Lawrence Berkeley National Laboratory
EETD – Applications Team

LBNL Low-Flow Fume Hood

Progress Report and Research Status

September 1999

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Executive Summary

LBNL has developed a containment technology that reduces required airflow through laboratory fume hoods. LBNL's Low-Flow Fume Hood incorporates an innovative design approach that is patent pending. We have successfully applied ASHRAE safety standards at 30% of typical fume hood airflow and verified containment. LBNL is in collaboration with various industrial partners to refine and apply the containment technology in research laboratories and in the microelectronics industry.

The containment technology introduces displacement airflow at the fume hood opening, creating an air dam between an operator and the contents of a hood. Air is provided through supply vents near the top and bottom of the sash into the hood while air is being simultaneously exhausted from the hood. This push/pull airflow technology is simple, protects the operator, and delivers dramatic cost reductions in a facility's construction and operation. LBNL is developing an "alpha" prototype of the low-flow hood for laboratory applications. Many configuration enhancements were realized during the past four months.

LBNL's patent application has been processed through its first Office Action by the U.S. Patent Office. We have refined the specification section of the application and will be making additional Invention Disclosures on configuration improvements developed recently. A further ruling by the Patent Trademark Office is expected by the end of the calendar year.

The low-flow arrangement successfully contains tracer gas, per the ASHRAE 110 fume test protocol, at an airflow volume that is more than three times less than in a conventional fume hood. However, sash face velocity, a commonly used method of verifying fume hood containment, can not be utilized to verify the low-flow hood's containment. Less expensive and complicated alternative methods for verifying the low-flow fume hood's were explored and identified. Barriers to using these alternative methods exist for particular approval agencies and code issuing authorities.

Direct material support was provide by LABCONCO by supplying a fume hood superstructure for modification. We have partnered with ATMI to develop the technology for the microelectronics industry (e.g. wet benches, and equipment cabinets). Through a contract with Montana State University, LBNL will be working with Fisher-Hamilton to develop a field test hood for an in-situ application of the containment technology.

Project Overview

Background

The Low-Flow Fume Hood project experienced major changes in stewardship and funding in FY1999. Dr. Helmut Feustel, originator of the containment technology as applied to a fume hood, left the project. Continued development was transferred to the EETD Applications Team with Dale Sartor PE as Principal Investigator and Geoffrey C. Bell, PE as Project Head. The Department of Energy (DOE) has provided direct funding to the project in concert with private industrial partners who are making like-in-kind hardware and technical contributions. Additional funding has also been provided through a contract with Montana State University.

Identified Goals

During the second quarter of FY1999, a series of goals were identified for the Low-Flow Fume Hood project including:

1) Review prior, relative patent art and applications. Some work in this area had been performed but a more extensive effort was required.

2) Determine all potential barriers to using the low-flow fume hood with respect to Uniform Building, Mechanical and Electrical codes (all states); OSHA regulations; Fire and Safety regulations (specifically NFPA); and existing "standard" design guidelines (especially ASHRAE and ACGIH). This review needed to culminate in a series of recommendations that could nullify all barriers to using the low-flow fume hood on a basis of the hood's advanced containment approach.

3) Identify and summarize changes that are imminent in the fume hood industry as they relate to proving an installed fume hood's efficacy, containment, and safety. ASHRAE is primarily involved in establishing tests for fume hoods. The Low-Flow Fume Hood must be able to meet or exceed all tests, new or existing.

4) Develop a new, simplified test procedure that provides verification that the Low-Flow Fume Hood is compliant with existing and new containment criteria. These kinds of "tests" will be performed on a regular basis by a facility's Environmental, Health, and Safety (EH&S) group; therefore the tests must be simple to conduct and repeatable.

5) Fabricate and test "alpha" generation of low-flow fume hood. Particular effort would be committed to analyzing supply air input arrangements, interior airflow dynamics, and monitoring methods and devices.

6) Perform extensive evaluations of the alpha hood including tests per ASHRAE standards. Additionally, these evaluations would incorporate extensive empirical tests to establish the hood's operational envelope, failure mode analyses, and user-interface studies.

7) Collaborate with our industrial partners during alpha-prototype hood development.

8) Implement hood design refinements. Fabricate modified components. Re-test hood during design and development process as necessary.

Project Development

Work Elements

The Identified Goals, above, were divided into a number of undertakings that were then rearranged into common work elements. Thus, the following nine work Elements were produced:

Element 1 - Fume Hood Patent Review

- **Scope:** Identify all patents relative to chemical/biological fume hoods. Determine potential barriers to using the low-flow fume hood with respect to Uniform Building, Mechanical and Electrical codes (all states); OSHA regulations; Fire and Safety regulations (specifically NFPA); and existing "standard" design guidelines (especially ASHRAE and ACGIH).

Element 2 - Fume Hood Implementation Barrier Identification

- **Scope:** Identify and analyze barriers to applying low-flow fume hood technique. Identify and become familiar with relevant building codes and regulations. Study performance guidelines for fume hoods as primary laboratory environmental safety devices. Develop methods to overcome institutionalized design practices that will influence application of the low-flow fume hood. This effort will culminate in a series of recommendations that will address and nullify real and perceived barriers to using the low-flow fume hood due to the advanced containment approach of the hood.

Element 3 - Fume Hood Safety and Containment Requirements

- **Scope:** Identify and summarize changes that are imminent in the fume hood industry as they relate to proving an installed fume hood's efficacy, containment, and safety. Develop a new, simplified test procedure that provides verification that the Low-Flow Fume Hood is compliant with existing and new containment criteria.

Element 4 - Fume Hood Test Methods

- **Scope:** Develop innovative test procedures that verify the Berkeley hood's performance. It is probable that a new test protocol will be developed for the Berkeley low-flow fume hood. The protocol may include a series of "tests". Since testing will be performed on a regular basis by a facility's Environmental, Health, and Safety (EH&S) group, the tests must be simple to conduct and repeatable. Design and evaluate protocols for new hood tests and employ the test protocol to validate modified low-flow hood components.

Element 5 - Screen Air-Flow Characterization

- **Scope:** Study and characterize airflow through a large family of screen-types for the Berkeley low-flow fume hood. Develop a test apparatus for studying and characterizing airflow through screens. Evaluations will incorporate practical application of fluid dynamics including: laminar and turbulent air flow studies; transitional air flow evaluation; wake influences and vortex streets; boundary layer interfaces, and edge effects on fluid flow.

Element 6 – Supply Air Plenum Arrangement

- **Scope:** Design and fabricate supply air plenum systems that incorporate various screen-types and equal pressure distribution. Particular effort shall be committed to analyzing supply air input influences on interior airflow dynamics.

Element 7 - Fume Hood Baffle Design

- **Scope:** Study and characterize airflow dynamics of air flowing out of the fume hood through and behind a baffle system as a result of air leaving the hood's interior chamber. Analyze flow along long flat-plates; evaluate entrance and boundary layer interfaces, alternate baffle designs, equal pressure distribution behind the baffle, and interior airflow dynamics. In addition, the exhaust ductwork connection to the Berkeley hood will be evaluated for geometric configuration and location.

Element 8 - Fume Hood Vortex Analysis

- **Scope:** Analyze vortex development and determine its relationship to hood effectiveness. Fabricate baffle systems incorporating various arrangements that enhance/defeat vortex development. Employ practical application of fluid dynamics including laminar and turbulent airflow studies and transitional airflow evaluations. Interface with computational fluid dynamic (CFD) modeling.

Element 9 - Fume Hood Performance Envelope

- **Scope:** Perform extensive evaluations of an alpha hood including tests per ASHRAE standards. Evaluations will incorporate numerous empirical tests to establish the operational envelope of the Berkeley hood, failure mode analyses, and user-interface sensitivity. Hood design refinements will be implement and modified components fabricated. The hood will be re-tested during design and development process as necessary. All results of these evaluations will be shared with our industrial partner during alpha-prototype hood development.

Task Development

The work Elements, above, were grouped to develop Tasks that could then be assigned and performed by staff. Combining these Elements produced the following four Tasks:

Task 1 - Fume Hood Patent Review and Barrier Identification

- Review prior, relative patent art and applications. Perform literature search for patent application features. Some work in this area has been performed but a more extensive effort is required. Collaborate with our industrial partner during alpha-prototype hood development.

- Identify and analyze barriers to applying low-flow fume hood technique. Become familiar with relevant building codes and regulations. Study performance guidelines for fume hoods as primary laboratory environmental safety devices. Develop methods to overcome institutionalized design practices that will influence application of the low-flow fume hood. This effort will culminate in a series of recommendations that will nullify real and perceived barriers to using the low-flow fume hood on a basis of the advanced containment approach of the hood.

Task 2 - Fume Hood Safety and Containment Requirements and Test Methods

- Study safety and performance issues for fume hoods. ASHRAE is primarily involved in establishing tests for fume hoods but other organizations have test criteria as well. Near term and short-term modifications to fume hood test and evaluation procedures need to be applied to the low-flow hood. The Low-Flow Fume Hood must be able to meet or exceed all tests, new or existing.

- Develop innovative test procedures that verify the Berkeley hood's performance. It is probable that a new test protocol will be developed for the Berkeley low-flow fume hood. The protocol may include a series of "tests". Testing will be performed on a regular basis by a facility's Environmental, Health, and Safety (EH&S) group; therefore, the tests must be simple to conduct and repeatable. Collaborate with our industrial partner during alpha-prototype hood development. Design and evaluate new hood tests and employ the test protocol to validate modified hood components. The hood shall be re-tested during design and development process as necessary. Share findings with our industrial partner(s).

Task 3 - Screen Air-Flow Characterization

- Collaborated in developing a test apparatus for studying and characterizing airflow through screens. Screens shall initially be evaluated independently of the Berkeley hood. Evaluations shall incorporate practical application of fluid dynamics including: laminar and turbulent air flow studies; transitional air flow evaluation; wake influences and vortex streets; boundary layer interfaces, and edge effects on fluid flow.

- Design and fabricate supply air plenum systems that incorporate various screen-types and equal pressure distribution. Particular effort shall be committed to analyzing supply air input influences on interior airflow dynamics. Assist with performing extensive evaluations of the alpha hood including tests per ASHRAE standards. Additionally, these evaluations will incorporate extensive empirical tests to establish the operational envelope of the Berkeley hood, failure mode analyses, and user-interface studies. Hood design refinements shall be implement and modified components fabricated. The hood shall be re-tested during design and development process as necessary. All results of these evaluations shall be shared with our industrial partner during alpha-prototype hood development.

Task 4 - Fume Hood Baffle Design and Vortex Development

- Develop the Berkeley hood's back baffle design. During development, analyze flow along long flat-plates; evaluate entrance and boundary layer interfaces, alternate baffle designs, equal pressure distribution behind the baffle, and interior airflow dynamics. In addition, the ductwork connection to the Berkeley hood shall be evaluated for geometric configuration and location. Collaborate with our industrial partner during alpha-prototype hood development. Fabricate modified components. Re-test hood during design and development process as necessary.

- Analyze vortex development and determine its relationship to hood effectiveness. Fabricate baffle systems incorporating various arrangements that enhance/defeat vortex development. Employ practical application of fluid dynamics including laminar and turbulent airflow studies and transitional airflow evaluations. Interface with computational fluid dynamic (CFD) modeling.

Work Completed

Task Coordination

The identified tasks included numerous aspects that needed to be handled before experimentation with the low-flow fume hood could begin including:

- Secure space a research space
- Ensure LABCONCO fume hood superstructure delivery
- Purchase hand tools
- Install fume hood (detail below)
- Modify standard fume hood(detail below)
- Design supply air systems(detail below)
- Install special low-flow components(detail below)
- Review ASHRAE 110 test procedure
- Purchase tracer gas ejector for AHRAE test
- Arrange testing of hood with Indoor Air Environment Group
- Determine instrumentation needs
- Identify alternative modes for airflow analyses
- Purchase Helium Bubble Generator
- Hire summer student help

Fume Hood Installation

Installing the LABCONCO fume hood superstructure for use during LBNL low-flow experimentation required coordination of several construction trades and interface with lab stores, metal shop, duct fabrication shop, and purchasing department. Highlights of the installation process included:

- Clear and arrange laboratory space
- Mount hood and seismically brace
- Determine exhaust duct routing for lowest cost
- Size exhaust fan and ductwork
- Select exhaust and supply fans

- Complete ductwork installation
- Upgrade electrical service
- Mount control rheostats for exhaust and supply fans
- Calibrate exhaust air flow through hood
- Mount helium tank for bubble generator
- Verify compressed air source
- Upgrade and install computer for data retrieval and storage
- Document all phases with digital photos

Low-flow Fume Hood Features

The LABCONCO fume hood superstructure was highly modified to allow observation of airflow within the hood and to accommodate installation of supply air systems that are integral to the low-flow technique. Changes and observations included:

- Removal of standard LABCONCO airfoils and upper cross bracing
- Reposition and re-install main internal cross bracing
- Install clear plastic side-wall for interior observations
- Design and build supply air plenums
- Mount supply air fans
- Calibrate supply air flows
- Monitor and analyze fan settings
- Establish stable operation by coordinating all fans speeds
- Verify containment visually
- Catalog vortexes inside hood
- Modify back baffle installation to allow experimental adjustments

Summer Students

To assist with attaining the identified goals, LBNL hired four students to work on each of the task groups, noted above. Four students were hired from various engineering disciplines of junior and senior college levels. A list of interested candidates was provided through the DOE….program. The students were attending universities from around the nation and abroad.

Once on board, the four students were given as much background information as possible that related to each of their assigned tasks. In addition, a computer was secured for each since a great deal of their individual efforts would require internet access and data manipulation and reduction. The first two or three weeks presented a steep learning curve to each student and progress on each task was minimal. However, once the background information was absorbed, the students made excellent progress towards completing their assigned task.

LBNL's experience with the DOE program was quite positive and the project was decidedly enriched by each student's commitment to their task. Keys to their successful involvement included the following:

1) a common sense of purpose

2) regular meetings to share information and problems

3) there input was relevant and really mattered

4) tangible and demonstrable results they could point to

5) involvement at all levels of the process including hood demonstrations

Principal Results

Fume Hood Containment

The "alpha" version of the Low-Flow fume hood achieved containment levels better than the majority of fume hoods "as manufactured". There is no exact number provided by any code or standard that will categorically state that a fume hood is considered "safe". Even the publishers of the most commonly cited standard, ASHRAE 110, will not stipulate a "safe" containment figure. The American Council of Governmental Industrial Hygienists (ACGIH) provides a containment figure of 0.10 ppm of tracer gas in their literature relevant to fume hood performance for a " recommended maximum" level of leakage. The low-flow alpha version has achieved a level of 0.02 to 0.01 ppm.

Task Completion

The Project's team efforts to complete the Tasks, as noted above, were highly successful although not every element of each Task was finished 100 percent. This was primarily due to new and divergent results from experiments concluded during the research. With close supervision from the project head and input from the principal investigator, the summer students provided a significant proportion of the work completed with the following results:

Task 1 - Fume Hood Patent Review and Barrier Identification

1) Typically after a patent application has been filed, the Patent Trademark Office (PTO) will respond with the first of what is called an office action. Typically, an application is comprised of two main parts: the specifications and the claims on the invention. In the current office action, we are re-evaluating the claims that were made in the original application.

2) Each of the patents cited has relative similarities to our hood; however in each case, there are important differences that distinguish our low flow fume hood from the others. Our hood uses laboratory air that has already been conditioned and directs the air through our fan vents and over the work surface in a unique push-pull ventilation system, significantly decreasing energy use while maintaining, if not improving, safety.

3) On August 4, 1999 we met with the private patent attorney and discussed how to restructure the claims for the second office action as well as for our overall goal of achieving the patent.

4) Stringent face velocity tests, such as required by the ASHRAE-110 test, serve as barriers to LBNL's low-flow energy efficient fume hood and ways to overcome them need to be devised. We must develop methods to overcome institutionalized design practices that will impact application of the low-flow fume hood.

5) ASHRAE-110 is a meticulous test that can also be rather time consuming and expensive. Most people will just stop with the face velocity tests, thinking that that will be adequate to test for containment. This is coupled with the fact that ASHRAE 110 does not specifically stipulate what face velocities are acceptable and instead most of the common standards recommendations of 100 fpm face velocity are then used. This serves as the most serious barrier at this point. Cal-OSHA is very stringent about maintaining a face velocity of about 60 fpm. The current hood configuration measures a face velocity of around 30 fpm. Upon hearing this, most dismiss our hood as being unsafe, yet we have passed the flow visualization and tracer gas tests that are far superior for determining containment and safety.

6) Contacts with several industrial hygienists, EH&S personnel, and other experts in the fields of fume hood testing and certification were made. We investigated to see if they could aid in developing methods or recommendations to overcome institutionalized design practices that might impact the application of the low-flow fume hood.

7) Finally, the face velocity issue is still widely disputed and Cal-OSHA does not seem willing to consider altering that standard for a few years. However, the low-flow hood has drawn much support from many of the contacts made, especially since LBNL can effectively prove containment using the flow visualization and tracer gas tests. Though the face velocity issue is an important barrier, the biggest issue is with the patent. To date persuading users and engineers that our technology works is difficult unless they understand how it works. However, lack of full legal protection constrains information transfer.

Task 2 - Fume Hood Safety and Containment Requirements and Test Methods

1) Hood regulating authorities are hard to define. Quite simply, there are more standards, methods, and recommendations then there are regulations and laws. The majority of these organizations, including ASHRAE have no binding on U.S. businesses.

2) Face Velocity is a measure of the average velocity at which air is drawn through the face to the hood exhaust. It has been the cause of debates among standards committees. No regulating body can seem to agree on a specific number. For the most part, the accepted face velocity measure falls within 80 – 100 fpm. Only in perfect laboratory conditions has 60 or 50 fpm been accepted.

3) Testing is a necessary to ensure that fume hoods provide containment, which in turn means that workers are protected. The most widely accepted method of testing Fume Hoods is the ASHRAE Standard 110 Method of Testing Performance of Laboratory Fume Hoods.

4) Many methods have been employed to prove containment. At the present time, the most recommended method is the ASHRAE-110 Method of Performance for Laboratory Fume Hoods. This is an elaborate three-part test that involves face velocity testing, flow visualization, and a tracer gas test. However, this test is so expensive and time-consuming that those who do use it only perform it on a one-time basis. In terms of annual testing, the tradition has been to use Face Velocity.

5) Statistics report that 30% - 50% of hoods leaking excessive levels of contaminants pass the traditional face velocity tests.

6) In a recent study conducted performed by Dale Hitchings, 59% of the hoods passed face velocity criteria. Only 13% of those same hoods met tracer gas standards set by industry. Had the face velocity measurements alone been used to determine adequate containment, 46% of the hoods would have passed based on face velocity

7) In another study, one investigator found that in a properly designed laboratory, fume hoods with face velocities as low as 50 fpm provided protection factors 2,200 times greater than hoods with face velocities of 150 fpm.

8) Another study indicated that with the exception of one particular type of hood operation, there was no difference in hood containment with face velocities between 59 and 138 fpm.

9) The ASHRAE 110 procedure is a performance test method and does not constitute a performance specification. It is analogous to a method of chemical analysis, which prescribes how to analyze for a chemical, constituent, not how much of the substance should be present. Another analogy would be a method for measuring airflow; it prescribes how the flow should be measured, not how much it should be.

10) The ASHRAE 110 procedure is both time-consuming and expensive. It requires complicated equipment such as mannequins, purpose built tracer gas ejectors, and electron capture instrumentation. To use this test on an annual basis would be overkill for any organization.

11) ASHRAE 110 does not closely approximate the conditions of human hood use. The manikin remains static throughout the testing procedure. One fume hood developer intimated that his company's laboratory found that the test makes no allowances for manikin height. As the height of the manikin is dropped, the test becomes more difficult to pass. If a leak is in the lower level of the hood, it tends not to drift to the breathing zone of a 5'7" manikin.

12) Alternative Test Methods for Laboratory Fume Hoods

- **User Tracer Gas Test.** The User Tracer Gas Test is actually a variation of the ASHRAE 110-tracer gas test using a human subject instead of the mannequin. In the original test procedure, all facets of the ASHRAE-110 tests are followed. This user tracer gas test was performed with a human subject standing in front of the hood making consistent, prescribed movements, such as extending both arms into the hood and pulling them back out in one motion every 30 seconds.

- **Air Monitoring Test.** The Air Monitoring test is very simple. The downside is that it may take a few days. The procedure is as follows: Allow someone to wear an air-monitoring device in the breathing zone while performing work in the hood. Evaluate the contamination levels at various velocities.

- **In-Use Testing Procedure.** This test is similar to the above user-tracer gas test. SF_6 was used in the original study, but other vapors and detectors could be used. It was designed to assess fume hood performance during normal work activities. The operator conducts usual work activities. Escape of the challenge gas is measured in the operator's breathing zone by a direct reading instrument.

- **Dioctylphthalate (DOP) Test.** DOP is a part of the NSF 49 test for Biological Safety Cabinets used to stimulate particles of less than 3 microns in size. A recent research study suggests that a more quantitative approach, using the NSF 49 procedure, might lead to a better understanding of fume hood limitations and the evaluation of exposure potentials to not only the fume hood worker, but those sharing the laboratory as well.

- **Dry-Ice Test.** The Dry- Ice test is relatively simple. All that is required is a bucket of water and dry ice. After placing a bucket of water in the fume hood, you drop in the ice. CO_2 evolves and spills out of the container and onto the work pane. You can see physically if the hood captures well. There is a drawback. Although the test is simple, it is not very convenient to carry buckets of water to each hood. There are also burn hazards involved due to the freezing temperature of the dry ice.

- **NIOSH Method 1500.** The test calls for air sampling pumps (e.g. SKC Model, Gillian, MSA Personnel Pump), human subject, and NIOSH Method 1300 equipment.

- **Photo Ionization Detector Test (PID).** PIDs are used to monitor the amount or concentration of toxic gas. Many industrial applications as well as for utility companies, fire fighters, and environmental applications. Environmental consultants use PIDs to detect small traces of toxic gas, inspect leaking underground storage tanks, monitor hazardous waste, personnel monitoring, confined space entry and as a survey instrument.

- **CO_2 Test.** The CO_2 test is very simple. A palm-sized CO_2 packet is placed inside the fume hood. As the CO_2 is emitted, an air monitoring device or wand is used to capture and record the amount of spillage. This test is ideal in terms of expense, time, and probability. This makes the test seem a very promising choice. However, the drawback to using CO_2 is the chance of producing erroneous values due to human contact.

13) **Performance Specifications.** Organizations responsible for standards and regulations must provide a clearer set of performance specifications and requirements for fume hoods.

14) **Uniform Standards**. Agreement on fume hood practices, testing, and common operations is needed between standards committees.

Task 3 - Screen Air-Flow Characterization

1) It was known that a mesh screen placed across an airflow will have an evening effect, distributing both the velocity and pressure across the screen. However, this effect had not been quantified and the effect of differing mesh geometry was unknown. It was desired to understand the relationship between airflow velocity, the pressure behind the screen and the free hole area of the screen. It was concluded that the developed pressure is proportional to the velocity for a given free hole area, and inversely proportional to free hole area for a given velocity. Screens with less free hole area also maintain laminar flow on exit for a greater distance.

2) The tests were carried out on a purpose built test apparatus constructed from acrylic tubing. This transparent construction allowed easy observation of flow patterns within the device. It consisted of an orifice-plate for flow measurement, an axial flow fan, several sections of honeycomb for flow straightening, and the screen holder. Measurements were taken from two pressure taps situated at either end inside the orifice plate and screen holder.

3) Before it could be used for any experiments, the rig was calibrated to obtain a relationship between the orifice pressure and the flow velocity since the pressure meter is more convenient than the anemometer. To calibrate the rig a series of velocity / pressure readings were taken and graphed, obtaining a fitted curve and equation. The pressure meter can provide time averaged results, whereas the anemometer gives instantaneous (and often wildly fluctuating results) results, thus the pressure meter is preferred.

4) Once calibrated it was possible to run the actual tests on the screens. Each screen in turn was placed between the two front plates and measurements were taken at the orifice plate and just behind the screen for the fan's entire velocity range. In addition to taking the numerical measurements, smoke was blown through the system and its behavior on exiting was observed.

5) The curves and equations were obtained by regression analysis from Microsoft Excel, fitting the points to a power law relation ($y=Ax^b$). They generally fit the results quite well, some deviation being evident on certain screens; however, they are not very large. Qualitatively it is possible to conclude that increasing the free hole area of a screen decreases the back pressure behind it and this is consistent for all of the tested screens.

6) The second phase in the screen test involved measuring the laminar distance of the flow upon exit. This was a difficult process as room air currents could disturb the flow very easily and thus the results are far from exact.

7) The flow results are too erratic to attempt to draw any mathematical relation. It is clear; however, that a smaller free hole area causes the flow to remain laminar for longer. It is unknown how this length will scale for different exit geometries and since the length is quite small (less than 3"), it is unlikely this property will have relevance on a larger scale.

8) Photos taken of the laminar flow after a screen illustrate a series of vortices developing at the edges of the flow. They were hard to see clearly in the two-dimensional images, but they appear to mimic a Karman Vortex Street in three dimensions. These vortices seem to be the mechanism by which the flow disperses and spreads out.

9) A numerical relation for screen pressure, velocity, and free hole area that confirmed the expected results was obtain. The relation between free hole area and laminar distance was a new discovery and raises many questions about the geometric exit effects. When the results with and without the screen are compared, it is clear that the presence of a screen causes the flow to remain collimated for a much greater distance before it disperses. The necessity of the screen will be determined by the application and this experiment provides a method of determining required fan capacity when screens are used.

10) During supply-air plenum evaluations, it had been noticed that the velocity profile emerging from the bottom plenum was very uneven, tending to be very concentrated in the center. To alleviate this a baffle was placed across the entire width of the box to force the airflow horizontally from the fan, rather than flowing directly into the opening.

11) Various other experiments were carried out using additional foils placed at the front and top of the baffle to try to redirect the flow more horizontally.

12) Measurements were taken of the velocity across a modified bottom plenum opening to determine the exact profile and regions of reverse flow. The resulting velocities were very erratic.

Task 4 - Fume Hood Baffle Design and Vortex Development

1) Numerous Computational Fluid Dynamic (CFD) runs were conducted to model airflow through the hood. The initial runs were directed at understanding supply air flow quantities and their relationship to overall exhaust quantity.

2) The team's next goal was to find a 2-dimensional arrangement that would eliminate, or reduce, induced vortices generated in the bottom and top of the fume hood. From these runs, an understanding the baffles' and fans' physical arrangements on vortices was gained.

3) To confirm theoretical results, the various configurations were experimented with and checked by empirical observation. Unfortunately, many runs were not successful in achieving containment or in eliminating the vortices. However, CFD modeling was indeed helpful in increasing our understanding of the airflow problems within the hood, and surely helped us as we progressed towards a physical solution to the problem with the vortices.

4) A great amount of time was spent with simple construction materials, primarily cardboard and tape, looking for the best baffle system to move air through the hood. The best arrangement will avoid spillage and stagnation (LEL concerns), maximize stability against changes in surrounding environmental conditions, and maximize re-capture capabilities.

5) After many configurations, a baffle system was constructed that all but eliminated unwanted vortices. The baffle system now reduces the upper vortex to a small, insignificant roll that does not leak out into the face or breathing zone. It also does not impede the air flowing in the top of the hood from becoming evacuated out the top. The bottom roll is all but gone and floor sweep is satisfactory. The sidewalls of the hood are also swept well as air moves through the hood.

6) A significant portion of my time was spent in preparations for and conducting of the ASHRAE-110 test including:

   - Collaborated with other EET Division members to complete the testing process.

   - Contacted prior outside consultants to learn more about testing procedures on the original low-flow hood prototype.

   - Contacted various companies concerning SF6 detectors, in an attempt to determine our best option for purchasing/renting a detector.

   - Pressure-tested the hood, ductwork, and plenums. Sealed all leaks possible with weather stripping and/or caulk.

   - Prepared apparatus for testing—installed mounting brackets, height adjustments to mannequin, calibration of velocity meter.

   - Participated in actual test runs and reduced data to leakage metrics.