# Work in Progress – Ohio Northern University Wind Tunnel Upgrade Senior Capstone

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***Abstract*** **– The Wind Tunnel Upgrade Capstone group has been asked to design a data acquisition and control system for the Aerolab™ Educational Wind Tunnel on the campus of Ohio Northern University. The motivation for this project is to increase the accuracy of data acquired from the wind tunnel. This will decrease the amount of experimental error that students will have in their experiments. A motor controller will be added to the fan. This will aid in improving data accuracy by decreasing the fluctuation of the wind speed once the desired speed is reached. A more accurate system will also increase the usefulness of the wind tunnel for novel research. The system must be able to measure the air speed, pressure, axial and normal forces, and angle of attack. Using the current methods for data acquisition, all measurements fluctuate substantially. An investigation will be done to determine whether or not the existing measurement systems are the best alternative, or if some other measurement method will be more appropriate for completion of the upgrade. Upon completion of the project, a user's manual and a validation report detailing the benefits of the upgrade will be delivered to the university.**

*Index Terms* - Capstone, Data Acquisition, Motor Control, Ohio Northern University, Wind Tunnel

## PROBLEM DEFINITION

The Ohio Northern University Aerolab™ open-circuit wind tunnel must be upgraded with data acquisition and control "DAC" system capabilities. The system must be able to measure the air speed, pressure, axial and normal forces, and angle of attack. The air speed, which is measured using a dynamic pressure system, must be controlled to tolerances equivalent to or better than the wind tunnels current capability. Axial and normal forces measured from the sting gauge need to be acquired using the existing interface between the sting and the wind tunnel. Pressure measurements from the wind tunnel, including the dynamic pressure system used for air speed, also need to be acquired using a system that will create a digital copy of the data

Expandability of the data acquisition system will allow for further investment in a wider range of improvements once funds become available. In addition to expandability, the system must also be upgradeable. This requires access to the hardware. The system requires that all software can be ported to a new computer system, which depends on a widely used programming language such as C++ or the LabVIEW™ graphical language. All measurements and settings will be displayed digitally on a user interface. The collected data will be exported to a file that will be saved to the student's home drive or portable flash drive.

## BACKGROUND

The current system is an Aerolab™ subsonic, open-circuit, educational wind tunnel "EWT." It is commonly used for experiments, research, and testing at Ohio Northern University. The figure below displays the wind tunnel:

FIGURE 1
OHIO NORTHERN AEROLAB™ EDUCATIONAL WIND TUNNEL

The airspeed of the wind tunnel ranges from 10 mph to speeds greater than 145 mph with an air turbulence level less than 0.2%. The test section has dimensions of 1 foot by 1 foot by 2 feet. The total length and width of the EWT is 15 feet by 42 inches, with a maximum height of approximately 6 feet. The electric motor power is rated at 10 horsepower, and is an AC motor. The wind tunnel uses 2 inch deep hexagonal cells made from expanded aluminum to straighten airflow. Turbulence is reduced through two mesh, stainless steel, screens at the airflow inlet. The test section includes an integrated yaw table made of anodized aluminum. Pressure taps and a sting gauge are included as part of the system. A rotating valve is used with the sting gauge to adjust the angle of attack. The analog display of the wind tunnel includes knobs for the calibration of airspeed, axial force, normal force, dynamic pressure, and moment. Measurements are read directly from the analog display during testing [1].

The analog display and control panel is shown below in the following figure:


FIGURE 2
WIND TUNNEL ANALOG CONTROL PANEL WITH DISPLAYS

Common uses for the current wind tunnel include:

- Lift and drag experiments
- Airfoil pressure measurements
- Boundary layer experiments

The motor control system for air velocity will be chosen from four possible solutions. Possible design considerations for the motor controller are:

- A Variable Frequency Drive
- AC 3-Phase Drive Controller
- Servo Speed Controller
- Programmable Logic Controller

Dynamic pressure taps and sting balances for moment and force measurement are currently the most sophisticated method of data collection. The most expensive option will be the Variable Frequency Drive, and the Programmable Logic Controller will cost the least.

The data acquisition of the wind tunnel will be performed using DATAQ, OMEGA, National Instruments, or Analog Devices hardware. The computer system will include up-to-date hardware and software appropriate for the project. The data acquisition program will be able to export data to Microsoft Excel and other commonly used files. The alternative to the ONU Aerolab wind tunnel upgrade will be the Aerolab company data acquisition and control upgrade which would cost the university and estimated $18,735.00. The student capstone group offers an upgrade with comparable capability at a lower cost to the engineering college.

## CONTRIBUTION

The project group was unable to find an instance of a PLC being used to control a wind tunnel, making this a novel approach. Other solutions by other groups used National Instruments equipment, and Agilent Data Acquisition/Switch Unit [2]. The benefits of using the PLC instead of the other practices are an increase in robustness of the system while maintaining similar accuracy as well as a decrease in cost. The programming will not have to be changed when future versions of Directsoft become available. PLC's are generally used in industrial setting, making the use of one in an academic setting unique. A PLC can provide a cheaper system that is just as accurate as standard DAC equipment, which is a benefit for academic environment. This idea can be applied in a variety of applications and is not limited solely to use with a wind tunnel.

## ABET REQUIREMENTS

The design team will meet the desired needs of the College of Engineering for the wind tunnel upgrade, as well as promote economic sustainability. This includes options for efficient energy use as well as easily disassembled and recycled components. Low maintenance cost will also be considered as one of the constraints for the wind tunnel upgrade. Realistic goals will be set for tolerances and wind tunnel capability. The design team will recognize what limits the current wind tunnel system has and design the upgrade to match or improve those limits whenever possible. The safety of students when using the upgraded wind tunnel will also be taken into account. The design team will make sure there are no hazards such as exposed wires that may cause harm to anyone operating the system.

## SYSTEM SPECIFICATIONS

The system specifications for the upgrade of the educational wind tunnel involve the accuracy at which measurements can be taken. The major system specifications are as follows:

- The data acquisition system will be capable of attaining a maximum sample rate of 10 samples per second.
- The airspeed will have a tolerance of $\pm$ 0.2 mph.
- The validation experiments which test angle of attack, airspeed, and dynamic pressures will have an error of 2% or less.
- The data will be exported to a computer for easier data reduction.
- The system will be easily upgraded throughout the course of its life.

## DESIGN DELIVERABLES

The Ohio Northern University College of Engineering will be given the following items once the project is complete. These deliverables will provide useful knowledge that will accompany the wind tunnel upgrade. The listed items will be completed by the end of the project and received by the college:

- A working data acquisition system, including full motor control for setting accurate, user defined airspeeds.
- A user's manual that includes full instruction for the hardware and software.
- A validation report that compares results from experiments conducted before and after the upgrade.
- A final budget that lists the expenses of all the components and the overall cost of the upgrade.

### PRELIMINARY VALIDATION

To validate that the new equipment meets or exceeds the tolerances of the existing setup, a series of test will be conducted. These tests will be performed before and after the installation of the data acquisition and motor control system. The following tests will be performed to validate that the new system is within previously stated tolerances:

- A digital anemometer will be placed in the free stream of the wind tunnel. The air speed will be read and compared at several speeds to verify the accuracy of the digital readout of the wind tunnel.
- Static loading will be used on the sting in a horizontal orientation and calibrated weights will be hung from the sting to simulate a normal force. The force of the sting then could be calculated and compared to the readout on the wind tunnel. This will be repeated several times with different weights.
- A spring force gage will be used to measure the axial force exerted on the sting. The calibrated weights cannot be used to measure the horizontal axial force because when the weights are hung from the sting they form a slight angle which will introduce error into our experiment.
- An air foil will be used to measure the pitch moment as it varies with speed. After the upgrades are complete the test will be repeated and compare for validation.

These tests will help to gauge the current accuracy of the wind tunnel. They will also aid with the calibration of the new instrumentation which is being installed.

### PRELIMINARY DESIGN OPTIONS

There are three major options that were considered for the upgrade of the Aerolab™ Educational Wind Tunnel. The first is the upgrade provided from Aerolab LLC which includes a new Dell™ Optiplex computer, National Instruments data acquisition equipment, and motor control hardware including a new variable frequency drive. The data acquisition as well as the motor control will be done using a PCI card installed in the computer. Virtual instruments programmed using LabVIEW will also be provided. This is also the most expensive design option at approximately $18730 in price.

The second design option was to use a National Instruments USB chassis as well as analog input and output modules. The use of the USB chassis allows the system to be easily upgraded and repaired. The rotational speed of the motor would be controlled through the current variable frequency drive. The current sting will still be used; however, the output signal will go directly to the analog input module instead of the wind tunnel front panel. Pressure transducers will be used to take readings from the dynamic pressure taps that are used for the wind speed reading, and to take pressures from the models that have pressure taps. All programming would be done within a LabVIEW programming environment to create a virtual instrument for student use as well as a more advanced virtual instrument used for research. This option would cost approximately $1659 not including the price of labor, LabVIEW software, or a computer [3].

The third option is the use of programmable logic controllers (PLCs). This method would require a user interface, a PLC unit with analog input and output as well as an Ethernet output. The analog input would be used to take readings from the force sting as well as the pressure transducers that were discussed in the previous design option. The user interface will show readouts of the force, pressure and wind speed data, as well as allowing the wind speed to be adjusted. All the data will be stored within the PLC and exported to a computer using the Ethernet once the user is finished with the experiment. Motor control will be done using a feedback loop and the current variable frequency drive. This option will cost $677. This is the price for the entire option. It will decrease if items are donated by the mechanical engineering department at Ohio Northern University [4].

### BUDGET

Estimated budgets for the second and third design options may be seen below. The actual expenses include items that the College of Engineering and design team will need to buy in order to complete the project. An estimate for donated items is shown below the total. The expense from donations will not need actual payment from either the design team or the engineering college.

TABLE I
BUDGET FOR NATIONAL INSTRUMENTS USB DESIGN OPTION

| Item | Cost |
|---|---|
| Pressure Transducers | $30.00 |
| Dell Precision 380 Workstation | $2680.00 |
| LabVIEW Software | $2600.00 |
| NI USB DAQ | $1250.00 |
| NI Analog Input Module | $379.00 |
| Labor ($18.50 per hr) | $16200.00 |
| **Total** | **$23139.00** |
| **Donated Item Estimate** | **$21480.00** |
| **Actual Expenditures** | **$1659.00** |

TABLE II
BUDGET FOR PLC DESIGN OPTION

| Item | Cost |
|---|---|
| Direct Logic 06 Micro Brick PLC | $229.00 |
| 8 Channel Analog Input Module | $129.00 |
| 3 Inch Micro Touch Panel | $189.00 |
| 2 Omega Pressure Transducers | $130.00 |
| Labor ($18.50 per hr) | $16200.00 |
| **Total** | **$16877.00** |
| **Donated Item Estimate** | **$16200.00** |
| **Actual Expenditures** | **$677.00** |

The budget for the Aerolab upgrade was quoted at a price of $18730 [5]. The total amount of this quote is the actual expenditure value for this design option. Donated Items include the price of labor in both budgets shown above.

### PRELIMINARY DESIGN EVALUATION

The decision matrix shown in the first figure illustrates the process used to determine the best design for the upgrade.

| Criteria | | Alternative Design Options | | | | | |
|---|---|---|---|---|---|---|---|
| | | Aerolab LLC Upgrade | | NI USB Chassis | | PLC | |
| | | Rank | Score | Rank | Score | Rank | Score |
| Cost | 35 | 0 | 0 | 9 | 3.15 | 10 | 3.5 |
| Compatibility | 15 | 10 | 1.5 | 6 | 0.9 | 5 | 0.75 |
| Ease of Assembly | 10 | 9 | 0.9 | 6 | 0.6 | 6 | 0.6 |
| Ease of Use | 15 | 10 | 1.5 | 7 | 1.05 | 8 | 1.2 |
| Maintenance | 5 | 8 | 0.4 | 8 | 0.4 | 8 | 0.4 |
| Sustainability | 5 | 8 | 0.4 | 5 | 0.25 | 9 | 0.45 |
| Safety | 15 | 10 | 1.5 | 8 | 1.2 | 7 | 1.05 |
| **TOTAL** | **100** | | **6.2** | | **7.55** | | **7.95** |

FIGURE III
WIND TUNNEL UPGRADE DECISION MATRIX

A ranking system of one to ten was used to rate the criteria. The project team determined the cost of the upgrade to be the most heavily weighted criterion for determining the final design. Compatibility, ease of use, and safety were among the second most critical factors used in the decision matrix. The PLC upgrade was determined to be the best design option.

### CURRENT PROJECT STATUS

Under the supervision the engineering faculty, the design team removed the instrument panel of the wind tunnel in order to determine the correct locations for the analog wiring connections to the PLC. It was discovered that the connections to the digital volt meters were connected to a common ground. The LED displays for angle of attack and airspeed shared a common ground separate from the digital volt meters. This required the design team to choose an analog input module that supplied two common grounds.

It was discovered that all five signals from the digital volt meters utilized a range of ±2 V. Also, it was revealed that the connections to the displays could be used as links to an op-amp circuit board, which would then amplify the voltage sent to the analog input module. This was required because of the analog input module’s incapacity to take bipolar voltage ranges. The op-amp circuit would allow the design team to use a range of 0.7 to 4.7 volts when programming. Averaged readings from the op-amp circuit board were required when calibrating the signals. These values were then included in the data acquisition programming to offset the numerical error resulting from the signal amplification.

### FUTURE WORK

Once the operational amplifier circuit board is complete, the design team will finish the installation of the PLC and digital display hardware. While investigating the circuitry of the wind tunnel a number of faulty connections were discovered. Before completing the installation of the upgrade hardware, these connections will be restored. The programming of the motor controller will be completed using the PID control loop function of the DirectSoft™ ladder logic programming language. The mathematical conversion and calibration of the forces and pressures will be completed in ladder logic as well. As stated in the previous section for validation testing, the upgraded system will be vigorously tested to ensure that tolerances set in the design specifications were met.

### CONCLUSION

The College of Engineering at Ohio Northern University has requested that the design team upgrade the Aerolab™ Educational Wind Tunnel for airspeed control and data acquisition. Three design options are currently being considered. The first is the upgrade provided from Aerolab™ LLC. The second design option is to use a National Instruments USB chassis as well as analog input and output modules. The third option is the use of programmable logic controllers (PLCs). This method would require a user interface, a PLC unit with analog input and output as well as an Ethernet output. A decision matrix was used to compare the alternatives. It was concluded that the best option would be the PLC upgrade. The wind tunnel instrument panel was removed and the appropriate connections for each variable were found. An operational amplifier circuit board was designed to account for the bipolar input signals. The appropriate cable was obtained to facilitate communication between the PLC and the touch screen. Programming and installation of the hardware will be completed in future endeavors. Once the system is programmed and running properly, validation testing will be done. The design team will attend the ASEE Conference in March to communicate the results of the project. ABET requirements and budget constraints will be continuously taken into account throughout the course of the project. The project completion date is currently set for May of 2010.

## REFERENCES

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