**Background:**
- Spirometry measures respiratory volume and flow rate.
- Test results displayed as a spirogram (Figure 1).

![Figure 1: An example of a spirogram. Air flow rate as a function of the volume of air a person expires. PEFR is peak expiratory flow rate and FEF75 is forced expiratory flow rate at 75% of the forced vital capacity maneuver. The dotted line indicates the expected flow-volume curve, while the solid line shows the actual data gathered during a maneuver.](image)

**Motivation:**
- Common tool for Chronic Obstructive Pulmonary Disease (COPD) and asthma diagnosis.
- COPD is fourth leading cause of death in the world.
- 600 million diagnosed worldwide; many lack treatment.
- Used to monitor drug efficacy, lung growth and aging.
- Commercial spirometers cost upwards of $1000 (Figure 2).

![Figure 2: Examples of spirometers on the market. SDI Diagnostics (left, $2395) and MicroDirect SpiroUSB (right, $1419.55).](image)

**Design Criteria:**
- Spirometers connect to computer via USB.
- Affordable for use in emerging countries.
- Handheld and durable.
- Standardized audiovisual coaching for patient.
- Easy to operate and disinfect.
- Minimize calibration.

**Final Design:**
- Spirometer body contains capillaries that produce laminar air flow (Fleisch design).
- Utilizes a differential pressure sensor to measure drop through spirometer (Figure 3).
- Pressure is proportional to flow, air volume obtained by software integration.

**Materials:**
- Capillary size: 0.625 x 0.625 mm
- Porosity: 83%
- Core length: 3.81 cm
- Spirometer body:
  - Length: 10.9 cm
  - Dia: 3.4 - 4.8 cm

**Shape:**
- Cordierite capillaries span the length of the body's core between the pressure sensor leads.
- T-shaped handle encourages good posture.

**Dimensions:**
- Thickness: 3.4 cm
- Width: 4.8 cm

**Budget:**

<table>
<thead>
<tr>
<th>Item</th>
<th>Prototype Cost per Unit</th>
<th>Total Cost</th>
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<tbody>
<tr>
<td>PC</td>
<td>$2.00 Sensor</td>
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<td>PCB</td>
<td>$0.00 Signal conditioner</td>
<td>$2.00</td>
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<tr>
<td>Vinyl tubing</td>
<td>$0.10 PIC 18 microcontroller</td>
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<tr>
<td>Tubing connectors</td>
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<tr>
<td>Cordierite Capillaries</td>
<td>$30.00 Accessory circuits</td>
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</table>

**References:**
3. Pressure vs. Flow. (1000 samples). R² = 0.9964. (n=30) (Figure 5).
4. Figure 5: Spirometer testing setup.
5. Linear Output Testing:
   - Capillaries → laminar airflow
   - Linear fit from laminar flow: $R^2 > 0.99$
   - Considerable noise due to test setup.
6. Liquid Degradation Test:
   - Core submerged in water.
   - Tests showed no visible degradation.

**Future Work:**
- Implement coaching software and test effectiveness.
- Improve calibration and follow ISO testing protocol.
- Perform clinical testing to further validate spirometer design.

**Possible Applications:**
- Minimize risk of disease.
- Encourages good posture.
- Applied weighted averaging techniques.
- Post-calibration, 28 of 30 tests were within 3.5% of 3 L (ATS req., Figure 7).

**Calibration:**
- 3 L syringe plunged 30 times at various speeds.
- Calibration based on flow conductance.
- Apply weighted averaging techniques.
- Post-calibration, 28 of 30 tests were within 3.5% of 3 L (ATS req., Figure 7).

**Testing Systems:**
- Measured constant air flow (Figure 5).
- Pressure vs. Flow.

**Error of 3 L Measurement:**

**Acknowledgements:**
We would like to give special thanks to David Hubanks, Eric Hoffman, and Isaac Wiedmann from ZMD who kindly donated us a signal conditioner and software. We also want to thank our client, Dr. David Van Sickle who has given us a lot of support on this project. Thanks also to Professor Mitch Tyler who served as our advisor and gave us invaluable guidance and to Amit Nirmukar, Jon Baran, Chris Essex, and Peter Klomberg who helped with logistics, PCB layout and programming. With these people’s help, we were able to design and build a solid proof of concept.

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**Problem Definition:**

Current low-cost spirometers on the market often have retail prices of over $1,000, making them unavailable to many physicians in emerging nations. We have designed and built a low-cost spirometry model that consistently generates a precise, linear signal output based on airflow. We have implemented software that displays data in real-time and a method for calibration utilizing a 3 L syringe. Post-calibration, 28 out of 30 measurements were able to meet ATS accuracy standards for volume measurements. A standardized coaching program will be developed so that motivation is uniform across multiple sites. Next semester we will also further validate the spirometer and software design through extensive testing.

**Abstract:**

We are designing a low-cost spirometer that meets functional and cost requirements. We have designed and built a device that consists of a spirometer body, capillaries, and an accessory circuit. The device meets ATS standards for volume measurements. We are utilizing a differential pressure sensor to measure drop through the spirometer. The final formation of the project is the incorporation of software that displays data in real-time and a method for calibration utilizing a 3 L syringe. Post-calibration, 28 out of 30 measurements were able to meet ATS accuracy standards for volume measurements. A standardized coaching program will be developed so that motivation is uniform across multiple sites. Next semester we will also further validate the spirometer and software design through extensive testing.

**Circuit Diagram:**

- User
- Spirometer
- Records
- Pressure Drop
- Microcontroller
- Converts signal to flow and volume
- Computer
- Final calculations and data display

**Figure 4:** Side view (top) and rear view (bottom) of the spirometer with labeled dimensions.

**Figure 7:** Histogram of percent error of measurements taken with 3 L syringe. (n=30)