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Development Of A Supersonic Wind Tunnel Rapid Real-Time Data Acquisition And Control System

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DEVELOPMENT OF A SUPERSONIC WIND TUNNEL RAPID REAL-TIME DATA
ACQUISITION AND CONTROL SYSTEM

By

Ndubuisi Emmanuel Okoro

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Aerospace
in the Department of Aerospace Engineering

Mississippi State, Mississippi

December 2005

DEVELOPMENT OF A SUPERSONIC WIND TUNNEL RAPID REAL-TIME DATA
ACQUISITION AND CONTROL SYSTEM

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As a part of the revitalization of the supersonic wind tunnel maintained by the Aerospace Engineering Department of Mississippi State University, a new data acquisition and control system became incumbent. Previous data acquisition and control systems used in the operation of the supersonic wind tunnel made use of now outdated hardware and functioned with two central processing units; one processor was used for recording system response, while the other monitored and controlled the tunnel. A new system is required to provide adequate rapid real-time control, along with rapid acquisition of raw tunnel feedback or response data and tunnel pressure data all implemented on one computer processor. This paper details the development of the supersonic wind tunnel data acquisition and control system employed in the revitalization project.

DEDICATION

I would like to dedicate this research to my wife, Constance Michelle Okoro, and my son, Kelechi Emmanuel Okoro. Thanks for standing by me through this period of long days and long nights.

ACKNOWLEDGMENTS

Inexpressible thanks to my family for all the love and support. Many thanks to Mr. Hannigan for sharing his data bank of knowledge with me and for teaching me most of what I need to know and what I was afraid to ask about. I appreciate the support provided by my major professor, Dr. Keith Koenig, and the encouragement from Dr. Greg Olsen.

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CHAPTER I

INTRODUCTION

Purpose of the Project

Research capabilities and educational training in aerospace engineering have improved with the addition of new technological experiential tools to the respective programs. Prior to the implementation of modern technology, research projects had to be completed with laborious and impeding programming routines, time consuming solvers, lethargic processing units, and inaccurate hardware. On the other hand, students sustained a full load of learning and understanding theories, concepts and problem solving methods with complicated software platforms, hard to comprehend programming processes and inadequate experiential tools.¹ Technological advancements have provided research and academic fields with fast computer processors, simple programming routines, easy to understand software platforms and accurate hardware.²

The supersonic tunnel at Mississippi State University is one of the great additions to research and educational training. The purpose of the project is to develop a modern data acquisition and control program to implement in the renovation of the supersonic wind tunnel in Patterson Laboratories of the Department of Aerospace Engineering at Mississippi State University.³

Background

In the midst of technological discoveries was the design and development of the supersonic wind tunnel located in Patterson Laboratories at Mississippi State University.

At the time of conception, the supersonic wind tunnel was designed to support the research activities of research teams funded by NASA. The supersonic wind tunnel served as a test bed for studying supersonic flutter in prototype airfoils and also served through life cycles of projects involving visualization of air flow.⁴ At the conclusion of the research activities, NASA contributed the tunnel to Mississippi State University as a major infrastructure for educational and research support. The supersonic tunnel is shown in Figure 1.1.

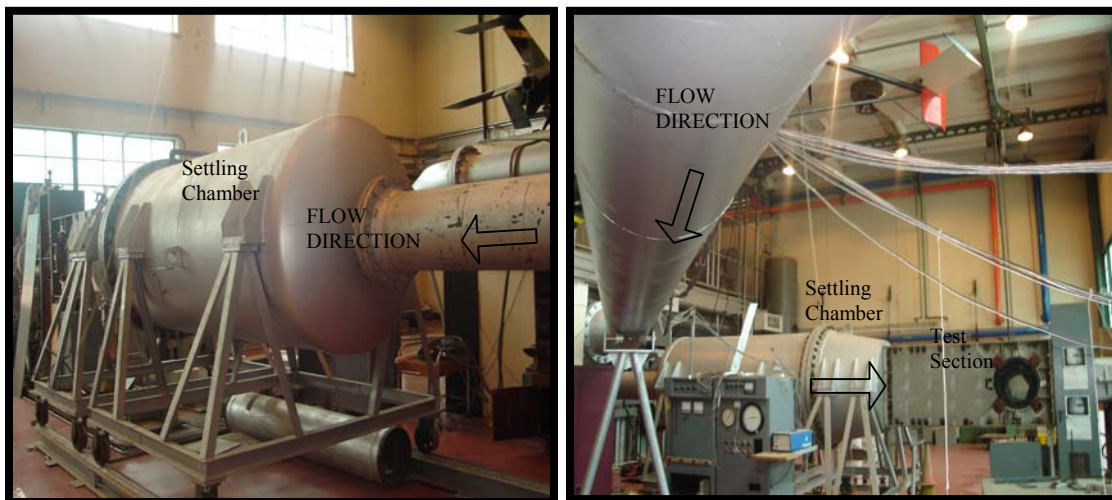


Figure 1.1 Left – Tunnel Downstream Section. Right – Tunnel Upstream Section.

This wind tunnel has provided an avenue for demonstrating and verifying new concepts, theories and methods to improve and aid student learning. The wind tunnel has also been used in studying knife-edged airfoils with schlieren visualization methods.⁵

Through the years, the supersonic tunnel at Patterson Laboratories has progressed through stages of development and advancement. The primal stage was the design and development of the supersonic tunnel by NASA. The department of Aerospace

Engineering inherited the supersonic tunnel after the primal stage because of the support provided to NASA research teams. The first enhancement stage involved making detailed modifications to the initial test section, introducing moveable models, and improving and automating the original manual control system. This generated a large accumulation of complex and difficult to understand (by today's standard) data acquisition and control equipment, hardware, and software. The next phase involved the development of a data acquisition and control system – a single user friendly control program. The goal was to make the supersonic wind tunnel available to students that were not necessarily familiar with the methods of programming and the processes of controlling the devices of the tunnel. The program involved the use of two central processing units to simultaneously perform data acquisition tasks and control tasks to successfully run and monitor the supersonic wind tunnel. The operation of the tunnel involved a group of operators stationed at key parts of the tunnel to manually shutdown the tunnel in case of system failure or any other unpredictable events. At the time, the tunnel data acquisition and control program successfully performed all assigned tasks, with only limitations such as were inherent in the acquisition rates of the data acquisition cards and in the processor speeds of the central processing units. The tunnel later suffered some physical damage to the control system, particularly the butterfly valve that controls air flow, and subsequently languished in disrepair as the search for replacement parts was protracted.

The continual and pace-setting development of technology, research fields and educational learning tools sparked and fueled the revitalization of the supersonic tunnel at

Mississippi State University. The supersonic wind tunnel in Patterson Laboratories has long been a legacy test and simulation infrastructure. The desire to use the supersonic wind tunnel as an educational tool, for demonstrating and confirming aerodynamics and compressibility concepts and theories to students, is a major reason for bringing the wind tunnel back to full operational conditions. The current revitalization phase involved acquiring a new high pressure valve, installing the original test section, and restoring all connections and seals in the 16 inch flow pipes. A major part of the revitalization project involves developing a modern general user interface and highly simplified data acquisition and control system. This paper discusses the development of a supersonic wind tunnel rapid real-time data acquisition and control system.

Previous Studies Supporting the Program Development

The characteristics of flow in a supersonic nozzle were studied in conjunction with this project. The behavior of pressure distributions and pressure loss was examined in an effort to determine a better way to provide suitable air pressure and sustained flow for the supersonic nozzle. The control system of the nozzle was also studied as a preliminary task for understanding the programming routines that can be used in performing data acquisition and control tasks through pressure scanning systems.⁶ The operation of the subsonic wind tunnel of the Aerospace Engineering Department was studied in an effort to develop and understand the order of events necessary for the data acquisition and control system for the supersonic wind tunnel. The control program of the subsonic wind tunnel was also examined in detail to determine methods and sub-level programs that are used for communicating with the multiplexer, which is a necessary

component of the supersonic tunnel system hardware. This multiplexer was used to control switches on a system of interlocks that served as safety mechanisms for the supersonic tunnel operation.

CHAPTER II
THE SUPERSONIC WIND TUNNEL
OPERATIONAL CHARACTERISTICS

The Supersonic Wind Tunnel Components

The supersonic tunnel is comprised of a high pressure reservoir, sixteen inch airflow routing pipes, and a test section that dumps into a vacuum tank or to the atmosphere. The tunnel control components start off with a butterfly valve located in the main feed pipe from the pressure reservoir. The butterfly valve regulates airflow in the supersonic tunnel.

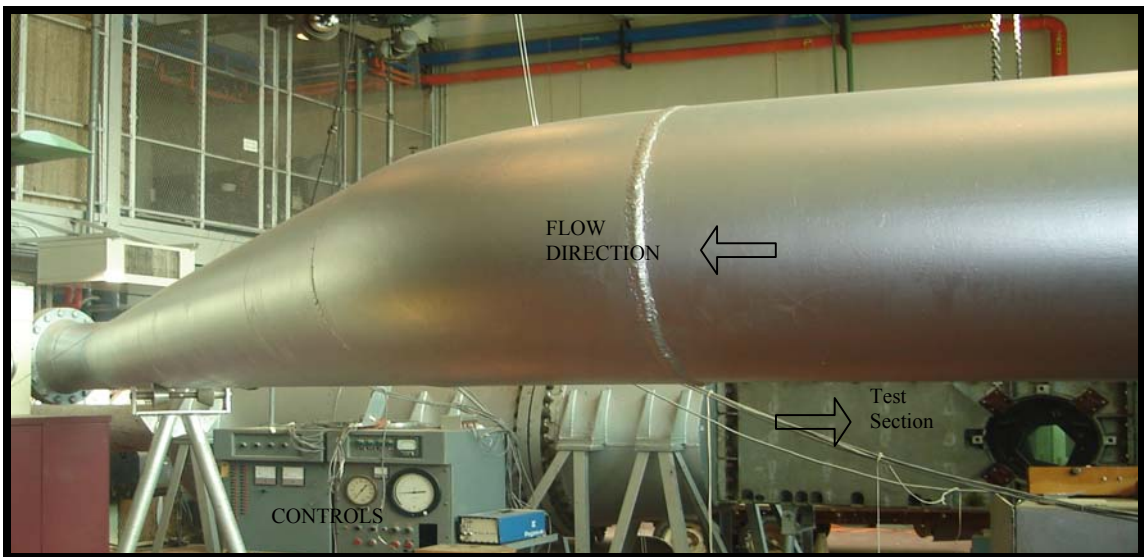


Figure 2.1 16 Inch Airflow Connector Pipes.

The butterfly valve is connected to the sixteen inch routing pipes, just upstream of the section shown in Figure 2.1, by dual sealing link flanges. The sixteen inch routing pipes extend from the valve to the settling chamber upstream of the original test section. The test section, most recently utilized, was a small nozzle used only for educational purposes. Now the original configuration, used by NASA researchers, is being implemented in the revitalization project. Before the test section is a settling chamber, shown in Figure 2.2. A pressure transducer in this chamber provides actual control feedback pressure for operating the tunnel. A moveable sting is mounted in the test section, shown in Figure 2.3, with the capability of moving the sting arm in two degrees of freedom, and provides the capability of supporting numerous airfoil prototypes or other models.



Figure 2.2 Settling Chamber

The test section exhausts to a diverging duct beyond the moveable sting to the blow-down exit that opens to a vacuum tank or the atmosphere. Interlocks are installed to allow for immediate shutdown of the tunnel during tunnel run or after complete tunnel runs. The interlocks are safety valves on the hydraulic system that insure adequate operating pressure and also switch the hydraulic mechanism moving the butterfly valve through high speed or low speed operation.



Figure 2.3 Supersonic Wind Tunnel Test Section Access and Viewing Port.

The interlocks are also set to open an emergency pressure relief valve, shown in Figure 2.4, for rapid air pressure evacuation during an emergency shutdown, as well as to automatically close the butterfly valve in case of loss of power to the interlocks. This would prevent catastrophic test section window failure.

Operating the Tunnel

The supersonic tunnel is controlled by first initiating the interlocks to arm and safety the pressure relief valve mechanism, and to insure that adequate hydraulic pressure has been accumulated for controlling the butterfly valve. The downstream valve is then moved to full open, hydraulically or manually. The downstream valve is located in the exhaust section at the exit of the tunnel. The manual hydraulic control arm used to open the downstream valve is shown in Figure 2.4. The butterfly valve controller can then be provided with a control input based on the desired pressure in the settling chamber. The control inputs are regulated by the tunnel control system and actuated by the Pegasus valve positioning system.



Figure 2.4 Downstream Valve Control Mechanism.

Overall, the butterfly valve is controlled with an automatic hydraulic valve positioning system shown in Figure 2.5. The hydraulic positioning system is linked to a servo module system that controls the flow of hydraulic fluid in the positioning system. After the hydraulic positioning system receives necessary commands, the positioning system sets the butterfly valve to allow the amount of air flow needed to put the settling chamber at the desired pressure. Background, or buffered, data acquisition is started prior to and continued during tunnel operation to continuously record the tunnel system control and response data.



Figure 2.5 Butterfly Valve Control Mechanisms.

Once the settling chamber pressure reaches the desired pressure, the butterfly valve is opened and closed by the servo-controller to maintain the pressure, by rapidly fluctuating in response to the desired pressure level with the aid of feedback signals and the determined error between the desired pressure level and the actual pressure level. After an elapsed run-time, the interlocks are restored and remaining pressure in the tunnel dissipates to the atmosphere. All wind tunnel operations are then subsequently terminated. If emergency shutdown is activated during tunnel run, the interlocks will insure that the emergency pressure release valve is opened in order to more rapidly relieve dangerous pressure buildup.

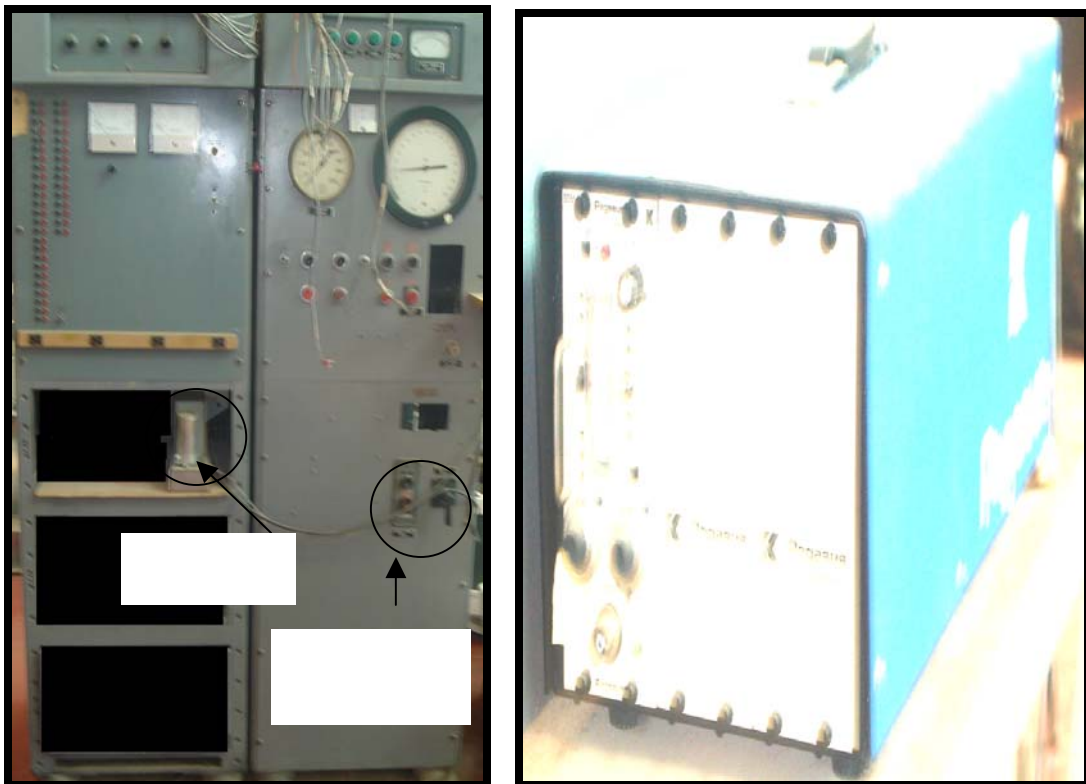


Figure 2.6 Left – Tunnel Main Power Supply. Right – Pegasus Servo-valve Controller.

Prior to initiating the tunnel interlocks, a series of operational requirements are verified and validated. Figure 2.6 illustrates the main power and Pegasus servo valve that must be turned on. The power supply for analog reference values must be turned on and set to 7 volts. The power supply for pressure transducers must be turned on. The power supply for valve position transducer must then be plugged in. The supersonic tunnel main power key must be turned on. The power supply chains are verified connected. The hydraulic pressure pumps are activated and required hydraulic pressure is confirmed. A minimum hydraulic pressure value of 450 pounds per square inch must be sustained before proceeding with the next item on the tunnel checklist. The mechanical pin-lock of the butterfly valve has to remain in-place and the operator is required to confirm that the pin-lock is in-place at this point in the process. The valve servo system module is activated and confirmed on. The air supply pressure is inspected and the tunnel shutdown process is reviewed with the team of operators. All emergency personnel are then assigned to their specific manual operating positions for specific shutdown tasks. The supersonic tunnel warning whistle is activated and all data recording devices are turned on, and the tunnel is ready to be run.

CHAPTER III
COMMUNICATION OF THE DATA ACQUISITION AND CONTROL SYSTEM
WITH THE TUNNEL

Devices

The communication devices consist of an operating system with high speed processors, a National Instruments software platform, LabVIEW version 7.1, two National Instruments PCI-6024E data acquisition and signal processing cards, screw terminal accessory boards, high voltage interference free cables, high pressure transducers, a multiplexer, high speed pressure scanners, and an interface pressure scanner connector box with power and communications over ethernet.⁷ The control devices are the Pegasus servovalve controller and servovalve module, butterfly valve hydraulic control arm, the tunnel settling chamber pressure fluctuation feedback, and the tunnel interlocks controlled through the multiplexer. The control devices and hardware monitored by the assembled supersonic tunnel data acquisition and control system are applied in three categorized phases: initialization phase, run-time phase, and shutdown phase. Zero voltages are secured through the assigned channels on the data acquisition cards in the initialization phase. The run-time phase makes use of devices that relay commands necessary to activate moveable parts of the tunnel resulting in desired run conditions. The shutdown devices provide a way to safely terminate the tunnel operation.

Program Phases

Initialization

The initialization phase consists of pre-run tasks that are required to initiate voltage input and output for communicating between the control system and the supersonic tunnel. The initialization tasks, as shown in Figure 3.1, start off by specifying the desired run-time settling chamber pressure. This pre-set value allows the control system to determine the required voltage output necessary to set the butterfly valve at a suitable level. Prior to placing the valve at the desired level, the downstream nozzle in the test section must be choked for sufficient pressure rise to occur in the settling chamber. After choking the nozzle, the butterfly valve allows the right amount of air flow necessary for reaching and maintaining the desired settling chamber pressure.

The default channels are the assigned channels.
Do not change the channels if you are not authorized to do so.

DAQ CARD 1 - D1
DMA DATA ACQUISITION DAQ CARD 2 - D2

Servo SSM IN - D1
CHAMBER PRESSURE - D2

Servo SSM METER - D1
Servo SSM Meter - D2

Valve Position - D1
Valve Position - D2

Servo SSM OUT - D1
Servo SSM OUT - D2

Cylinder LO SIDE - D1
Cylinder LO SIDE - D2

Cylinder HI SIDE - D1
Cylinder HI SIDE - D2

Hydraulic Pressure - D1
Hydraulic Pressure - D2

Available 8 - D1
AVAILABLE 8 - D2

FOLLOW THESE INSTRUCTIONS TO INITIALIZE THE TUNNEL:
1) INPUT THE DESIRED SETTLING CHAMBER PRESSURE.
2) INPUT THE CUTOFF FRACTION.
3) INPUT THE TOTAL RUNTIME.
4) INPUT THE MAX SUPPLY VOLTAGE.
5) INPUT THE CURRENT ATMOSPHERIC PRESSURE AND THE CURRENT TEMPERATURE.
6) CONTROL THE TUNNEL WITH FEEDBACK PRESSURE BY CLICKING THE "MONITOR AND CONTROL THE TUNNEL BASED ON FEEDBACK PRESSURES" BUTTON. DO NOT CLICK THE BUTTON TO CONTROL THE TUNNEL ONLY WITH VOLTAGE OUTPUT
7) CHOOSE A LOCATION TO STORE RECORDED DATA.
8) INITIALIZE THE TUNNEL. CONTINUE TO MAIN PROGRAM AFTER INITIALIZING.

Desired Settling Chamber Pressure 0
Cutoff TIME of Initial press/volt 0
SST RUNTIME IN SECONDS 0
Input Max Supply Voltage 0
Atmospheric Pressure in MM HG 0
Temperature in DEG C 0
Rho (slug / ft³) 0
Temperature (Deg F) 0

Path To Store Recorded Data

Servo SSM IN Zero Voltage - D1 0
Servo SSM Meter Zero Voltage - D1 0
Valve Position Zero Voltage - D1 0
Cylinder LO SIDE Zero Voltage - D1 0
Cylinder HI SIDE Zero Voltage - D1 0
Hydraulic Pressure Voltage - D1 0

READ ALL INSTRUCTIONS BEFORE CLICKING ANY BUTTONS

Initialize Tunnel

MONITOR AND CONTROL THE TUNNEL BASED ON FEEDBACK PRESSURES

CONTINUE TO MAIN PROGRAM

Figure 3.1 Initialization General User Interface.

A start-up cutoff time is then set to allow the control system to output a maximum supply voltage for a short length of time. This task allows the tunnel airflow to start off by first sending a high voltage, which is the maximum supply voltage, to the butterfly valve controller ordering the valve toward the wide open tunnel full throttle level to choke the downstream nozzle. The air flow then commences allowing the maximum possible flow into the tunnel. The butterfly valve must be opened toward the maximum position to initiate airflow quickly. The nozzle will choke then pressure will rise in the settling chamber. If the valve is not opened quickly, the reservoir air pressure will be depleted prior to reaching the desired conditions. The maximum voltage corresponding to flow that chokes the nozzle is replaced with another voltage value determined by the desired target settling chamber pressure. A commanded feedback voltage from the settling chamber pressure transducers regulates the butterfly valve at the desired settling chamber pressure. The initial full throttle command of the valve is terminated at the set cutoff time to proceed with the next necessary sequence of events. The total tunnel run time is set to control how long the tunnel stays activated. The amount of pressure in the supply tank has been pre-determined to only sustain a short run time length during which all data acquisition and control must be successfully accomplished. The supply voltage for the feedback pressure transducers must be turned on and set at a pre-determined value as appropriate for the transducers. The current atmospheric conditions are set to be used in subsequent analysis of recorded data from the wind tunnel. There are two ways to control the tunnel with the new data acquisition and control program. The tunnel can be controlled either by simply writing a voltage value to the servo valve controller to set a

desired feedback voltage and equivalent pressure level or by monitoring the feedback signals above or below the desired settling chamber pressure voltage value, while varying the voltage command. Although the servovalve controller uses a variable gain, different gain schemes can be explored with the developed program. The latter method of controlling the tunnel is an option to be chosen or set in the initialization phase. The tunnel is automatically controlled via raw voltage output as indicated by the first method. The tunnel is controlled by feedback pressure only if the operator selects this option. A file path must be set to store the data recorded via background data acquisition. The background data acquisition is done during run-time to document continuous, historical system response data. Real-time communication is successfully completed since background data acquisition allows the control system to input and output response and command signals without any foreground interruption. The initialization phase is completed by getting the reference voltages from the transducers.

Run-time

The run-time phase consists of a series of events that are necessary for starting up and running the tunnel. This phase consists of background data acquisition along with real-time monitoring of feedback pressure voltages needed for controlling the tunnel. The data acquisition task is first started in the computer background via direct memory access, DMA. DMA is a real-time process that bypasses all foreground events such as user input, software execution, virus scanning backlog, and all processor sensors. This provides an accurate way to record data from a range of monitored channels in an allocated part of the computer memory. A voltage command starts up the tunnel by

commanding a particular settling chamber pressure transducer voltage level through foreground communication. The pressure voltage level is ultimately maintained until the set run-time length has elapsed.

Shutdown

Shutdown is accomplished by first sending an output command that sets a zero pressure feedback voltage. The control system then proceeds to wait until flow in the tunnel subsides. The interlocks are subsequently restored to insure that the tunnel is secured. If the interlocks are restored without writing out a zero command level and then waiting for an amount of time, the servovalve controller becomes disabled and the interlock release produces valve closure and the safety. The servovalve will no longer be available to operate the valve once the interlocks are replaced. The shutdown phase uses the multiplexer and general purpose interface bus, GPIB (synonymous with Hewlett Packard interface bus), to communicate with components of the tunnel that execute run-time termination. GPIB controllers energize high voltage relays and switches through the multiplexer. These relays and switches are connected to hydraulic controllers that hold the interlocks in place. Once the commands in the shutdown phase are sent by GPIB through the multiplexer, the hydraulic controllers immediately release the interlocks.

CHAPTER IV
THE REAL-TIME SYSTEM LOGIC:
USER INPUT EVENTS

Control System Logic

The idea behind the development of the tunnel data acquisition and control of the supersonic wind tunnel is to give the operator an easy way to run the tunnel without any knowledge of the inner workings of the supersonic tunnel. The logic of the control program is built on limiting user input, thereby, preventing a backlog of the processor on the workstation in use. Real-time control logic affords the system a series of events synchronized to produce rapid control input and output response. All events are linked to a main program with a general user interface that simply displays when stages have been completed and also provides the user with specific instructions needed during the activation of the tunnel. The algorithm for the data acquisition and control program that has been developed is included in Appendix A, and will now be described.

Order of Events

Startup Checklist

The first event in the program is a sub-level program that informs the user of all necessary steps to verify and validate before initializing the tunnel. This user interface is called the supersonic tunnel startup checklist, as shown in Figure 4.1. The circuit

diagram on Figure 4.1 of the checklist interface consists of a group of Booleans that must be changed from false to true, by pressing the appropriate buttons, before proceeding with the next event.

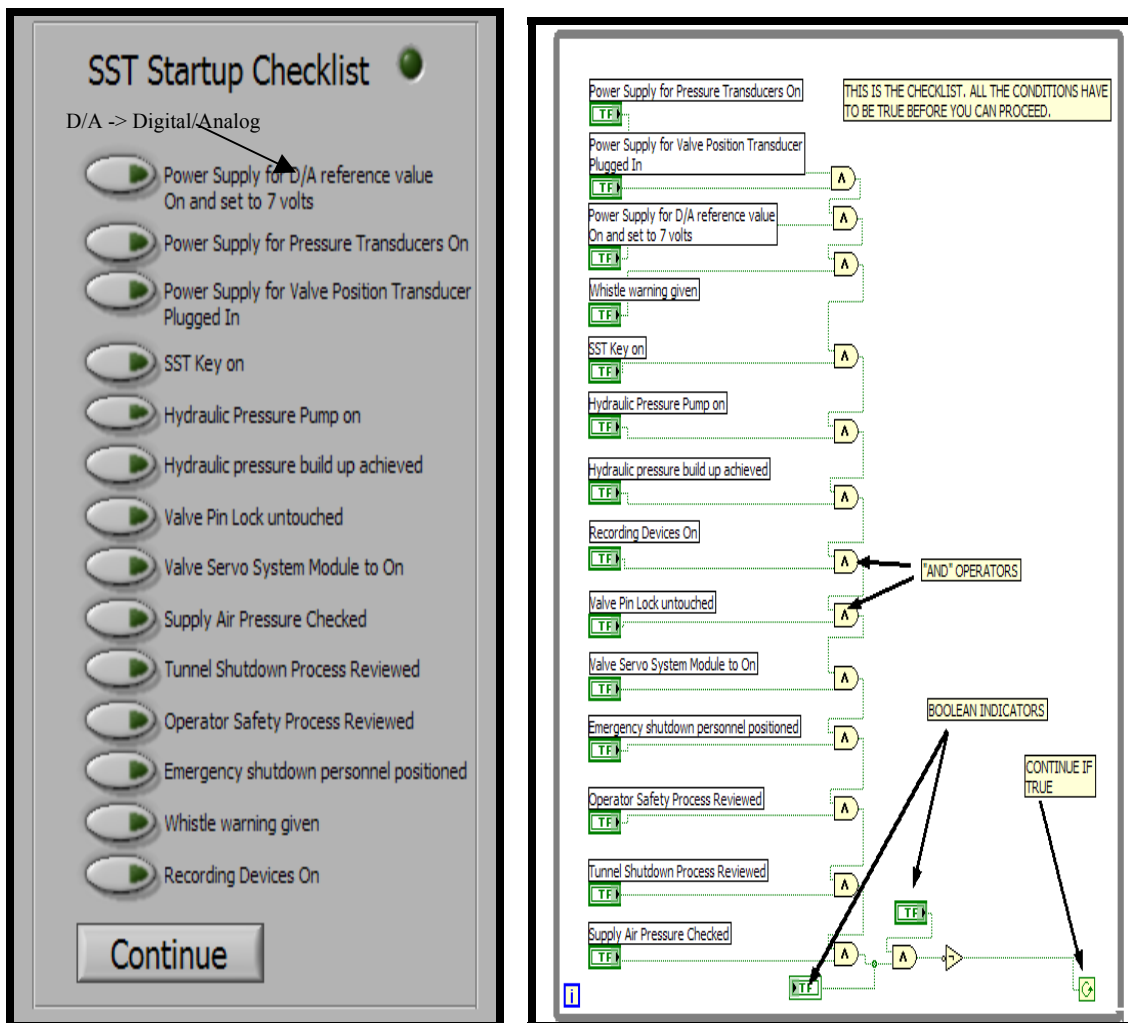


Figure 4.1 Left – Front Panel of Startup Checklist. Right – Wiring Diagram for Startup Checklist

The inverted hat connectors are called “AND” logical operators. These “AND” operators insure that none of the items on the checklist remains false. If any item on the checklist is unchecked the program will not be able to proceed and will prevent the user from

starting the tunnel. The sub-level program is controlled by setting the circuit loop to continue in a while loop until all checklist items are turned on and set to true. This should insure that the verification process will be completed and all safety measures will be reviewed regarding each aspect of the tunnel.

Initialization Instructions

The operator is provided with another sub-level program, whose front panel is shown in Figure 4.2, informing the user of details about the channels used in communicating with the tunnel. This panel tells the user not to change the pre-set channels, only if a change is authorized.

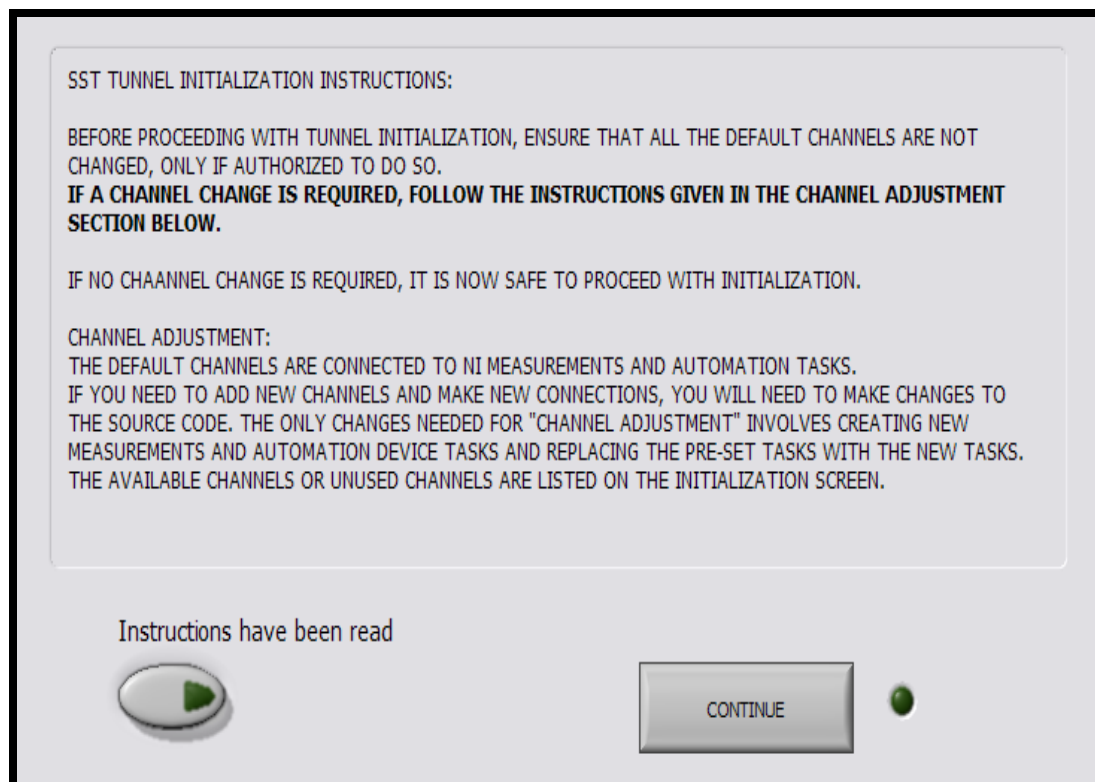


Figure 4.2 Tunnel Initialization Instructions.

The user is also informed of how a new channel change can be implemented in the source code of the control program.

Editing Assigned Channels

National Instruments LabVIEW software package comes with a Measurement and Automation Explorer that is used to create these run-time tasks. Changes to channel assignments are done by accessing the data neighborhood section of the measurement and automation platform.

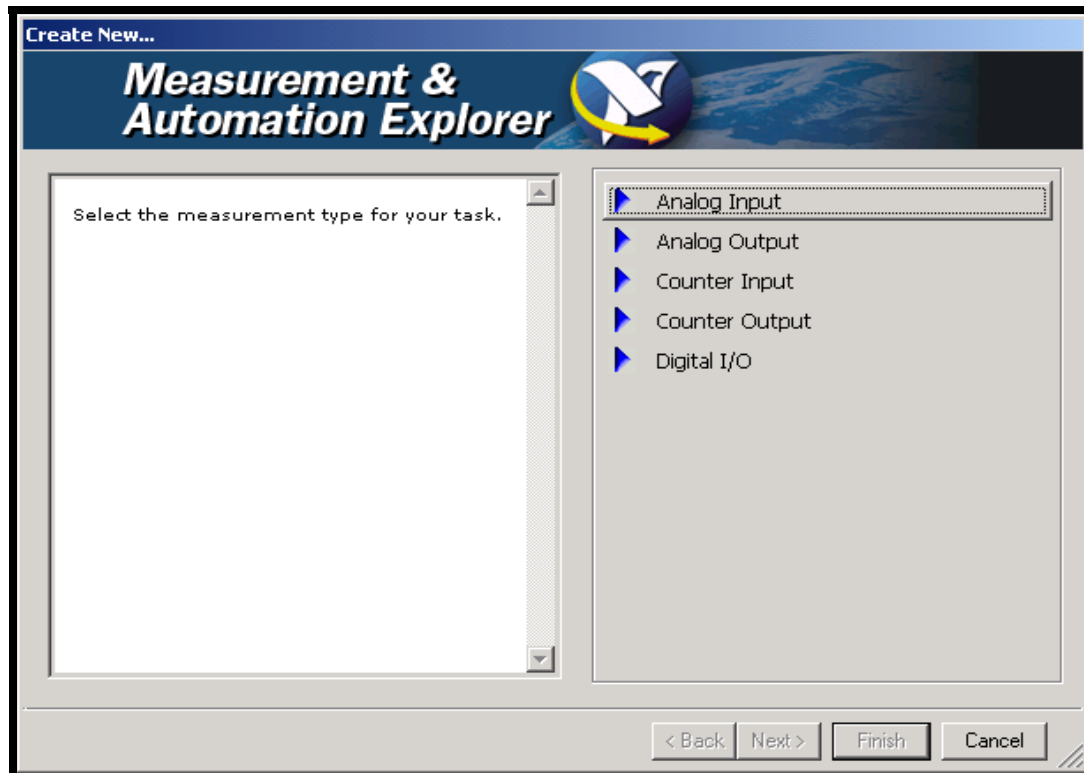


Figure 4.3 Measurement & Automation Explorer Wizard.

Under data neighborhood is a sub-folder called NI-DAQmx Tasks. Input and output tasks can be created via the NI-DAQmx Tasks folder. The operator editing the source

code has to right click on the folder to reveal the create task option. Once this option is clicked, a wizard, shown in Figure 4.3, pops up to allow the user to select the type of task that is needed for the input or output function. The wizard will already have the two PCI-6024E devices loaded and a drop down list of all the available channels will be shown. To select multiple channels, the user should hold the CONTROL button and left click on all the necessary channels. The user can now select next and choose a name for this specific task. A pictorial guide of how to change channel assignments and tasks is shown in the new task selection section of Appendix B.

Obtaining Reference Values

At this stage, the user is directed to the front panel of the initialization code. The user is required to set the various control values essential for operating the tunnel. Then, the initialization code obtains reference voltages and stores the values in different global variables. These reference, or zero voltages, are recorded via a series of acquire waveform sub-level codes. The front panel of this initialization event allows the operator to select the control mode of the tunnel. The operator can choose to control the tunnel with voltage signals to the Pegasus servo controller or choose to supplement this controller to enhance system response during run of the tunnel by monitoring feedback pressure signals and by varying the output commands. This selection is stored in a global variable for future reference in the list of execution events.

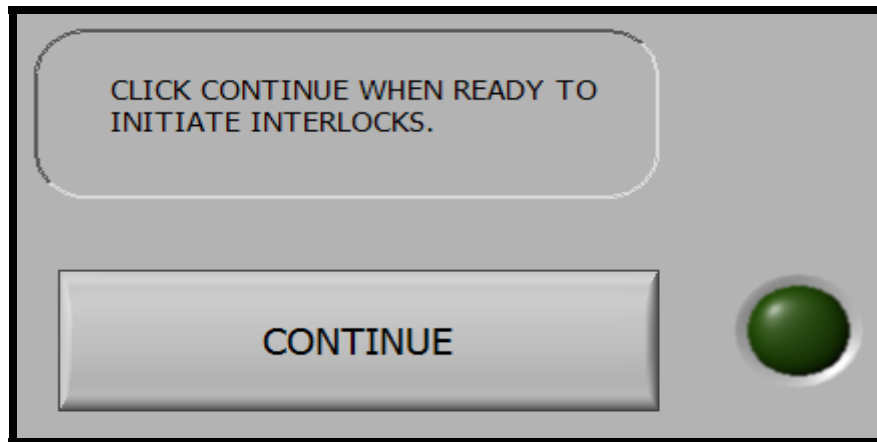


Figure 4.4 Remove Interlocks Dialogue.

Return to Main Program

Following the initialization of the tunnel, the operator is redirected to the main control program, and prompted to confirm that the interlocks of the tunnel can be released. The prompt screen is shown in Figure 4.4. The interlocks are released as soon as the continue button is clicked on the prompt screen. After completing the release interlocks task, the control program displays another prompt screen. The operator is prompted to remove the pin lock of the butterfly valve, Figure 4.5, and proceed to the main program.

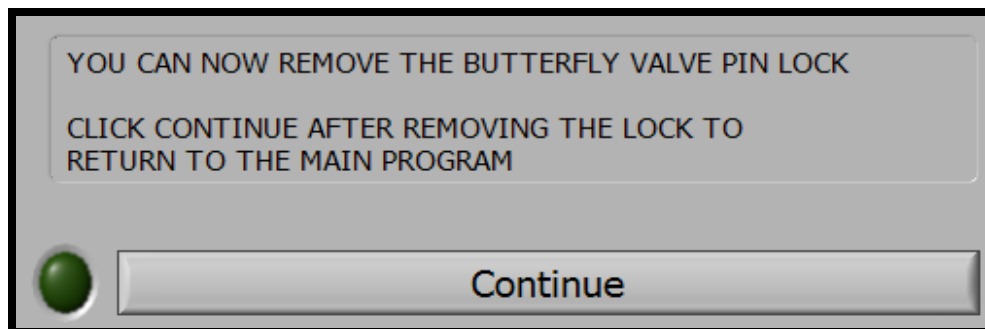


Figure 4.5 Remove Butterfly Valve Pin Lock.

Run-time execution

The “tunnel is ready to start” Boolean of the main program, Figure 4.6, is turned on when the system is ready for the run-time phase. The operator can now click the “start tunnel” button, when prompted, to begin actual tunnel operation. The program gets the clock start up time and starts background data acquisition before making any command output signals.

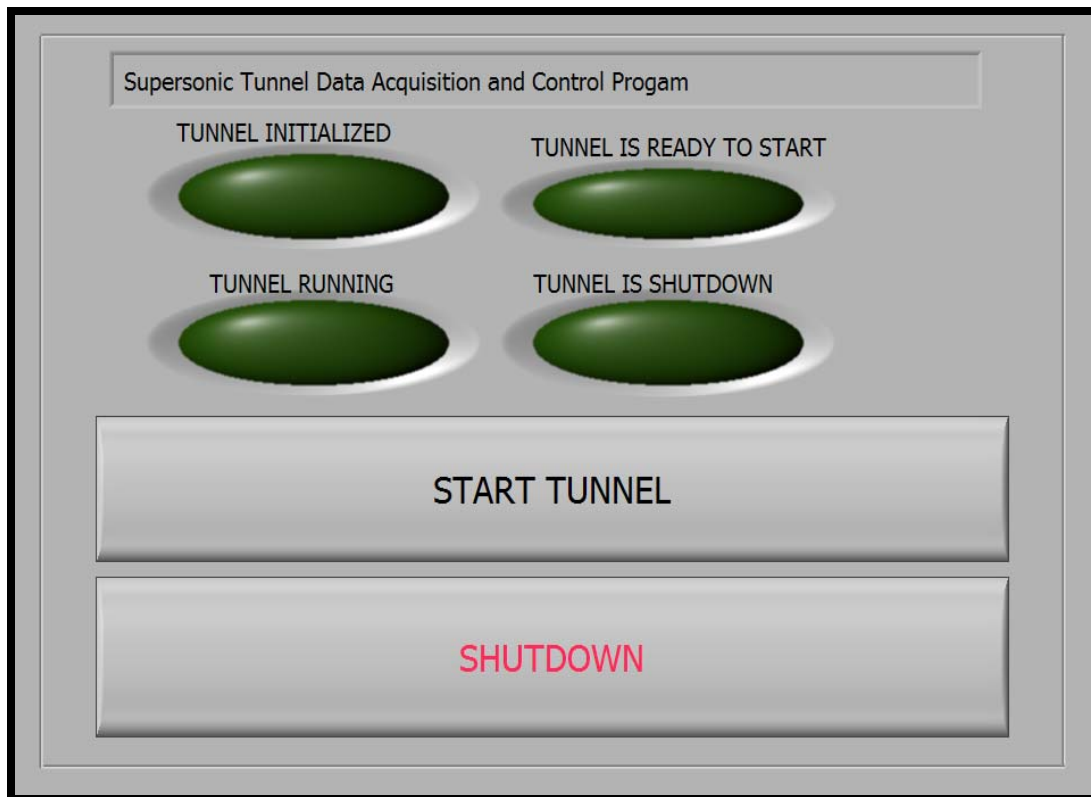


Figure 4.6 Supersonic Tunnel Main Program Front Panel.

The programmed output signal sequence structures are in series with each other. The first signal specifies the maximum feedback voltage, as previously stated. This is done for a short period of time before the signal is changed to a zero value. Basically, this zero value commands the valve to start returning back to the closed position to avoid

overshooting the desired feedback level. The program later starts the actual setup of regulating the feedback pressure following another elapsed time. If the operator previously chose to control the tunnel with feedback pressure, the program will output the voltage level determined from the desired pressure and monitor the fluctuations from the desired voltage level, while making necessary corrections to return the output voltage to the exact desired voltage level. All of this is done within a specified tunnel run-time. After the elapsed time is the same as the set run-time, the tunnel terminates all output commands and waits for about a short time to allow the exhaustion of choked air before releasing the interlocks through the multiplexer. The tunnel is completely shutdown at this point and the program terminates. The wiring diagram of the main program is included in Appendix C.

CHAPTER V

TESTING THE DATA ACQUISITION AND CONTROL FUNCTIONALITIES

Tunnel Revitalization State

The supersonic tunnel is currently in an inoperable state. The components of the tunnel have been reassembled with the previously damaged high pressure valve to allow the realignment of the tunnel components and also to allow the installation of the original test section. The reassembly of the tunnel progressed after the completion of major structural repairs to the high bay floor underneath the tunnel settling chamber. The floor was damaged by a broken water main and a resulting flood from the main. The new high pressure valve will be put in place of the previous valve in the near future. Due to the current inoperable state of the tunnel, the functionalities of the program are tested to verify that the various tasks can be performed.

Elementary Functionality Test

A different program with the same functionalities as the tunnel control program was developed for testing purposes. Another program was needed to simply verify that the compiled tunnel program can perform data acquisition and control tasks via direct memory access, without making use of the multiplexer. The test program bypasses the various user prompt codes in the initialization phase and goes directly to the run-time phase where direct interaction between the program and the supersonic tunnel occurs.

The concept used in this test program is to perform all background data acquisition with one card, while simultaneously monitoring feedback and output of analog control signals on the other card. All connections from the voltage source to the screw terminal accessory boards are made with differential reference voltage formats. The successful execution of the test program tasks will confirm that the supersonic tunnel program can monitor a series of channels set for differential interchange, while monitoring pressure and controlling the butterfly valve.

Difficulties Encountered

During the testing phase of the program, various issues occurred that revealed program structure problem. Some problems were easily solved while others required some assistance from the application engineers at National Instruments. The previous pin-out connection chart is shown in Figure D.1 of Appendix D. This connection chart was used as a guide for making connections for testing the new system. The standard pin-out chart for the National Instruments connector box, used in the new program, is shown in Figure D.2 of Appendix D.

Rudimentary Problem

The first problem encountered came while trying to determine that the data acquisition card was outputting the correct voltage value. A digital multimeter, (DMM), was connected to read raw voltage values from one data acquisition card, while the same

voltage value was sent to the second card. The DMM read voltage values correct, demonstrating that the card would output correct voltage values. The input values did not match up with the DMM. At the time this problem was encountered, the issue was determined to be that the input channel was not set up for the correct connection type.⁸ The solution to the problem was to determine the correct connection type, either Referenced Single Ended or Differential, and then fix the specific channels as the selected connection type. The correct connection type was found to be the Differential type. Once this connection was chosen, the voltage values from the input channel matched up with the output voltage read by the DMM.

Buffer Read and Record Problems

When setting up the test program for synchronized write functions, the format of first creating a virtual channel then writing the voltage value, with a subsequent clear task code, appeared to be the correct format. This format was implemented in the simultaneous read and record functions with additional timing functions for the read task. Though the format correctly read the voltage values when the rudimentary problems were fixed, the side by side output and record functions did not perform the tasks correctly. Numerous format setups were implemented and tested to verify that synchronized output and input can be done. With recurring problems of not reading the voltage values and writing a desired series of voltage values, the application engineers at National Instruments were contacted for professional assistance.⁹ After probing and

troubleshooting the problem, the engineers reconfirmed that the correct format was needed. After swapping the positions of the read and write functions in the series of events, the solution was discovered to be that all setup sequences for buffered read functions must be placed one after the other without any other functions interrupting the tasks. Any output or write command can be placed before or after those read functions with a subsequent clear task. Once a working format was found, a test program was developed to perform the required task using the discovered format and then tested.¹⁰

Create Virtual Channel and Sampling Rate Errors

Before a read or write function can be executed, a channel has to be created. The problem was found to be that the specific location of the “create virtual channel” function in the sequence of events was of great importance. The create channel function was first moved to determine how to fix the problem, while attempting to maintain the format that was found to work. The problem then switched from just being “create virtual channel” errors to sampling rate errors. The executed code repeatedly stated that data was no longer available to be acquired and stored. After implementing multiple changes, the problem kept recurring. The “create virtual channel” sub-level program was then taken out of the picture and the channels for acquisition or output were created as tasks in Measurement and Automation Explorer of LabVIEW.¹¹ This new format that omitted the “create virtual channel” function was implemented throughout the code and then tested.

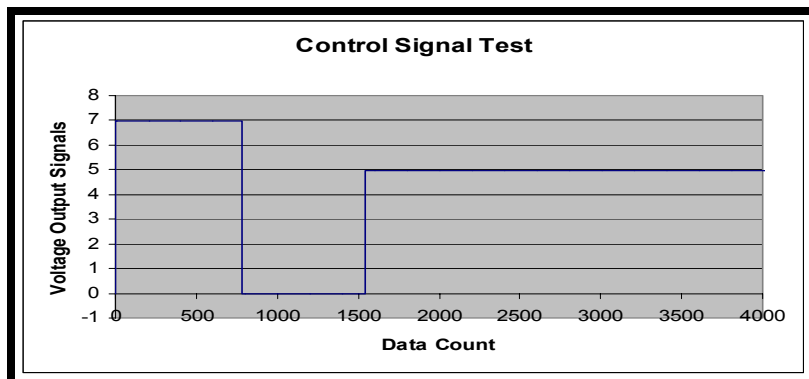


Figure 5.1 Simulated Control Response.

Successful Implementation

The functionalities test was a success. Two tests were setup, with the first test being a setup to output a voltage value for a short amount of time, cut off the signal then output a different voltage level, as shown in Figure 5.1.

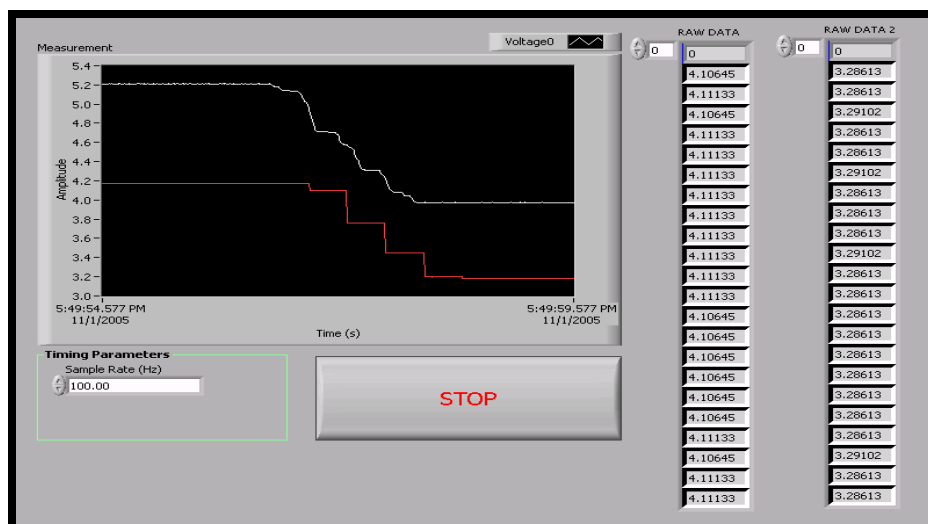


Figure 5.2 Simulated Functionalities Response.

This test was done to confirm the control capabilities of the program. In the second test, a Hewlett Packard 6236B triple output power supply was used to supply variable voltage values to the test setup. With the goal of verifying voltage input and output signals, a series of test runs were done by increasing and decreasing the supply voltage to check the system response. The system response matched up to the varied voltage inputs as shown in Figure 5.2. A slight time delay was noticed in the response of the test program. This occurred because the test program used separate side by side routines, as shown in Figure C.7. The delay in the system response was eliminated by placing the real time control section inside the “while loop” of the background data acquisition routine. With the conclusion of the successful tests, a virtual platform was developed for recreating and demonstrating the control capabilities of the program.

CHAPTER VI

CONCLUSIONS

Overview

The present task of developing a modern real-time data acquisition and control program for the supersonic wind tunnel has been achieved. The tunnel is started up and controlled by first going through the checklist, initializing the tunnel, initiating the interlocks and then maintaining a desired settling chamber pressure. After completing the tasks within a specified amount of time, the tunnel is automatically shutdown with a first output command of zero, a system wait and a subsequent release of the interlocks. The program logic has been simplified for easy editing. The current format is a verified working format that can be changed if necessary. The outlined steps for assigning channels to tasks or editing channels must be followed when needed. Test programs can then be developed to test the program functionalities. The tunnel hardware and communication devices must be installed and tested on the central processing unit being used for operating the tunnel. Physical equipment needed for running the tunnel, such as the hydraulic pumps and air supply pumps, should also be checked before running the tunnel. When the revitalization project is completed, the supersonic tunnel data acquisition and control program will be executed in the control workstation of the tunnel. The availability of this supersonic tunnel will strengthen the academic curriculum of the Aerospace Engineering Department.

Concluding Remarks

The supersonic tunnel data acquisition and control program was developed based on previous control programs compiled in HP BASIC and Turbo-Basic.¹² The functionalities portrayed in the previous programs have been duplicated to make a modern version of the previous working data acquisition and control systems. From the startup phase of getting zero voltages through the command output controlling the mechanical actions of the butterfly valve, the necessary details needed for understanding the functionalities of the developed modern real-time data acquisition and control program have been discussed. The posed tasks of initiating interlocks, obtaining a desired pressure level and shutting down the tunnel have been deemed feasible. The new control program source code can be easily edited with the information provided in this document.

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- ⁶ Okoro, Ndubuisi E., “Supersonic Nozzle Flow Analysis and Control System Design, A Research-Based Study”, Mississippi State University, Aerospace Engineering Laboratories, 2005.
- ⁷ National Instruments LabVIEW version 7.1, 2005
- ⁸ Mintzer, Justin, “Service Request Case 735337 – Call 1-7: Direct Memory Access Troubleshooting”, Applications Engineer, National Instruments, 2005.
- ⁹ Torba, M., Mintzer, J., “Service Request Case 735337 – Call 8-15: Direct Memory Access Configuration Setup”, Applications Engineer, National Instruments, 2005
- ¹⁰ National Instruments Development Zone, <http://zone.ni.com>
- ¹¹ National Instruments, “DAQ PCI 6024E User Manual”, <http://www.ni.com>
- ¹² Hewlett-Packard Company, “Programming with HP Basic”, Corvallis, OR: Corvallis Information Systems, 1989.

APPENDIX A

THE DATA ACQUISITION AND CONTROL PROGRAM ALGORITHM

Supersonic Wind Tunnel Data Acquisition and Control Program Algorithm

1. **Mainprogram.vi**
 - a. Sequence 0
 - SST CHECKLIST.vi (This vi contains a list of various precautions that must be done before running the tunnel)
 - b. Sequence 1
 - SST INIT.vi (Contains a list of used channels and dummy channels and initializes the tunnel)
 1. Initialization instructions
 - a. Continue Button
 - b. Turn Boolean Lights off
 2. Initialize
 3. Get initial voltages – acquire waveforms and write to global variables
 4. Ready
 5. Assign Values
 6. Continue
 - c. Sequence 2
 - SST RELEASE INTERLOCKS.vi (This vi releases the interlocks via the multiplexer)
 - d. Sequence 3
 - SST SAFE TO REMOVE PIN LOCK.vi (This vi prompts the user to remove the pin lock and continue)
 - e. Sequence 4
 - Assign values from global variables to local variables.
 - f. Sequence 5 – contains internal loop
 - This sequence contains the tunnel start up button. The program pauses in the internal loop contained in this sequence until the start up button is clicked.
 - g. Sequence 6 – contains internal loop
 - DMA is initiated and started before valve control begins
 - Runtime commands
 1. Check time
 2. Output max voltage and check voltage until max voltage is reached for a short period of time
 3. Clear port – write zeros out
 4. Output previously converted desired pressure – desired pressure is already in volts
 5. Check time

6. Adjust pressure with feedback pressure if user selects this option

Loop is terminated after the specified elapsed time.

h. Sequence 7

SST Stop Tunnel.vi (This vi shuts down the tunnel via the multiplexer)

i. PROGRAM TERMINATION

The program stores data in previously specified location.

APPENDIX B
EDITTING THE ASSIGNED CHANNELS

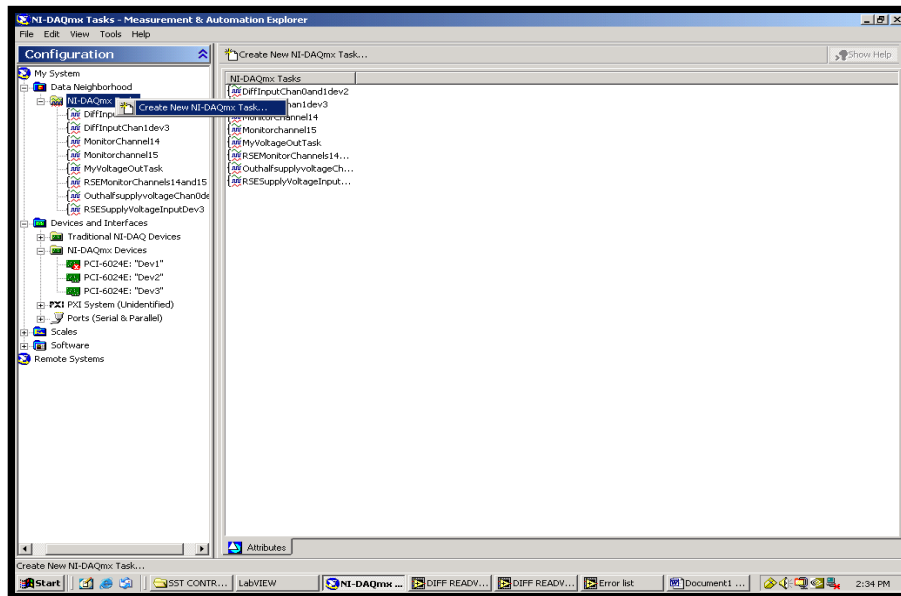


Figure B.1: Load Measurement and Automation Explorer and right click on NI-DAQmx task to create a new task.

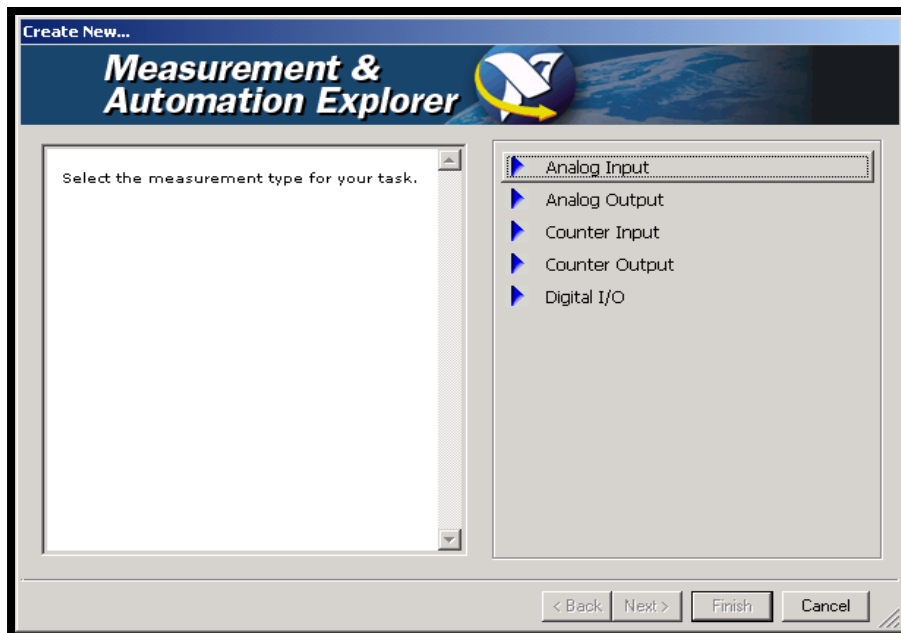


Figure B.2: Measurement & Automation Explorer wizard.

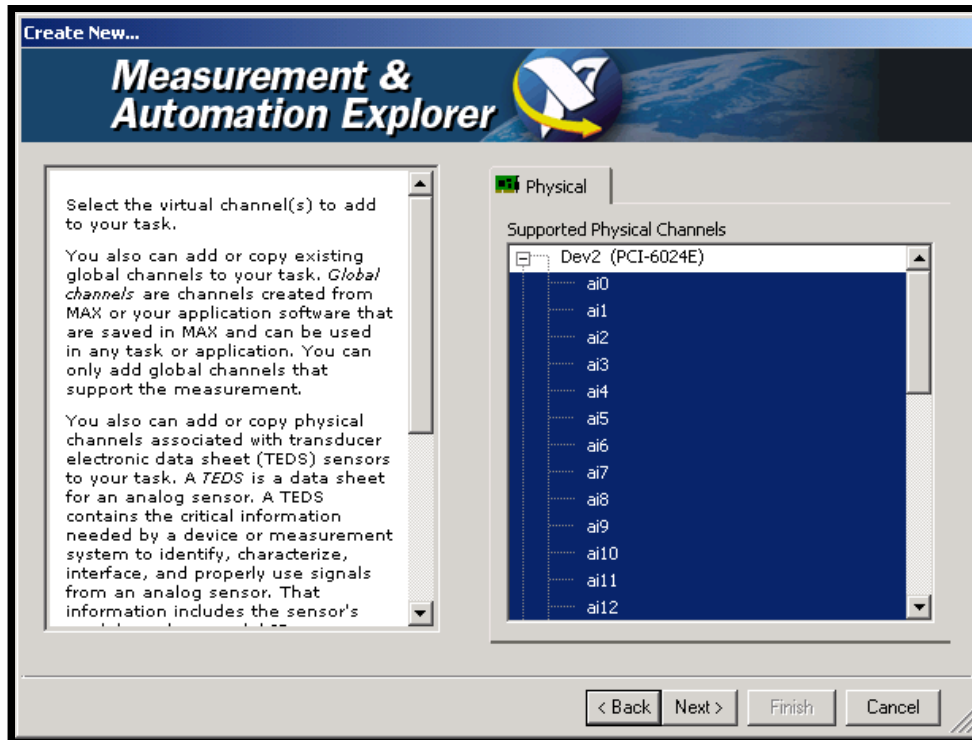


Figure B.3: Select Single or Multiple Channels and click next.

APPENDIX C
WIRING DIAGRAM OF THE MAIN PROGRAM

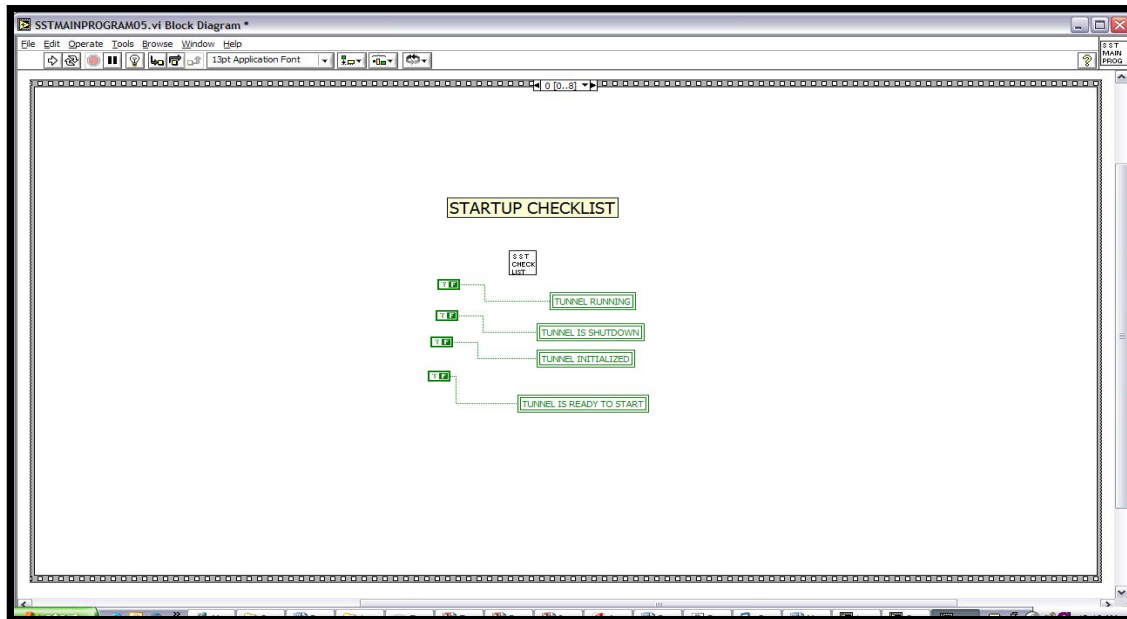


Figure C.1: Main Power Sequence 0 – Checklist.

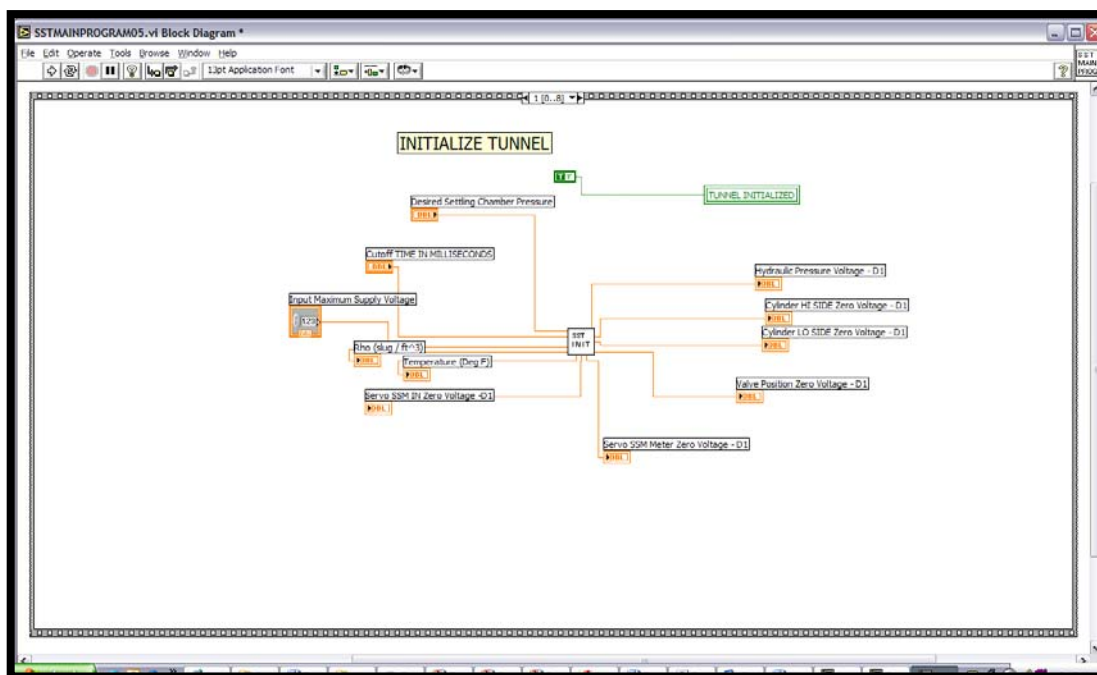


Figure C.2: Main Power Sequence 1 – Initialization.

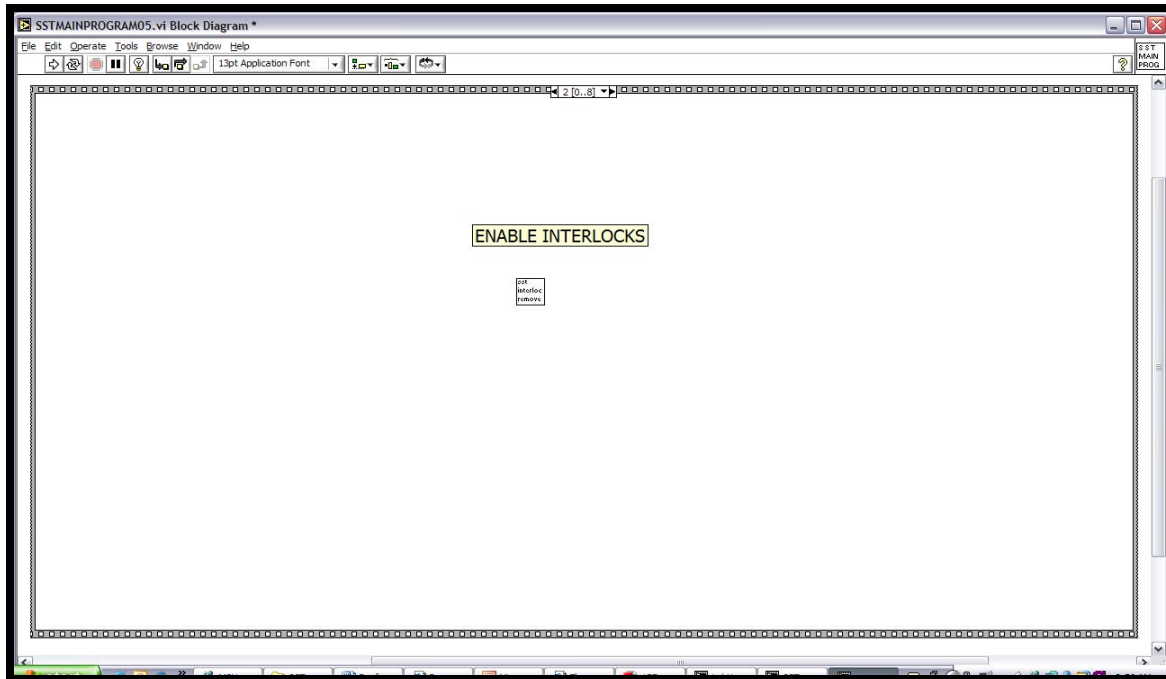


Figure C.3: Main Power Sequence 2 – Enable Interlocks.

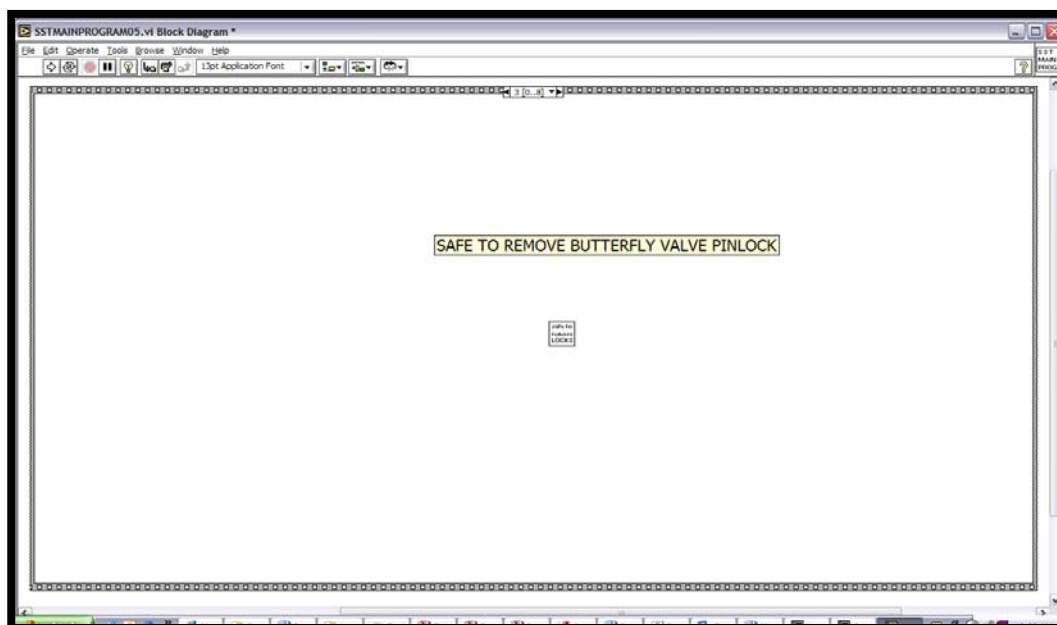


Figure C.4: Main Power Sequence 3 – Remove Pinlock.

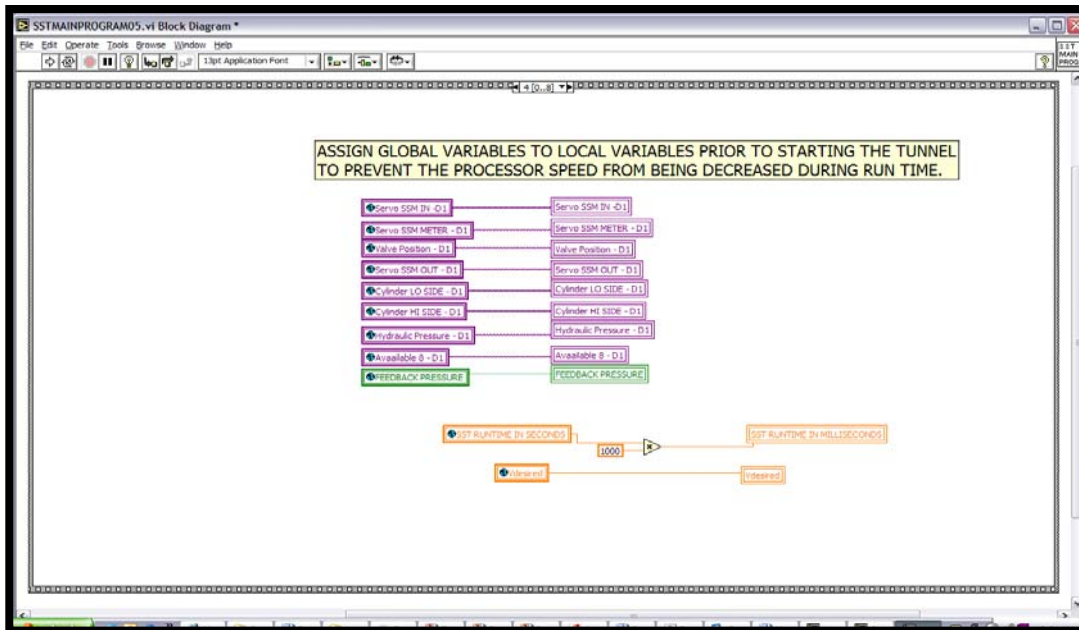


Figure C.5: Main Power Sequence 4 – Global to Local.

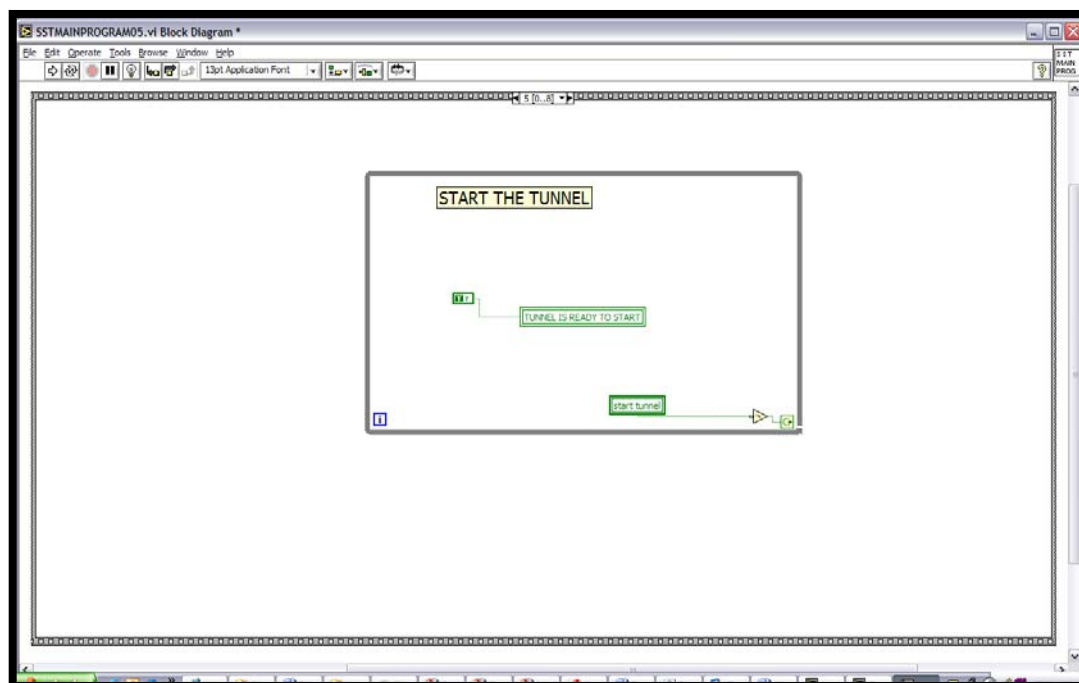


Figure C.6: Main Power Sequence 5 – Start the Tunnel.

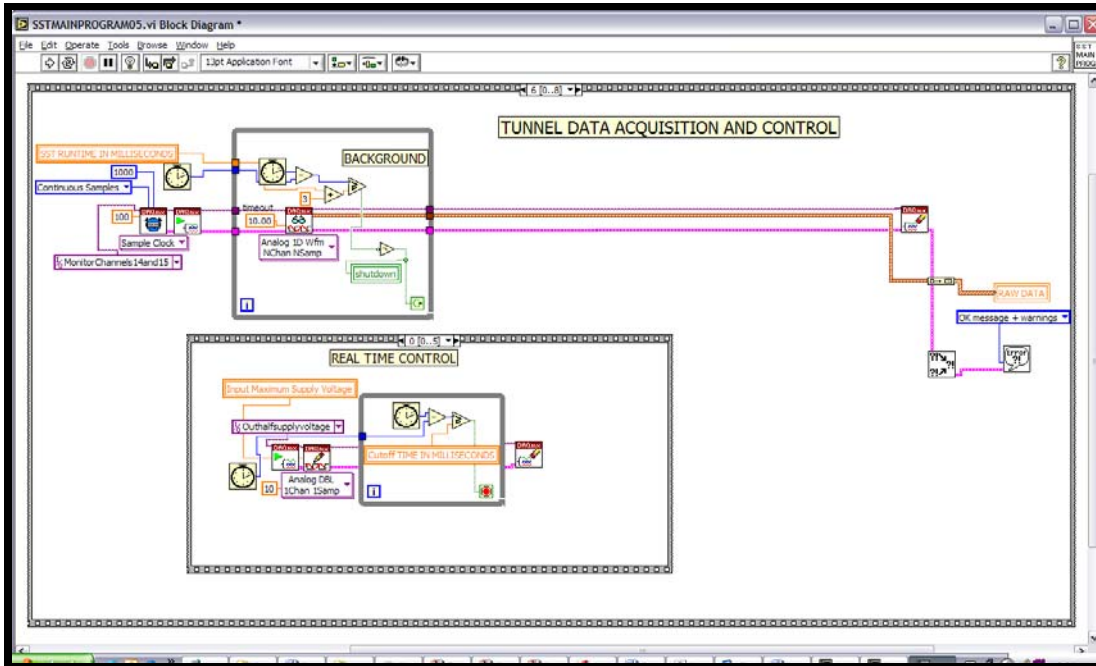


Figure C.7: Main Power Sequence 7 – Background Data Acquisition and Real-time Control.

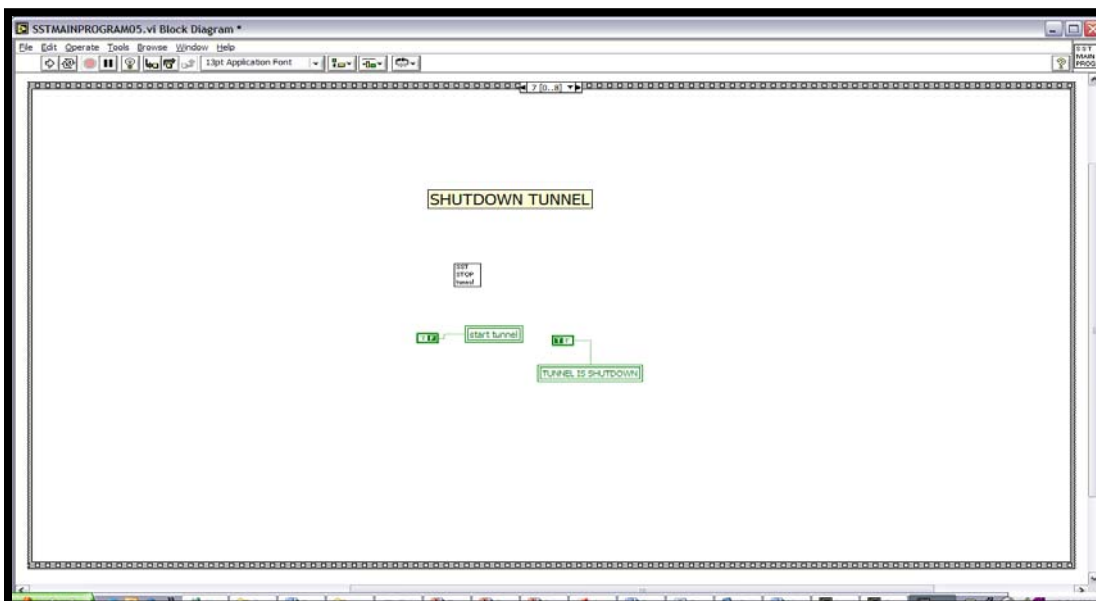


Figure C.8: Main Power Sequence 8 – Shutdown.

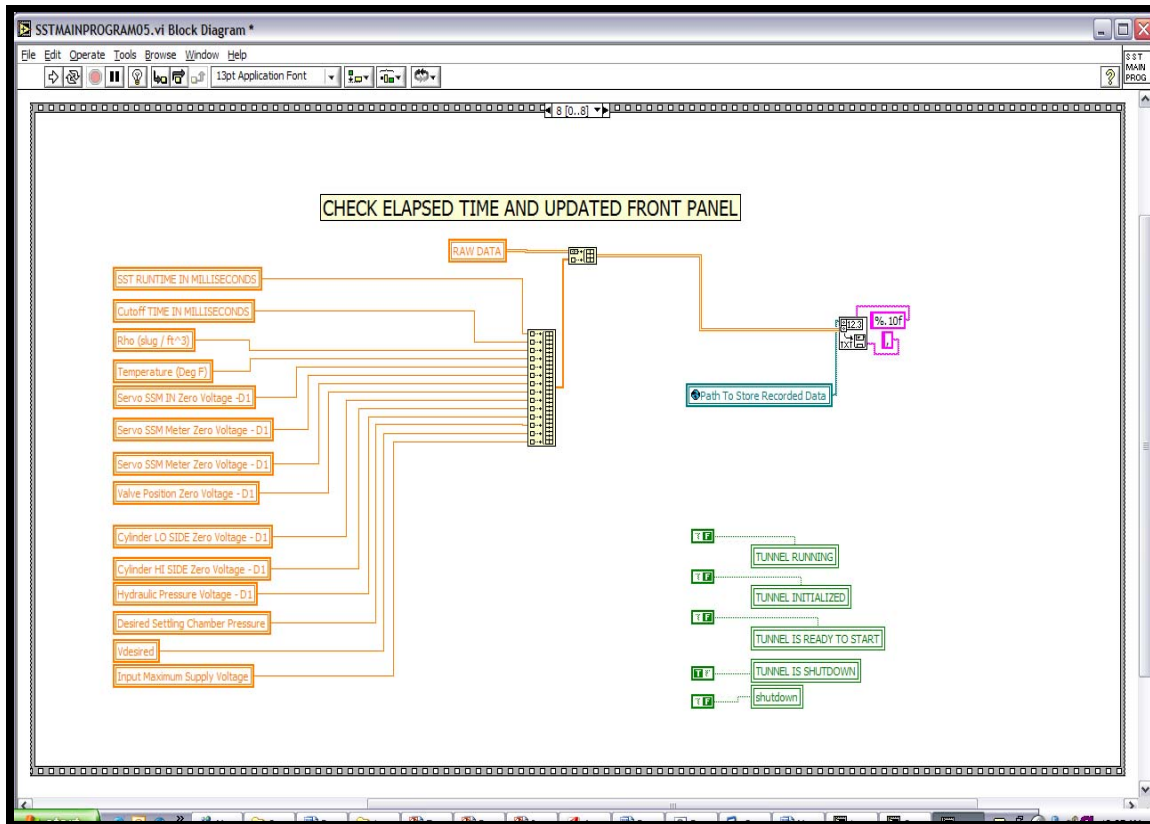


Figure C.9: Main Power Sequence 8 – Write Stored Data to a File.

APPENDIX D

PREVIOUS DAS 16 CONNECTION DIAGRAM AND NEW SCREW TERMINAL

ACCESSORY BOX DIAGRAM

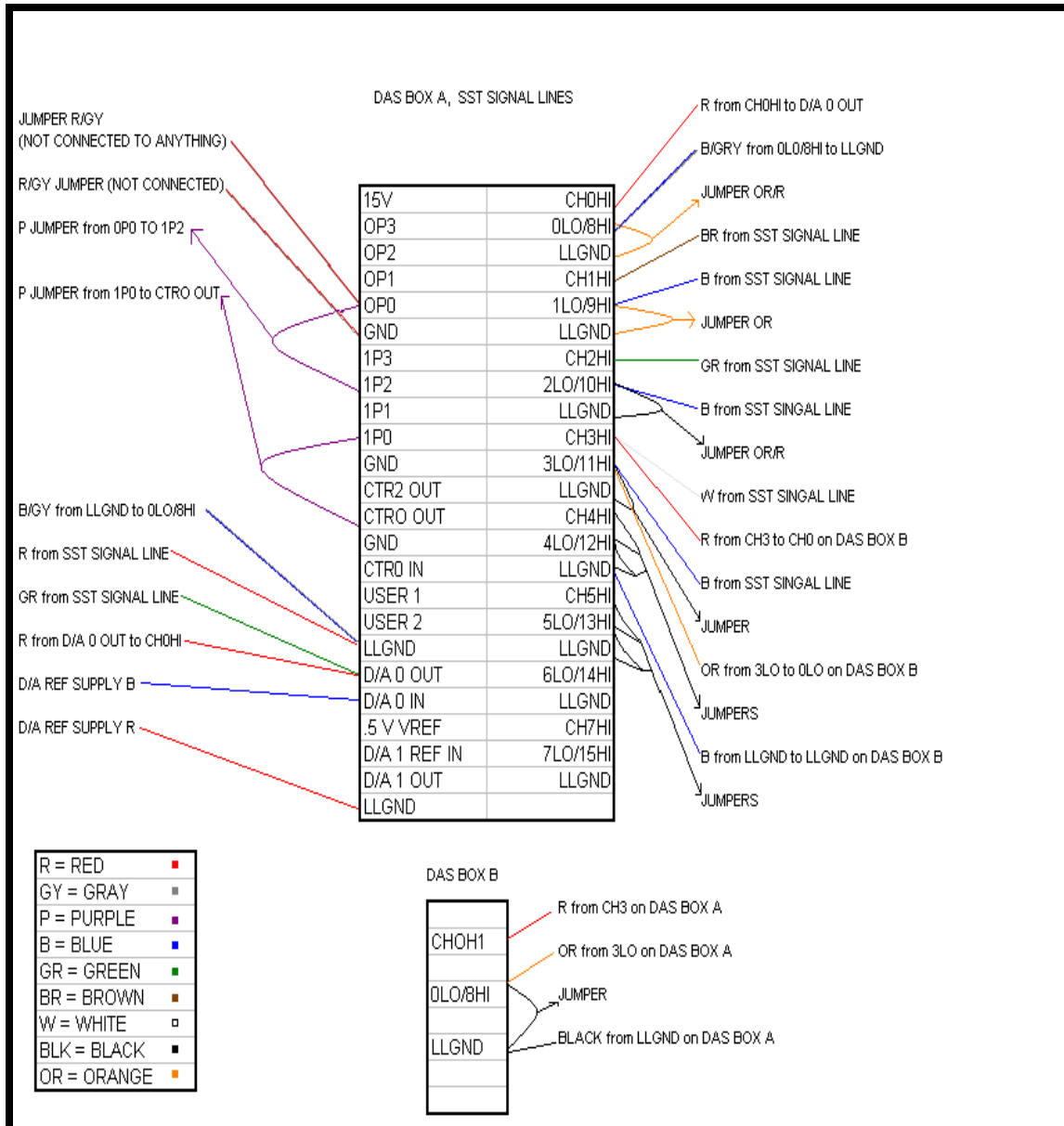


Figure D.1: Connections on the earlier Data Acquisition DAS 16 Boxes.

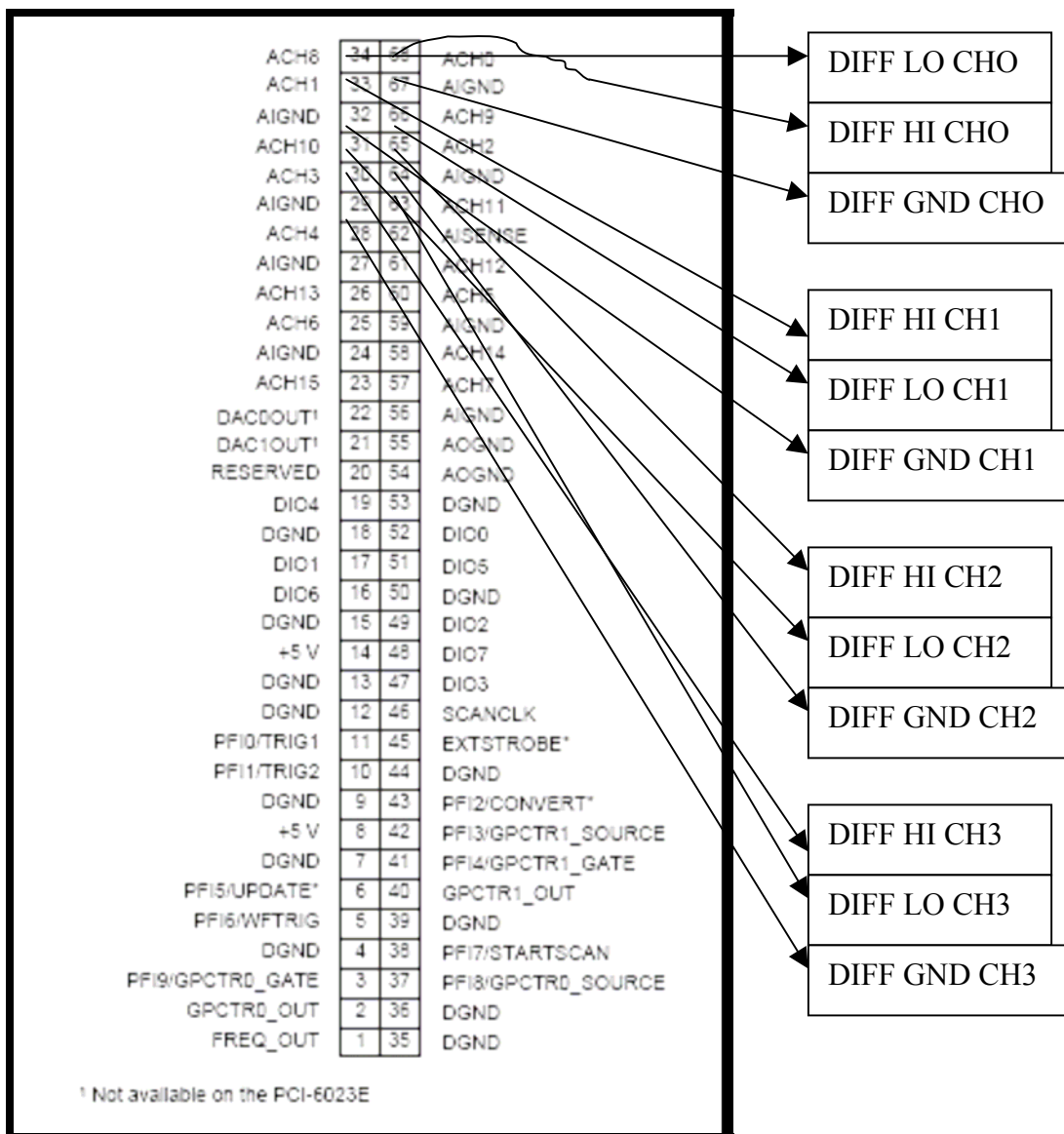


Figure D.2: Pinout Connector Diagram for the National Instruments PCI-6024E data acquisition cards. Differential Channel High is the channel number. Differential Channel Low is the channel number plus eight. Differential Ground is the closest Analog Input Ground.

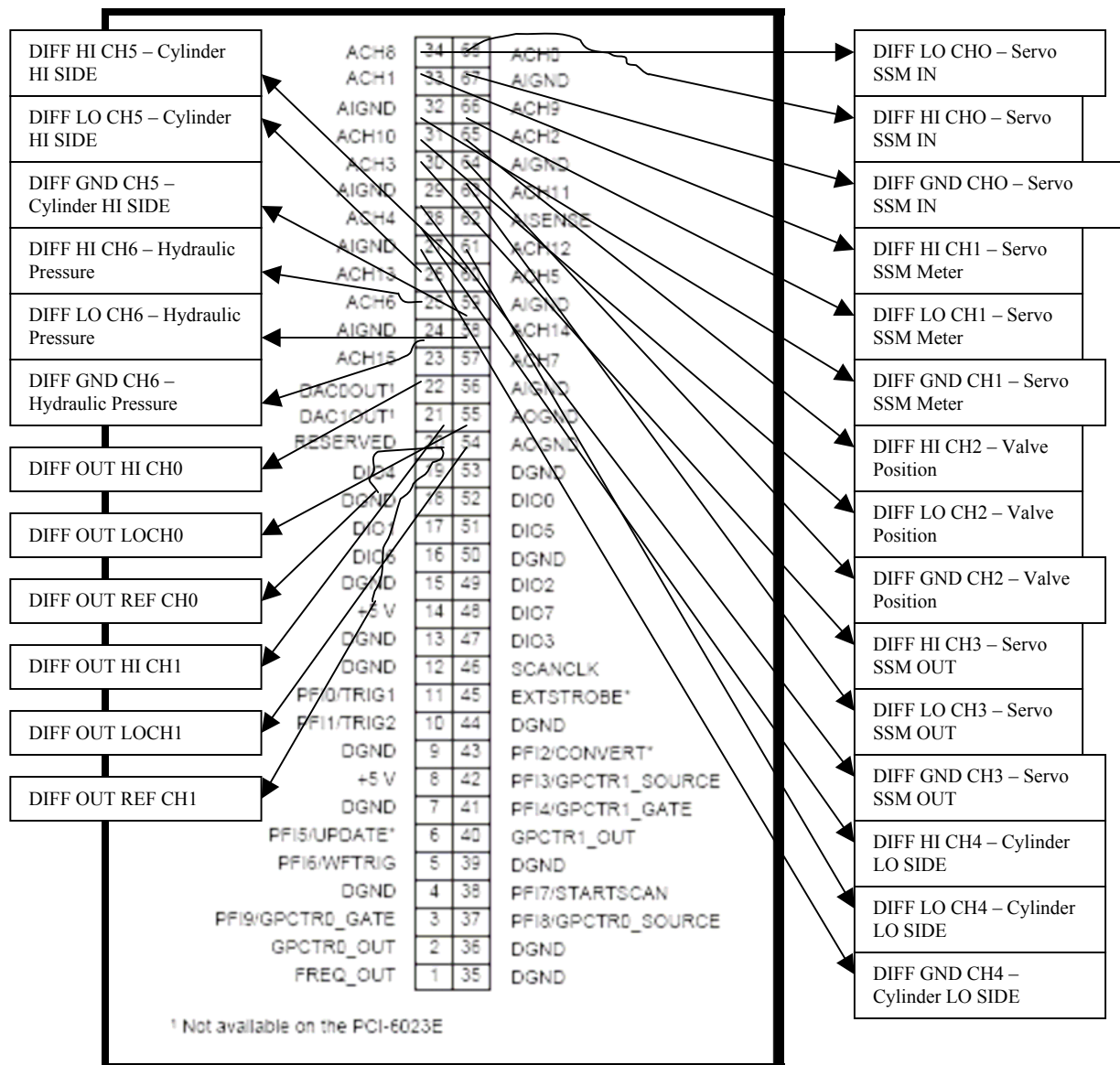


Figure D.3: New Control / Foreground Screw Terminal Accessory Board Connections

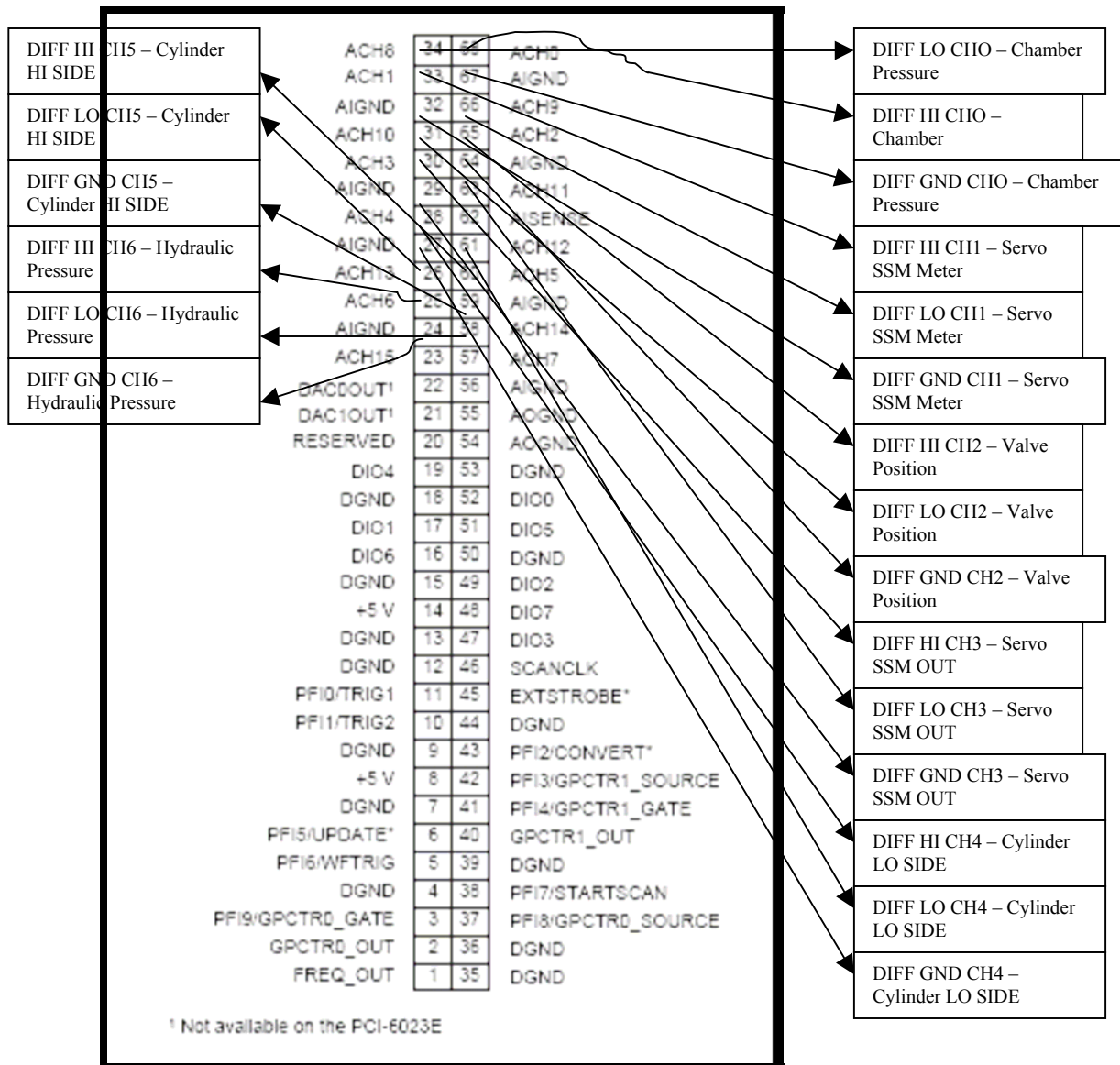


Figure D.4: New Background Screw Terminal Accessory Board Connections