Project Description: Metal Foam Flow Performance Test Facility

For winter quarter 2009-2, several sections of the Thermal-Fluids Laboratory 2 course were engaged in a collaborative project with faculty members from Mechanical Engineering and the Chemical & Biomedical Engineering department at RIT to construct a flow performance test facility to characterize metal foam specimens for Rochester-based AirFlow Catalyst Systems (ACS). ACS specializes in the advancement of leading-edge materials for catalytic converter technologies, especially for diesel engine applications. A unique aspect of their catalytic converter design is the deposition of the surface-active agent onto metal foam sheets, as opposed to the more traditional porous ceramic carrier. The metal foam itself is more expensive, but allows for smaller and lighter components, and realizes a reduced pressure drop in final applications. Please refer to the ACS website at *www.airflowcatalyst.com* for more information on the company, and a link to various technical publications detailing their design and testing achievements.

In application, the metal foam sheets are arranged in a stacked formation inside a metal box through which the engine exhaust flows, resulting in a chemical reaction between the active agents on the metal foam, and the noxious exhaust gas components. The porosity of the foam sheets, the size and spacing of the sheets, and the overall number of foam sheets are all important factors in determining the effectiveness of the catalytic conversion process, and the suitability of the device for retro-fitting onto existing engines. A key factor is the pressure drop that occurs over the collection of sheets, since this determines the effective back pressure that the engine is subjected to, and this in turn affects the operation of the engine (higher back pressure causes a lower engine efficiency and lower power output). Thus, as a starting point for engineering analyses and predictions, the test facility was constructed to measure the pressure drop that occurs over one or more sheets of foam as a function of air flow rate through the foam.

The test facility is finished and fully operational, and all required data have already been collected. It consists of a high-performance blower that pulls air through an inlet pipe with a separable test section containing one or more sheets of the metal foam "sandwiched" and sealed between two round flanges. Pressure taps on either side of the test section, arranged in a piezometer ring assembly, are connected to corresponding inputs of a differential pressure sensor. Air exits the test section into the blower, and then exits the blower through another length of pipe containing a

rotary vane anemometer used to measure the flow rate of the air (air speed). Both the inlet and outlet sections of pipe contain internal flow straighteners. The blower is of the bypass type, meaning that none of the main flow is diverted for cooling the motor, thereby guaranteeing that all of the air passing through the test section is indeed measured at the flow meter (notwithstanding any leaks). Also, the blower has a brushless dc motor with integrated analog speed control that allows a low-level analog input voltage to specify its operating speed. The following is a list of the complete component specifications, including details for connection to a generic DAQ device:

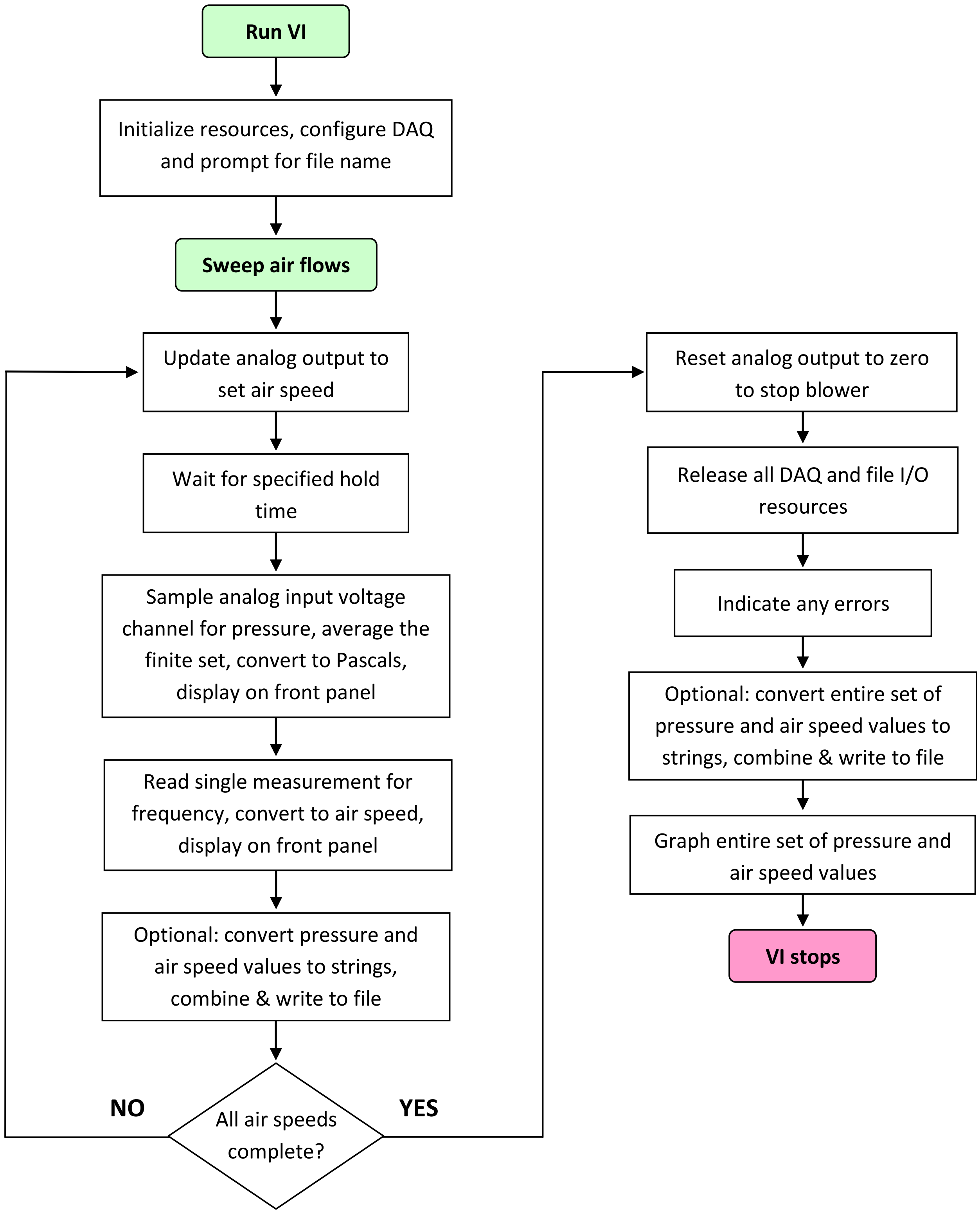
- Ametek model #116643 brushless DC blower with integrated analog speed control. Note that the voltage control range for this blower is specified by the manufacturer as 0-10 VDC, but in practice it is typically operated between a specified minimum voltage (lowest speed) to a specified maximum voltage (highest speed), each within the allowable overall range. From the perspective of the DAQ device, the analog control for the blower is an analog output, with the overall allowable range given.

- Pacer Instruments Model AP275 Rotating Vane Anemometer Probe. The AP275 probe (sensor) outputs a calibrated, single-ended, 50% duty cycle, 5 VDC square wave whose frequency corresponds to airflow by the following formula: $U = 3.1595f + 36.4$, where f is the measured frequency in Hz, and U is the measured air velocity in feet per minute (fpm). The sensor is capable of measuring between 40-7800 fpm. From the perspective of the DAQ device, the output from this sensor is to be measured as a frequency, which is therefore a counter-based measurement (not an analog input as most of the examples in class emphasized).

- Adjustable-range differential pressure sensor from Omega Engineering, model #PX277-05D5V. For this application, the sensor is set to measure differential pressure over the range 0-1250 Pascals (Pa), and output a linearly-correlated analog voltage between 0-5 VDC. From the perspective of the DAQ device, the signal from this sensor is a differential analog input.

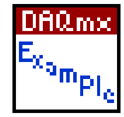
The basic operation of the facility includes setting the blower speed with an analog voltage, measuring the resulting flow rate and pressure drop across the specimen, and then repeating with a new blower speed. The entire control and measurement process can be automated to sweep the full range of blower speeds available, thereby constructing a complete curve of pressure-flow performance data for the specimen. For even more detailed design specifications and collected test results from 2009, please refer to *people.rit.edu/jdweme/emem551_20092/emem551.htm*.

With this basic description in mind, **the specific purpose of the project in the Measurements, Instrumentation, & Controls course is to create a LabVIEW interface that connects to the finished test facility, and automatically collects and records sufficient data to construct a complete pressure-flow curve for a metal foam specimen** that is supplied for testing. The following flow chart outlines the process that your VI must follow:

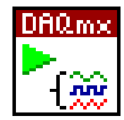


In addition to the basic features indicated by this flow chart, please pay attention to the following things:

- The sensor and blower component details provided above are to be used to configure the LabVIEW interface. Signal connections are made through a National Instruments PCI-6052E data acquisition device (or equivalent), with all wiring completed by the course instructors. Wherever applicable, default configuration options have been maintained. Students are not required to make any physical hardware connections.
- For a single start of your VI, it must sweep through all of the available flow rates with a selectable number of increments, starting at a selectable minimum voltage (lowest speed), and measure the flow rate and pressure drop at each increment. Upon reaching the selectable maximum voltage (highest speed), the program will then decrement the flow rate through the reverse sequence back to the minimum, and then reset to zero (shutdown). Thus, the upward sweep, and subsequent downward sweep, of the flow rate are both specified as a simple sequence of analog output voltages sent to the blower. Your VI should include on the front panel a numeric control whereby the user can select a number of steps to divide the upward sweep into, a numeric control to set the minimum voltage to use, and a numeric control to set the maximum voltage to use.
- The basic process includes a “hold time” to wait at each flow rate setting before measurements are made, to allow the conditions in the system to reach steady state. The duration of this hold time must be accessible to the user as a control on the front panel.
- Note that the flow chart refers to “sampling” the pressure drop signal. To do this, you are to configure the acquisition in this step to collect a finite number of samples from the pressure sensor, at a rate and sample number that the user can select via front panel controls before the VI executes. Following a single burst of the finite data sample, the resulting set of numbers is to be averaged to a single value which will constitute the pressure drop at the current flow rate. In other words, instead of making just a single-value measurement of pressure drop, a whole set of data values will be averaged each time to help smooth any noise or errors in the measurements.
- No such averaging of data for the air speed is required, since the frequency measurement works by counting a series of pulses from the sensor over time. You may run a single instance of a measurement from the flow sensor in each increment/decrement step where required.
- Despite what the flow chart indicates, it does not really matter which of the air speed or pressure drop measurements is made first, so long as the hold time is observed before either is accessed.
- Data are to be saved to a text-based file organized as two columns of data, where the first column contains the measured air speed, and the second column contains the measured pressure drop. The VI should automatically prompt the user to select a filename for the data file, and should (minimally) create basic headings in the file to identify the parameters and associated units. You may elect to save the data incrementally as they are measured, or all at once after the full set is collected.



- Three NI DAQmx examples accessible through the Example Finder are directly relevant to this project. For the analog output control, the example *Gen Voltage Update* captures the basic programmatic details. For the analog input with finite samples, the example *Acq&Graph Voltage-Int Clk* captures the basic programmatic details. For the counter-based frequency measurement, the example *Meas Dig Frequency-Low Freq 1 Ctr* captures the basic programmatic details. In-class exercise #15 *DAQmx Modifications* outlines the basic elements of the file I/O steps required. As always, these examples contain salient features for your use, but they will need to be modified (and combined) for this particular application. All of these have been extracted from the directory structure, and uploaded to the course website *people.rit.edu/jdweme/emem280.htm* for your use. Should you need to find them yourself from the Example Finder, you can search on the VI names as shown. **Note:** in the example *Acq&Graph Voltage-Int Clk*, the DAQmx *Start Task* subVI is used prior to the loop structure. For the finite sample scenario, the *Start Task* is not required, and in fact it would be better if you excluded it from your program.



- Include a graph on the front panel that shows all of the collected data for the entire run. The graph is to show measured pressure drop vs. air speed, with appropriate labels and units shown on the axes of the graph. It is acceptable for the graph to wait until all data are collected to update and display the data set. That is, the graphical display does not need to continuously update as the data points are collected. You may include simple numeric indicators to display the "real time" or current values of the air speed and pressure drop if you wish.
- Because the test facility is connected to single "test computer," your solution must be capable of easily adapting to the switch from the generic lab computer to the test computer. In other words, your developed VI must minimally include front-panel controls to select physical channels for each input and output device, as well as any other required features as appropriate. Note that because of this, the DAQ Assistant is not appropriate for the VI! Conversion information for each sensor should be hard-coded into the VI, and not included as DAQmx scales (this is not the preferred method, but is required nonetheless for this classroom scenario).
- A functioning solution—minus the block diagram—may be placed on the course website to assist you. If so, then you may refer to the solution for guidance on the basic functionality of the program and front panel layout. Your solution does not need to look exactly the same, but may if you wish, and should include similar elements in any event. Please note that if you run the provided solution on any computer other than the test computer, you must have a comparable simulated device present for it to work, and even then you may need to change some of the settings for proper operation. Also, please note that simulated devices do not always handle counter-based operations very well, so some of the functionality in the VI will not seem to work as expected. In particular, simulated counters seem to always indicate zero frequency when measured. These notes also apply to your own simulated solution.

- This project is meant to be an independent effort by each student, and therefore no collaborations are allowed. You may consult either of the course instructors—Professor Wellin or Dr. Kempski—but no other students. You are allowed and encouraged to consult any of the course resources you wish, including online information from National Instruments and any of the examples included with LabVIEW.
- Finished VI's are to be uploaded to the Dropbox on myCourses before the deadline given.

This is an independent project—no working together!

Good luck!