the equipment stays cool.

Figure 20 and table 3 show the details of front panel Versa Module Europa (VME) slot configuration in 494.20 console. The VME slots are numbered 1 through 20, and this number is used to identify the hardware location within the AeroPro software.

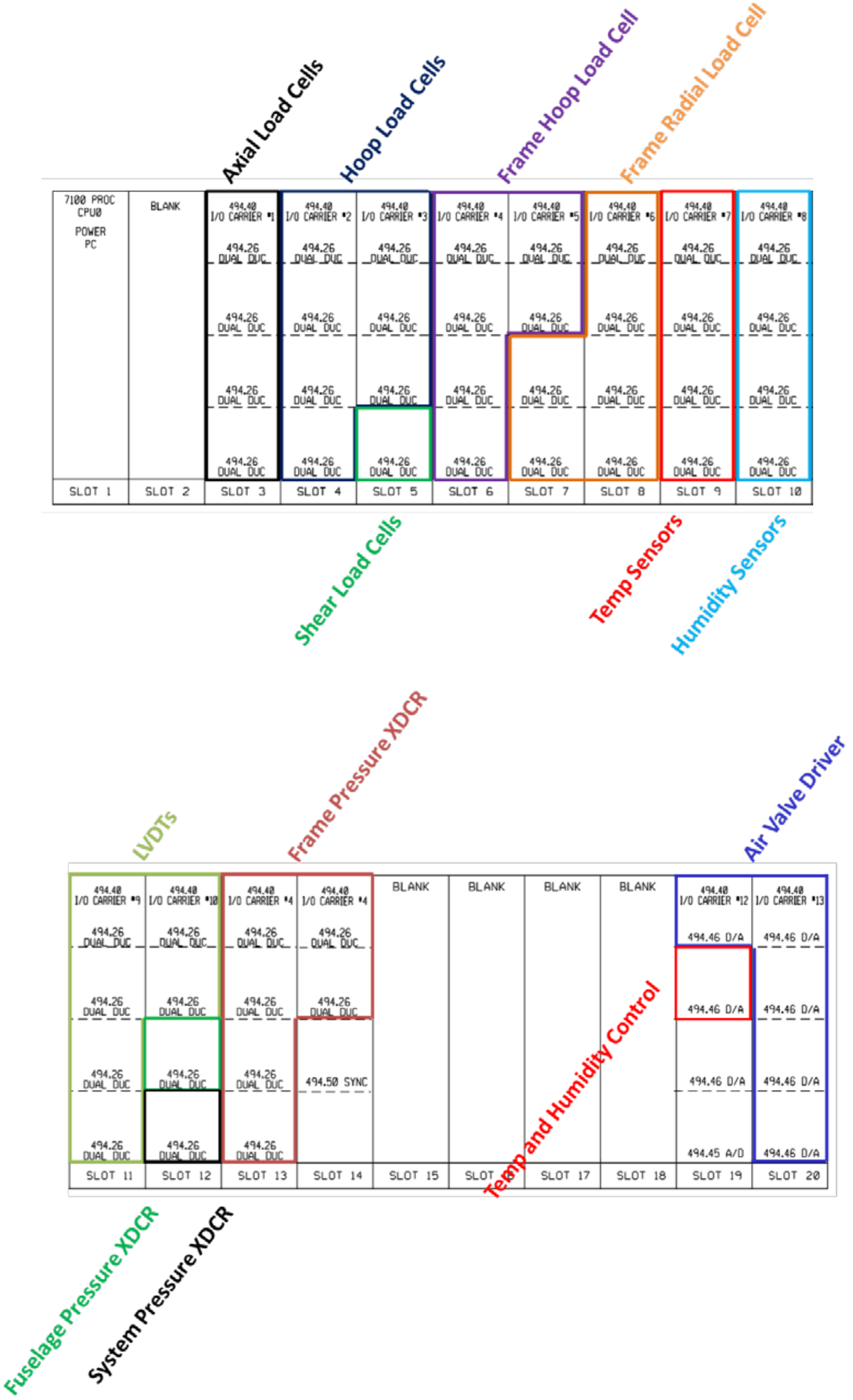


Figure 20. Front panel VME slot configuration

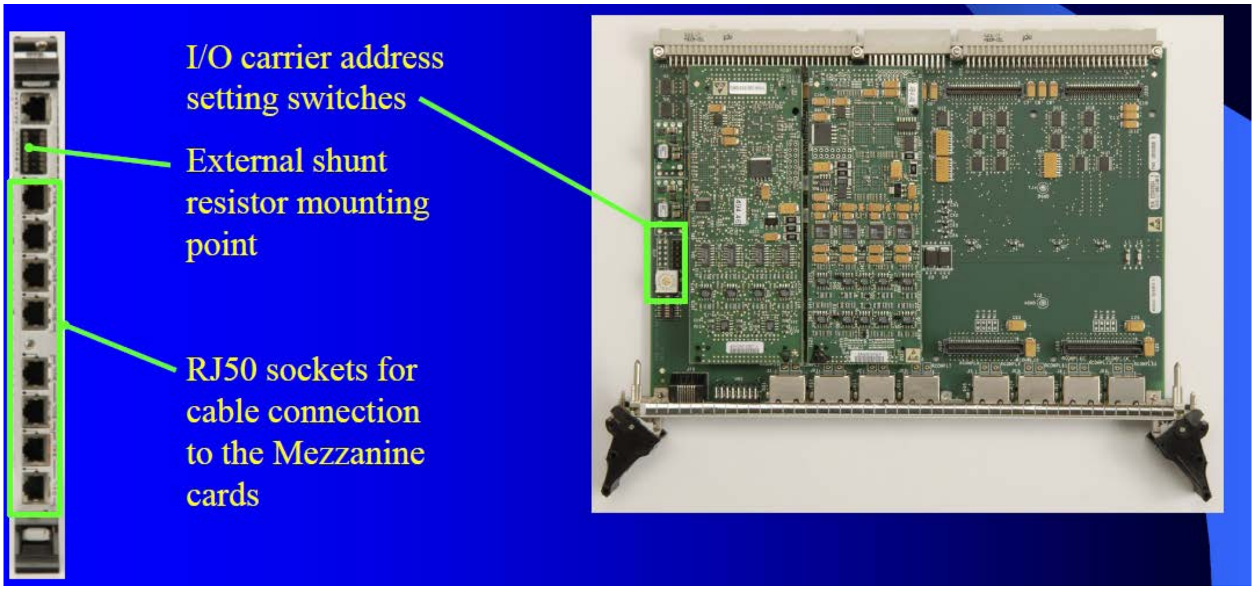
Table 3. Front panel VME slot configuration

Qty	Model#	Type
1	494.20	FlexTest 200 chassis
1		Full-height console assembly, stand-alone
1		Power PC processor
14	494.40	I/O carrier boards
46	494.26	Dual digital universal conditioner (DUC)
1	494.45	8-channel A/D input card
7	494.46	8 channel D/A output card
2	493.72	Digital input/output card
1	494.74	HSM interface
1	493.73	HPU interface
1	494.75	8-channel A/D input card
1	494.76	8-channel D/A output card

Slot 1 is used to connect to the server PC through Gigabit Ethernet. This board also has flash memory to record a second shutdown recorder file as redundancy for this critical data. Slot 2 remains empty for a standalone FlexTest. Slots 3 through 20 are used for 494.40 I/O carrier board, which is used to mount up to four “Mezzanine cards,”. Mezzanine card could be any type of digital universal conditioner (DUC) card. 494.26 dual DUC and 494.46 D/A converter card are used in the current system. Connections to the Mezzanine cards are through a standard RJ50 connector. If an amplifier is mounted on the I/O carrier, external shunt resistors may be mounted on the I/O carrier front, as shown in Figure 21 . The designation of RJ 50 port is shown in figure 22.

The 494.26 is a full-range DUC. The input signal range is ±10 Volts. This amplifier offers two inputs of state-of-the-art signal conditioning with a resolution greater than 19-bit analog-to-digital signal conversion and the ability to condition both AC and DC signals. Each amplifier is fully configurable through software.

The 494.46 D/A converter adds the ability to bring out any digital signal from within the controller as a high-level analog voltage signal to feed into any external system or measuring device at a signal resolution of 16 bits. The full-scale output of this converted signal is ±10 Volts. Each 494.46 D/A mezzanine card (2 RJ50 ports) supports eight output signals. The 494.46 plays a special role within the FlexTest. The FlexTest system uses a 494.46 converter and a multiple universal driver (MUD) to create a combination that provides the ability to drive eight channels of servo valve drive. To establish this relationship, it is necessary to feed signals from the 494.46 D/A converter to the MUD board with external cables. MUD is located on the lower back of the 494.20 console. The cables from MUD board run directly to the E/P valves, as shown in figure 23.



I/O carrier address setting switches

External shunt resistor mounting point

RJ50 sockets for cable connection to the Mezzanine cards

Figure 21. 494.40 I/O carrier

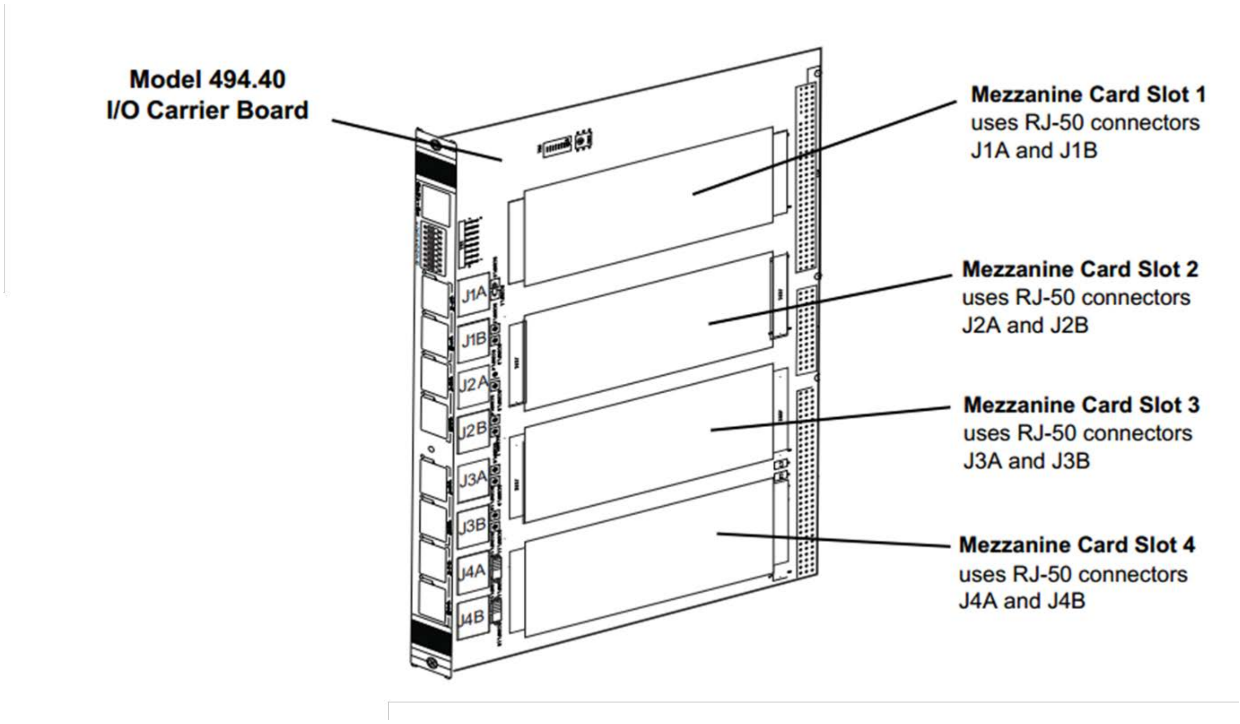


Figure 22. Designation of RJ 50 port in 494.40 I/O carrier with four mezzanine cards [4]

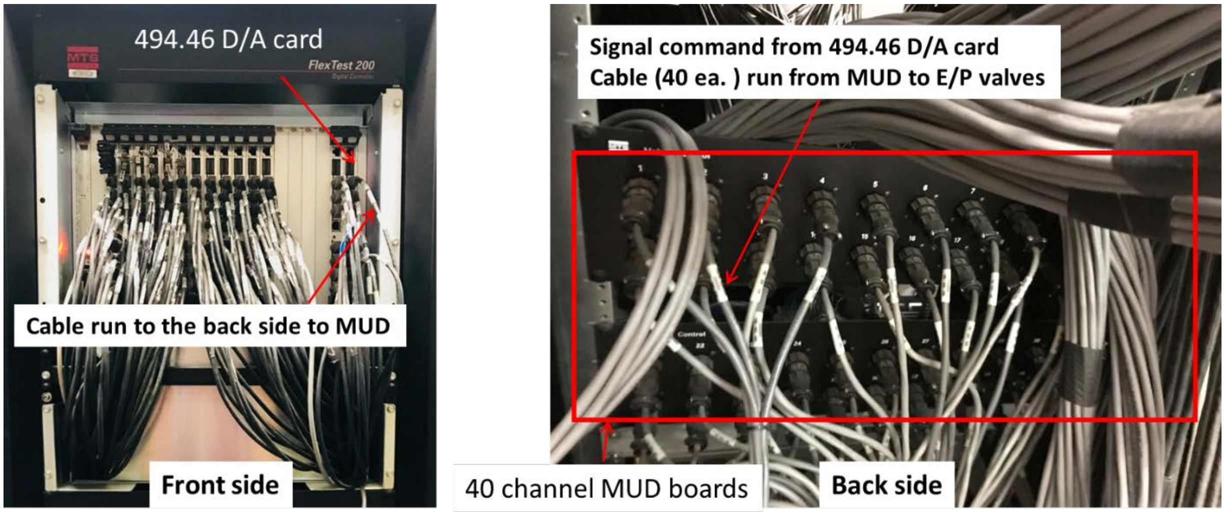


Figure 23. Connection between 494.46 D/A card to MUD

The back panel has transition slots numbered from 19 to 0, and this number is used to identify the hardware location within the AeroPro software, as shown in figure 24. The transition slots are numbered in the opposite order of the VME slot in the front side of the 494.40 chassis.

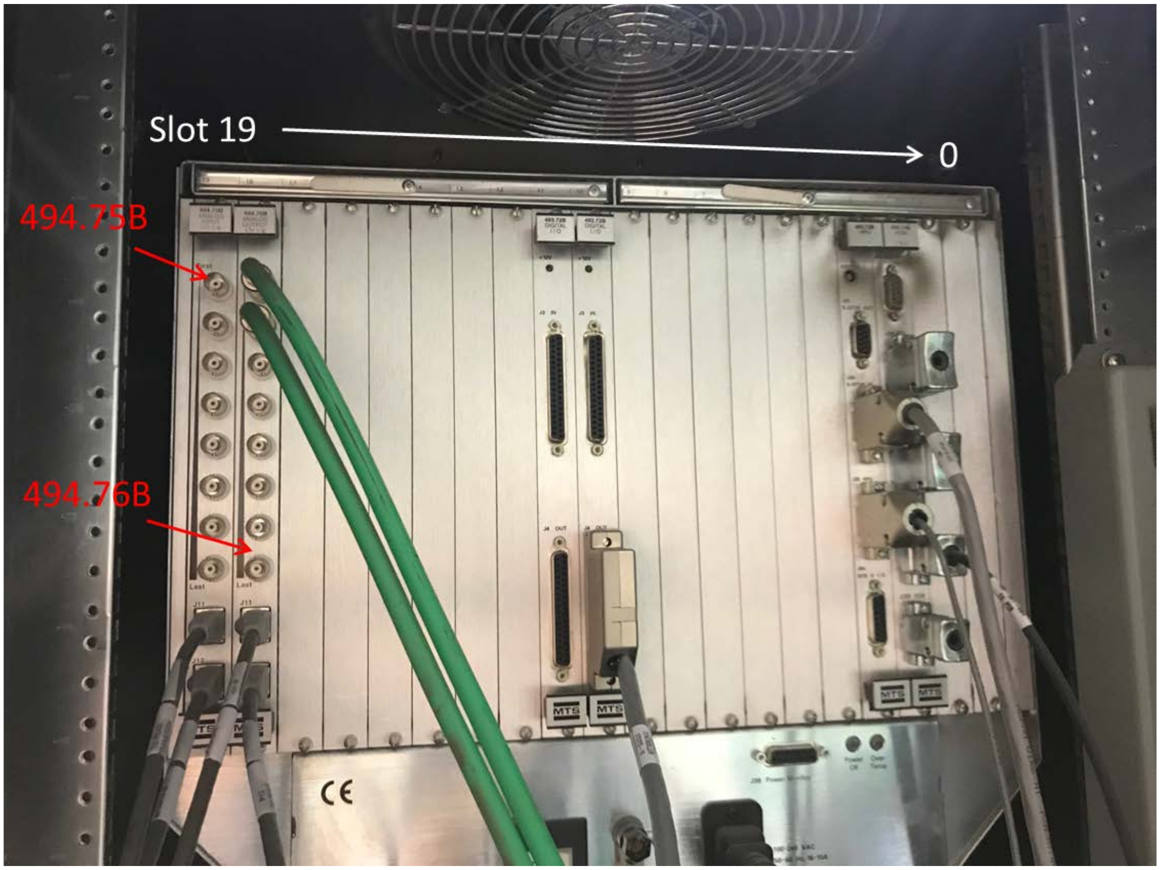


Figure 24. Picture of the back panel

The hydraulic pressure unit (HPU) provides the ability to control an MTS pump and controlling the overall interlock chain for the FlexTest (all stations). Any FlexTest box with hydraulic control must have this card (dependent boxes in a multi-box configuration do not have this card).

The hydrologic service manifold (HSM) is a one-slot card and provides individual hydraulic control and safety interlock for two stations.

Transition slots 14 through 5 are free to be populated with any of the following transition boards:

- 493.72 Digital Input Output Board
- 494.76 Analog Output Breakout Panel
- 494.75 Analog Input Breakout Panel

The 494.75 analog output/input boards are simply a breakout facility to make simple connection to analog inputs or outputs on a standard BNC connection. The card draws no power and does not require hardware definition. The analog input board can also be ordered with a built-in signal filter.

CONTROL LOOP

The control channels include operation of the E/P valves using a full proportional integral derivative (PID) closed-loop feedback error-control process, as shown in the block diagram in figure 25.

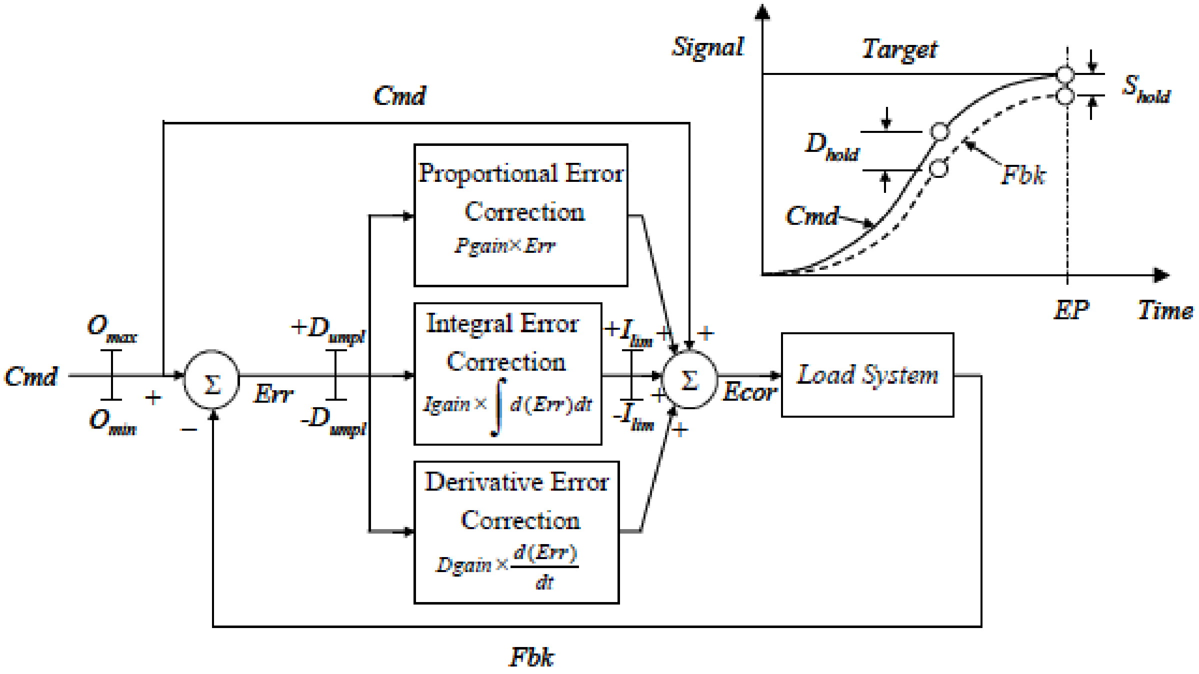


Figure 25. Schematic of the PID closed-loop error-correction process

In the figure, lines indicate the path of a signal, ± the sign of the signal, Σ within a circle designates a summation junction of signals and the boxes a process done to the signal. The controlling signals shown in the figure are the command signal, Cmd, the feedback signal from the loading system, Fbk, and the error signal Err, which is the difference in the Cmd and Fbk signals. The error signal is used to adjust the response of the load system using proportional error-correction, integral error-correction, and derivative error-correction processes. The proportional error-correction process scales the error by parameter Pgain to obtain a quick response. The integral error-correction process takes the history of the error and integrates over time and scales to parameter Igain to reduce steady state error of the response. The derivative error-correction process takes the rate of change of the error and scales to parameter Dgain to help damp the response. The final control input signal, Cin, is the summation of the Cmd signal, and the signals from the proportional, integral, and derivative error correction processes given by:

$$Cin = Cmd + Pgain \times Err + Igain \times \int sign(Err)dt + Dgain \times \frac{d(Err)}{dt}$$

This signal is then used as input to the E/P value of a loading system, as shown in figure 25. Limit parameters are used to ensure that the system does not run unstable or inadvertently overload the system. These parameters include maximum and minimum limits on the command signal, Omax and Omin, a limit range on the integral error correction, ±Ilim. In addition, a limit is set to shut the system down if the error exceeds parameter ±Dumpl.

A target signal specifies the level the command signal must obtain over a certain time interval called the end level. The ramping functions are used to define the path the command signal follows to get to the target level, Sine, Ramp, or user defined waveform. To synchronize the loading mechanisms, two other control parameters are used: the static null pacing and the dynamic null pacing. The null pacing parameters are limits on the amount of error between the command signal and the feedback signals at the target signal end point and between the target signal end points, respectively. If the error values for all test channels are not within their error bands within this timeout period, then the associated timeout event occurs.

DATA-ACQUISITION SYSTEM

MTS FLEXDAC 20

Two 64-channel FlexDAC 20 remote strain-gauge conditioner units are used, which provide a total of 128 strain-gauge channels, as shown in figure 26. Strain-gauge cables connect to the unit with standard RJ-45. The excitation, filtering, bridge type, bridge completion, and limit detection are programmable on a per-channel basis [5].

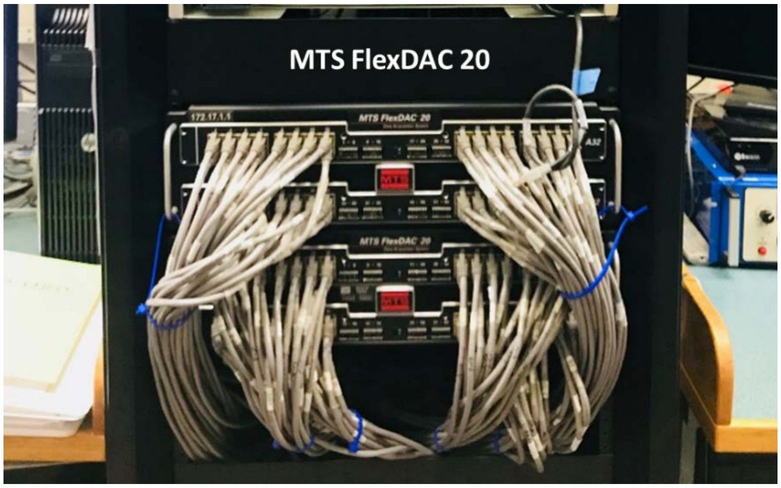


Figure 26. Picture of MTS FlexDAC 20

AGILENT EX1629

This is a 48-channel DAQ system from Agilent. EX1629 supports quarter-bridge (120 Ohms, 350 Ohms, or user defined), half-bridge, or full-bridge transducers, and voltage, ratiometric, and linear measurements, as shown in figure 27. The options of programmable excitation and selected bridge completion are all integrated into unit and configurable per channel [6].

Figure 27. Picture of VTI EX1629

HBM MGCPLUS

This is a standalone DAQ system developed by HBM, as shown in figure 28. The current configuration has three AP805 strain-gauge boards and three AP801 thermocouple boards. All use ML801 amplifiers on the front side of the chassis [7]. The license was purchased to synchronize MGCplus with the MTS system.

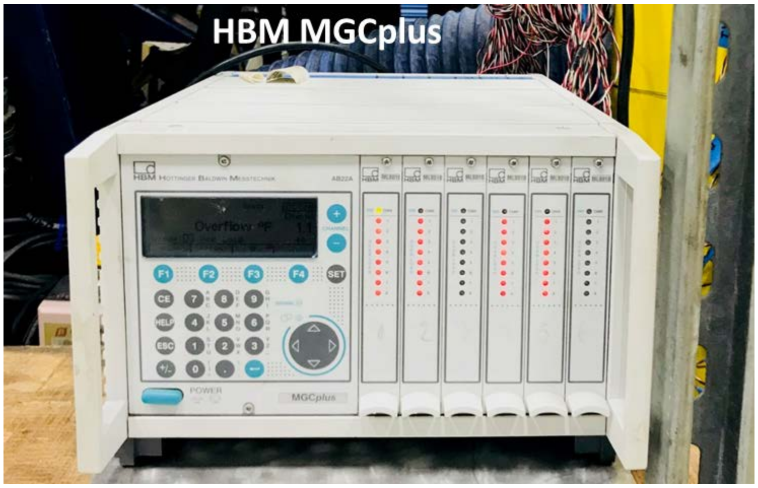


Figure 28. Picture of HBM MGCplus

The scanning rate of the data acquisition is programmable in AeroPro software. The maximum rate of scanning is 256 Hz.

PCS AND CABLES

The details of PCs and cables are as follows:

Aeropro server PC

- Intel Xeon 6 Core E5-2640, 2.5 GHz processor
- (2) 500 GB sATA hard disks w/ RAID 1
- 8 GB memory
- DVD R/W drive
- (3) PCIe Ethernet 1 Gb connection
- 23" LCD flat panel monitor
- Operating System: Windows 7 64-bit
- Windows 7 recovery disk

AeroPro Client PC

- Intel i5 4570 3.2 GHz processor
- 8.0 GB memory
- (2) 500 GB sATA III hard disks w/ RAID 1
- Integrated PCIe Ethernet 1Gb connection
- DVD R/W drive
- Dual 23" LCD flat panel monitors
- Operating System: Windows 7 64-bit
- Windows 7 recovery disk

Cables

- Qty: 40—Drive cables–55 ft
- Qty: 4—Temp/humidity command–55 ft
- Qty: 48—Load cell cables–55 ft
- Qty: 16—Pressure cell cables–55 ft
- Qty: 16—Temp/humidity sensors–55 ft
- Qty: 12—LVDT cables–55 ft
- Qty: 4—DIO cables–55 ft

CHAPTER V: GRAPHIC USER INTERFACE

AeroPro software was used to create and define test setups, including test channels, test stations, and data acquisition. The operator can define test sequences, control test operation, display test status, and plot test data. The software features explorer-like tree view, drag and drop capability, multi-level user security, and customizable user interface. The controller interface provides quick access to configuration, calibration, load sequence, and test execution. Unlike the original VXI interface, tuning can be done while the test is running. Both static and fatigue tests are accessible from the same user interface. The test spectrum can include events to trigger other systems, including an ARAMIS camera using digital output. The data can be saved at specified points during the test and exported together or separately. For example, the static data can save when feedback reaches the command target and can save another point after 10 seconds. The details of user interface are provided in appendix C.

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5. MTS. (2018). *MTS FlexDAC20 Data Acquisition System.* Available at: http://www.mts.com/cs/groups/public/documents/library/dev_002324.pdf

6. VTI Instruments. (2017). *Agilent VTI EX1629 Manual*

7. HBM. (n.d.). *HBM MGCPlus Manual*

APPENDIX A—ENVIRONMENTAL SYSTEM

Overview

In a joint effort, the FAA and The Boeing Company investigated the safety and structural integrity issues of adhesive bonded repair technology through test and analysis of metallic B727 fuselage panels using the Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) facility. The program objectives were to characterize the fatigue performance of bonded repairs under simulated service load conditions and to investigate tools for evaluating and monitoring the repair integrity over the life of the part. This included the effect of environment in terms of temperature and humidity.

Working with Boeing, Modifications were made to fully integrate an environmental system with the FASTER fixture to apply synchronous mechanical-temperature-humidity load profiles. The environmental system consists of a remote conditioner to control temperature and humidity, and a chamber on the test panel to contain the environment, as shown in figure A-1. The environmental system was fully integrated with the fixture's mechanical loading system for synchronous mechanical-temperature-humidity loading profiles. With this new enhancement, fuselage panels can be tested under a variety of operating environments ranging from hot-wet (165°F and 85-95% humidity) to extreme cold (-50°F) conditions.

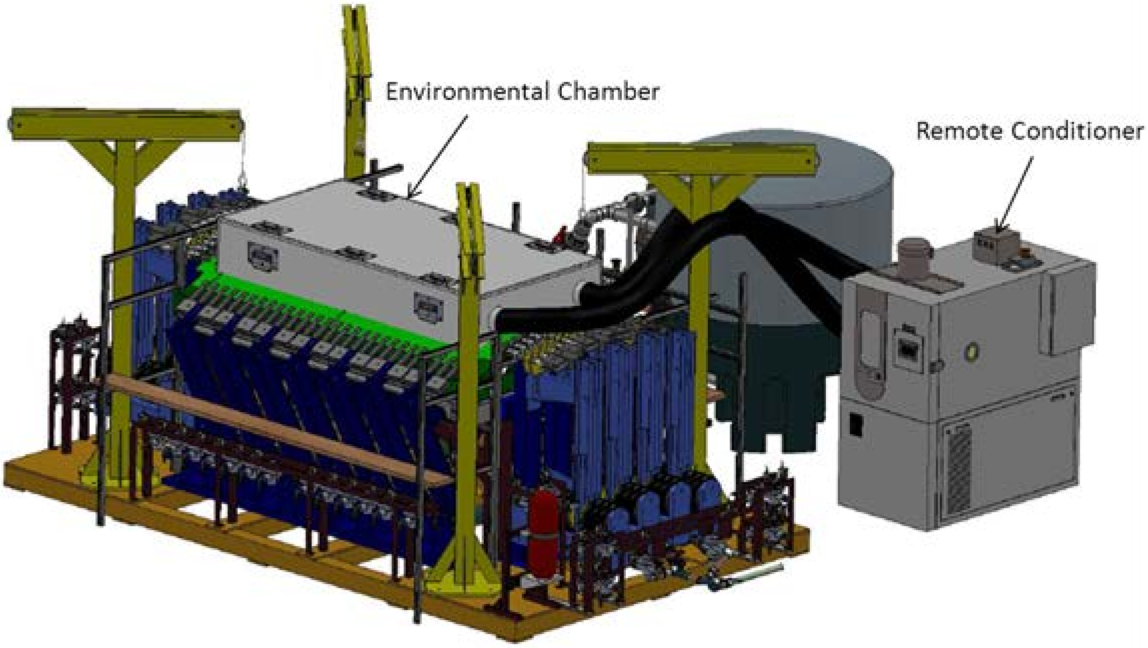


Figure A-1. FASTER fixture for mechanical and environmental loading of fuselage panels

The system consists of an environmental chamber and a remote conditioner with the following requirements:

- Closed loop conditioning control at remote location
- Heating, cooling, and humidity control

- Use of ambient pressure air for control

The environmental test conditions are shown in table A-1. Figure A-2 shows the conceptual design for the chamber.

Table A-1. Environmental test requirements for test panel

Condition	Temperature	Relative Humidity
Operational Environmental		
Hot-Dry	96F (+/-5F)	3-8%
Hot-Wet	96F (+/-5F)	85-95%
Cold	-25F (+/-5F)	Tending toward saturation
Post Fatigue Residual Strength		
Hot-Dry	165F (+/-5F)	3-8%
Hot-Wet	165F (+/-5F)	85-95%
Cold	-65F (+/-5F)	Tending toward saturation

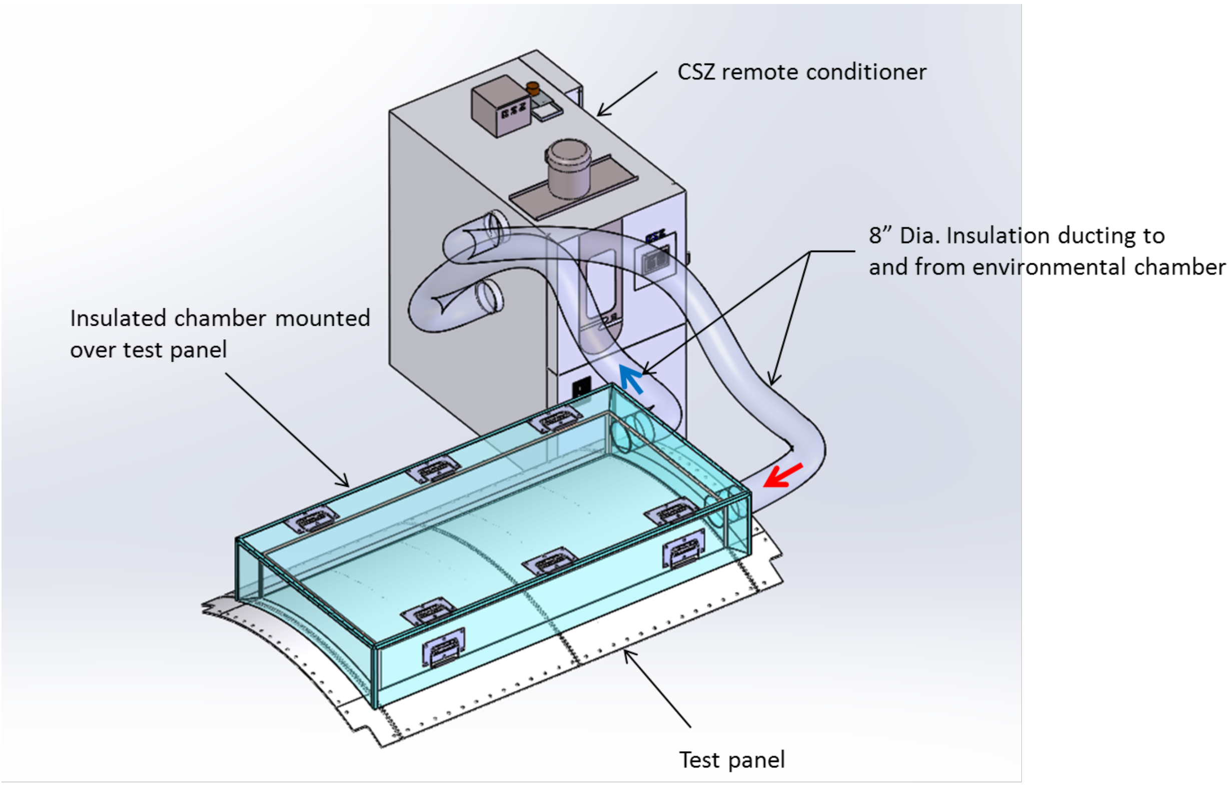


Figure A-2. Conceptual design of enviormental chamber on the test panel

Equipment Specification

Environmental Chamber: An environmental chamber was designed to contain the temperature and humidity conditions outlined in table A-1 to a 4-by-9-by-1-foot volume covering the outer surface of the fuselage panel, as shown in figure A-3. The chamber was built using prefabricated insulated panels constructed with 4-inch-thick expanded polystyrene foam core insulation material having a thermal resistance rating R of 4.17 per inch thickness, sandwiched between 26-gauge galvanized polar white stucco embossed steel sheets, as shown in figure A-4. An airtight interface between the chamber and fuselage panel was accomplished using a double layer of rubber bulb seals and 1-inch-thick weather-resistant neoprene foam. The chamber is secured to the fuselage panel with mechanical straps.

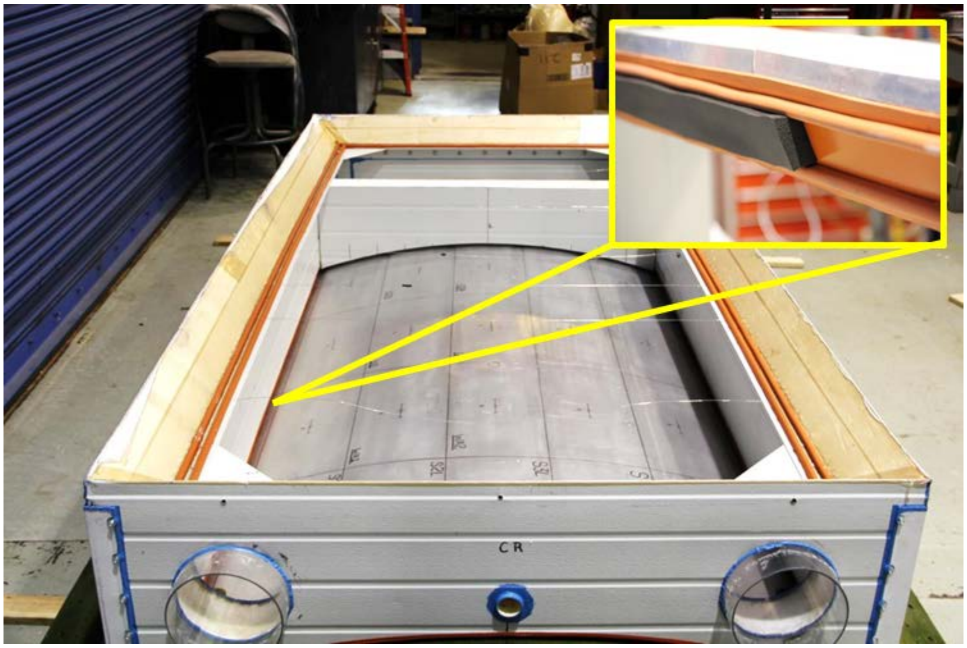


Figure A-3. Environmental chamber with airtight seal; insert shows the bottom seal consisting of rubber bulb seal and weather-resistant neoprene foam

Figure A-4. Insulation material for environmental chamber

Remote Conditioner: A remote conditioner is used to generate the temperature and humidity conditions in the environmental chamber to the specifications in table A-1. For this, a commercially available unit was used, namely a Cincinnati Sub-Zero (CSZ) Z-plus remote conditioner (P/N Model ZPRCHS-816-6-6-SC/AC), which can be operated both locally and remotely. Locally, the unit has a built-in 30 inch^3 volume chamber used to condition coupons and small components. Remotely, the unit is interfaced with the environmental chamber using a pair of 8-inch inside-diameter insulated ducts, one inlet and one outlet, for a closed-loop environmental conditioned system. The performance as a remote conditioner is shown in figure A-5. A control interface was added to the existing FASTER graphic user interface to allow for full operation of the remote conditioner, including system startup, defining temperature and humidity profiles, adjusting set point values, and setting tolerances while running a fatigue test.

An acceptance test was conducted to verify the functionality of the integrated system. An array of sensors was used throughout the environmental chamber to measure the temperature and humidity distribution. The fully integrated system was run to verify that all conditions in table A-1 were met (i.e., at steady-state, both temperature and humidity were evenly distributed throughout the environmental chamber within ±3°F and ±5% RH, respectively).

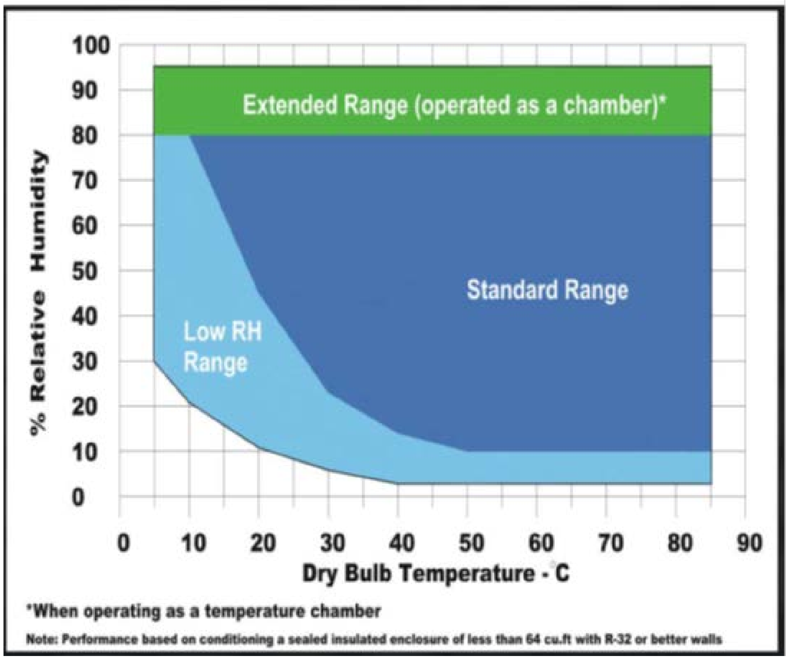


Figure A-5. CSZ remote conditioner humidity performance

The remote conditioner, a CSZ Z-plus remote conditioner, is connected to the environmental chamber through two insulated, 8-inch diameter ducts that facilitate passage of conditioned air into and out of the environmental chamber. The section of the chamber connected to the ducts is the conditioned region, whereas the section on the other side of the internal vertical wall is the ambient region. The two internal volumes allow for simultaneous testing of both conditioned and unconditioned repairs to a fuselage structure.

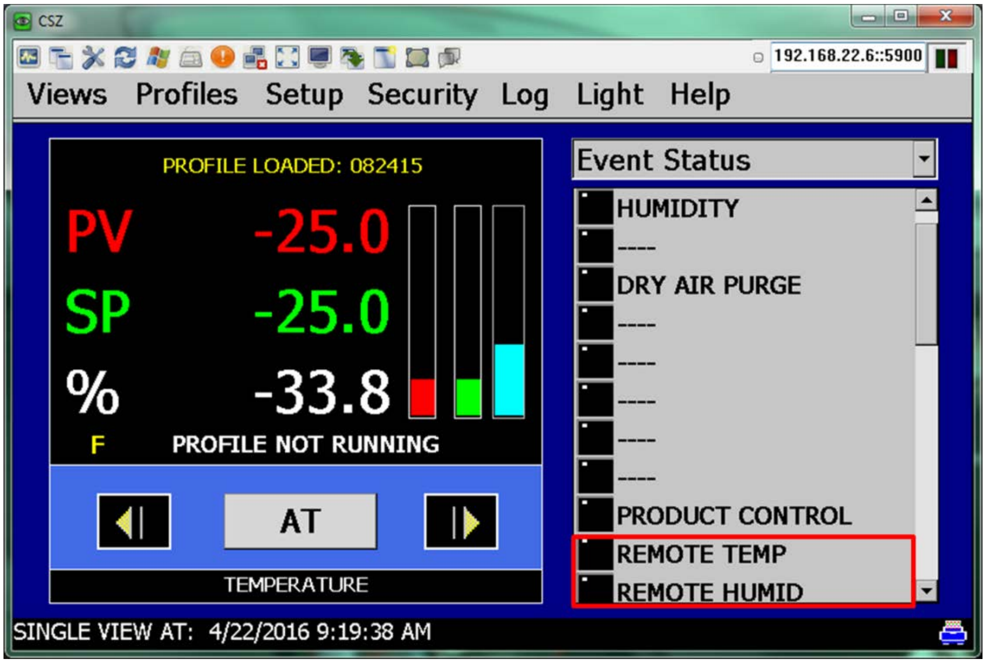
The environmental chamber, which is strapped to the external surface of the fuselage structure, as shown in figure A-6, consists of four external vertical walls and a lid that define its external volume and an internal vertical wall that separates the internal volume into two regions, as shown in figure A-3: 1) the conditioned region, and 2) the ambient region. Each wall is comprised of polystyrene foam core insulation sandwiched between 26-gauge galvanized steel sheets. An impermeable interface between the environmental chamber and the external surface of the fuselage structure was achieved using rubber bulb seals and weather-resistant neoprene foam.

Figure A-6. Environmental chamber strapped to fuselage panel

General Control and Data-Acquisition Instrumentation:

The environmental system was fully integrated with the fixture’s mechanical loading system for synchronous mechanical-temperature-humidity loading profiles.

CSZ remote conditioner uses the EZT-570i environmental controller, which can have up to five analog inputs for remote setpoint inputs. EZT-570i uses chamber event 11 through 15 for remote setpoint 1 through remote setpoint 5. A digital input card (P/N 36662), a digital output card (P/N 36663), and an analog card (P/N 36638) were installed to control and monitor the remote conditioner. Event 11 is used for remote temperature control, and event 12 is used for remote humidity control. The events must be enabled for use. By default, the EZT-570i uses the setpoint entered manually from the loop view screen. If the event is enabled, the setpoint selected for the input is overwritten and controlled by the input signal. Figure A-7 shows the loop view screen where the events can be enabled. Check CSZ-570i user manual 8.7 for more details of optional analog and digital inputs and outputs.



PROFILE LOADED: 082415

PV -25.0

SP -25.0

% -33.8

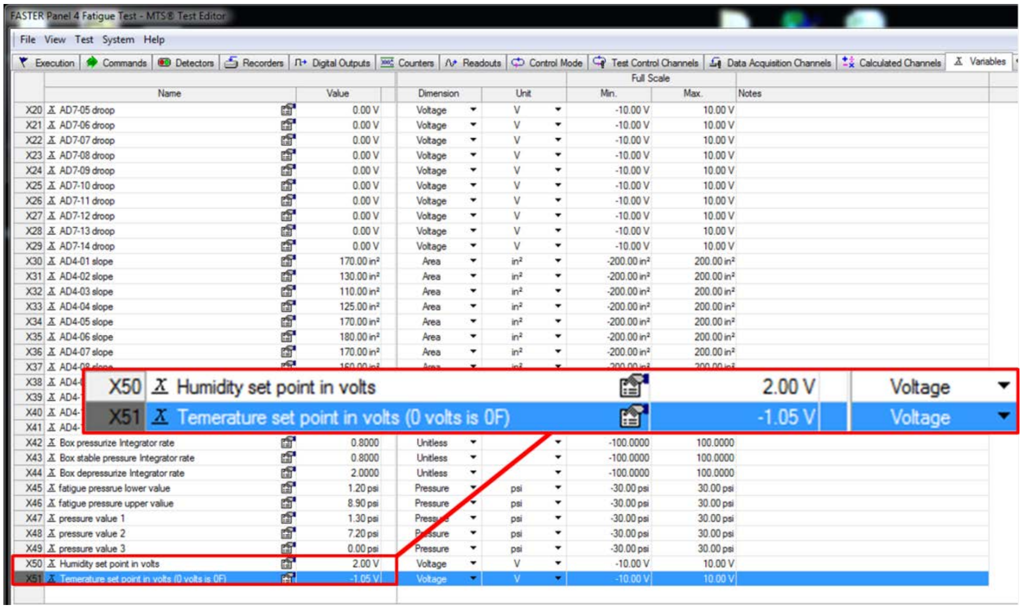
F PROFILE NOT RUNNING

- HUMIDITY
- ----
- DRY AIR PURGE
- ----
- ----
- ----
- ----
- ----
- PRODUCT CONTROL
- REMOTE TEMP
- REMOTE HUMID

SINGLE VIEW AT: 4/22/2016 9:19:38 AM

Figure A-7. Remote control event setting

The Volts signal from 0 to 10V is used as input signal for both temperature and humidity. As the analog input signal is varied, it will provide a linear setpoint change from the minimum to maximum value over the range of the input. Figure A-8 shows the locations to change the setpoints for temperature and humidity in AeroPro software.



	Name	Value	Dimension	Unit	Full Scale Min.	Full Scale Max.	Notes
X20	AD7-05 droop	0.00 V	Voltage	V	-10.00 V	10.00 V	
X21	AD7-06 droop	0.00 V	Voltage	V	-10.00 V	10.00 V	
X22	AD7-07 droop	0.00 V	Voltage	V	-10.00 V	10.00 V	
X23	AD7-08 droop	0.00 V	Voltage	V	-10.00 V	10.00 V	
X24	AD7-09 droop	0.00 V	Voltage	V	-10.00 V	10.00 V	
X25	AD7-10 droop	0.00 V	Voltage	V	-10.00 V	10.00 V	
X26	AD7-11 droop	0.00 V	Voltage	V	-10.00 V	10.00 V	
X27	AD7-12 droop	0.00 V	Voltage	V	-10.00 V	10.00 V	
X28	AD7-13 droop	0.00 V	Voltage	V	-10.00 V	10.00 V	
X29	AD7-14 droop	0.00 V	Voltage	V	-10.00 V	10.00 V	
X30	AD4-01 slope	170.00 in²	Area	in²	-200.00 in²	200.00 in²	
X31	AD4-02 slope	130.00 in²	Area	in²	-200.00 in²	200.00 in²	
X32	AD4-03 slope	110.00 in²	Area	in²	-200.00 in²	200.00 in²	
X33	AD4-04 slope	125.00 in²	Area	in²	-200.00 in²	200.00 in²	
X34	AD4-05 slope	170.00 in²	Area	in²	-200.00 in²	200.00 in²	
X35	AD4-06 slope	180.00 in²	Area	in²	-200.00 in²	200.00 in²	
X36	AD4-07 slope	170.00 in²	Area	in²	-200.00 in²	200.00 in²	
X37	AD4-08 slope						
X38	AD4-						
X39	AD4-						
X40	AD4-						
X41	AD4-						
X42	Box pressurize Integrator rate	0.8000	Unitless		-100.0000	100.0000	
X43	Box stable pressure Integrator rate	0.8000	Unitless		-100.0000	100.0000	
X44	Box depressurize Integrator rate	2.0000	Unitless		-100.0000	100.0000	
X45	fatigue pressrue lower value	1.20 psi	Pressure	psi	-30.00 psi	30.00 psi	
X46	fatigue pressure upper value	8.90 psi	Pressure	psi	-30.00 psi	30.00 psi	
X47	pressure value 1	1.30 psi	Pressure	psi	-30.00 psi	30.00 psi	
X48	pressure value 2	7.20 psi	Pressure	psi	-30.00 psi	30.00 psi	
X49	pressure value 3	0.00 psi	Pressure	psi	-30.00 psi	30.00 psi	
X50	Humidity set point in volts	2.00 V	Voltage	V	-10.00 V	10.00 V	
X51	Temerature set point in volts (0 volts is 0F)	-1.05 V	Voltage	V	-10.00 V	10.00 V	

X50	Humidity set point in volts	2.00 V	Voltage
X51	Temerature set point in volts (0 volts is 0F)	-1.05 V	Voltage

Figure A-8. AeroPro software screen for temperature and humidity setpoint input

For example, an input can be programmed to generate a setpoint between -50°F to 200°F for a 0 to 10V input signal.

It was found that CSZ-570i will show error if the voltage input is 0V. An offset is required to avoid 0V input signal. For humidity setpoint, no voltage input lower than 0.1V (0.1%RH) is allowed, which is also impractical; 10V corresponds to 100%RH. Table A-2 gives voltage input needed for typical temperature setpoints of panel testing.

Table A-2. Typical voltage input for panel testing

Temperature Input Voltage	Temperature Setpoint (°F)
-2.1	-100
-1.05	-50
-0.53	-25
0	0
1	47.5
3.47	165

The EZT-570i's VNC viewer was set to allow the user to remotely monitor and control the conditioner by directly viewing and manipulating the touch screen over the network. All activity preformed over the VNC viewer will be viewed as if the user was actually touching the EZT-570i's touch screen. To use this function, the VNC server has to be enabled by touching the "VNC Server On/Off" button, as shown in figure A-9. Practically, it is more convenient to monitor and control the chamber using the VNC server.

Modbus Add/Parity: 1 Even

Modbus Timeout 200 ms

VNC Add/Password: 0 None

VNC Device Name: Device

VNC Password:

DEVICE IP ADDRESS = 192.168.1.102

Figure A-9. EZT-570i VNC server settings

APPENDIX B—SYSTEM ACCEPTANCE TEST

This appendix summarizes results of the System Acceptance Test Program conducted to demonstrate full functionality of the current Full-Scale Aircraft Structural Test Evaluation and Research fixture configuration.

Introduction

The System Acceptance Test consists of the performance of a series of quasi-static and fatigue/dura tests, as shown in table B-1.

1. The test system was developed to provide a variety of structural and environmental loading and data-acquisition capabilities to be applied to curved fuselage panels including, but not limited to, static tension and compression tests.
2. Fatigue/dura tests.
3. Individual control of each loader.
4. Ability to pause and continue with a load transition, unload to zero, or dump a test at any time.
5. Automatic load regulation and data acquisition—all loading are controlled or measured automatically.
6. Servo controlled processes with error sensing and speed modulation to maintain desired error limits.
7. Real-time display of all loads and strains in both tabular and graphical formats.

All quasi-static tests were conducted at 10% load increment up to maximum designed load. The operator should have options to change the load increment, the loading rate, and the input of each loader separately.

The dura test for tension-tension and compression-compression was conducted at the rate of 2 cycles per minute. The dura test for a full reversible tension-compression-tension was conducted at the rate of 1 cycle per minute. Thirty minutes worth of cycles at normal operating speed were required for all dura tests, as listed in table B-2.

The operator is able to tune each loader independently during both the static test and the dura test without stopping the test.

All tests have the capability to synchronize with an environmental load profile. Tables B-2 and B-3 listed two representative tests with environmental loads at 165°F & 85% RH, both static and fatigue test. The operators have the capability to change set points for both temperature and humidity, and to see the live display of both parameters. The dura test spectrum included set points for both temperature and humidity and was able to be applied synchronously with the mechanical loads. See appendix A for details of the environmental system.

Table B-1. Acceptance test data sheet

Test Sequence	Description	Panel Pressure (psi)	Longitudinal Load (lb)	Pass	Fail
1	Static Tension	0	0 to 20,000	√	
2	Static Compression	0	0 to -20,000	√	
3	Dura Tension/Compression	0	+20,000 to -20,000	√	
4	Static Pressure with Axial Tension	9	0 to 9,000	√	
5	Static Pressure with Axial Tension	15	15,000	√	
6	Dura Pressure with Tension	9	0 to 9,000	√	

Acceptance Test Procedure

- Several static tests were performed as outlined in this section to the full-scale values in table B-1. Must demonstrate that error is less than 1% of full scale values at each endpoint. Table B-2 shows an example of the static test point matrix with environmental conditions.

Table B-2. Static test point matrix

Endpoint	Freq (Sec)	Pressure (lb)	Hoop (lb)	Frame (lb)	Long. (lb)	Temperature	Humidity (%)
1	15	0.8	800	856	136	165	85
2	15	1.6	1600	1711	271	165	85
3	15	2.4	2400	2567	407	165	85
4	15	3.2	3200	3423	543	165	85
5	15	4.0	4000	4279	679	165	85
6	15	4.8	4800	5134	814	165	85
7	15	5.6	5600	5990	950	165	85
8	15	6.4	6400	6846	1086	165	85
9	15	7.2	7200	7702	1222	165	85
10	15	8.0	8000	8557	1357	165	85

- The final portion of the acceptance test was the durability tests conducted, as listed in table B-1. 250-point load condition spectrum was used to demonstrate performance during the durability test No testing record sheet was used because test point selection and verification were accomplished automatically by the test station controller.

Table B-3. Dura test point matrix

Endpoint	Freq (Sec)	Pressure (lb)	Hoop (lb)	Frame (lb)	Long. (lb)	Temperature (°F)	Humidity (%RH)
1	15	0.86	920	150	1300	165	85
2	15	8.6	9200	1500	10800	165	85
3	15	0.86	920	150	1300	165	85
4	15	8.6	9200	1500	10800	165	85
5	15	0.86	920	150	1300	165	85
. .	. .	. .	. .	. .	. .	. .	. .
248	15	0.86	920	150	1300	165	85
249	15	8.6	9200	1500	10800	165	85
250	15	0.86	920	150	1300	165	85

An acceptance test using a calibration panel was conducted to verify the system functioned properly.

The calibration panel was made of a 0.375-inch-thick 2024-T3 aluminum by the Rose Corporation, per the engineering drawing, as shown in figure B-1.

The test setup and strain gauge locations are shown in figures B-2 through B-5. Thirty-three strain gauges were installed on the calibration panel, including 17 external skin gauges, eight internal skin strain gauges, and six strain gauges on frames.

Axial load performances are shown in figures B-6 and B-7. Both static tension and static compression tests were conducted at 10% load increments. Performance during the loading was satisfactory, with the feedback from load cell closely following the command up to the maximum load.

Figure B-8 shows the performance of axial load during the fatigue test. The range is from full-scale tension to full-scale compression load up to 20,000 lb and cycled at a rate of two cycles per minute.

Figures B-9 and B-10 show the good correlation between strain gauge measurement and analytical calculation under axial-load-only conditions up to 20,000 lb and pressure combined with axial load up to 15 psi, respectively.

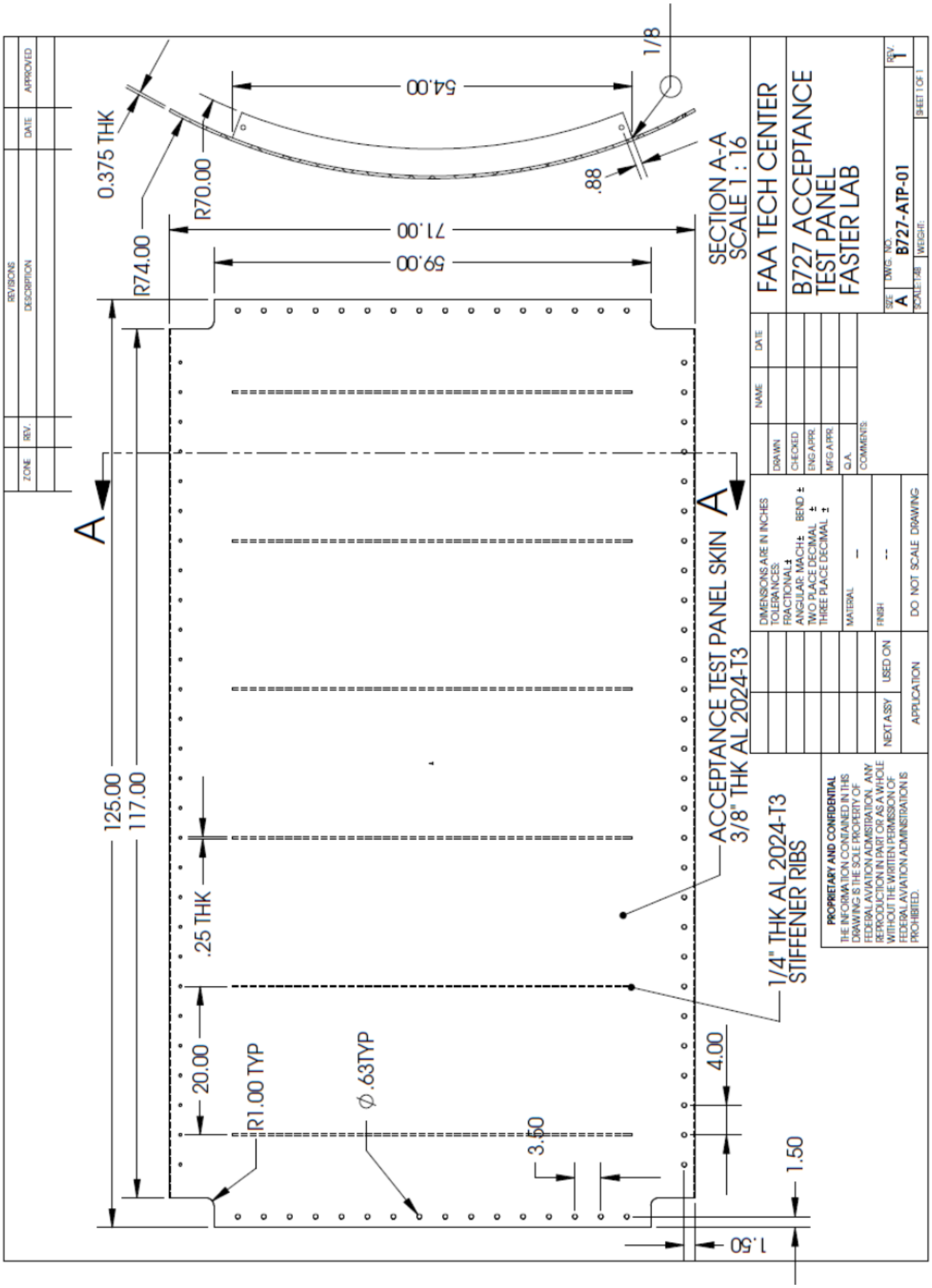


Figure B-1. Acceptance test panel engineering drawing

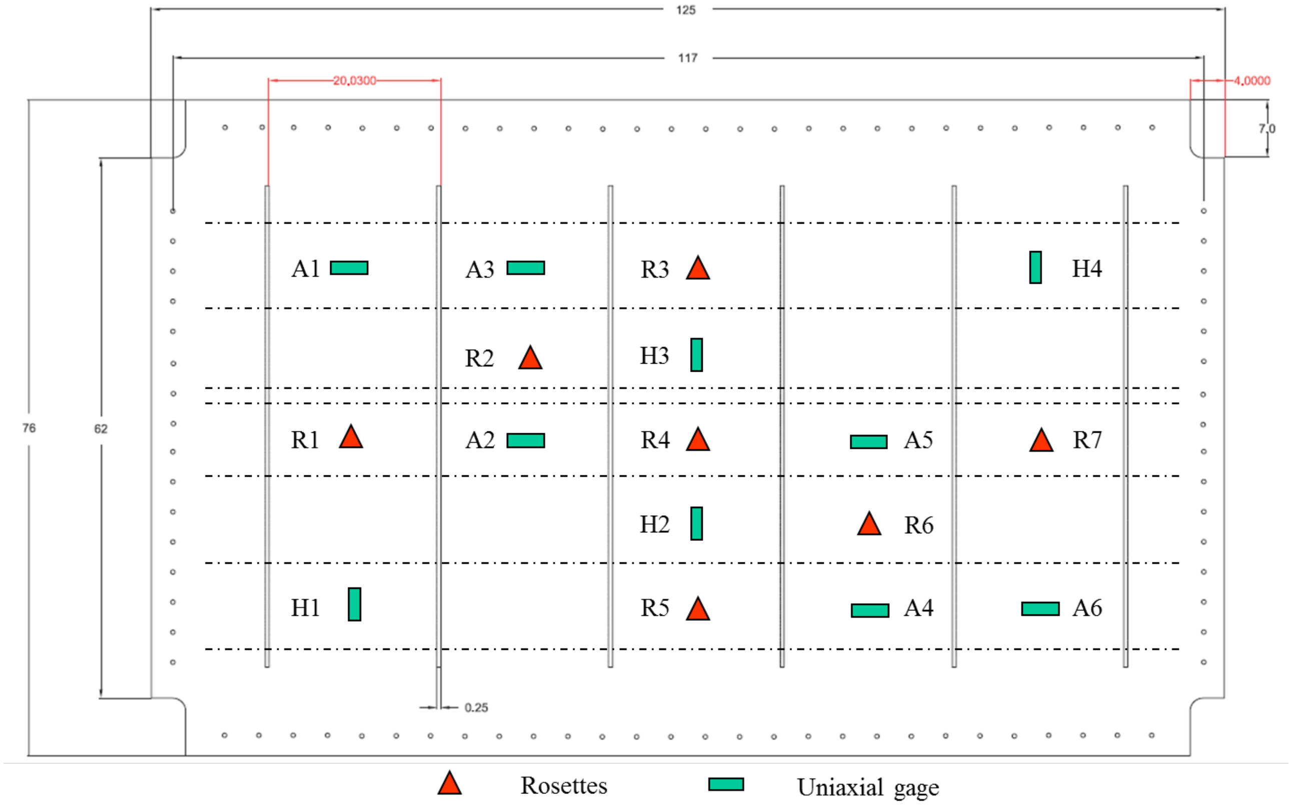


Figure B-2. Acceptance test setup—external strain gauges

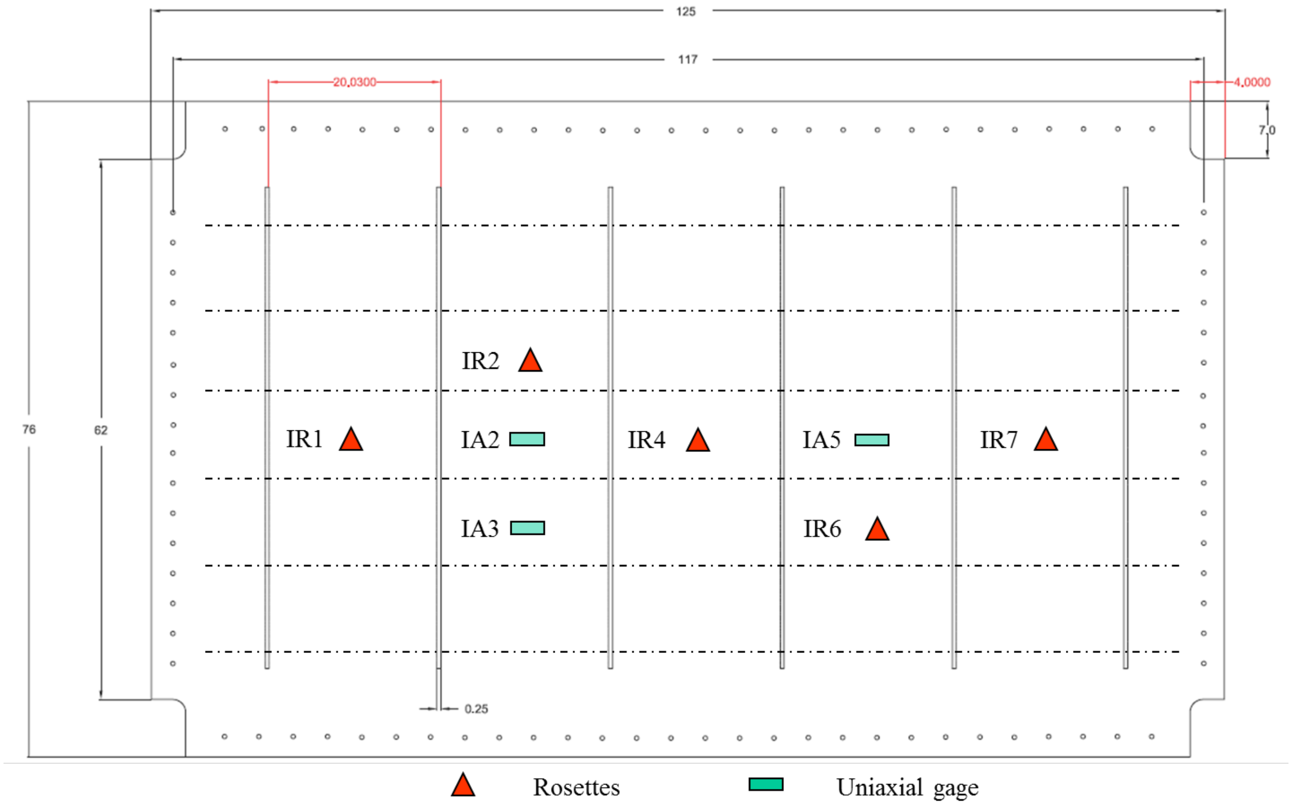


Figure B-3. Acceptance test setup—internal stain gauges

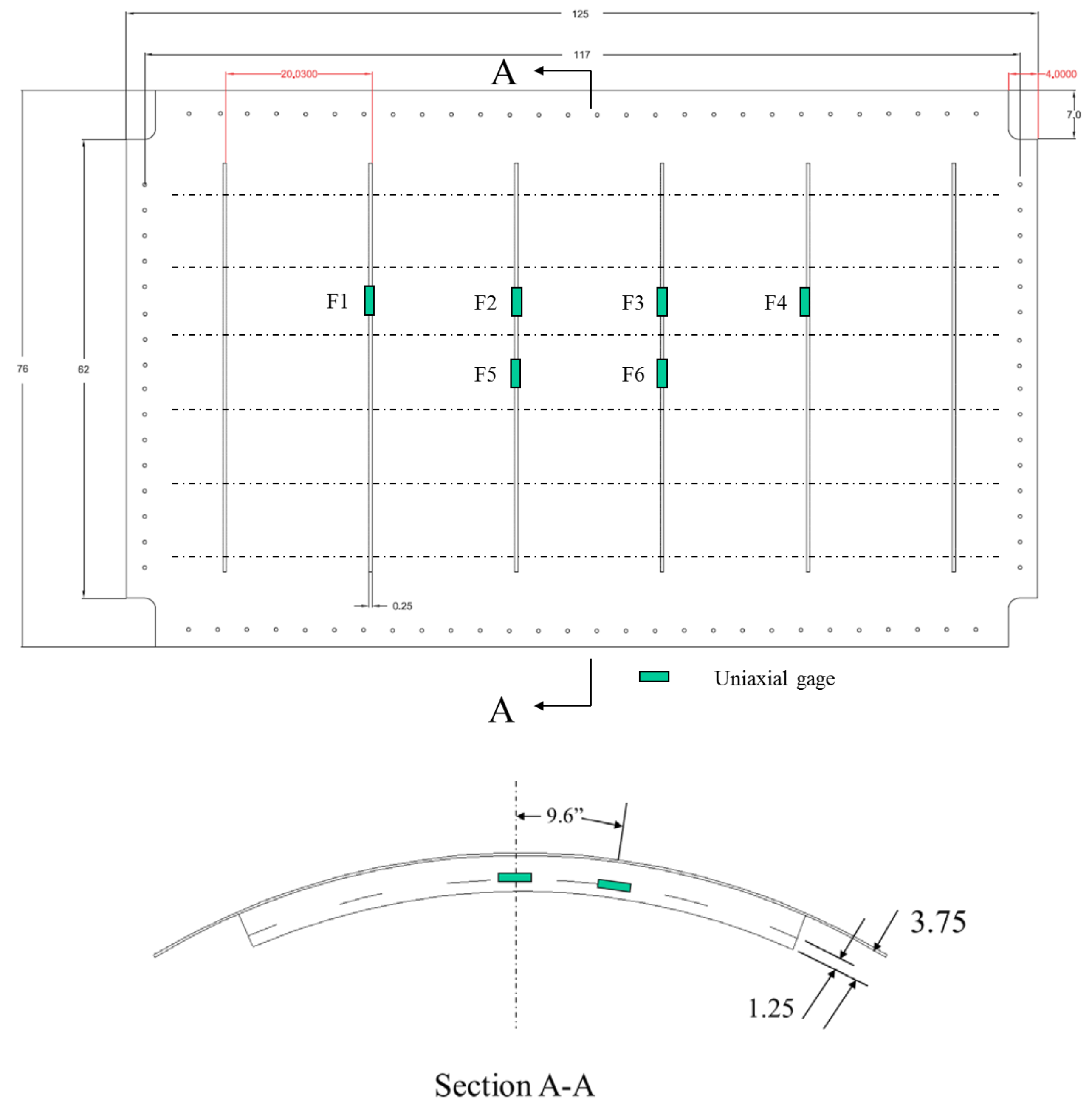


Figure B-4. Acceptance test setup—frame strain gauges

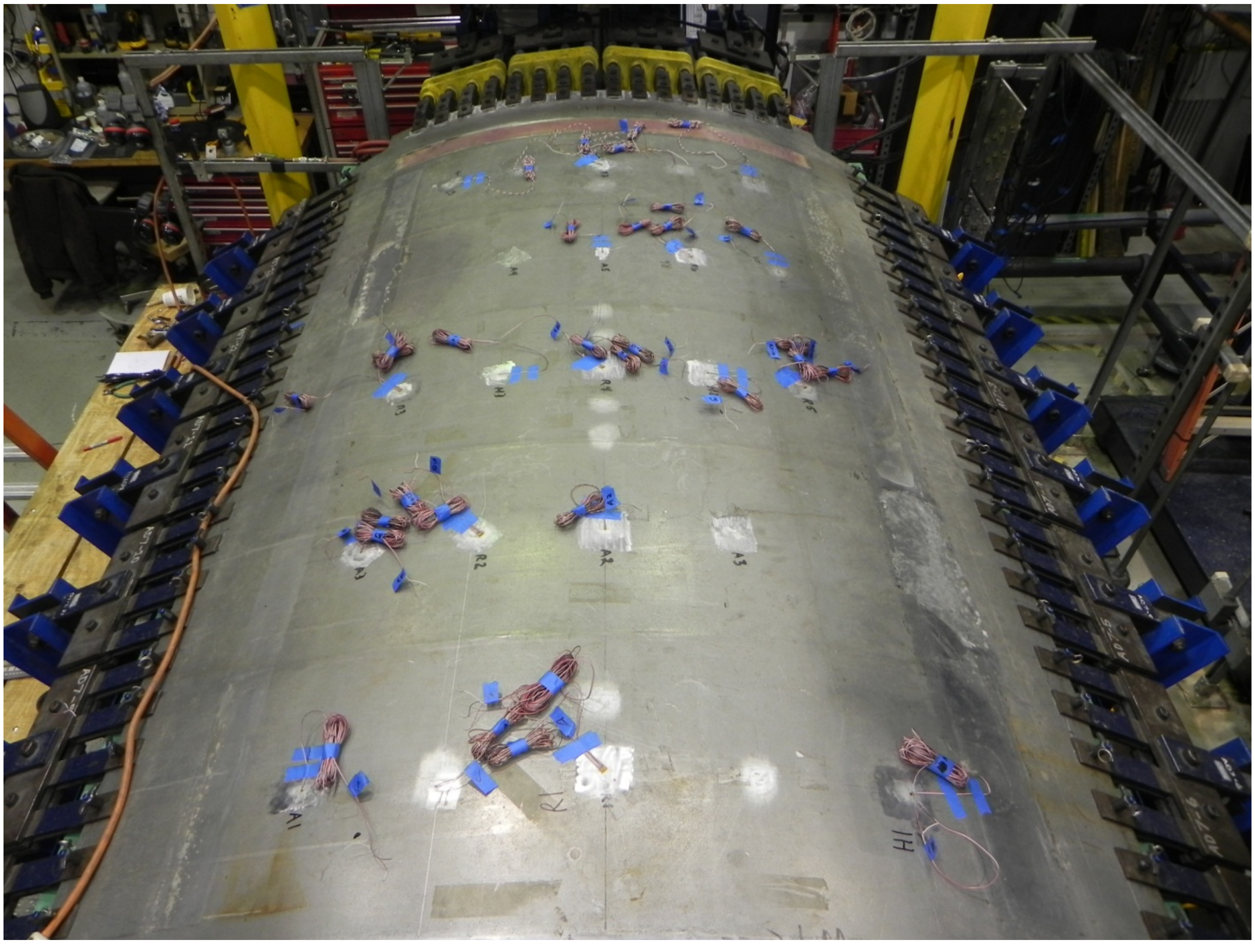


Figure B-5. Photo of acceptance test setup

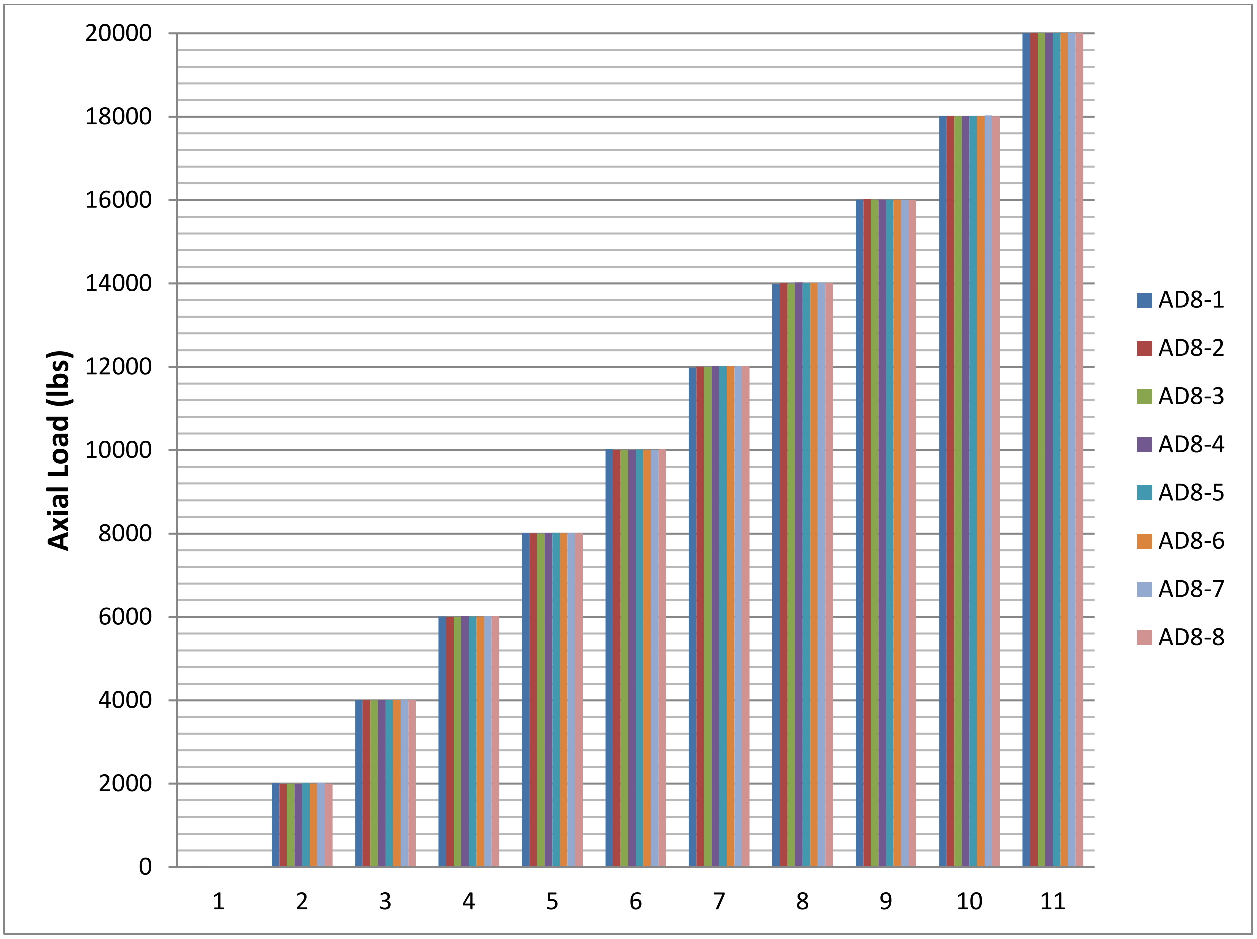


Figure B-6. Static axial tension load performance

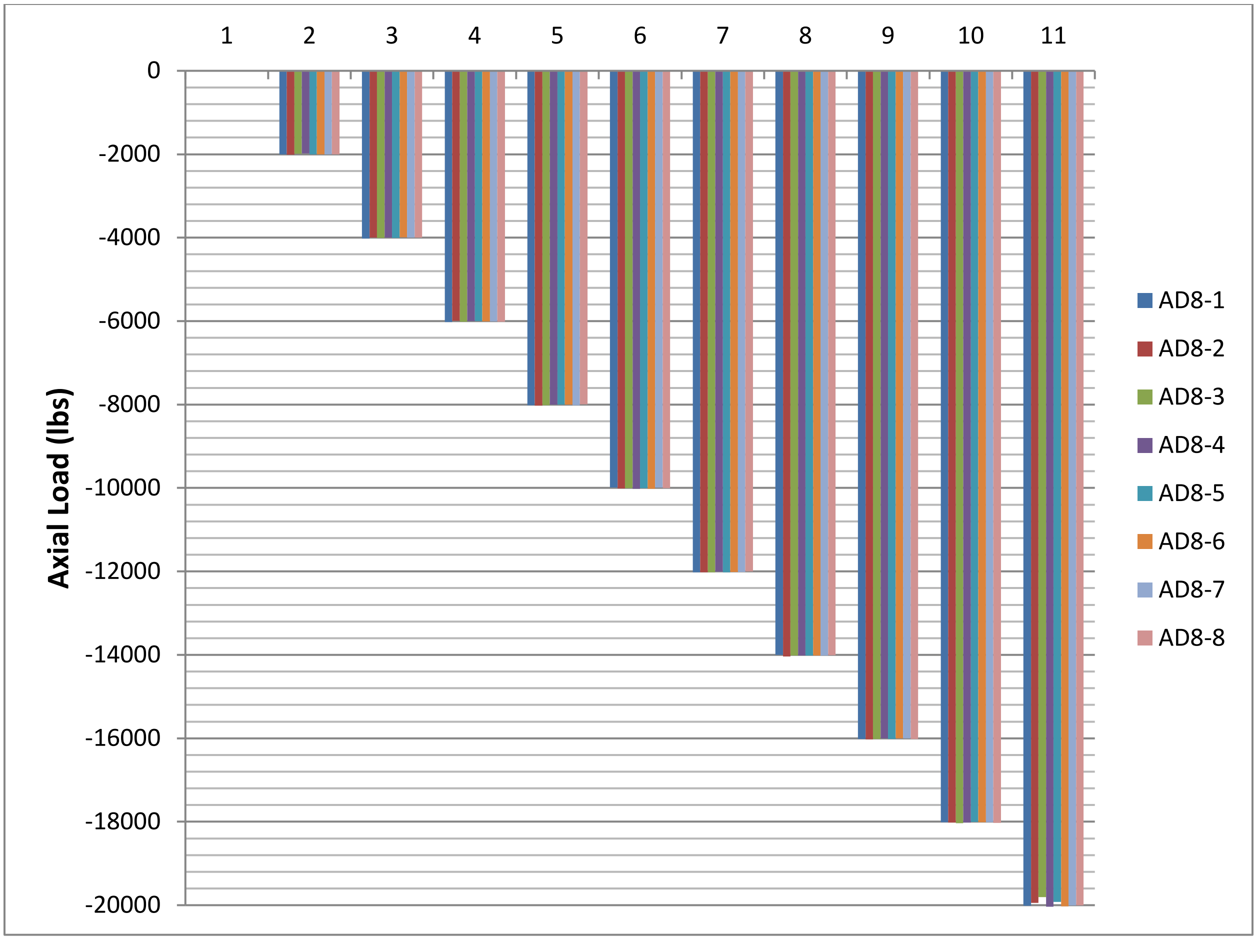


Figure B-7. Static axial compression load performance

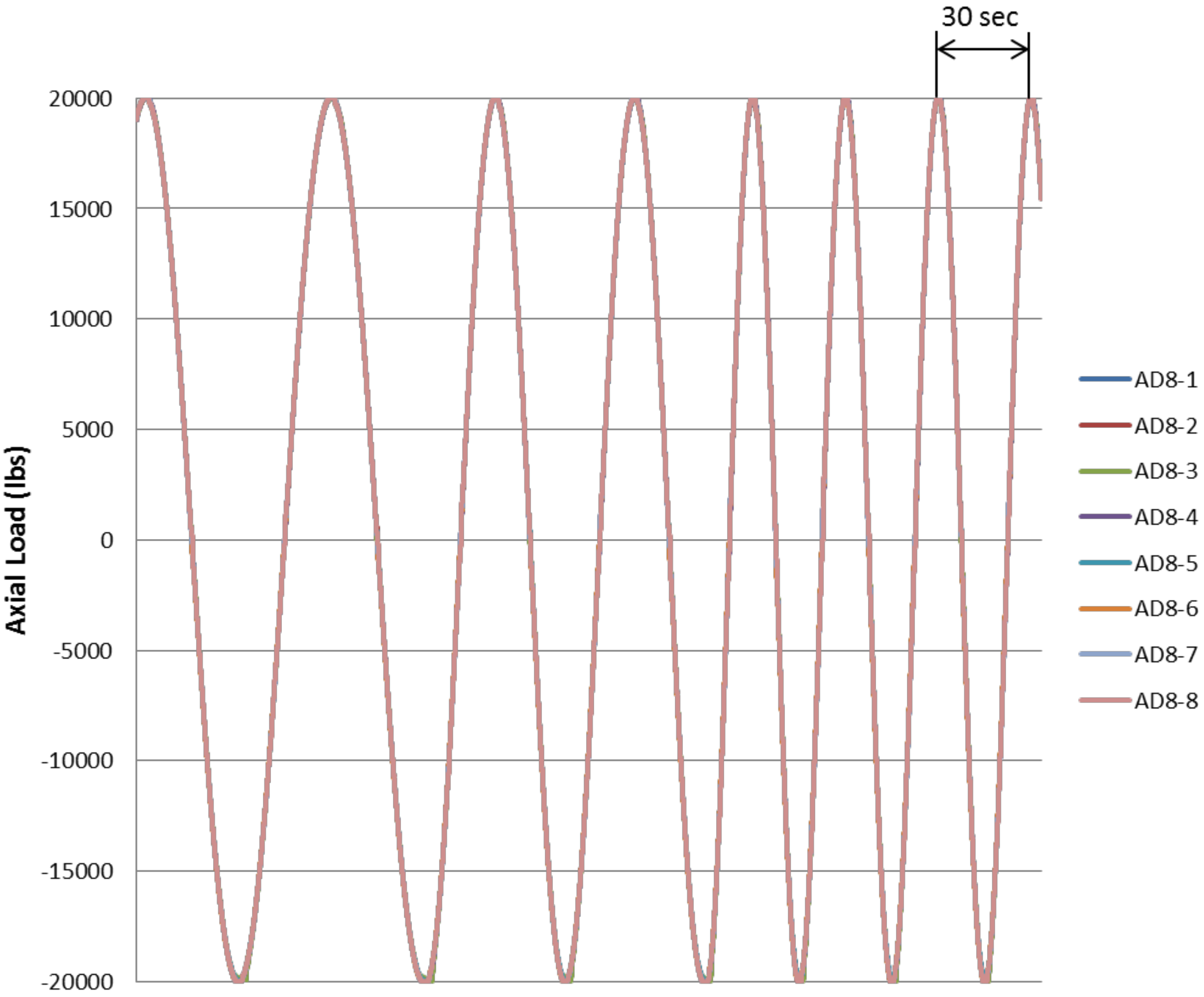


Figure B-8. Fatigue axial load performance

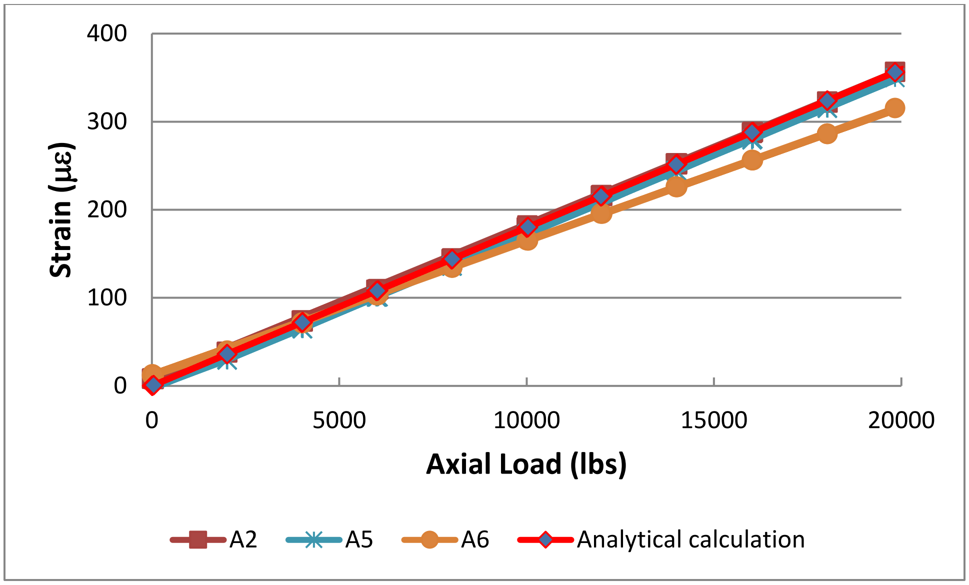


Figure B-9. Comparison between strain measurement and analytical calculation—axial load

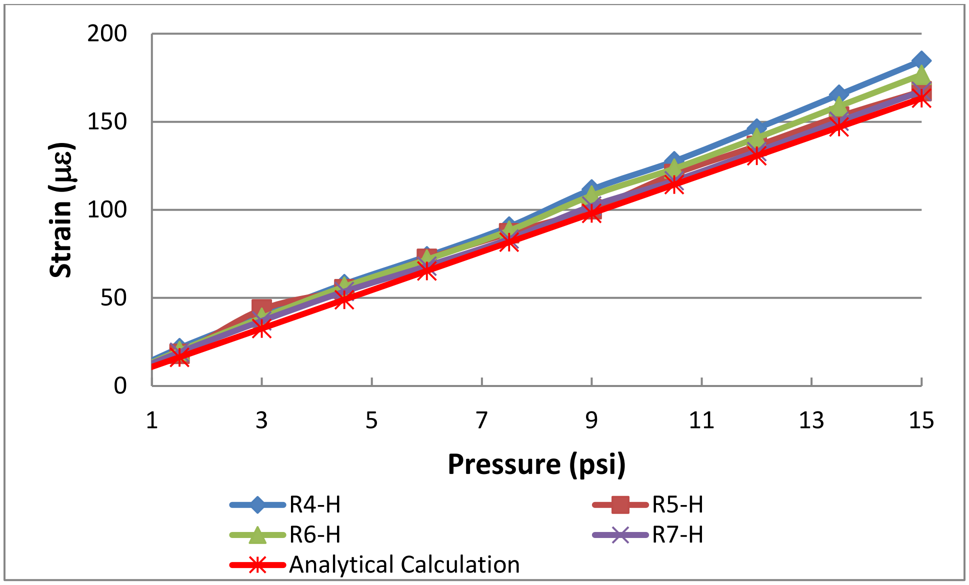


Figure B-10. Comparison between strain measurement and analytical calculation—combined load

The ATP demonstrates that the upgrade is fully operational as follows:

(i) Demonstrates that longitudinal, frame, hoop, and shear loads can be independently applied to a test panel and the loads are within 1% and 5% of the nominal full-scale values for static and fatigue loading (both constant amplitude and complex load spectrum) operations.

The load capability for:

a. The longitudinal loading is up to 20,000 lb.

b. The pressure loading is up to 15 psi, matched with hoop loading applied (30 psi structural ultimate capability positive pressure).

(ii) Ensure that pressure, hoop, frame, and longitudinal loads can be applied quasi-statically and dynamically at a rate of up to 0.033 Hz (two cycles per minute) as demonstrated by test. The load control system will track each actuator at a rate up to 256 Hz.

(iii) Ensure that temperature and humidity loads are synchronized with mechanical loads under a hot-wet condition (165°F and 85–95% humidity) and extreme cold (-50°F) condition.

(iv) The data analysis applications can interpret the results both in real time and off line. Ensure that strains (strain gauges), displacements (LVDTs), applied loads, temperature, and humidity are accurate.

(v) Ensure that the data-storage process follows formats in appendix D and includes the following:

a. For static test, have the ability for operator to store endpoint data (all control and DAQ channels) in ASCII format that can be read in Microsoft® Excel.

b. For durability test, automatically store endpoint data (all control and DAQ channels) in ASCII format that can be read in Microsoft Excel.

(vi) The upgraded applications would retain identified peak and valley data (end-point data) for permanent record.

APPENDIX C—USER MANUAL AND SOFTWARE SCREEN DESCRIPTIONS

This document presents the screen graphics of each stage of a program's operation. The graphics are presented in the normal sequence of operation from startup through test and unload or failure, for the static screens, and through cycling operations for durability testing. Along with each screen a narrative of what each screen is presented. The data and control parameters required for the operation of the curved panel test system are organized into logical processes. This manual provides only the details of operation procedure that needed to run typical static and fatigue tests. More details regarding each function are provided in the AeroPro™ software manual.

System Power-up Procedure

Figure C-1 shows the layout in the control room, including the controller console, the Agilent E1649 strain gauge DAQ, the server PC, the client PCs, and the emergency dump switch. All PCs are connected through an Ethernet switch. All PCs share one keyboard and mouse through "Mouse without Borders" free software to save the working spaces, and also allow users to drag and drop files across PC screens.

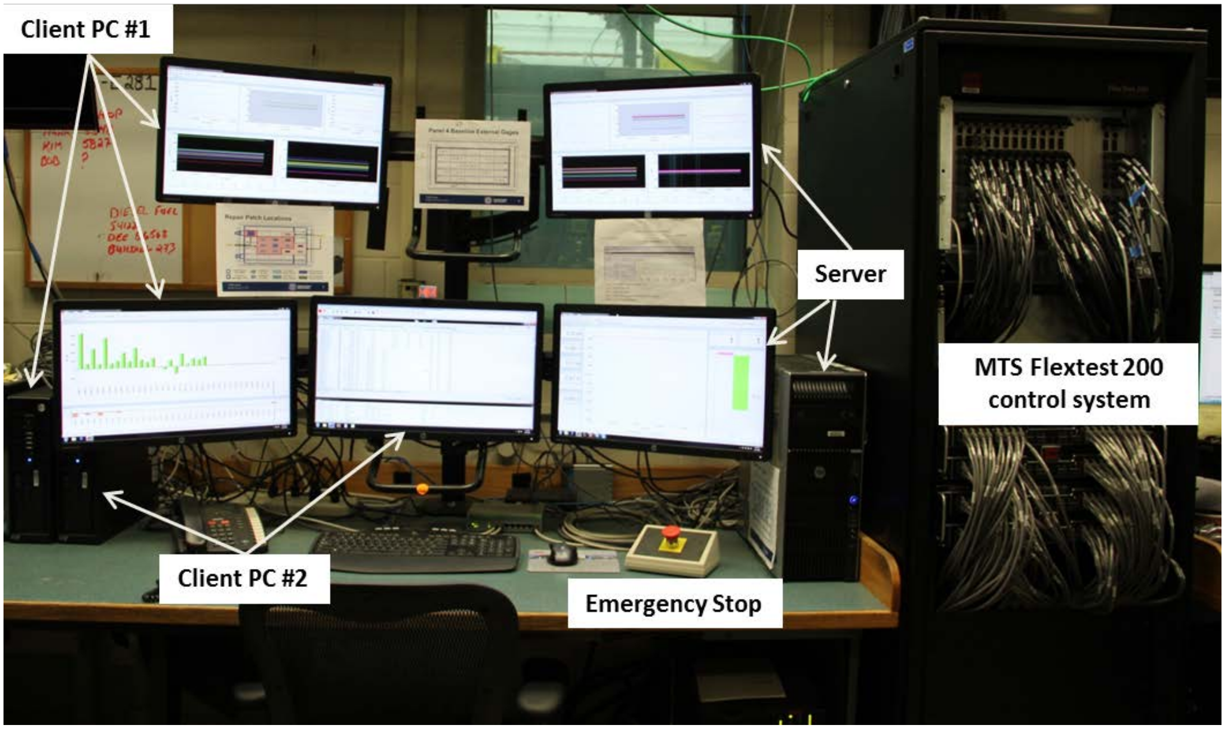


Figure C-1. Control room layout

The power-up procedure for an AeroPro control and data-acquisition system is very straight-forward. The simple rule is to power up the server PC first and log into the AeroPro account. The log ID is **Aeropro**, and password is **system1** for all PCs. When the server PC is up and running, turn on all remaining system hardware, and wait until the power-up is complete. Now you may launch the AeroPro software. Normally, the server PC is used to communicate with the controller, and the client PC is used to run the test file. Use "Controller Management Tool" on the serve PC desktop to check the status of the controller, as shown in figure C-2.

Load the Test

It is necessary to ensure the air manifold supply valve is closed before starting the test, as shown in figure C-3. The next step is to launch AeroPro software in the client PC#2, choose the right test file, and load the test on **TEST STATION1 ONLY,** because only test station 1 is connected with the emergency dump.

Display Description

Figure C-4 shows the basic screen of the display. There are three main areas. The top one is the control panel, which shows the hydraulic and data-acquisition status. The middle part is the test editor, which covers all functions that would be used for the test. The top of the editor has the main tabs for different components, and the sub tabs are located on the bottom for each component. For example, the data-acquisition channels tab has 10 sub tabs, including limits, conditioning and offsets. The bottom section is log viewer, which records all changes to the test file. Check the AeroPro Software Manual for the details of each tab. This appendix shows only the functions that will be used to run typical static and fatigue tests.

Procedures to start static/fatigue test

1. Select Test Execution in the Station Mode drop-down menu.
2. Select the appropriate procedure under Select Test Procedure. The test procedure determines whether it is a static test or a fatigue test.
3. Click Next End Level and make sure the next level is 1, which is the 0% load. The plot on the right-hand side will show the loading procedure selection. The triangle indicator in the plot shows the next level.
4. Input the right number for Master Time: 100% Master Time means the time from one level to the next is the same as specified in the procedure; 200% means the time will double.
5. Input the right number for Master Span: 100% Master Span means the maximum load level is the 100% load level specified in the procedure; 200% means the maximum will be double the 100% load level in the procedure. Double check this number to avoid damaging the test panel by overloading.
6. Load time and unload time are the time to the level #1 and the time from the last level to zero.
7. Offset strain gauges in the Data Acquisition Channels tab. See figure 8 for details.
8. Offset load cells and pressure transducers in the Test Control Channels tab.
9. Enable Data Acquisition. Different types of data scan modes can be used with the customized recording rate up to 256 Hz.
10. Make sure the station reset is off.
11. Enable the hydraulic.
12. Click Enable Integrator and Enable Null Pacing before starting the test, as shown in figure C-5.
13. Open the data display on the server PC and client PC #1. The display can be customized by the operators as needed to show different channels or different types of plots. The typical display windows are shown in figures C-6 and C-7.

Procedures to shut down

1. Disable the data acquisition.
2. Retrieve test data.
3. Stop the hydraulic.
4. Unload the test from the test station.
5. Power off the server PC and the client PCs.
6. Power off UPS in the controller console.

Offset Strain gauges, load cells, and pressure transducers

Before zero anything, make sure the air supply manifold valve is closed. The normally open valve will ensure there is no pressure in the system. Offset the data-acquisition channels (i.e., the strain gauges under the offset tab) by selecting all strain gauge channels, and click auto, as shown in figure C-8. **DO NOT** zero/offset temperature and humidity sensors. The offset values for these channels are from the two-point calibration. Offsetting these channels will cause incorrect temperature and humidity measurement.

The load cells (axial, hoop, and frame load cells) and pressure transducers can be zeroed under the Test Control Channels tab. Similar to strain gauge channels, select all channels that need to be zeroed, and click auto offset.

Calibration

Strain Gauge Calibration Procedure:

1. The following steps are under the Data Acquisition Channels tab.
2. Check the connection from the strain gauge to the connection board.
3. Pick the correct excitation voltage under the Conditioning tab. Check the strain gauge specification sheet for the recommended excitation voltage, as shown in figure C-9.
4. In the Calibration tab, choose **Shunt Cal**, input strain gauge factor, and auto shunt. For example, the shunt resistor used in FlexDAC 20 is 55K Ohms resistor, for 350 Ohms strain gauge with F_G setting of 2.17, the expected shunt value is 2914 με given by

$$R_c = \frac{R_G \times 10^6}{F_G \varepsilon_S(\mu)} - R_G$$

5. Shunt verify: the current reading from shunt verification is compared with a previously stored value to verify that conditioner values are within calibration tolerances. The failed channels will be highlighted in yellow and **Verify Result** boxes display **Failed**. See figures C-10 and C-11 for details.

Load Cell and Pressure Transducer Calibration:

All calibration sheets should be available for calibration. Check the AeroPro software manual for the difference between different calibration methods. The calibration used is based on the calibration sheets from the OEMs, as listed in table C-1:

Table C-1 Calibration Method for Different Load Cells and Transducers

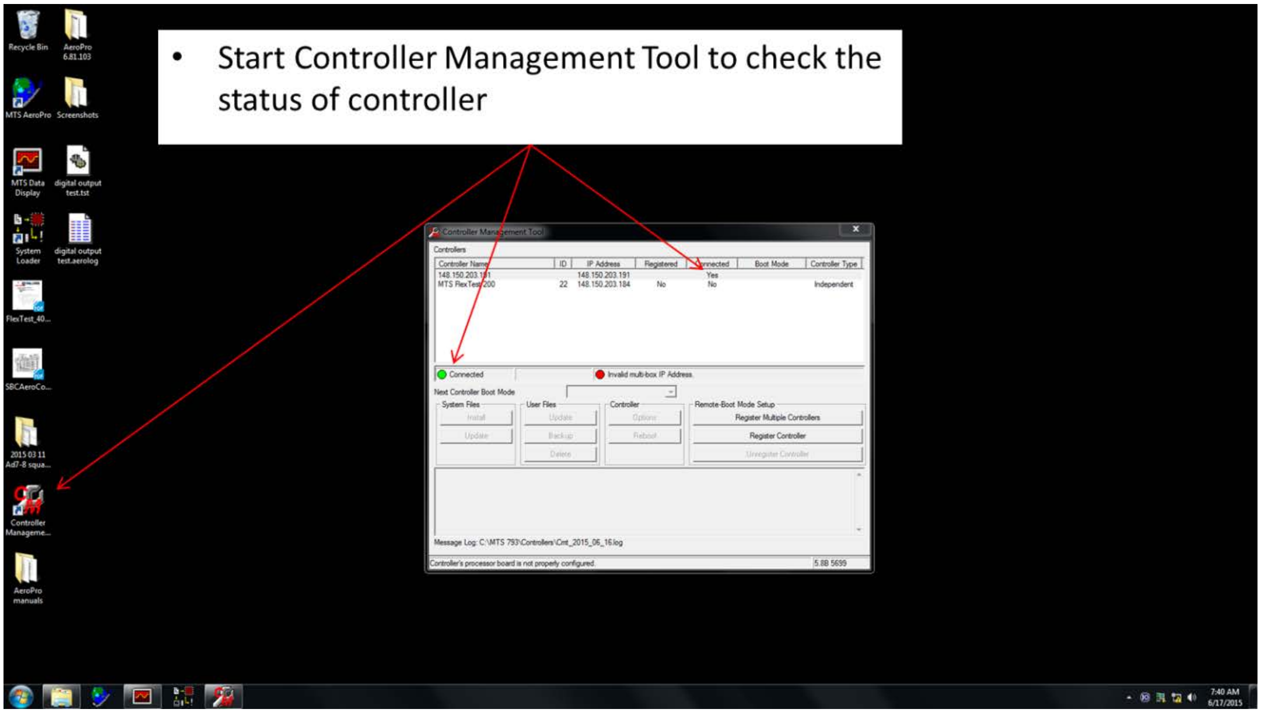
Sensors	Calibration method
Axial load cell	Sensitivity Cal
Hoop load cell	Sensitivity Cal
Frame load cell	Sensitivity Cal
Pressure transducer	Sensitivity Cal

Tuning

Servo loop controls are used for each of the loading mechanisms. The command signal for all servo channels is a voltage driver signal. The control channels should be tuned to achieve maximum response without adverse effects and to achieve the maximum cycling rate for the fatigue test. The tuning process requires the knowledge of proportional integral derivative control and how the actuators interact with each other. It is highly recommended that this process be done by the test engineer or trained personnel.

Retrieve Test Data

The test data can be retrieved during or after the test if the recorded data has not been cleared. Follow the pop-up window to specify the path to save test data. To display post-test data or save data to another format (i.e., txt for Excel post processing), the saved data must be retrieved using MTS Data Display, as shown in figure C-12. Figure C-13 shows an example of how to export single-scan mode data for post processing. Check the MTS Data Display manual for other details of this software.



- Start Controller Management Tool to check the status of controller

Controllers

Controller Name	ID	IP Address	Registered	Connected	Boot Mode	Controller Type
148.150.203.191		148.150.203.191		Yes		
MTS FlexTest 200	22	148.150.203.184	No	No		Independent

● Connected

● Invalid multi-box IP Address.

Message Log: C:\MTS 793\Controllers\Cmt_2015_06_16.log

Controller's processor board is not properly configured.

5.8B 5699

Figure C-2. Controller management tool to check controller status

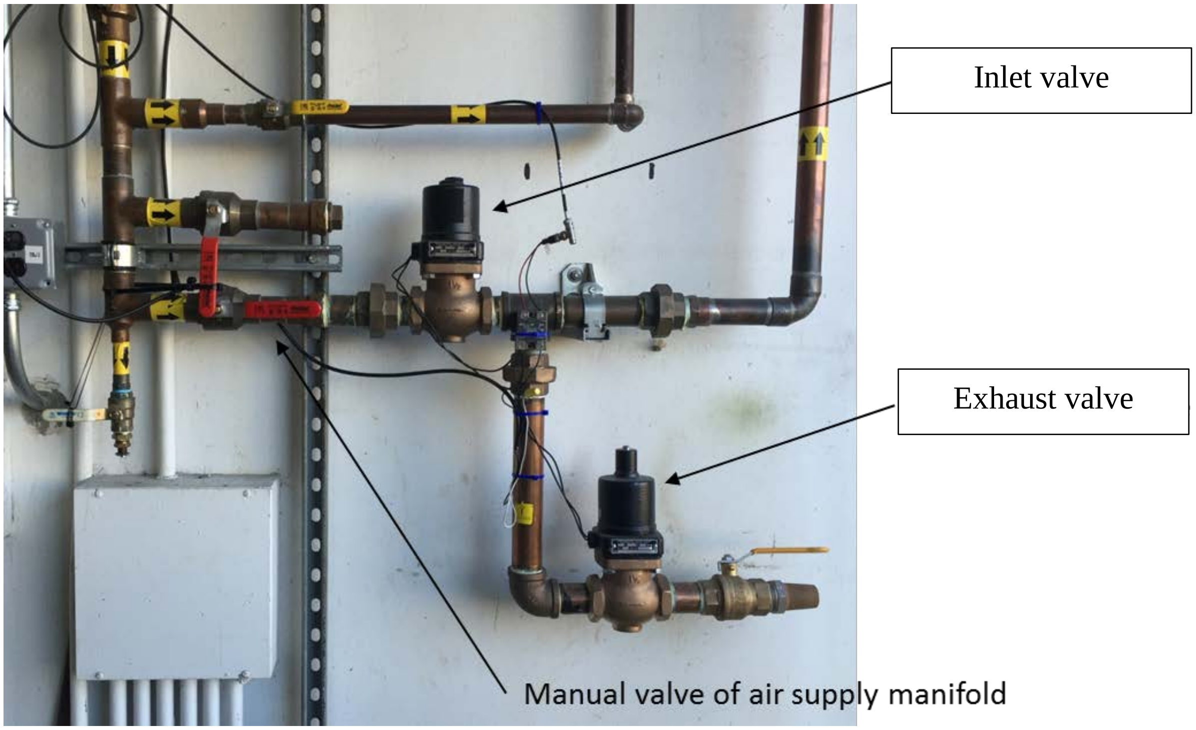
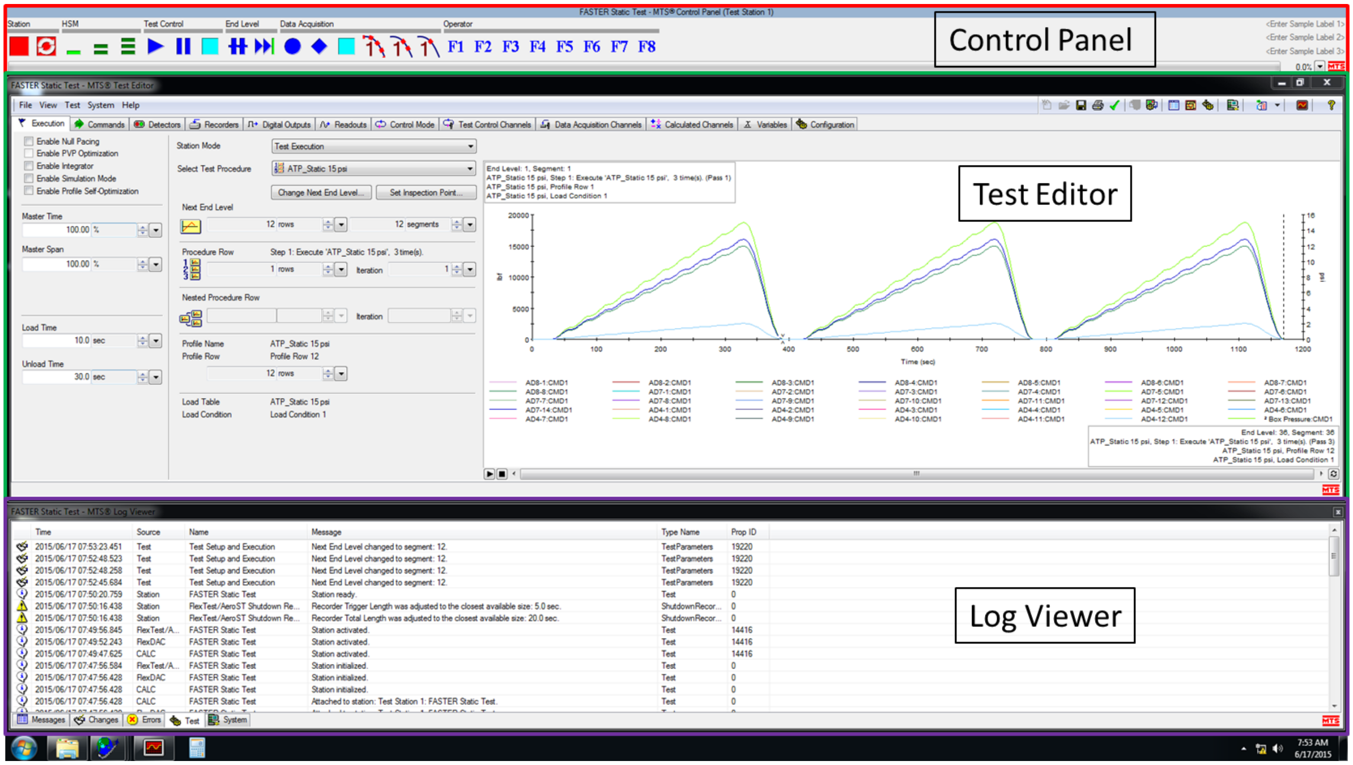


Figure C-3 Manual valve of air supply manifold



☐ Enable Null Pacing
☐ Enable PVP Optimization
☐ Enable Integrator
☐ Enable Simulation Mode
☐ Enable Profile Self-Optimization

Master Time: 100.00 %
Master Span: 100.00 %
Load Time: 10.0 sec
Unload Time: 30.0 sec

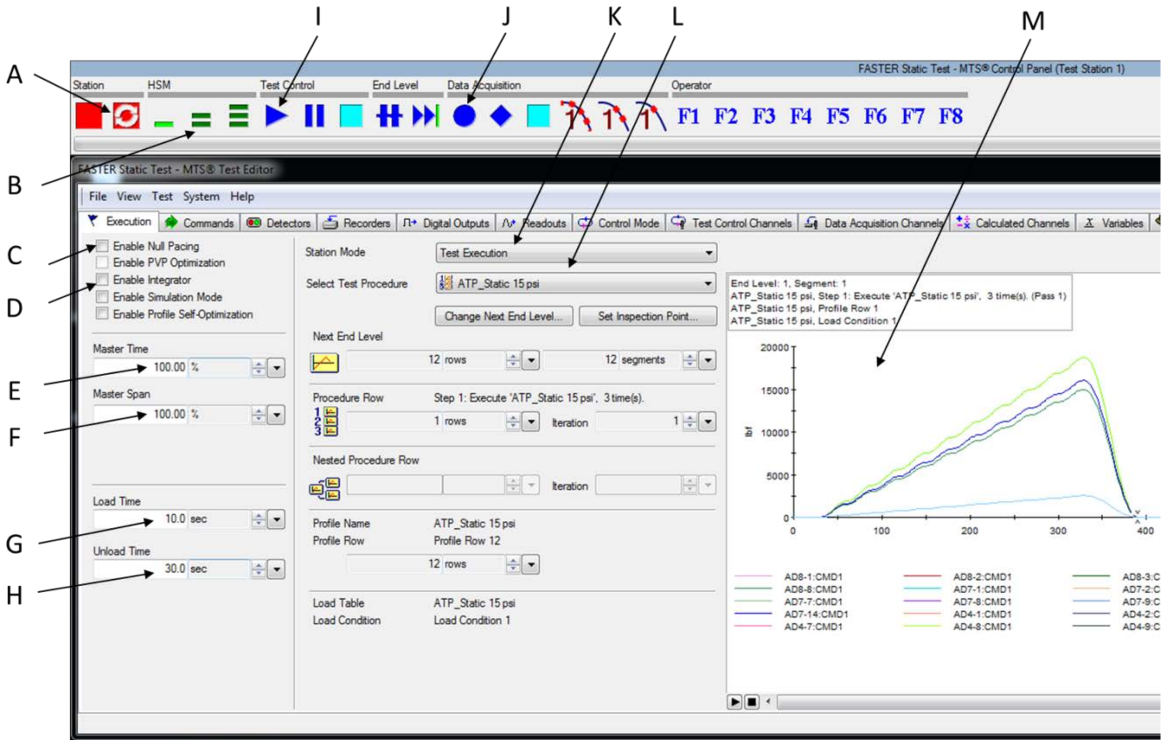
Station Mode: Test Execution
Select Test Procedure: ATP_Static 15 psi
Next End Level: 12 rows, 12 segments
Procedure Row: Step 1: Execute 'ATP_Static 15 psi', 3 time(s). 1 rows, Iteration 1
Nested Procedure Row
Profile Name: ATP_Static 15 psi
Profile Row: Profile Row 12
12 rows
Load Table: ATP_Static 15 psi
Load Condition: Load Condition 1

End Level: 1, Segment: 1
ATP_Static 15 psi, Step 1: Execute 'ATP_Static 15 psi', 3 time(s). (Pass 1)
ATP_Static 15 psi, Profile Row 1
ATP_Static 15 psi, Load Condition 1

End Level: 36, Segment: 36
ATP_Static 15 psi, Step 1: Execute 'ATP_Static 15 psi', 3 time(s). (Pass 3)
ATP_Static 15 psi, Profile Row 12
ATP_Static 15 psi, Load Condition 1

```
Time                     Source       Name                        Message                                                                 Type Name         Prop ID
2015/06/17 07:53:23.451  Test         Test Setup and Execution    Next End Level changed to segment: 12.                                  TestParameters    19220
2015/06/17 07:52:48.523  Test         Test Setup and Execution    Next End Level changed to segment: 12.                                  TestParameters    19220
2015/06/17 07:52:48.258  Test         Test Setup and Execution    Next End Level changed to segment: 12.                                  TestParameters    19220
2015/06/17 07:52:45.684  Test         Test Setup and Execution    Next End Level changed to segment: 12.                                  TestParameters    19220
2015/06/17 07:50:20.759  Station      FASTER Static Test          Station ready.                                                          Test              0
2015/06/17 07:50:16.438  Station      FlexTest/AeroST Shutdown Re...  Recorder Trigger Length was adjusted to the closest available size: 5.0 sec.  ShutdownRecor...  0
2015/06/17 07:50:16.438  Station      FlexTest/AeroST Shutdown Re...  Recorder Total Length was adjusted to the closest available size: 20.0 sec.  ShutdownRecor...  0
2015/06/17 07:49:56.845  FlexTest/A...  FASTER Static Test        Station activated.                                                      Test              14416
2015/06/17 07:49:52.243  FlexDAC      FASTER Static Test          Station activated.                                                      Test              14416
2015/06/17 07:49:47.625  CALC         FASTER Static Test          Station activated.                                                      Test              14416
2015/06/17 07:47:56.584  FlexTest/A...  FASTER Static Test        Station initialized.                                                    Test              0
2015/06/17 07:47:56.428  FlexDAC      FASTER Static Test          Station initialized.                                                    Test              0
2015/06/17 07:47:56.428  CALC         FASTER Static Test          Station initialized.                                                    Test              0
2015/06/17 07:47:56.428  CALC         FASTER Static Test          Attached to station: Test Station 1: FASTER Static Test.                Test              0
```

Figure C-4. Basic screen of AeroPro software display



☐ Enable Null Pacing
☐ Enable PVP Optimization
☐ Enable Integrator
☐ Enable Simulation Mode
☐ Enable Profile Self-Optimization

Master Time 100.00 %

Master Span 100.00 %

Load Time 10.0 sec

Unload Time 30.0 sec

Station Mode: Test Execution

Select Test Procedure: ATP_Static 15 psi

Next End Level: 12 rows, 12 segments

Procedure Row: Step 1: Execute 'ATP_Static 15 psi', 3 time(s).
1 rows, Iteration 1

Nested Procedure Row, Iteration

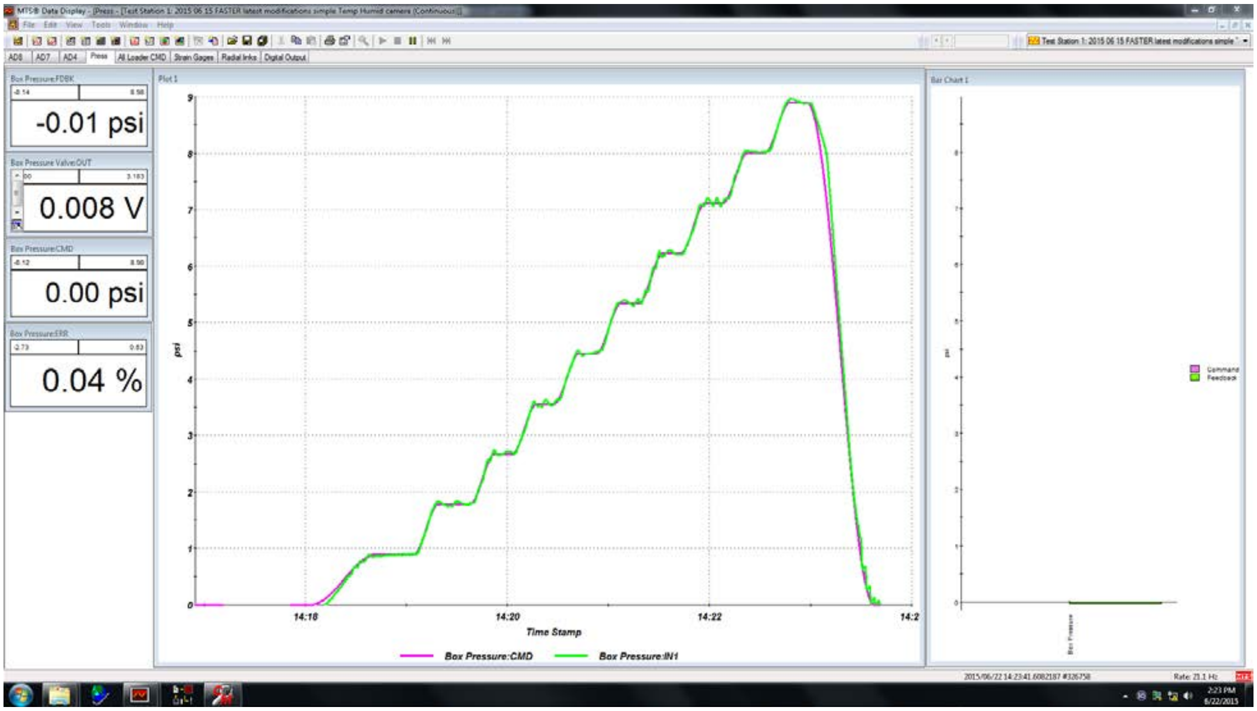
Profile Name: ATP_Static 15 psi
Profile Row: Profile Row 12
12 rows

Load Table: ATP_Static 15 psi
Load Condition: Load Condition 1

End Level: 1, Segment: 1
ATP_Static 15 psi, Step 1: Execute 'ATP_Static 15 psi', 3 time(s). (Pass 1)
ATP_Static 15 psi, Profile Row 1
ATP_Static 15 psi, Load Condition 1

A: A button that allows a user to reset station.
B: A button that allows a user to enable hydraulic.
C: A checkbox to enable null pacing.
D: A checkbox to enable integrator.
E: A text box that allows a user to change Master Time.
F: A text box that allows a user to change Master Span.
G: A text box that allows a user to change load time.
H: A text box that allows a user to change unload time.
I: A button that allows a user to start test procedure.
J: A button that allows a user to enable data acquisition.
K: A drop-down manual that allows a user to select Station Mode.
L: A drop-down manual that allows a user to select Test Procedure.
M: An area that shows plot of selected test procedure.

Figure C-5. Procedure to start static/fatigue test



Box Pressure:FDBK -0.14 8.98 -0.01 psi

Box Pressure Valve:OUT 00 3.183 0.008 V

Box Pressure:CMD -0.12 8.90 0.00 psi

Box Pressure:ERR -2.73 0.83 0.04 %

Figure C-6. Typical data display in server PC monitor

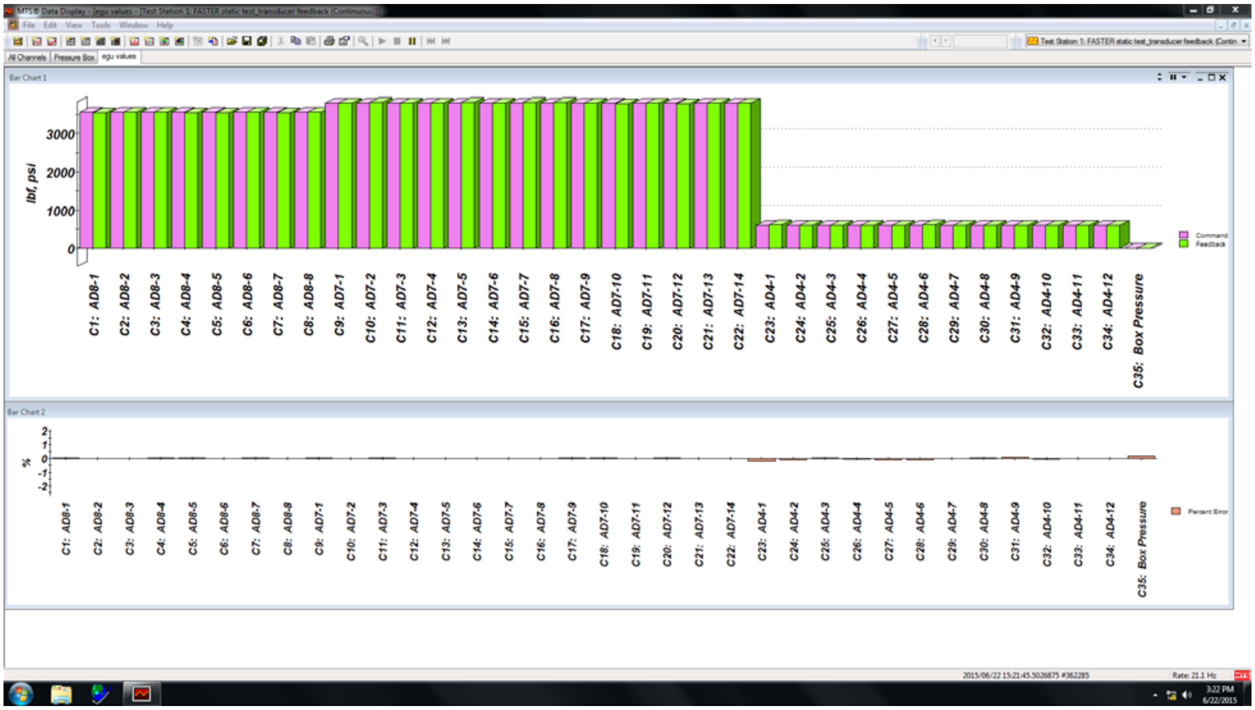
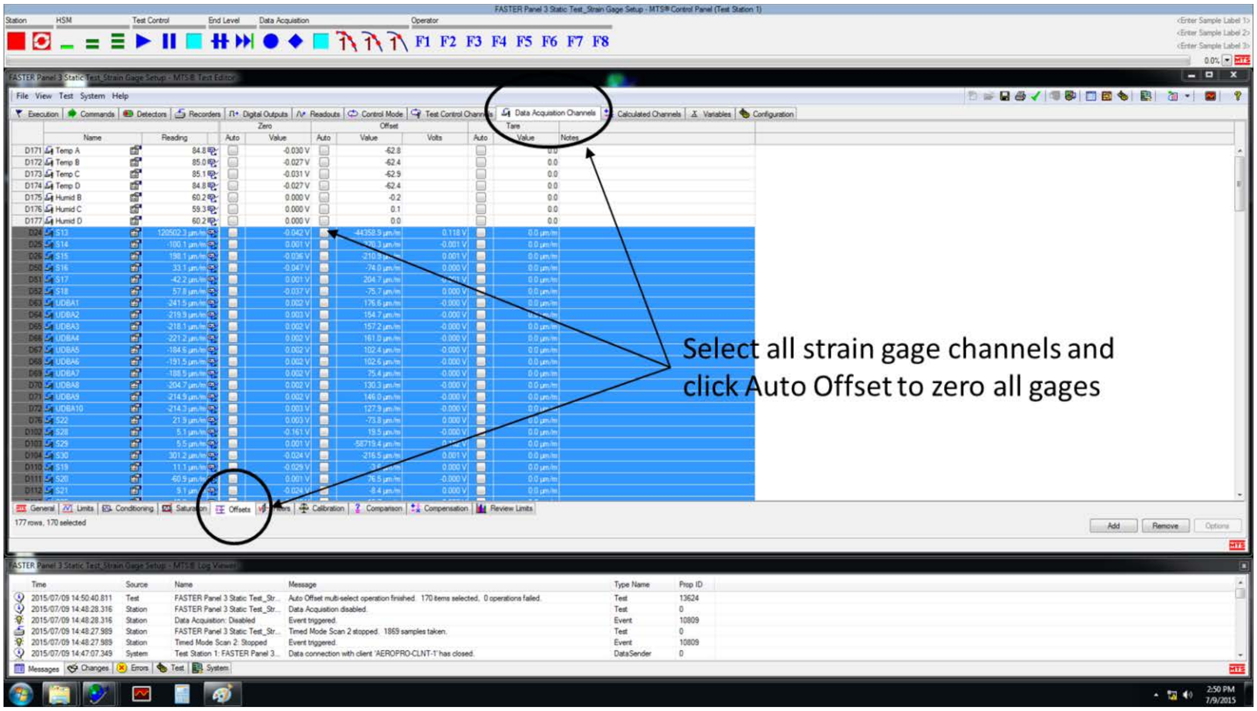


Figure C-7. Typical data display in client PC#1



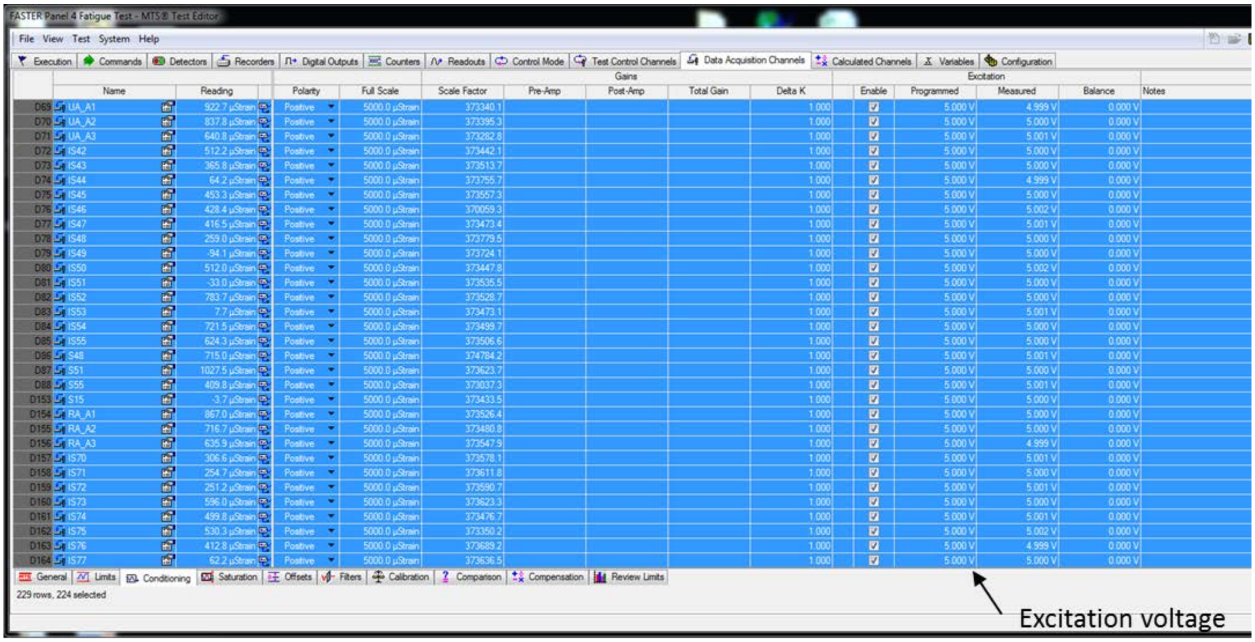
Select all strain gage channels and click Auto Offset to zero all gages

	Name	Reading	Zero Auto	Zero Value	Offset Auto	Offset Value	Offset Volts	Tare Auto	Tare Value	Notes
D171	Temp A	84.8	☐	-0.030 V	☐	-62.8		☐	0.0	
D172	Temp B	85.0	☐	-0.027 V	☐	-62.4		☐	0.0	
D173	Temp C	85.1	☐	-0.031 V	☐	-62.9		☐	0.0	
D174	Temp D	84.8	☐	-0.027 V	☐	-62.4		☐	0.0	
D175	Humid B	60.2	☐	0.000 V	☐	-0.2		☐	0.0	
D176	Humid C	59.3	☐	0.000 V	☐	0.1		☐	0.0	
D177	Humid D	60.2	☐	0.000 V	☐	0.0		☐	0.0	
D24	S13	120502.3 μm/m	☐	-0.042 V	☐	-44358.9 μm/m	0.118 V	☐	0.0 μm/m	
D25	S14	-100.1 μm/m	☐	0.001 V	☐	[illegible]	-0.001 V	☐	0.0 μm/m	
D26	S15	198.1 μm/m	☐	-0.036 V	☐	-210.9 μm/m	0.001 V	☐	0.0 μm/m	
D50	S16	33.1 μm/m	☐	-0.047 V	☐	-74.0 μm/m	0.000 V	☐	0.0 μm/m	
D51	S17	-42.2 μm/m	☐	0.001 V	☐	204.7 μm/m	[illegible]	☐	0.0 μm/m	
D52	S18	57.8 μm/m	☐	-0.037 V	☐	-75.7 μm/m	0.000 V	☐	0.0 μm/m	
D63	UDBA1	-241.5 μm/m	☐	0.002 V	☐	176.6 μm/m	-0.000 V	☐	0.0 μm/m	
D64	UDBA2	-219.9 μm/m	☐	0.003 V	☐	154.7 μm/m	-0.000 V	☐	[illegible]	
D65	UDBA3	-218.1 μm/m	☐	0.002 V	☐	157.2 μm/m	-0.000 V	☐	0.0 μm/m	
D66	UDBA4	-221.2 μm/m	☐	0.002 V	☐	161.0 μm/m	-0.000 V	☐	0.0 μm/m	
D67	UDBA5	-184.6 μm/m	☐	0.002 V	☐	102.4 μm/m	-0.000 V	☐	0.0 μm/m	
D68	UDBA6	-191.5 μm/m	☐	0.002 V	☐	102.6 μm/m	-0.000 V	☐	0.0 μm/m	
D69	UDBA7	-188.5 μm/m	☐	0.002 V	☐	75.4 μm/m	-0.000 V	☐	0.0 μm/m	
D70	UDBA8	-204.7 μm/m	☐	0.002 V	☐	130.3 μm/m	-0.000 V	☐	0.0 μm/m	
D71	UDBA9	-214.9 μm/m	☐	0.002 V	☐	146.0 μm/m	-0.000 V	☐	0.0 μm/m	
D72	UDBA10	-214.3 μm/m	☐	0.003 V	☐	127.9 μm/m	-0.000 V	☐	[illegible]	
D76	S22	21.9 μm/m	☐	0.003 V	☐	-73.8 μm/m	0.000 V	☐	0.0 μm/m	
D102	S28	5.1 μm/m	☐	-0.161 V	☐	19.5 μm/m	-0.000 V	☐	0.0 μm/m	
D103	S29	5.5 μm/m	☐	0.001 V	☐	-58719.4 μm/m	[illegible]	☐	0.0 μm/m	
D104	S30	301.2 μm/m	☐	-0.024 V	☐	-216.5 μm/m	0.001 V	☐	0.0 μm/m	
D110	S19	11.1 μm/m	☐	-0.029 V	☐	[illegible]	0.000 V	☐	0.0 μm/m	
D111	S20	-60.9 μm/m	☐	0.001 V	☐	76.5 μm/m	-0.000 V	☐	0.0 μm/m	
D112	S21	9.1 μm/m	☐	-0.024 V	☐	-8.4 μm/m	0.000 V	☐	0.0 μm/m	

177 rows, 170 selected

```
Time                     Source   Name                              Message                                                                     Type Name   Prop ID
2015/07/09 14:50:40.811  Test     FASTER Panel 3 Static Test_Str... Auto Offset multi-select operation finished.  170 items selected.  0 operations failed.  Test  13624
2015/07/09 14:48:28.316  Station  FASTER Panel 3 Static Test_Str... Data Acquisition disabled.                                                  Test        0
2015/07/09 14:48:28.316  Station  Data Acquisition: Disabled        Event triggered.                                                            Event       10809
2015/07/09 14:48:27.989  Station  FASTER Panel 3 Static Test_Str... Timed Mode Scan 2 stopped.  1869 samples taken.                              Test        0
2015/07/09 14:48:27.989  Station  Timed Mode Scan 2: Stopped        Event triggered.                                                            Event       10809
2015/07/09 14:47:07.349  System   Test Station 1: FASTER Panel 3... Data connection with client 'AEROPRO-CLNT-1' has closed.                     DataSender  0
```

Figure C-8. Offset strain gauges before test

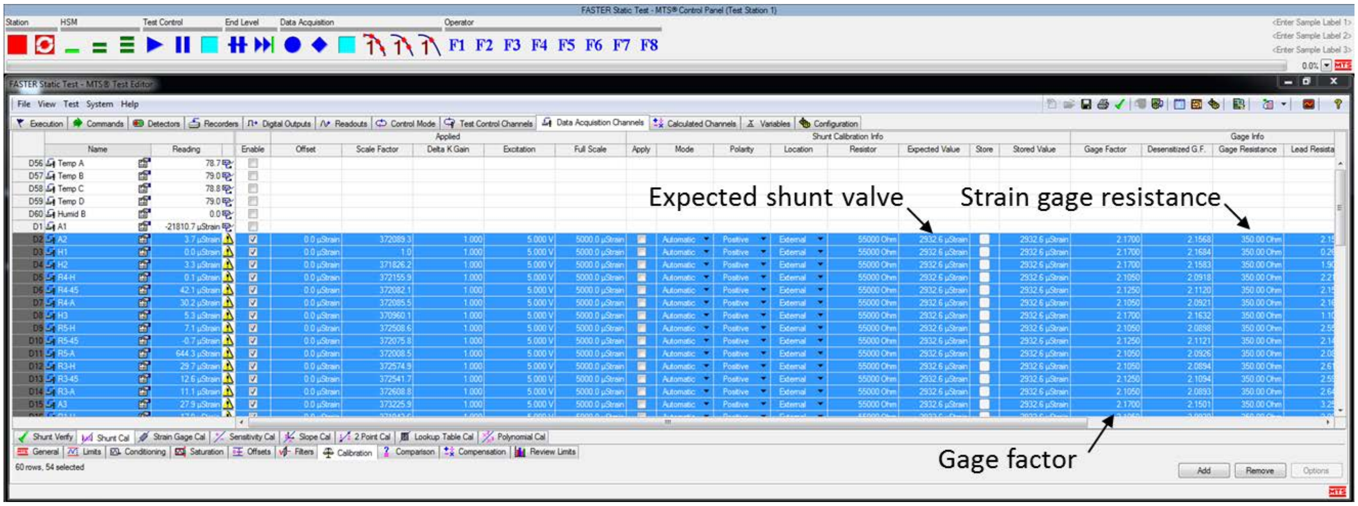


	Name	Reading	Polarity	Full Scale	Scale Factor	Gains Pre-Amp	Gains Post-Amp	Gains Total Gain	Delta K	Excitation Enable	Excitation Programmed	Excitation Measured	Excitation Balance	Notes
D69	UA_A1	922.7 μStrain	Positive	5000.0 μStrain	373340.1				1.000	☑	5.000 V	4.999 V	0.000 V	
D70	UA_A2	837.8 μStrain	Positive	5000.0 μStrain	373395.3				1.000	☑	5.000 V	5.000 V	0.000 V	
D71	UA_A3	640.8 μStrain	Positive	5000.0 μStrain	373282.8				1.000	☑	5.000 V	5.001 V	0.000 V	
D72	IS42	512.2 μStrain	Positive	5000.0 μStrain	373442.1				1.000	☑	5.000 V	5.000 V	0.000 V	
D73	IS43	365.8 μStrain	Positive	5000.0 μStrain	373513.7				1.000	☑	5.000 V	5.000 V	0.000 V	
D74	IS44	64.2 μStrain	Positive	5000.0 μStrain	373755.7				1.000	☑	5.000 V	4.999 V	0.000 V	
D75	IS45	453.3 μStrain	Positive	5000.0 μStrain	373557.3				1.000	☑	5.000 V	5.000 V	0.000 V	
D76	IS46	428.4 μStrain	Positive	5000.0 μStrain	370059.3				1.000	☑	5.000 V	5.002 V	0.000 V	
D77	IS47	416.5 μStrain	Positive	5000.0 μStrain	373473.4				1.000	☑	5.000 V	5.001 V	0.000 V	
D78	IS48	259.0 μStrain	Positive	5000.0 μStrain	373779.5				1.000	☑	5.000 V	5.000 V	0.000 V	
D79	IS49	-94.1 μStrain	Positive	5000.0 μStrain	373724.1				1.000	☑	5.000 V	5.000 V	0.000 V	
D80	IS50	512.0 μStrain	Positive	5000.0 μStrain	373447.8				1.000	☑	5.000 V	5.002 V	0.000 V	
D81	IS51	-33.0 μStrain	Positive	5000.0 μStrain	373535.5				1.000	☑	5.000 V	5.000 V	0.000 V	
D82	IS52	783.7 μStrain	Positive	5000.0 μStrain	373528.7				1.000	☑	5.000 V	5.000 V	0.000 V	
D83	IS53	7.7 μStrain	Positive	5000.0 μStrain	373473.1				1.000	☑	5.000 V	5.001 V	0.000 V	
D84	IS54	721.5 μStrain	Positive	5000.0 μStrain	373499.7				1.000	☑	5.000 V	5.000 V	0.000 V	
D85	IS55	624.3 μStrain	Positive	5000.0 μStrain	373506.6				1.000	☑	5.000 V	5.000 V	0.000 V	
D86	S48	715.0 μStrain	Positive	5000.0 μStrain	374784.2				1.000	☑	5.000 V	5.001 V	0.000 V	
D87	S51	1027.5 μStrain	Positive	5000.0 μStrain	373623.7				1.000	☑	5.000 V	5.000 V	0.000 V	
D88	S55	409.8 μStrain	Positive	5000.0 μStrain	373037.3				1.000	☑	5.000 V	5.001 V	0.000 V	
D153	S15	-3.7 μStrain	Positive	5000.0 μStrain	373433.5				1.000	☑	5.000 V	5.000 V	0.000 V	
D154	RA_A1	867.0 μStrain	Positive	5000.0 μStrain	373526.4				1.000	☑	5.000 V	5.000 V	0.000 V	
D155	RA_A2	716.7 μStrain	Positive	5000.0 μStrain	373480.8				1.000	☑	5.000 V	5.000 V	0.000 V	
D156	RA_A3	635.9 μStrain	Positive	5000.0 μStrain	373547.9				1.000	☑	5.000 V	4.999 V	0.000 V	
D157	IS70	306.6 μStrain	Positive	5000.0 μStrain	373578.1				1.000	☑	5.000 V	5.001 V	0.000 V	
D158	IS71	254.7 μStrain	Positive	5000.0 μStrain	373611.8				1.000	☑	5.000 V	5.000 V	0.000 V	
D159	IS72	251.2 μStrain	Positive	5000.0 μStrain	373590.7				1.000	☑	5.000 V	5.001 V	0.000 V	
D160	IS73	596.0 μStrain	Positive	5000.0 μStrain	373623.3				1.000	☑	5.000 V	5.000 V	0.000 V	
D161	IS74	499.8 μStrain	Positive	5000.0 μStrain	373476.7				1.000	☑	5.000 V	5.001 V	0.000 V	
D162	IS75	530.3 μStrain	Positive	5000.0 μStrain	373350.2				1.000	☑	5.000 V	5.002 V	0.000 V	
D163	IS76	412.8 μStrain	Positive	5000.0 μStrain	373689.2				1.000	☑	5.000 V	4.999 V	0.000 V	
D164	IS77	62.2 μStrain	Positive	5000.0 μStrain	373636.5				1.000	☑	5.000 V	5.000 V	0.000 V	

229 rows, 224 selected

Excitation voltage

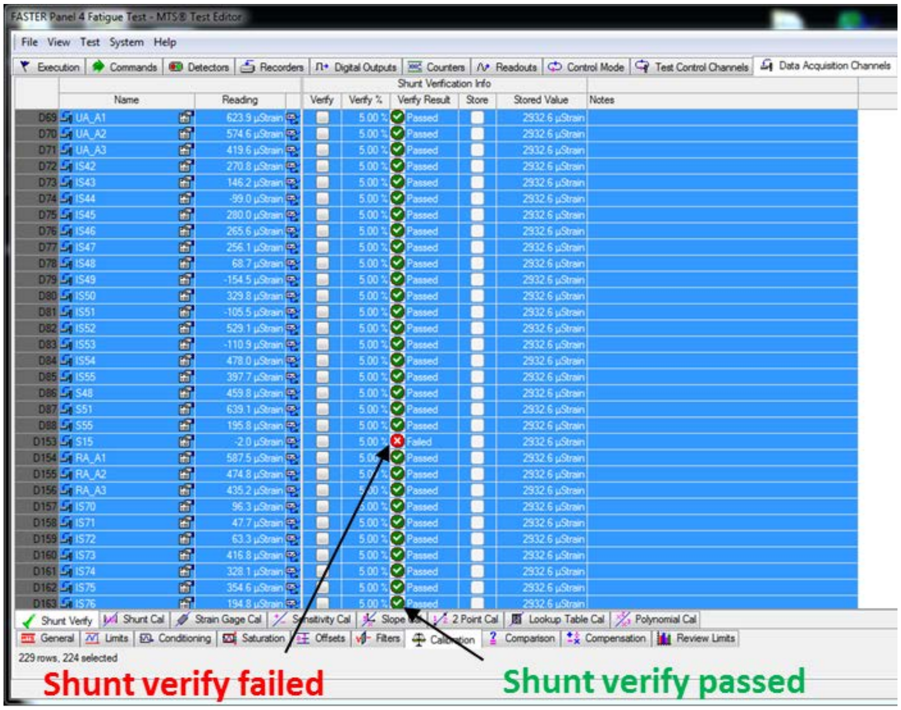
Figure C-9. Strain gauge excitation voltage



						Applied							Shunt Calibration Info						Gage Info	
	Name	Reading	Enable	Offset	Scale Factor	Delta K Gain	Excitation	Full Scale	Apply	Mode	Polarity	Location	Resistor	Expected Value	Store	Stored Value	Gage Factor	Desensitized G.F.	Gage Resistance	Lead Resista
D56	Temp A	78.7	☐																	
D57	Temp B	79.0	☐																	
D58	Temp C	78.8	☐																	
D59	Temp D	79.0	☐																	
D60	Humid B	0.0	☐																	
D1	A1	-21810.7 µStrain	☐																	
D2	A2	3.7 µStrain	☑	0.0 µStrain	372089.3	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1700	2.1568	350.00 Ohm	2.15
D3	H1	0.0 µStrain	☑	0.0 µStrain	1.0	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1700	2.1684	350.00 Ohm	0.26
D4	H2	3.3 µStrain	☑	0.0 µStrain	371826.2	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1700	2.1583	350.00 Ohm	1.90
D5	R4-H	0.1 µStrain	☑	0.0 µStrain	372155.9	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1050	2.0918	350.00 Ohm	2.21
D6	R4-45	42.1 µStrain	☑	0.0 µStrain	372082.1	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1250	2.1120	350.00 Ohm	2.15
D7	R4-A	30.2 µStrain	☑	0.0 µStrain	372085.5	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1050	2.0921	350.00 Ohm	2.16
D8	H3	5.3 µStrain	☑	0.0 µStrain	370960.1	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1700	2.1632	350.00 Ohm	1.10
D9	R5-H	7.1 µStrain	☑	0.0 µStrain	372508.6	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1050	2.0898	350.00 Ohm	2.55
D10	R5-45	-0.7 µStrain	☑	0.0 µStrain	372075.8	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1250	2.1121	350.00 Ohm	2.14
D11	R5-A	644.3 µStrain	☑	0.0 µStrain	372008.5	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1050	2.0926	350.00 Ohm	2.03
D12	R3-H	29.7 µStrain	☑	0.0 µStrain	372574.9	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1050	2.0894	350.00 Ohm	2.61
D13	R3-45	12.6 µStrain	☑	0.0 µStrain	372541.7	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1250	2.1094	350.00 Ohm	2.55
D14	R3-A	11.1 µStrain	☑	0.0 µStrain	372608.8	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1050	2.0893	350.00 Ohm	2.64
D15	A3	27.9 µStrain	☑	0.0 µStrain	373225.9	1.000	5.000 V	5000.0 µStrain	☐	Automatic	Positive	External	55000 Ohm	2932.6 µStrain	☐	2932.6 µStrain	2.1700	2.1501	350.00 Ohm	3.25

60 rows, 54 selected

Figure C-10. Strain gauge shunt calibration



			Shunt Verification Info					
	Name	Reading	Verify	Verify %	Verify Result	Store	Stored Value	Notes
D69	UA_A1	623.9 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D70	UA_A2	574.6 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D71	UA_A3	419.6 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D72	IS42	270.8 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D73	IS43	146.2 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D74	IS44	-99.0 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D75	IS45	280.0 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D76	IS46	265.6 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D77	IS47	256.1 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D78	IS48	68.7 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D79	IS49	-154.5 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D80	IS50	329.8 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D81	IS51	-105.5 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D82	IS52	529.1 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D83	IS53	-110.9 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D84	IS54	478.0 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D85	IS55	397.7 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D86	S48	459.8 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D87	S51	639.1 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D88	S55	195.8 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D153	S15	-2.0 µStrain	☐	5.00 %	☒ Failed	☐	2932.6 µStrain	
D154	RA_A1	587.5 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D155	RA_A2	474.8 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D156	RA_A3	435.2 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D157	IS70	96.3 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D158	IS71	47.7 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D159	IS72	63.3 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D160	IS73	416.8 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D161	IS74	328.1 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D162	IS75	354.6 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	
D163	IS76	194.8 µStrain	☐	5.00 %	✓ Passed	☐	2932.6 µStrain	

229 rows, 224 selected

Figure C-11. Strain gauge shunt verify

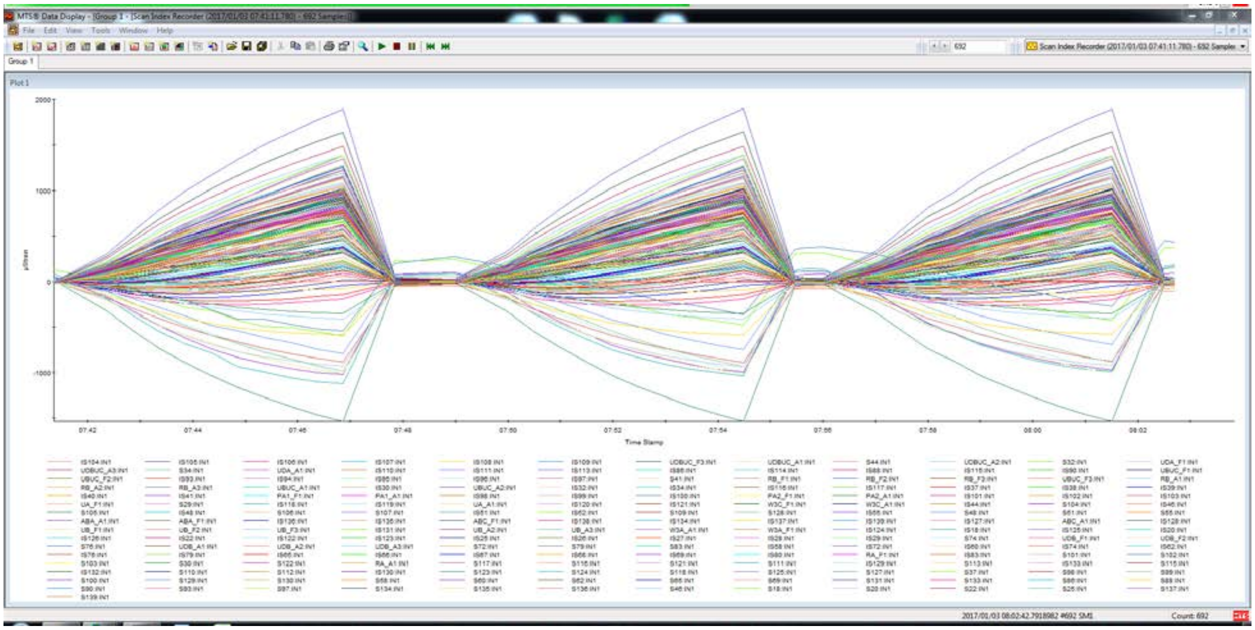
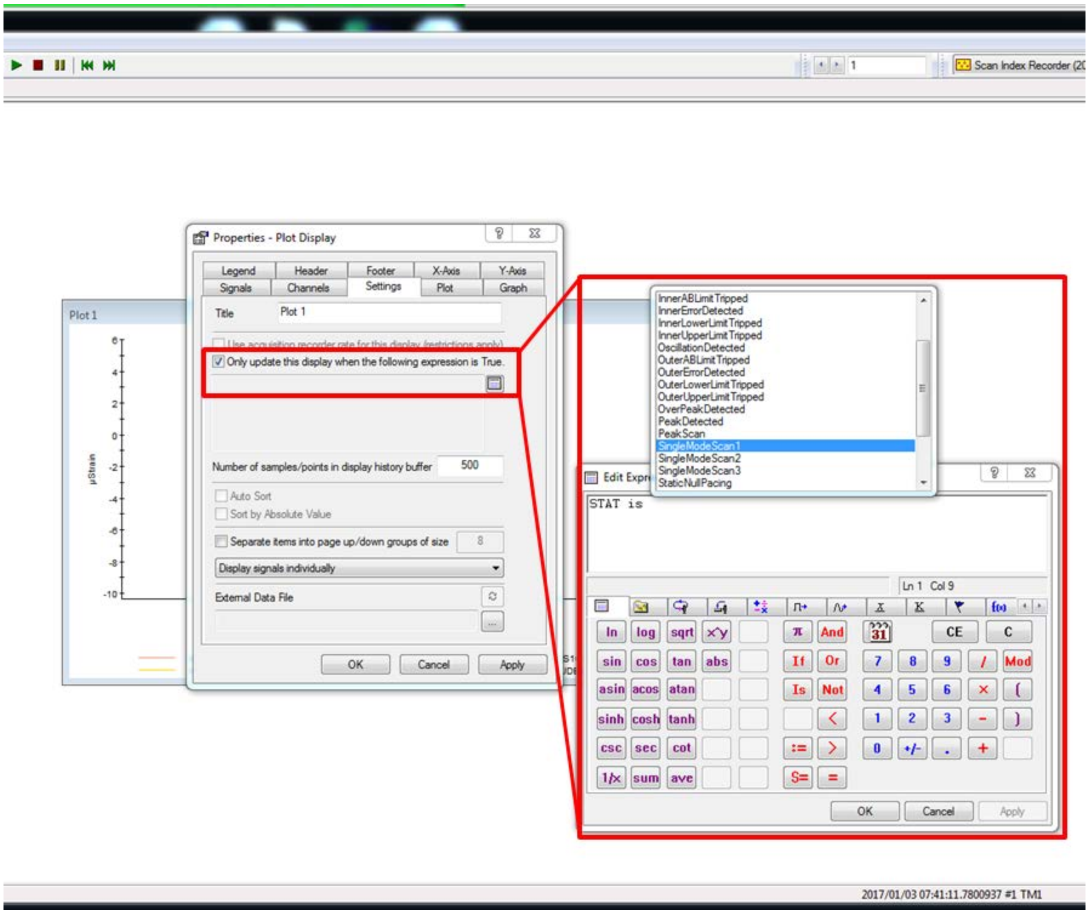


Figure C-12. MTS data display



Title: Plot 1

☑ Only update this display when the following expression is True.

Number of samples/points in display history buffer: 500

☐ Auto Sort

☐ Sort by Absolute Value

☐ Separate items into page up/down groups of size 8

Display signals individually

```
STAT is
```

InnerABLimitTripped
InnerErrorDetected
InnerLowerLimitTripped
InnerUpperLimitTripped
OscillationDetected
OuterABLimitTripped
OuterErrorDetected
OuterLowerLimitTripped
OuterUpperLimitTripped
OverPeakDetected
PeakDetected
PeakScan
SingleModeScan1
SingleModeScan2
SingleModeScan3
StaticNullPacing

2017/01/03 07:41:11.7800937 #1 TM1

Figure C-13. Example of exporting single scan mode data

APPENDIX D—AXIAL LOAD MODIFICATION FOR RESIDUAL STRENGTH TEST

The Full-Scale Aircraft Structural Test Evaluation and Research fixture was modified for FAA-ARCONIC Emerging Structures Technologies (ESMT) project to enhance the axial load capacity required for the residual strength test.

The original axial load capacity is 20,000 lb on all eight axial loaders, P/N: Futek LCB450. Normally, the specified loads for the same type of loaders are the same. However, to achieve better load distribution in the test area and comparison with the Finite Element Model, the loads used for this project depend on locations. The target axial load for the residual strength test for the FAA-ARCONIC ESMT Project is pressure plus 2.5G bending load, which is equivalent to 35,767 lb at all four corner locations.

The axial loader modification included structural modifications to the axial loader lever arm, replacing existing loaders with higher capacity loaders, P/N: Futek LCM550, and fabricating the matching adaptor and clevis parts, as shown in figures D-1 and D-2. The maximum supply air pressure is 120 psi; theoretically, the maximum axial load capacity is 38,400 lb using the same bladder type loading mechanism.

The axial loader levers were removed from the fixture. Steel strips that were 0.25 inches by 35 inches long were welded onto each of the levers for reinforcement purposes. A new clevis and adapter were fabricated for the new load cell, as shown in figures D-3 and D-4. As shown in figure D-2, the bladder performs at a high load level with the same pressure. To achieve the target load, a 2.5-inch-thick shim was added on each side of the bladder.

The other axial loaders can also be modified in the same way to increase the capacity if needed for future testing. The residual strength loading profile has been applied pristine panel #1, and all four-corner axial loaders reached the required loads, as shown in figure D-5.

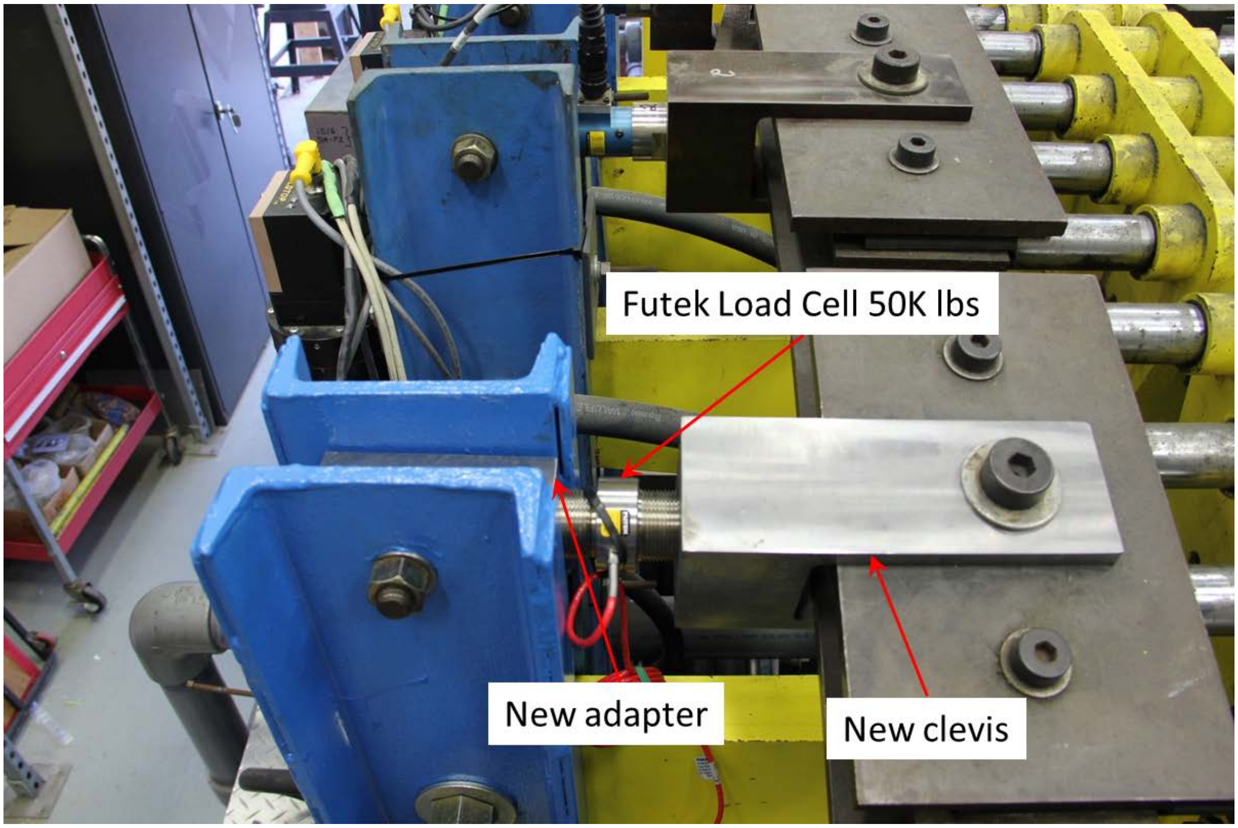


Figure D-1. Picture of modified axial load assembly—top view

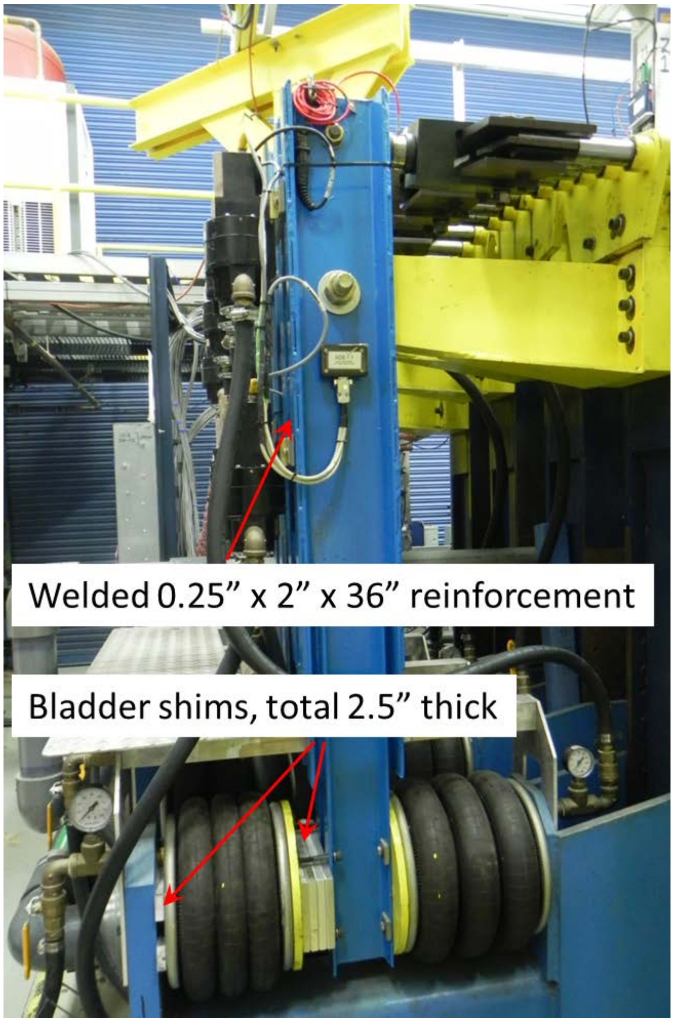


Figure D-2. Picture of modified axial load assembly—side view

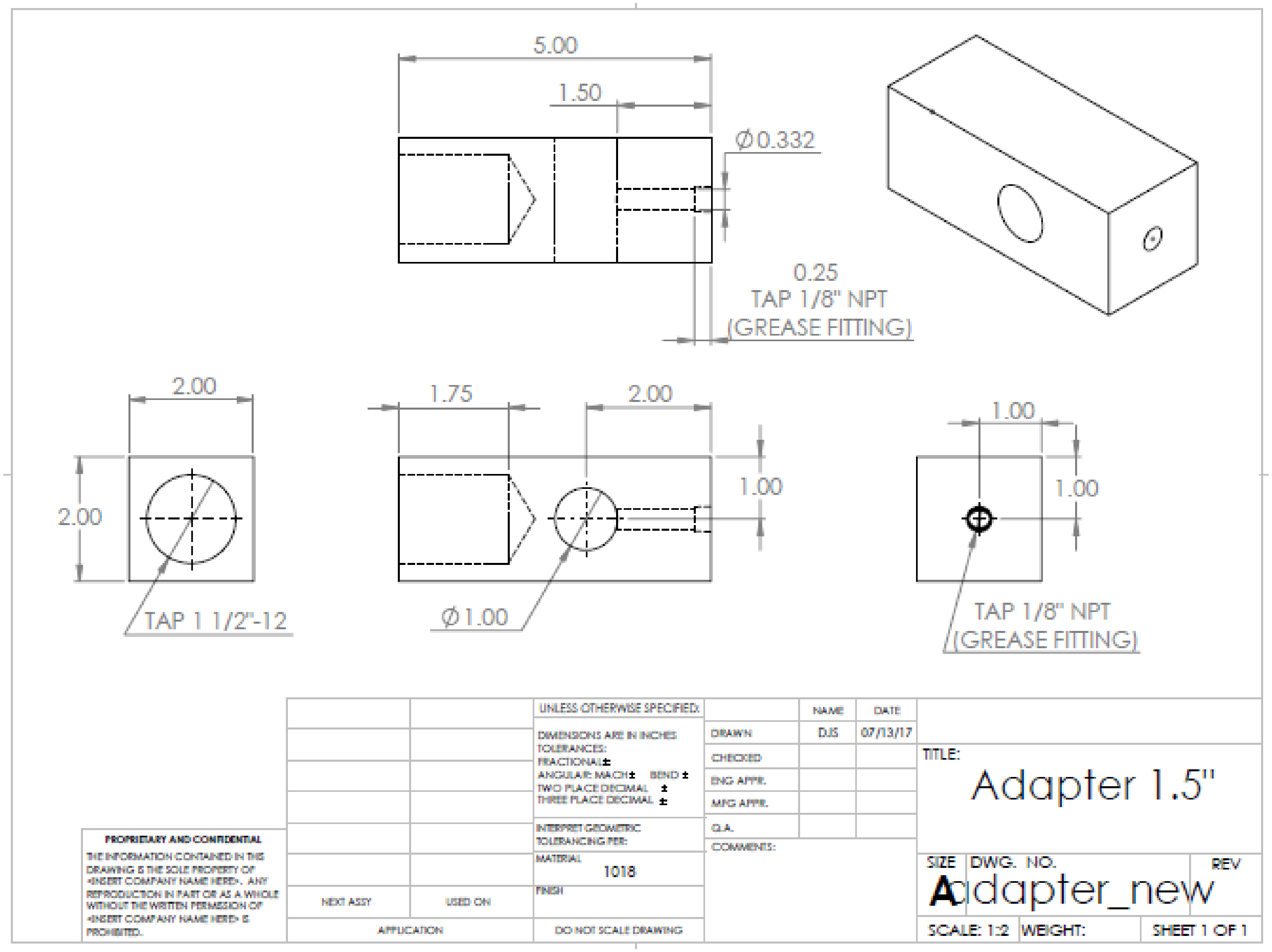


Figure D-3. Drawing of adapter

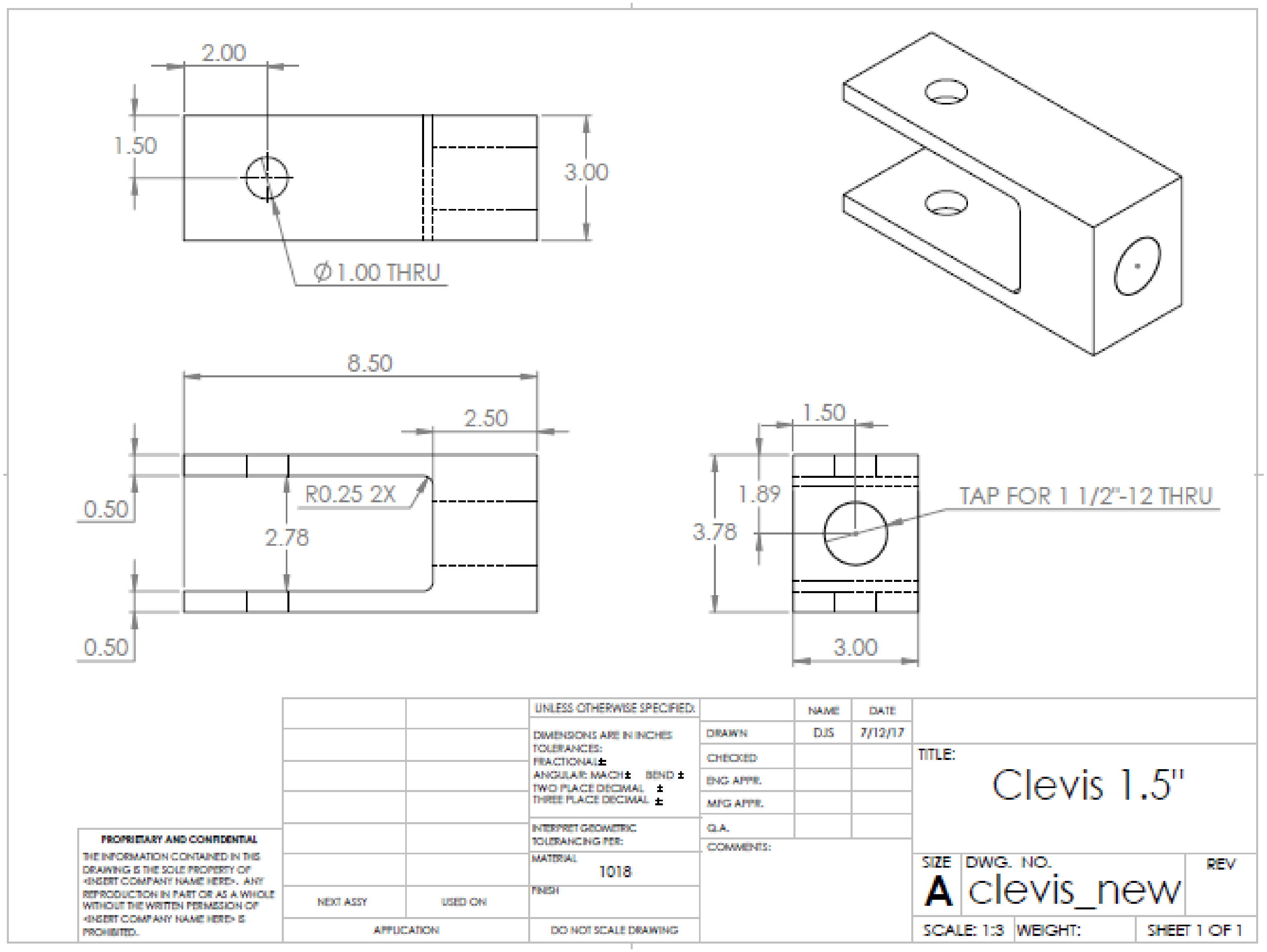


Figure D-4. Drawing of clevis

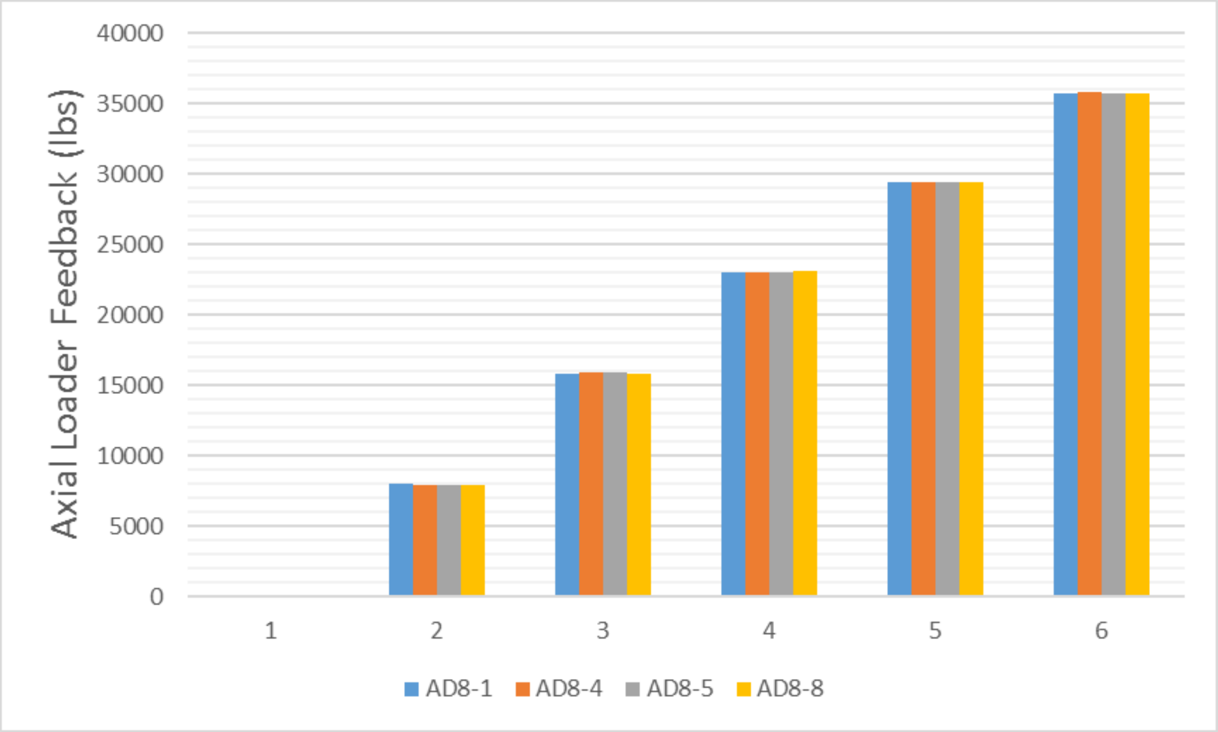


Figure D-5. Axial residual strength load profile on pristine panel #1