Vertical Integration with a Vortex Tube

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Abstract

Vortex tubes are made by small groups of students in a freshman engineering 'concepts and design' class. The tubes are made from specially prepared kits with details important to performance left un-finished. Students in an elective manufacturing methods class produce the kit components once they are designed.

An upper division fluid mechanics class will use laboratory sessions to measure and compare the performance of the freshman teams' vortex tubes. Design, CAD and team dynamic are essential components of the learning[10].

Background

The vortex tube is a very simple device in which a single stream of high pressure air is divided into two streams of low pressure air, one colder than the supply and one hotter than the supply. Exair has an excellent dynamic model on their website[6]. Within the device a stationary tangential nozzle imparts rotation to the air. That rotation produces concentric flows with same sense of rotation but with opposite pitch so that the outer flow moves toward the hot end and the inner flow moves back toward the cold end. A valve at the hot end determines the fraction of the air that will leave either end.

The vortex tube was a fascinating and disputed device from its introduction in 1933 by inventor Georges Ranque[1]. After lying unattended for several years, it was reintroduced by Rudolph Hilsch in the mid-forties and slowly became a commercial success. Tubes and even experimental kits are available from several manufacturers[2 - 7]. With features as no moving parts, simplicity of manufacture and obvious applications to direct cooling or heating the success is obvious in environments with an existing compressed air source. The ever-growing view of 90 [psi] compressed air as an industrial necessity makes implementation of the vortex tube very easy. But on the other hand, the vortex tube is greedy for compressed air and hence prohibitively expensive to operate continuously in a cost sensitive application. With the current commercial mindset of extreme cost trimming the vortex tube is often limited to electrically quiet, small size or emergency cooling applications.

Further, the broad spectrum of explanations of the physical phenomena interacting in the flow makes a rich environment for learning. The experience brings forth a curiosity about the strange anomalies of thermodynamics and fluid dynamics[8,9].

Context

At JBU the second Concepts and Design Class is taught spring semester freshman year as two 90-minute weekly meetings. To support preparation to design, the material covered is a light taste of economics, ethics, probability distribution, toleranceing, professional information, device logic, mechanical concepts and electrical concepts. Experiential visits are made to laboratory equipment like the gas turbine, wind tunnel and high-pressure test vessel. Industrial and professional engineers are invited for presentations on employment prospects, safety, liability and industrial expectations.

The vortex tube project commences about one-third of the way into the semester and extends to semester's end. The project is interleaved with several shorter team design projects with duration of one class to three weeks. From the first lecture introduction of the project, students are challenged check patents and to surf the 'web' with keywords "vortex tube","ranque", "hilsch", and "air coolers", and from the search create a URL list. Using different search engines and pursuit strategies a few of the seekers arrive at a wide variety of loosely linked facets of vortex tube information.

In the first phase of the project commercial vortex tubes from Exair©[5,6] are laid out on a table along with a digital vernier caliper and a 1" micrometer. Individually, the students measure dimensions and create drawings in a Solidworks© environment. They start by preparing isometric and orthographic drawings of the six elements of the disassembled commercial tube. Finally they created an exploded isometric of the vortex tube with balloon ID and an accompanying bill of materials. Typical student drawings are shown as Figures 1-4.

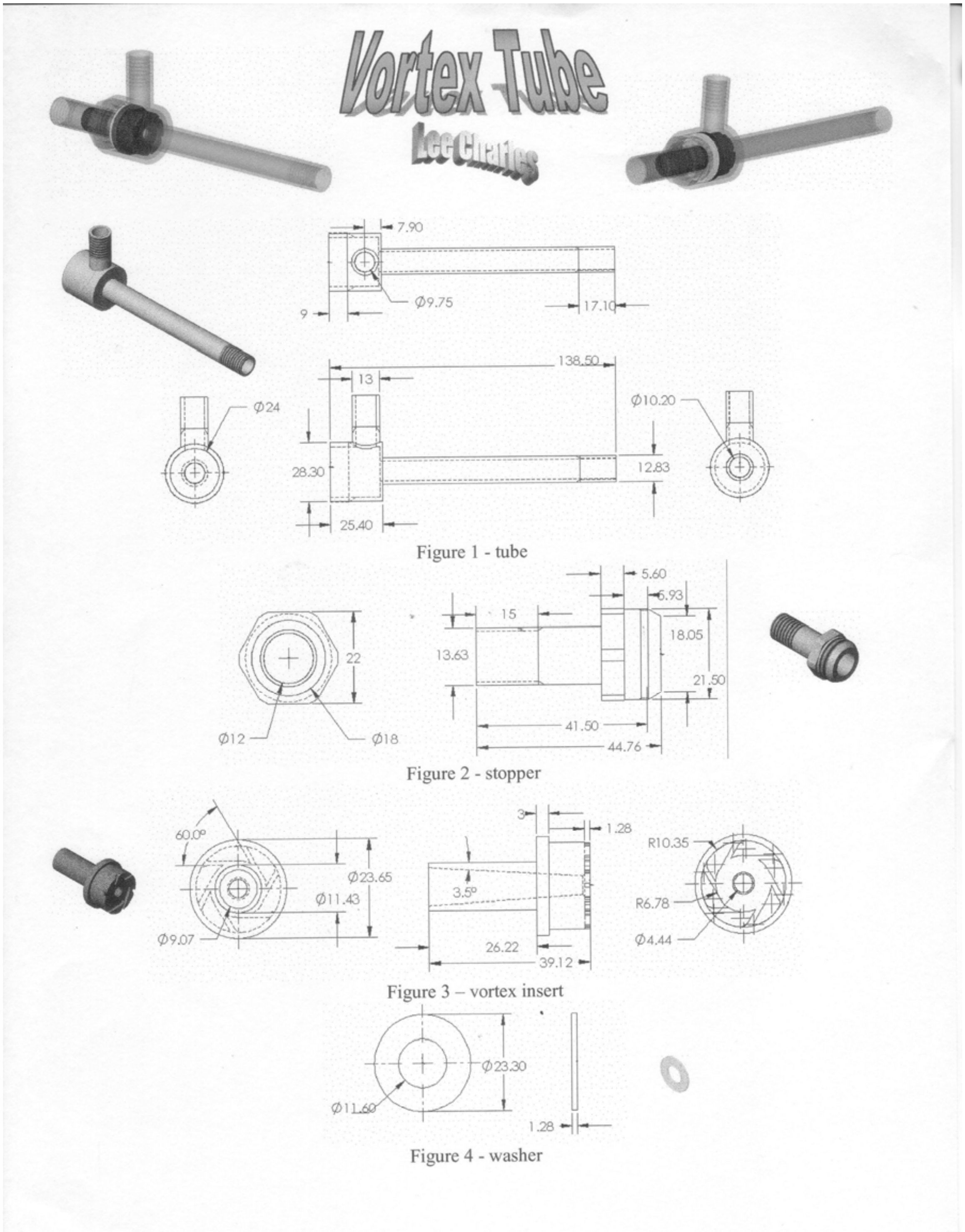

Figure 1 Student Assignment - vortex tube components

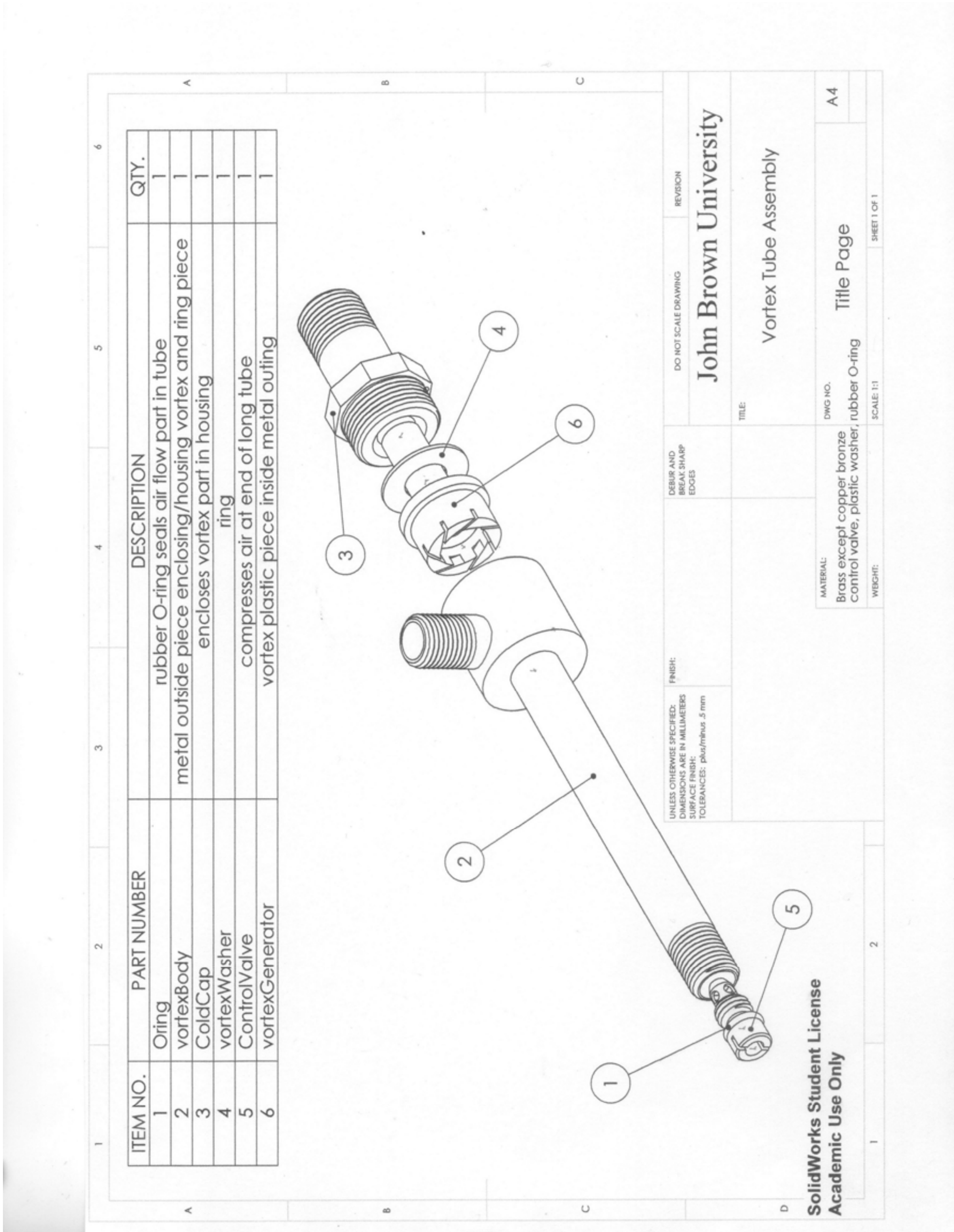

Figure 2 Exploded View - Bill of Materials

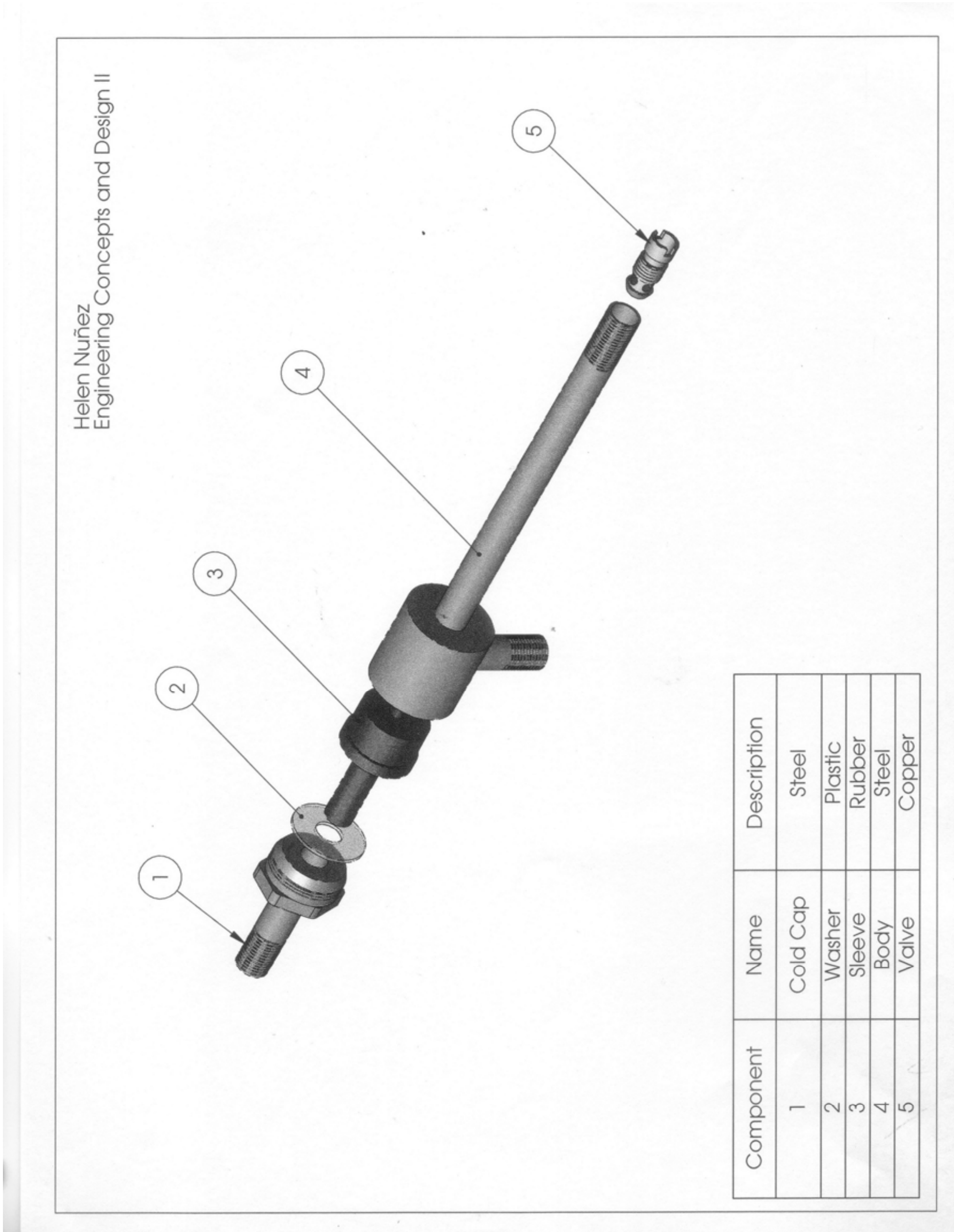

Figure 3 Exploded View Solid Model

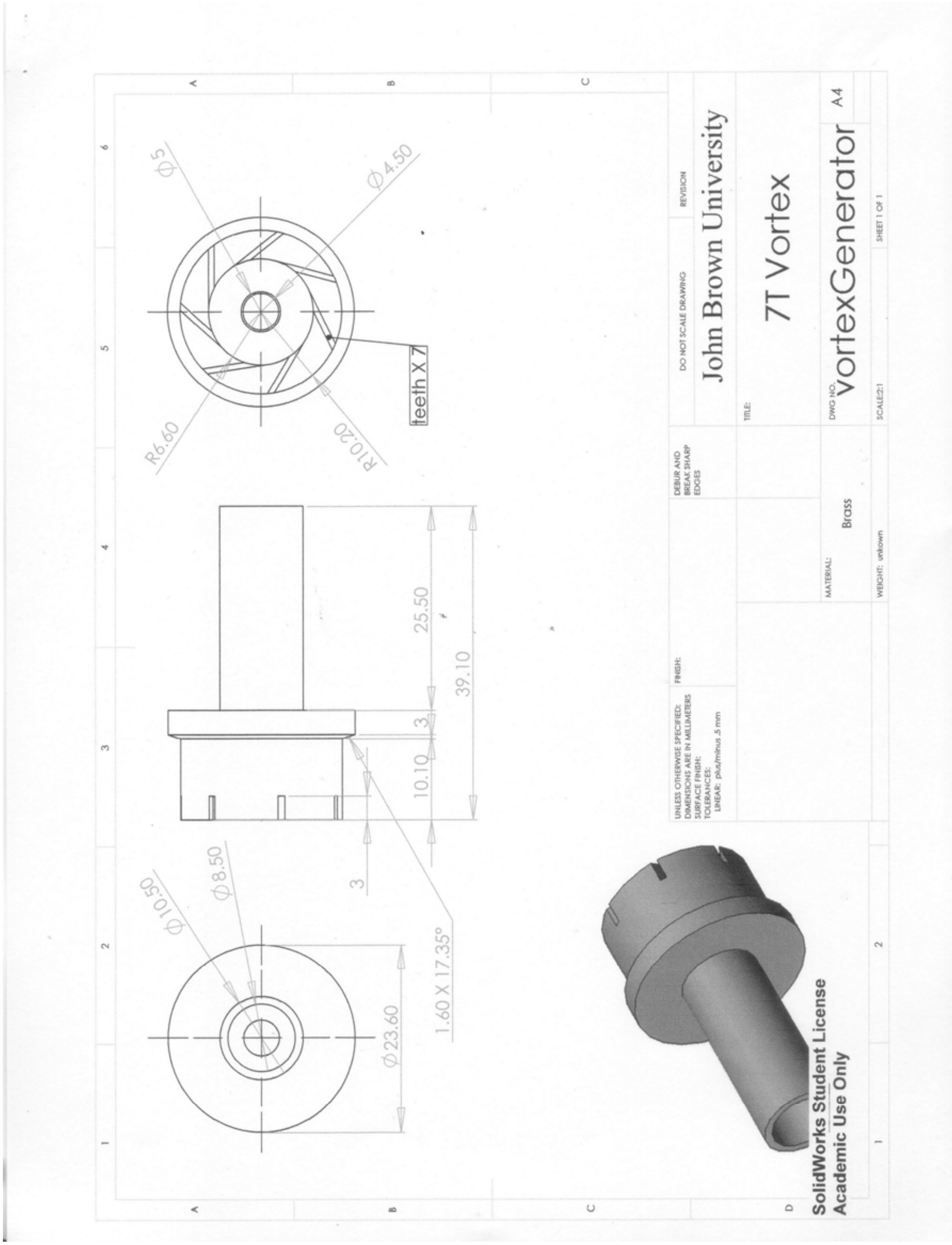

Figure 4 Nozzle Detail Sheet - Seven Entry

The basic premise was that all but two elements of the student built vortex tubes would be OEM. The components are available at local hardware stores with descriptions, sizes, and prices provided. (See Figure 2 Bill of Materials). The two elements that the students were to design and create were the vortex generator and the flow-proportioning valve. The operation of a vortex tube is most sensitive to the design of these two elements. The kit given to each student team consists of seven items. (See Figure 6) Six items are cast or drawn brass NPT OEM items: ½"x ½" F-F coupler, two ½"x ¼" hex reducer bushings, a long (6") and a short (2") ¼" nipple, and a ¼" cap. One part is an aluminum quick-disconnect with ¼" NPT thread.

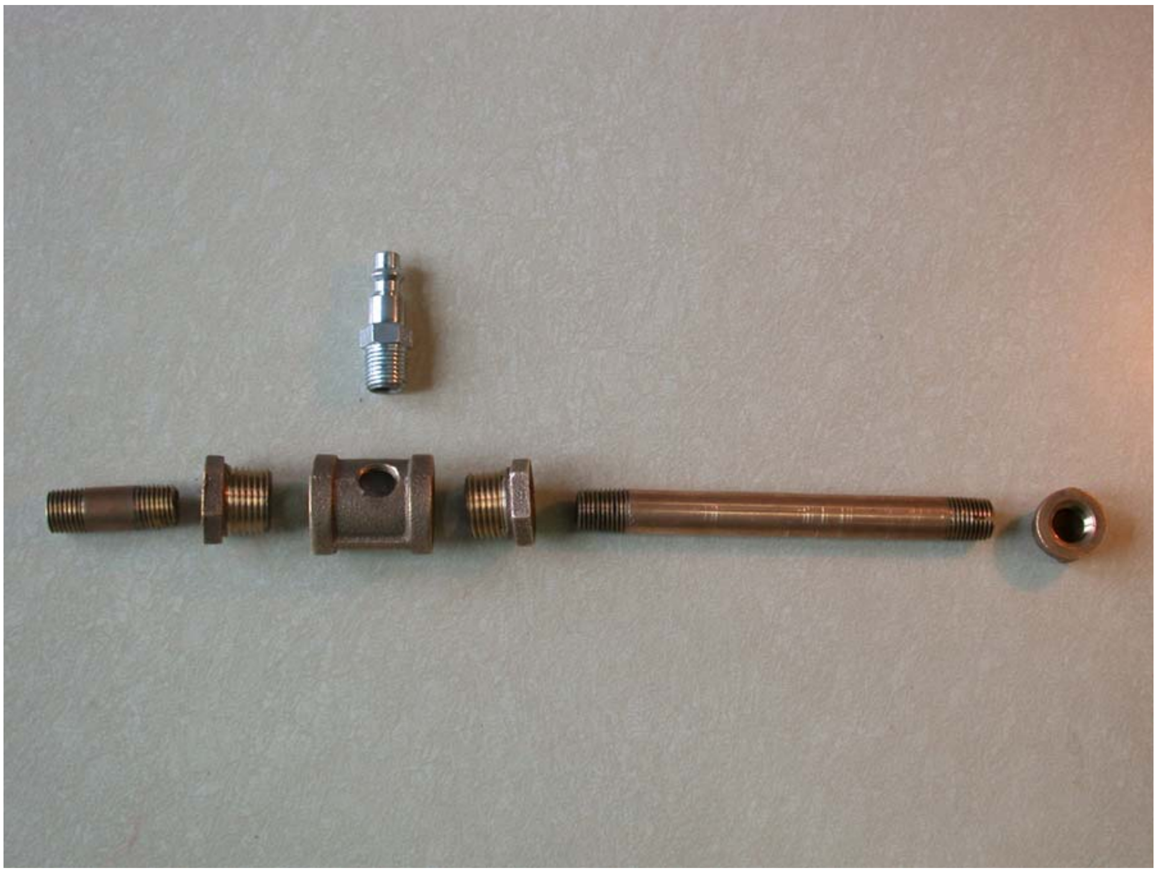

Figure 5 Vortex Tube Kit

The students are pursuing the project usually with ten-minute end-of-class team meetings, and occasional longer evening meetings. The team members choose leaders and peer rating is used for participation and the oral presentation. Some basic fluid mechanics and thermodynamics concepts ware explained 'JIT' in the preparation lecture. The teams then respond to various challenges to CAD and fluid flow design. As teams they will develop criteria and constraint lists for the design, prepare 'solid' and orthographic drawings, and apply for patents (course) to protect and reveal their intentions.

Design

In the second phase, a handout was distributed with a compilation of industrial explanations of the operation of the vortex tube. The handout included the two performance equations to be used in design and testing. Mass conservation, <1>, and the relation between mass flow rate, density and volume flow rate were explained in class along with some discussion of some new units that would be seen in the lab equipment; viz psia, SCFH, °F, BTUH, etc. The subscripts are for input, cold and hot.

$$\mathbf{mdot_i = mdot_c + mdot_h} \qquad \mathbf{<1>}$$

The cold fraction relationship with a Joule-Thompson correction of 4 [°C] is given as equation[6] **<2>**.

$$\mathbf{CF = 100 * (Th - Ti + 4)/(Th - Tc)} \qquad \mathbf{<2>}$$

As the designs progressed each team submitted drawings detailing their evolving design for the vortex generator and valve. As much as possible the team's design work was kept private.

Testing arena

A five horsepower compressor with a 100 gallon reservoir was dedicated to the test arena during the test. The compressed supply air was not dried or cooled. Nor was the vortex tube hot end insulated, all three conditions would be required to meet the performance predicted by equations. Before and during the testing safety is emphasized and eye-protection is provided and required near the air source.

The performance testing is conducted during a regular session of the Concepts and Design class. The fluid mechanics students set-up the apparatus (see Figure 6) and modular instrumentation to indicate pressure difference, four temperatures, and volume flow rate. Ultimately, the results for each team's vortex tube performance will be displayed as a "vi"® panel designed by the fluid mechanics students in National Instrument's Labview Environment®[7].

The closure of the project was the performance test with the teams sharing the test equipment and collecting the other teams' data as well as their own using the form shown in Figure 7. Team members rated their own and the other member's dedication, effort and effectiveness. Each team prepared a written final report and presented an oral report with all individuals participating and peer rating.

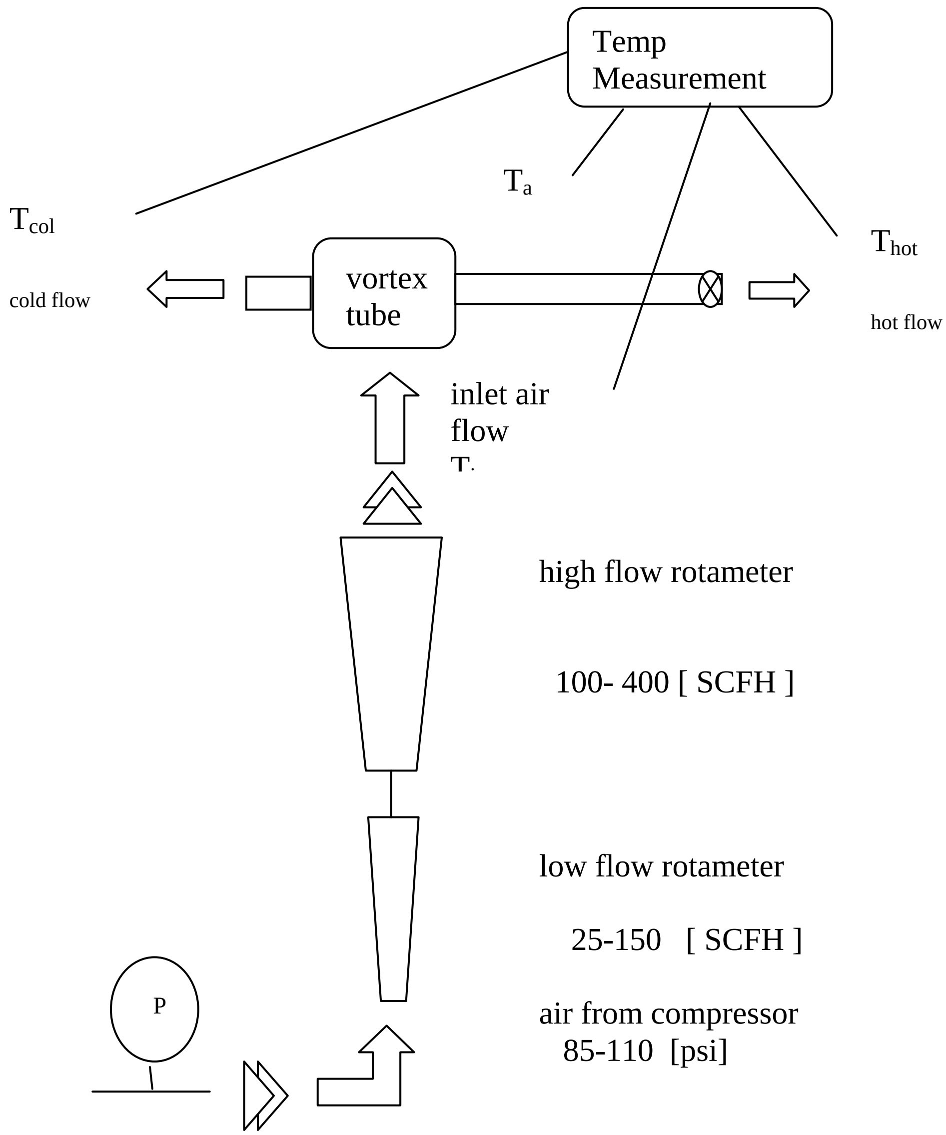

Figure 6 Schematic of the testing Arena

Team Name:			Test Date & Time:			
P start (psi)	P end	Q (SCFH)	T amb (°F)	T in	T cold	T hot

Figure 7 Test Report Sheet

Learning outcomes

The student outcomes for each class will be different. All students will understand the basic operation of a vortex tube and the advantage of a cooling or heating source with no moving parts or electrical noise. The "Concepts and Design" students will understand the use of process to manage a team design, peer evaluation, CAD and communication skills. The Fluid Mechanics students will understand design and implementation of an experiment. The manufacturing students will be able to read drawings, shape brass or HDPE and perform precision measurements.

Figure 8 Team Testing

The courses run simultaneously during the Spring Semester at John Brown University. The freshmen class Vortex Tube experience completed its second round in May 2005.

Bibliography

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[7] http://www.ni.com
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[9] Eckert, E.R.G, Experiments on Energy Separation in Fluid Streams," Mechanical Engineering, ASME, October 1984.
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Biography

Ken French has been teaching engineering at John Brown University for three decades. His degrees are from Purdue, University of Minnesota and Stony Brook SUNY. Ken has spent sabbaticals at Louisiana State University, University of Minnesota and Olivette University and has spent resident summers at NASA JSC and MSC. He is a PE and has participated in a wide variety of expert witness projects supporting litigation. Ken has been active in officer positions of the local chapters of SME and ASME.