

## UNIT FIVE: BASIC SPIROMETRIC CALCULATIONS

Several spirometric values can be calculated by hand from mechanically produced volume/time spirograms. As discussed in **Unit Two: Overview of Spirometry**, this allows the information obtained to be usable, even if the electronically produced printout malfunctions. See **Appendix H. Outline of Spirometric Calculations** for a summary of this unit. Also see **Appendix I. Basic Mathematic Calculations** and **Appendix J. Metric Conversions**.

### A. Forced Vital Capacity (FVC)

#### **DEFINITION:**

The maximal amount of air that can be exhaled forcefully after a maximal inspiration or the most air a person can blow out after taking the deepest possible breath. The FVC is useful for detecting restrictive diseases, since lower than expected results may be a sign that the lungs cannot inflate as fully as normal. The FVC may also be reduced in severe obstructive diseases.

#### **HOW TO CALCULATE:**

1. After the subject has produced three acceptable tracings, calculate the total volume for each tracing (count the volume lines on the graph paper). Remember that acceptable tracings are free from error, as explained in **Unit Four: Spirometric Technique, Section E: Check the Acceptability and Reproducibility of the Test**.
2. Check for excessive variability between the two largest FVCs to determine if additional maneuvers are needed. (See the next section, **Calculating Excessive Variability for FVC** for instructions.) If the reproducibility criteria are not met, continue the test as needed, assuming that the subject is able to continue.
3. If the reproducibility criteria are met, use the FVC with the largest volume for future calculations unless otherwise noted.

**EXAMPLE:** (See Figure 5-1. Volume Time Curve - FVC Measurement): The FVC for curve A is 3.55 L.

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**EXERCISE:** What are the FVCs for curve B and C? Which of the three curves has largest FVC?

**FEEDBACK:** Curve B - FVC = 3.33 L  
Curve C - FVC = 3.26 L  
Largest FVC - Curve A (3.55 L)

**POINTS TO REMEMBER:**

1. Always use the largest volume from an acceptable tracing to ensure that the maximal results are used.
2. FVC should be given in liters rounded to 2 decimal places (e.g., 4.25 L.).
3. Remember to convert the answer to BTPS when needed. (For a definition of BTPS and calculating instructions, see **Section I.: Conversion to BTPS**, which appears later in this unit.)

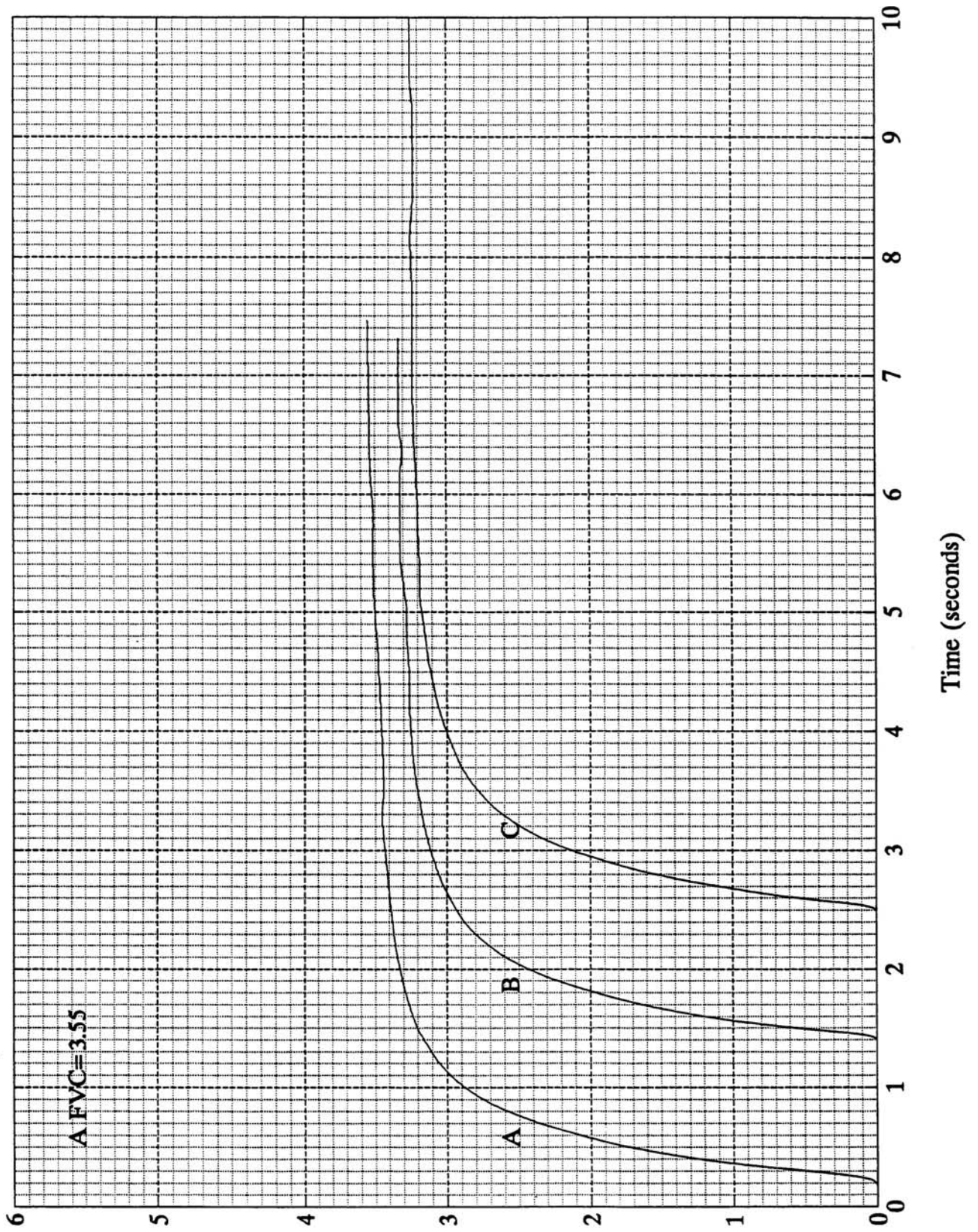
**B. Calculating Excessive Variability for FVC**

**DEFINITION:**

Using three acceptable spiromgrams (tracings), the two with the largest FVCs are examined to determine whether there is more than a **200 milliliter** difference (0.20L) between them. [**Note (optional):** reproducibility criteria have changed over the last 20 years: ATS-1994, 200 ml; ATS-1987 5% or 100 ml (whichever is greater); Cotton Dust-1979, 10% or 100 ml (whichever is greater). To determine “whichever is greater,” if the difference is greater than 100 ml (100 ml for Cotton Dust as well), then the percentage criterion should be used. If the difference is **not** greater than 100 ml, then the percentage criterion does not need to be used as the tracings do not have excessive variability.] (See **Unit Four: Spirometric Technique, Section E.: Check the Acceptability and Reproducibility of the Test**, for the criteria for acceptable spiromgrams.)

FIGURE 5-1. VOLUME TIME CURVE - FVC MEASUREMENT

Figure 5-1. Volume Time Curve - FVC Measurement



## HOW TO CALCULATE:

To find if the difference is greater than 200 ml (calculate Best FVC - Second Best FVC):

1. Determine the volumes for the two acceptable tracings with the largest FVCs.
2. Subtract the volume of the second largest FVC from the volume of the largest FVC.

To find if the difference is excessive expressed in percentage (OPTIONAL):

1. Follow steps 1 and 2 above.
2. Proceed if the difference is greater than 200 ml (100 ml for Cotton Dust as well).
3. Divide the answer (the difference) by the volume of the largest FVC.
4. Multiply the answer by 100 to find the percentage of the difference, or:

$$\% \text{ Reproducibility} = \frac{\text{Best FVC} - \text{Second Best FVC}}{\text{Best FVC}} \times 100$$

**EXAMPLE:** (See Figure 5-2. Volume Time Curve - FVC Variability).

Curve A (FVC - 3.55 L) and Curve B (FVC - 3.33 L) are the two largest curves so they are the ones to use.

$$3.55 - 3.33 = 0.22$$

Since 0.22 is greater than 200 milliliters (0.20L), there is excessive variability between curves A and B.

Since 220 ml is greater than 100 ml (ATS-1987) the 5% criterion can be appropriately applied. In addition, 220 ml is greater than 100 ml (Cotton Dust). Therefore, the percent reproducibility (optional) can appropriately be used for both the ATS-1987 and the Cotton Dust and is calculated by:

$$\% \text{ Reproducibility} = \frac{\text{Best FVC} - \text{Second Best FVC}}{\text{Best FVC}} \times 100$$

$$0.22/3.55 = .062$$

$$0.062 \times 100 = 6.2\%$$

Since 6.2% is greater than 5%, there is excessive variability between curves A and B using the ATS-87 (5% criterion) but not using the Cotton Dust (10% criterion).

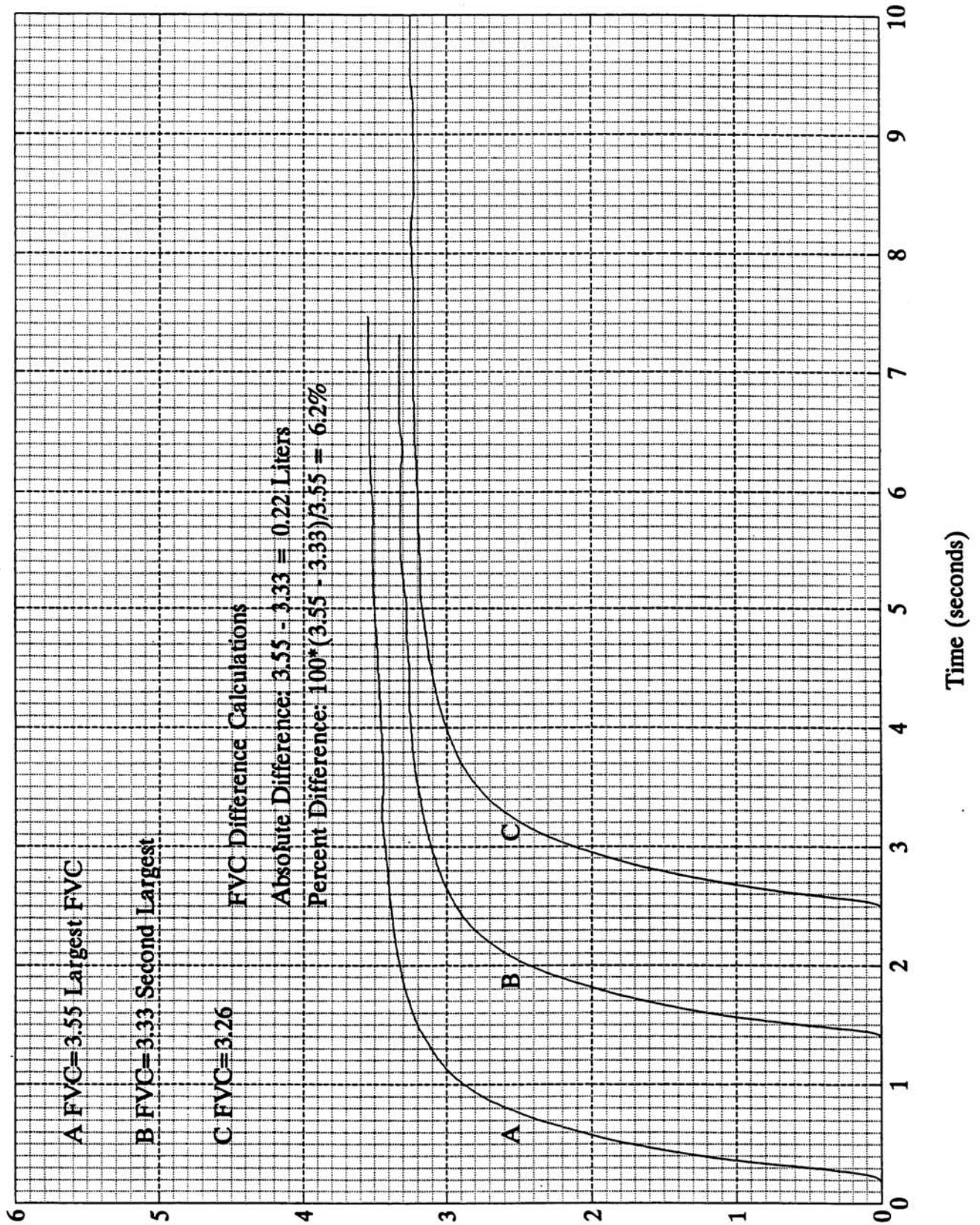
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**EXERCISE:** (See Figure 5-2. Volume Time Curve - FVC Variability). How much variability would there be if curves B and C had been the two largest curves?

**FEEDBACK:** 0.07L or  $[(3.33 - 3.26)/3.33] \times 100 = 2.1\%$

FIGURE 5-2. VOLUME TIME CURVE - FVC VARIABILITY

Figure 5-2. Volume Time Curve - FVC Variability



**EXERCISE:** Three otherwise acceptable tracings had the following FVCs: A = 1.90 L., B = 1.19 L., C = 1.97 L. How much variability would there be between the two largest FVCs?

**FEEDBACK:** 70 ml. Since this is less than 200 ml (ATS-1994 criterion), there is no excessive variability. Optional: There is no excessive variability using the 100 ml ATS-1987 or Cotton Dust criteria as well.

**POINTS TO REMEMBER:**

1. 1 liter = 1000 milliliters (ml)
2. The ATS Standardization of Spirometry--1994 Update recommends that reproducibility be a goal to strive for in testing. It suggests that the reproducibility criteria be used as a guide to determine whether more maneuvers are needed and not to exclude subjects (1). The rationale for this is discussed in **Unit Four: Spirometric Technique, Section E. Check the Acceptability and Reproducibility of the Test.**

### C. Forced Expiratory Volume in One Second (FEV<sub>1</sub>)

#### DEFINITION:

The volume of air exhaled during the first second of a forced expiratory maneuver. The FEV<sub>1</sub> is useful for detecting obstructive diseases since a person with obstructed airways will not be able to exhale as much air in the first second as a person with normal lungs. The FEV<sub>1</sub> may also be low if the person has severe restrictive disease.

#### HOW TO CALCULATE:

1. Find the starting point of a forced expiratory maneuver along the baseline of an acceptable spirogram. A more accurate way for determining the start of the test will be described later in this unit in **Section E. Back Extrapolation**. This is the point where time (t) = zero. Note the scale on your graph paper to determine the length of one second. Measure the appropriate distance from t = 0 to t = 1 second.
2. Draw a straight line vertically up from the point on the baseline where t = 1 to where it intersects with the curve. Determine the volume on the graph paper at the point of the intersection. This is the FEV<sub>1</sub>.

**EXAMPLE:** (See Figure 5-3. Volume Time Curve - FEV<sub>1</sub> Measurement):

For curve A, t = 0 is at 0.24 seconds, therefore t = 1 is at 1.24 seconds. A straight line drawn vertically at t = 1 intersects the curve at 3.15 liters. Therefore, the FEV<sub>1</sub> for curve A is 3.15 liters.

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**EXERCISE:** Calculate the FEV<sub>1</sub>s for curves B and C.

**FEEDBACK:** Curve B - FEV<sub>1</sub> = 2.98 L.  
Curve C - FEV<sub>1</sub> = 2.82 L.

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**OPTIONAL EXERCISE:** Calculate the FVC for curves A, B and C in Figure 5-3 and determine if there is excessive variability.

**FEEDBACK:** Curve A - FVC = 3.98 L.  
Curve B - FVC = 3.86 L.  
Curve C - FVC = 3.65 L.

$$3.98 - 3.86 = 0.12\text{L}$$

$$\% \text{ Reproducibility (optional)} = (0.12)/3.98 \times 100 = 3.0\%$$

The variability between curves A and B is only 120 milliliters and 3.0% so the FVCs do not have excessive variability for all the criteria. Note (optional) that 120 milliliters is greater than 100 ml; therefore, the percentage criterion is used to determine excessive variability under the Cotton Dust criteria.

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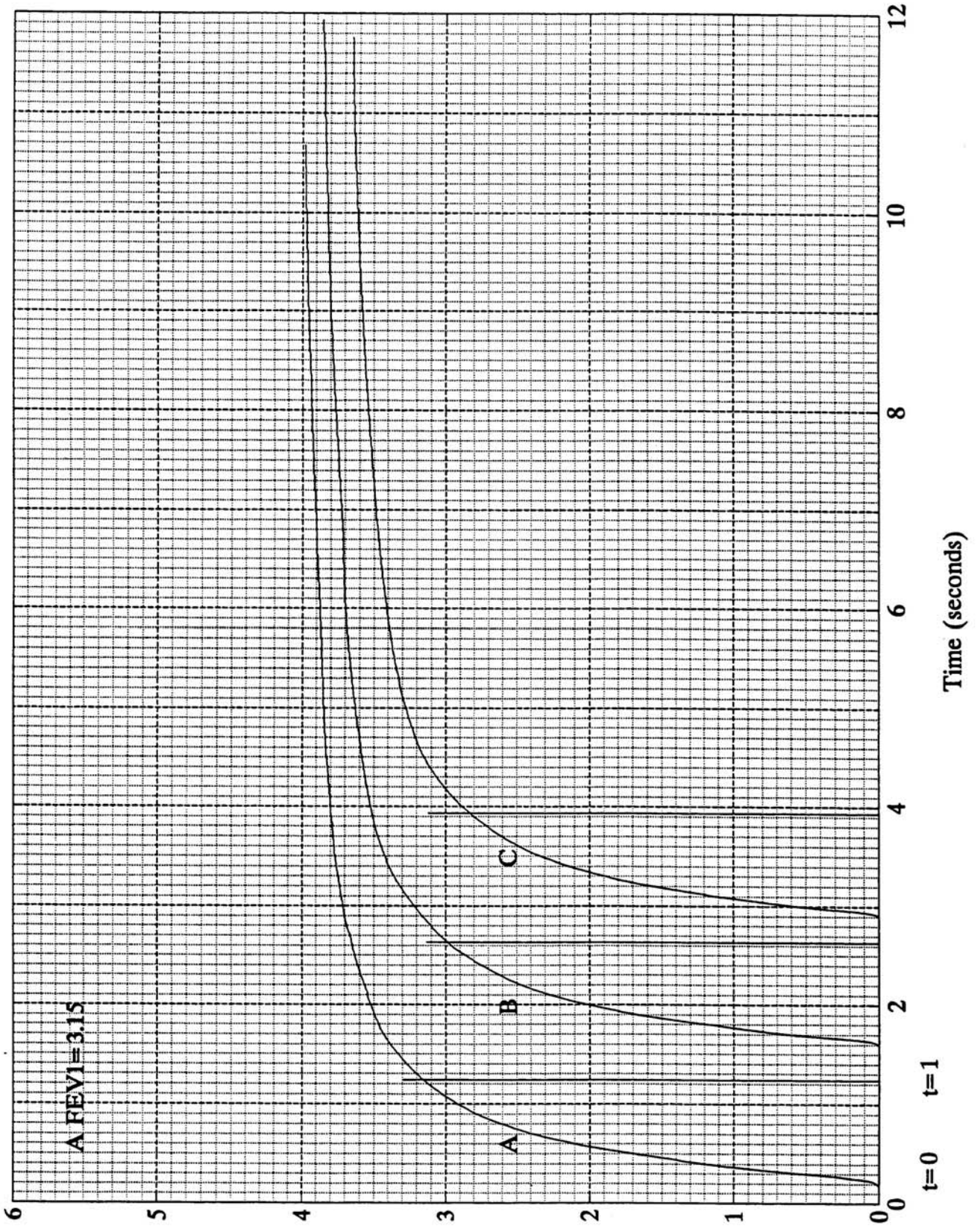
**POINTS TO REMEMBER:**

1. The FEV<sub>1</sub> to be used for subsequent analyses should be the largest one, regardless of the curve on which it occurs. For example, the largest FEV<sub>1</sub> may not be on the curve with the largest FVC.
2. The FEV<sub>1</sub> should be given in liters rounded to 2 decimal places (e.g., 3.15).
3. Excessive variability and extrapolated volume must be calculated to determine if additional maneuvers are needed. See the following three sections for details.
4. Remember to convert the answer to BTPS when needed. For a definition of BTPS and calculating instructions, see **Section I: Conversion to BTPS**, which appears later in this unit.



FIGURE 5-3. VOLUME TIME CURVE - FEV<sub>1</sub> MEASUREMENT

Figure 5-3. Volume Time Curve - FEV<sub>1</sub> Measurement



## D. Calculating Excessive Variability for FEV<sub>1</sub>

### DEFINITION:

Using three acceptable spirograms, select the two with the largest FEV<sub>1</sub> and determine whether there is more than a **200 ml** difference between the two. [**Note (optional)**: reproducibility criteria have changed over the last 20 years: ATS-1994, 200 ml; ATS-1987 5% or 100 ml (whichever is greater); Cotton Dust-1979, 10% or 100 ml (whichever is greater). To determine “whichever is greater,” if the difference is greater than 100 ml, then the percentage criterion should be used. If the difference is **not** greater than 100 ml, then the percentage criterion does not need to be used as the tracings do not have excessive variability.] Remember that acceptable tracings are free from error, as explained in **Unit Four: Spirometric Technique, Section E: Check the Acceptability and Reproducibility of the Test.**

### HOW TO CALCULATE:

To find if the difference is greater than 200 ml (calculate Best FEV<sub>1</sub> - Second Best FEV<sub>1</sub>):

1. Determine the FEV<sub>1</sub> for each of the tracings of an acceptable spirogram.
2. Subtract the second best FEV<sub>1</sub> from the first best FEV<sub>1</sub>.

To find if the difference is excessive expressed in percentage (OPTIONAL):

1. Follow steps 1 and 2 above.
2. Proceed if the difference is greater than 200 ml (100 ml for Cotton Dust as well).
3. Divide the answer (the difference) by the volume of the largest FEV<sub>1</sub>.
4. Multiply the answer by 100 to find the percentage of the difference, or:

$$\% \text{ Reproducibility} = \frac{\text{Best FEV}_1 - \text{Second Best FEV}_1}{\text{Best FEV}_1} \times 100$$

**EXAMPLE:** (Figure 5-4. Volume Time Curve - FEV<sub>1</sub> Measurement.) Curve A (FEV<sub>1</sub> = 3.15 L.) and Curve B (FEV<sub>1</sub> = 2.92 L.) have the two largest FEV<sub>1</sub>s.

$$3.15 - 2.92 = 0.23\text{L}$$

To express the reproducibility in a percentage (OPTIONAL):

$$0.23/3.15 = 0.073 \quad \text{and} \quad 0.073 \times 100 = 7.3\%$$

Since 230 ml is greater than 200 ml, there is excessive variability.

**OPTIONAL:** 7.3% is greater than 5% but less than 10%, therefore these tracings would not meet the ATS-1987 criterion but would meet the Cotton Dust criterion.

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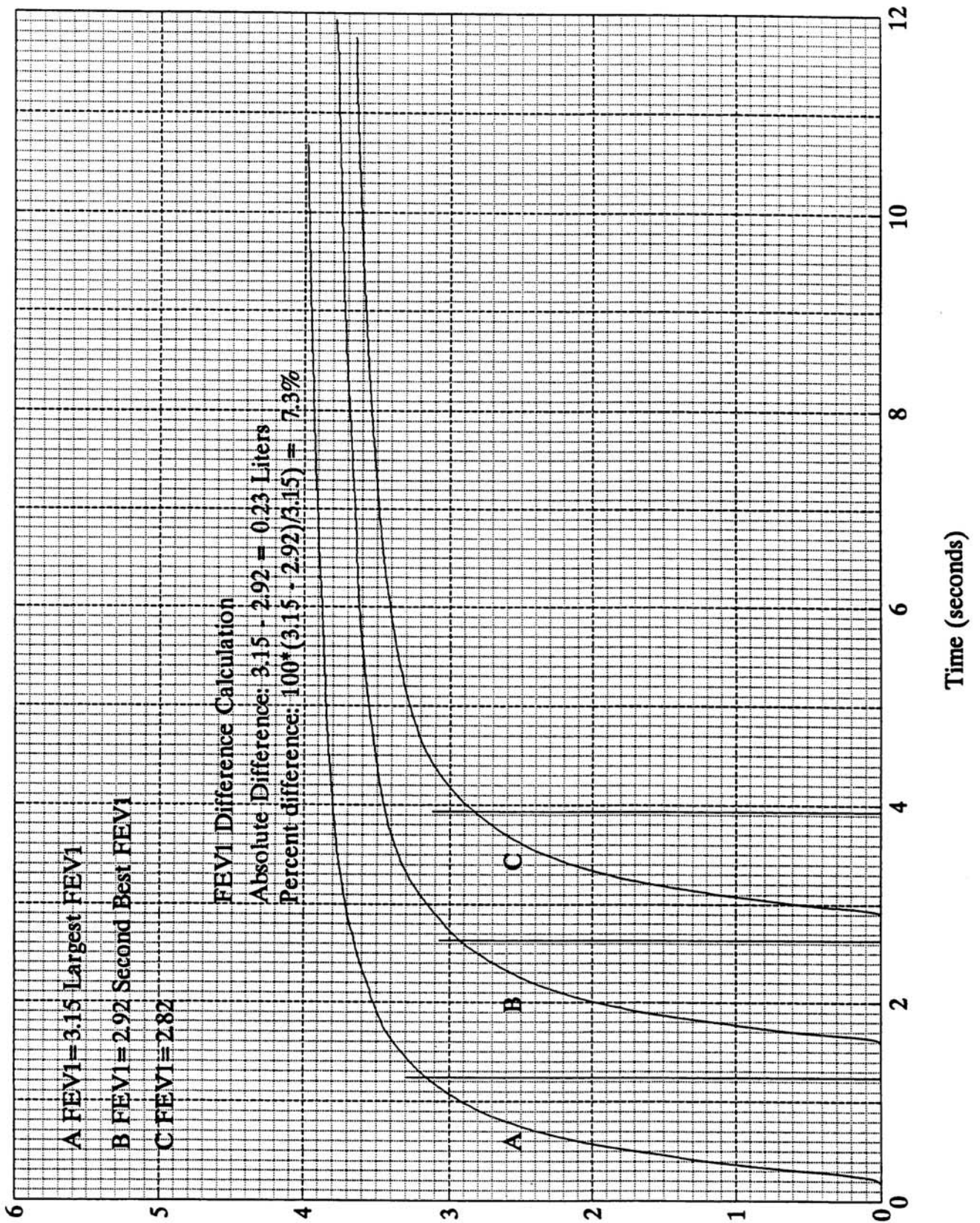
**EXERCISE:** Suppose that the largest FEV<sub>1</sub>s in Figure 5-4 had come from curves B and C. Would there be excessive variability?

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**FEEDBACK:** No, because 100 ml is less than 200 ml. **OPTIONAL:** These tracings would also meet the ATS-1987 and Cotton Dust criteria because 3.4% is less than 5%.

FIGURE 5-4. VOLUME TIME CURVE - FEV<sub>1</sub> VARIABILITY

Figure 5-4. Volume Time Curve - FEV<sub>1</sub> Variability



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**EXERCISE:** Three otherwise acceptable tracings had the following FEV<sub>1</sub>s: A = 1.77 L., B = 1.71 L., C = 1.98 L. Would there be excessive variability between the two largest FEV<sub>1</sub>s?

**FEEDBACK:** Yes, because 210 ml is greater than 200 ml. **OPTIONAL:** Since 210 ml is greater than 100 ml (ATS-1987 and Cotton Dust), the percentage criteria should be used. Since  $(0.21/1.98L = 10.6\%)$ , the FEV<sub>1</sub>s for these tracings exhibit excessive variability using the ATS-1987 (5%) and the Cotton Dust (10%) reproducibility criteria.

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**POINTS TO REMEMBER:**

1. 1 liter = 1000 milliliters (ml)

## E. Back Extrapolation

### DEFINITION:

The preferred method for determining zero time on a tracing when the exact starting point of a forced expiratory maneuver is not obvious. Since the  $FEV_1$  is affected by the point on the graph that is selected as the start, a uniform way to determine this point must be used.

### HOW TO CALCULATE AND EXAMPLE:

1. Using an otherwise acceptable tracing (see Figure 5-5), look at the FVC curve obtained and lay a straight edge along the steepest portion of the curve. (See Figure 5-6.)
2. With a sharpened pencil, draw a line along the straight edge and along the steepest portion of the curve, and extend the line to intersect the baseline. (See Figure 5-7.)
3. Where the straight line intersects the baseline is the new zero time to be used for calculating  $FEV_1$ . Mark the intersection  $t=0$ , and find the point on the baseline one second later and mark this  $t=1$ . (Note the distance for one second on your graph paper to measure  $t=1$ .) (See Figure 5-7.)
4. Proceed with the usual step for calculating  $FEV_1$ . (For the curve in Figure 5-7, the  $FEV_1$  is 2.33 L.)

**NOTE:** To see the significance of back extrapolation to the zero time point, mark the point at which the tracing actually leaves the baseline, and the point exactly one second later. As seen in Figure 5-8, the  $FEV_1$  would have been 2.16 L. That is a sizeable difference.



**FIGURE 5-5. VOLUME TIME CURVE  
FEV<sub>1</sub> AND EXTRAPOLATED VOLUME (VEXT)**

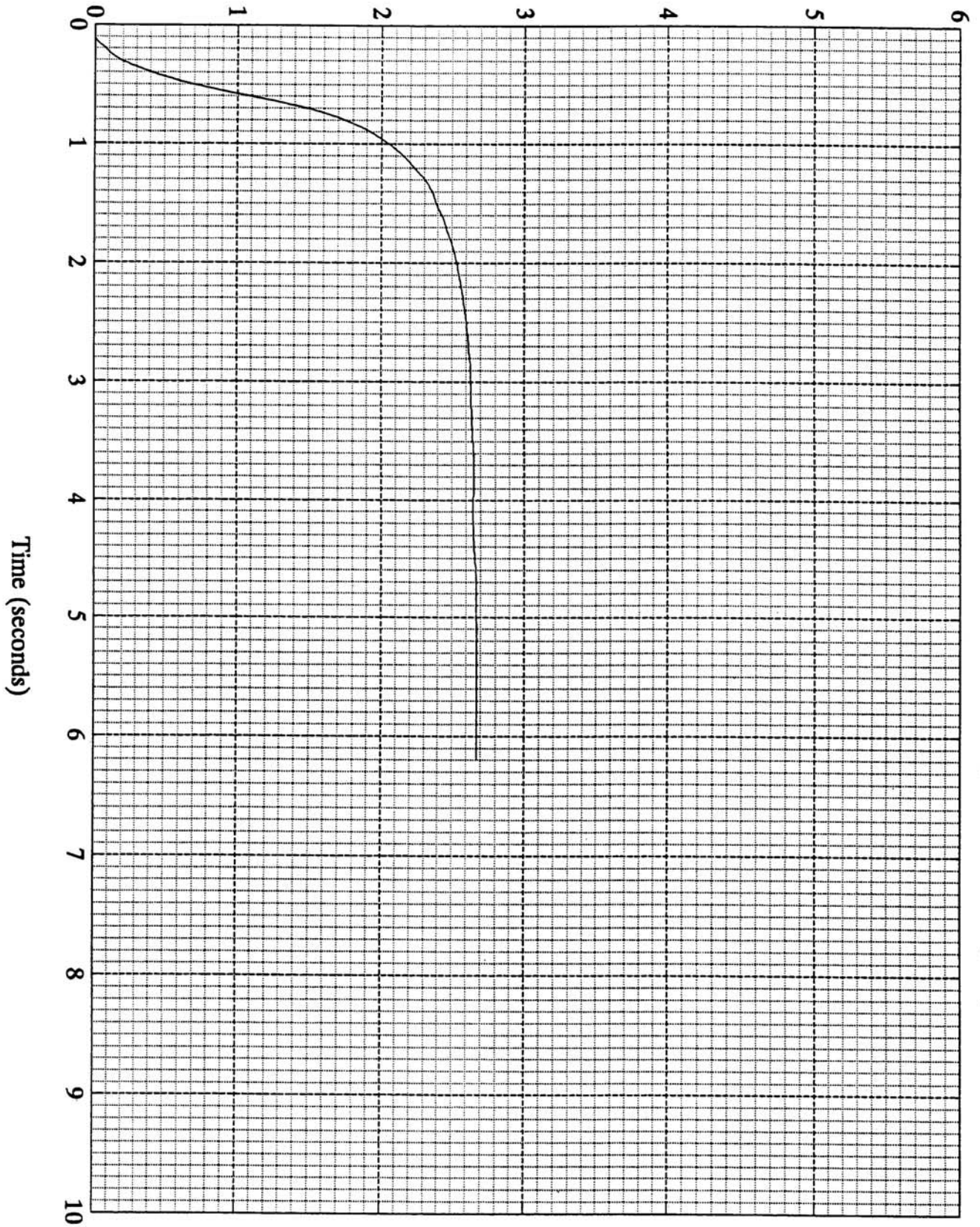


Figure 5-5. Volume Time Curve - FEV<sub>1</sub> and Extrapolated Volume (Vext)

FIGURE 5-6. VOLUME TIME CURVE - DRAW LINE FOR TEXT

Figure 5-6. Volume Time Curve - Draw Line for Vext

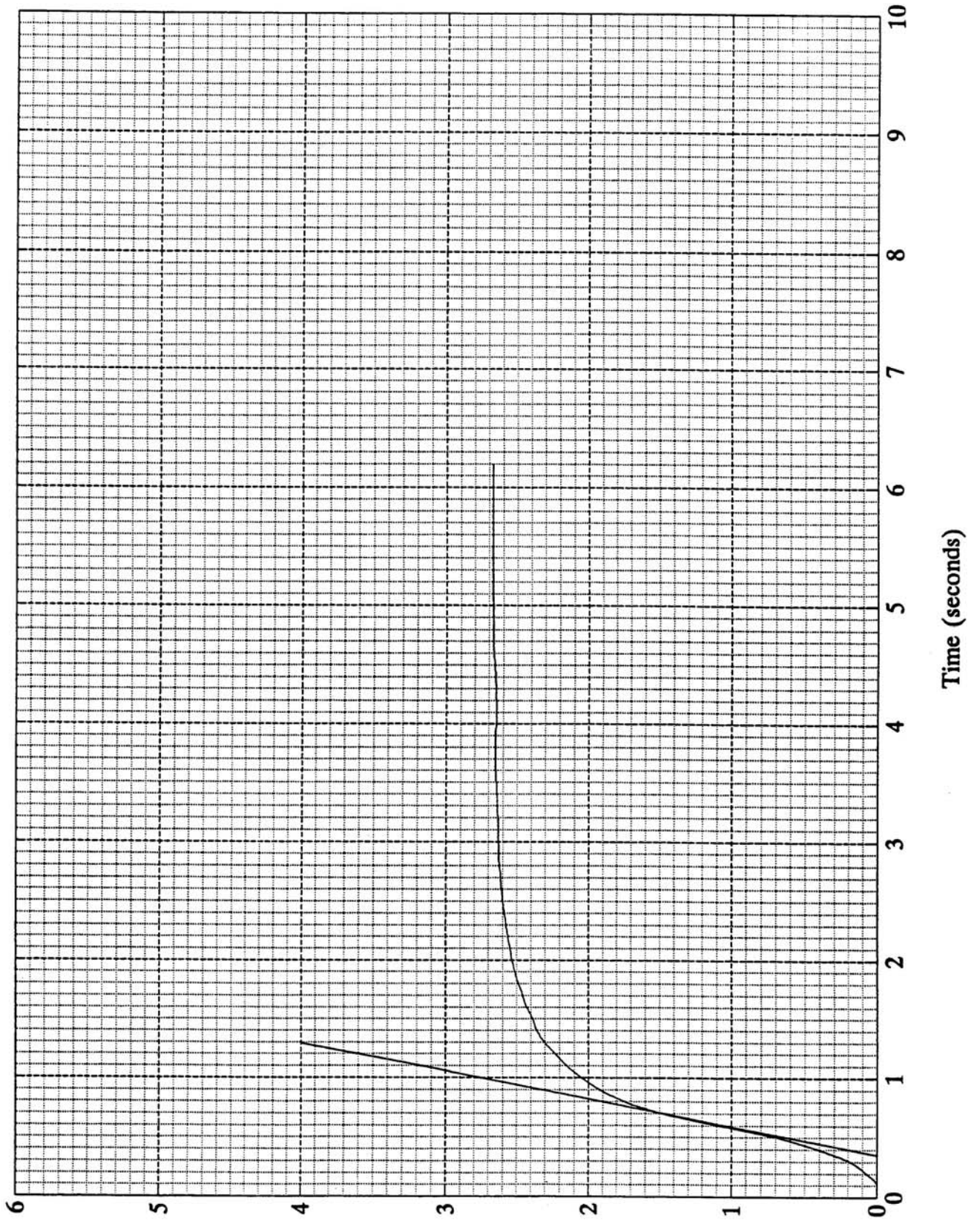




FIGURE 5-7. VOLUME TIME CURVE - MEASURE TIME ZERO AND FEV<sub>1</sub>

Figure 5-7. Volume Time Curve - Measure Time Zero and FEV<sub>1</sub>

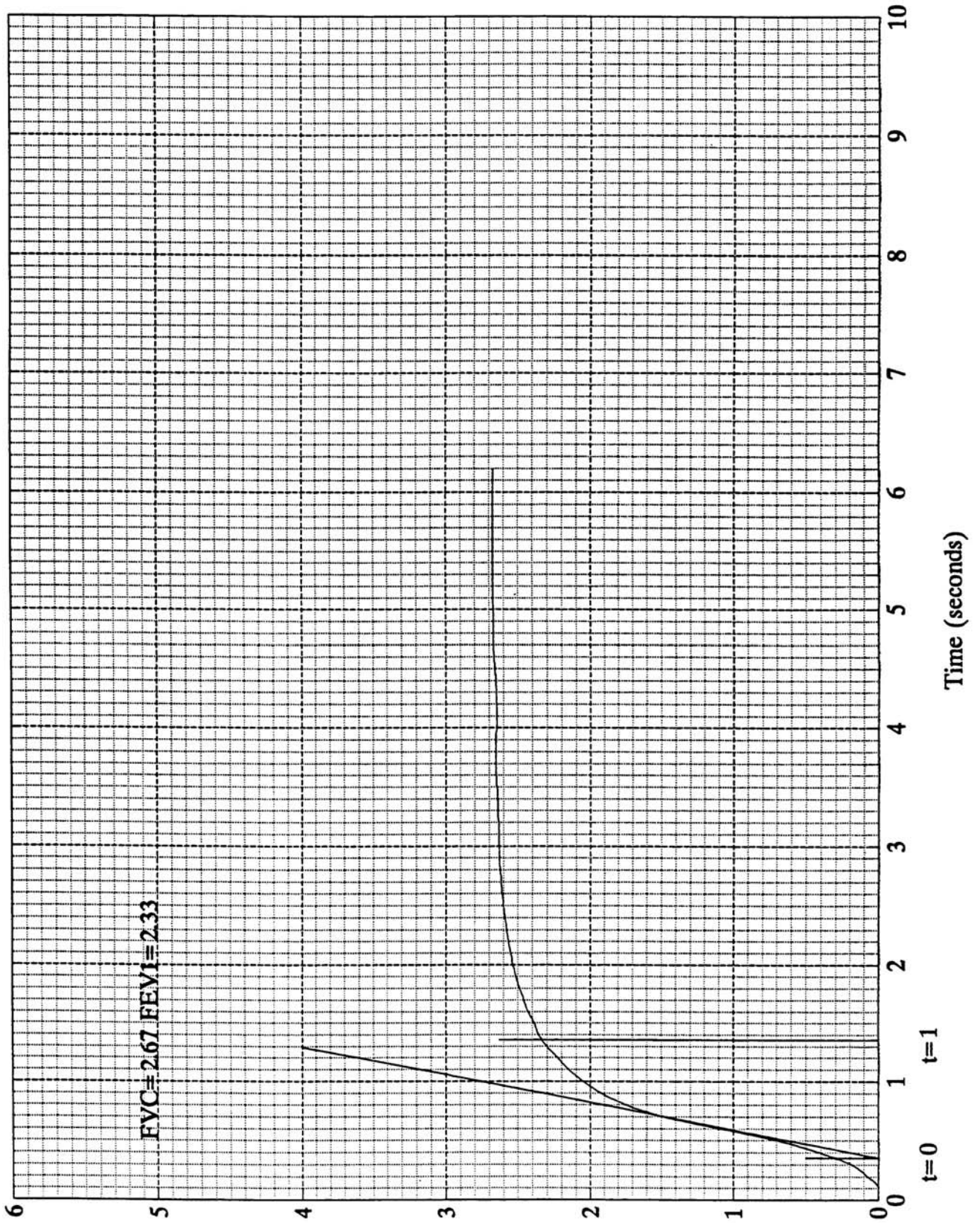
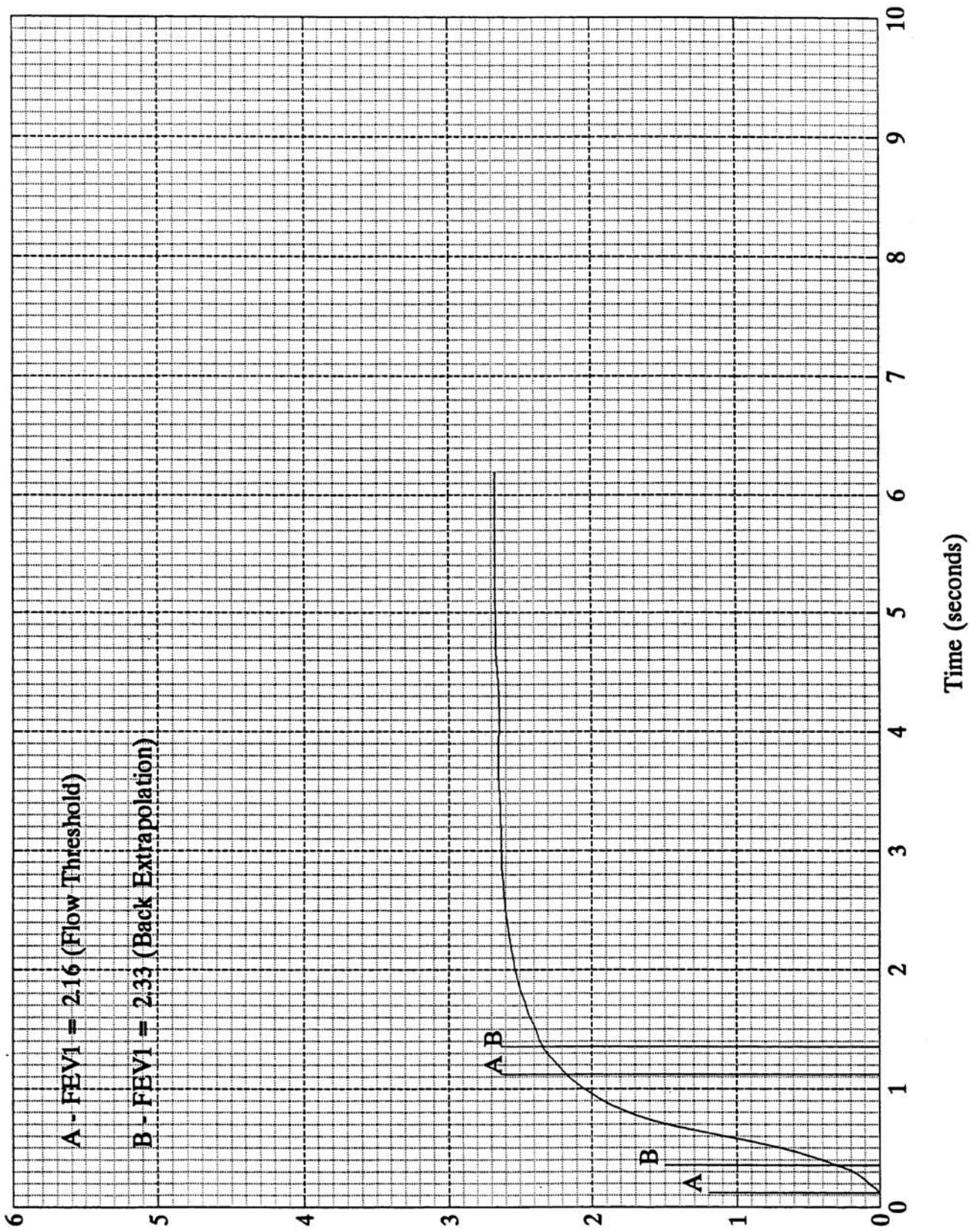




FIGURE 5-8. VOLUME TIME CURVE - TWO POSSIBLE TIME ZEROS

Figure 5-8. Volume Time Curve - Two Possible Time Zeros



**EXERCISE:** Using the curve in Figure 5-9, calculate the FEV<sub>1</sub>, using back extrapolation.

**FEEDBACK:** FEV<sub>1</sub> = 3.08 L.

FIGURE 5-9. VOLUME TIME CURVE – EXERCISE

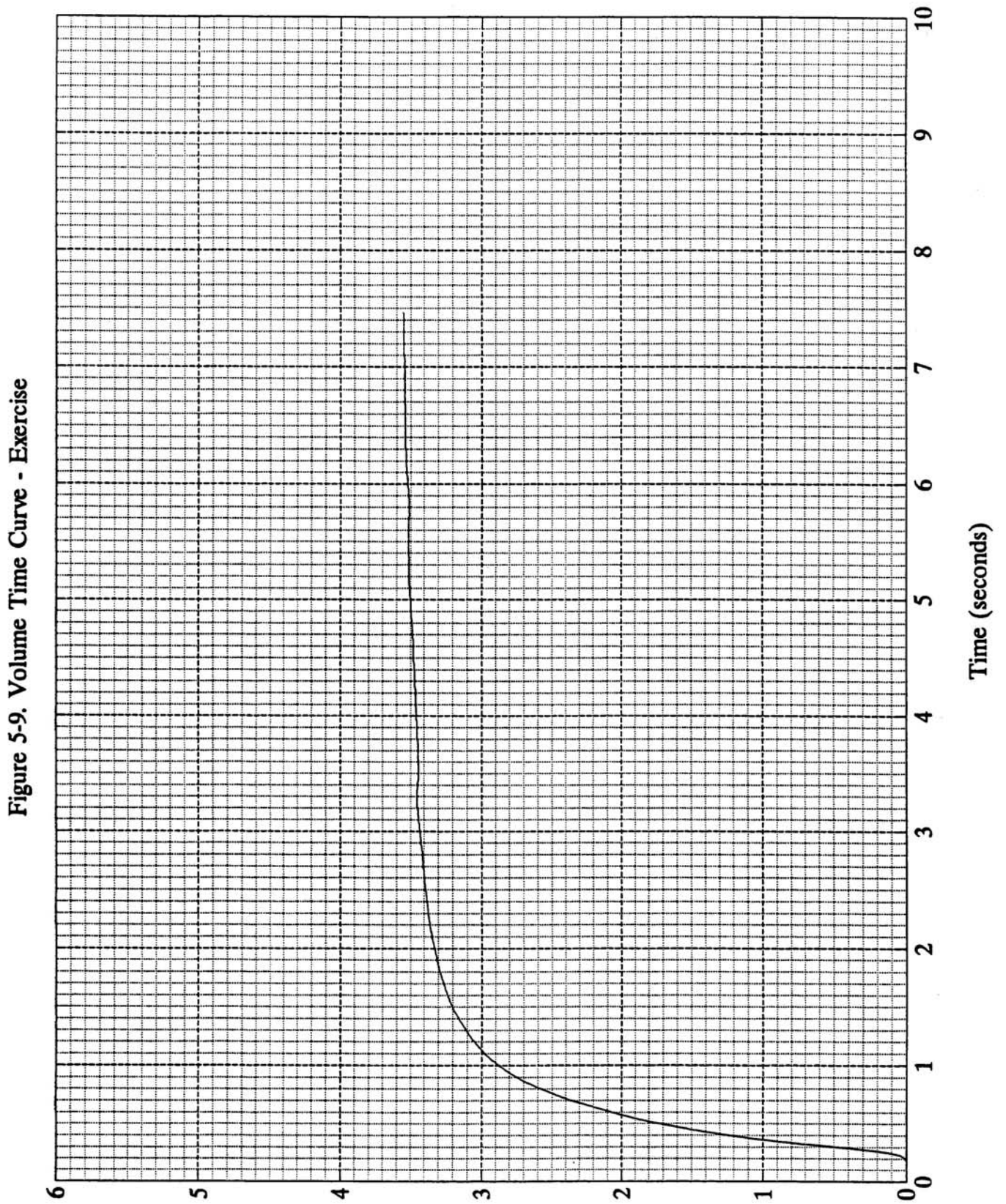


Figure 5-9. Volume Time Curve - Exercise

**EXERCISE:** Using the curve in Figure 5-10, calculate the FEV<sub>1</sub>, using back extrapolation.

**FEEDBACK:** FEV<sub>1</sub> = 1.56 L.

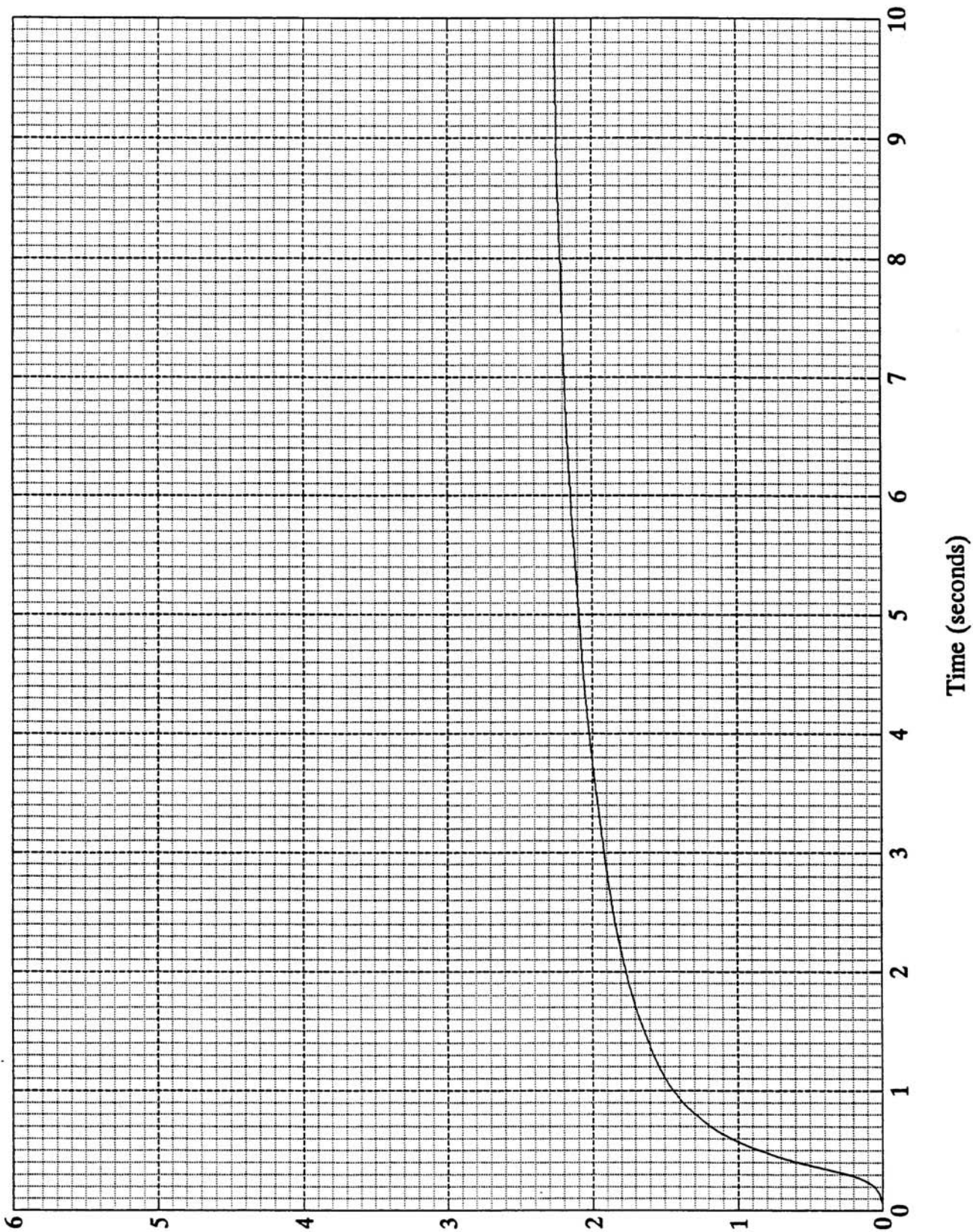
**POINTS TO REMEMBER:**

1. The American Thoracic Society has identified the back extrapolation method as the most consistent and accepted technique for determining the zero point and has recommended its use for every calculation of the FEV<sub>1</sub>. (1)
2. After using back extrapolation, extrapolated volume must be computed to determine the acceptability of the tracing for calculating the FEV<sub>1</sub>. (See the next section for details.)



FIGURE 5-10. VOLUME TIME CURVE – EXERCISE

Figure 5-10. Volume Time Curve - Exercise



## F. Calculating Excessive Extrapolated Volume

### DEFINITION:

As described earlier, extrapolated volume is the volume exhaled before the timing of the maneuver has started -- "time zero". Extrapolated volume should not be greater than 5% of the FVC or 150 ml, whichever number is greater (1). Extrapolated volume is used to determine whether or not the tracing is acceptable to use for calculating FEV<sub>1</sub>. Excessive extrapolated volume is a type of hesitation or false start and is one of the criteria for determining acceptability. Excessive hesitation can exhibit several different shapes -- two examples are given in Figures 5-11 and 5-12.

### HOW TO CALCULATE AND EXAMPLE:

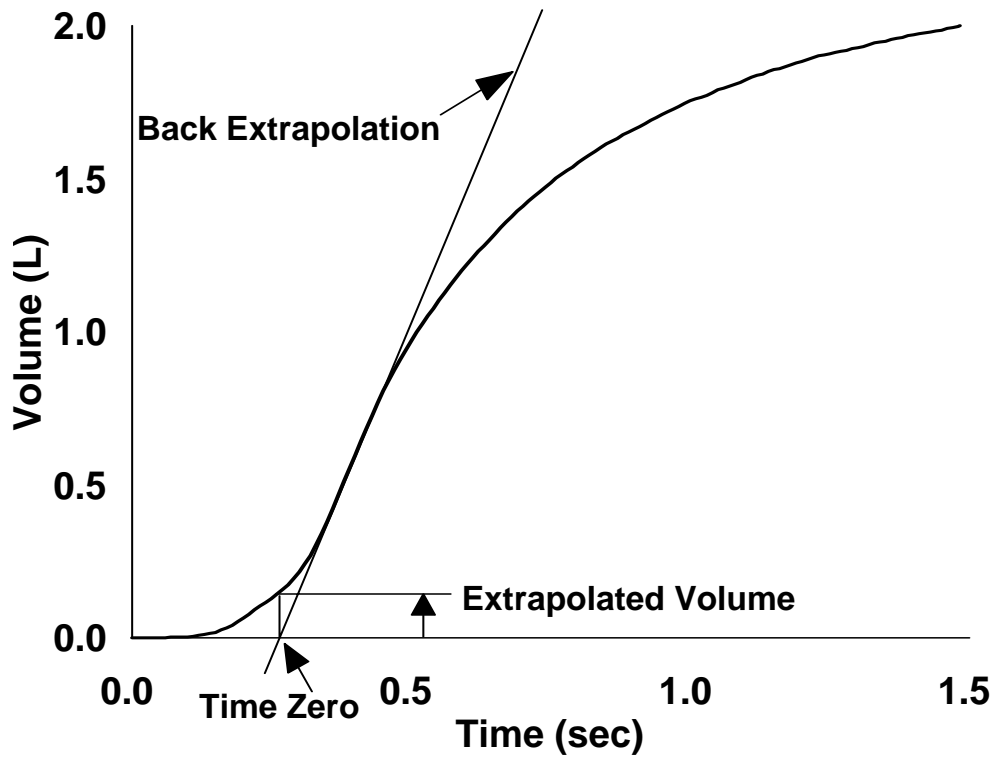
To find if the extrapolated volume is greater than 150 ml (use for FVCs that are 3 liters or less):

1. Take the point at which t=0 was found by the back extrapolation method. (See Figure 5-13.)
2. Draw a vertical line through t=0 up to the FVC curve and read the volume at the intersection. This number is the extrapolated volume. (In Figure 5-13, the extrapolated volume is 0.175 L or 175 ml.)
3. Check to see that the extrapolated volume does not exceed 150 ml. (In Figure 5-13, the extrapolated volume of 175 ml exceeds 150 ml. Therefore this tracing would not be acceptable to use for calculating the FEV<sub>1</sub>.)

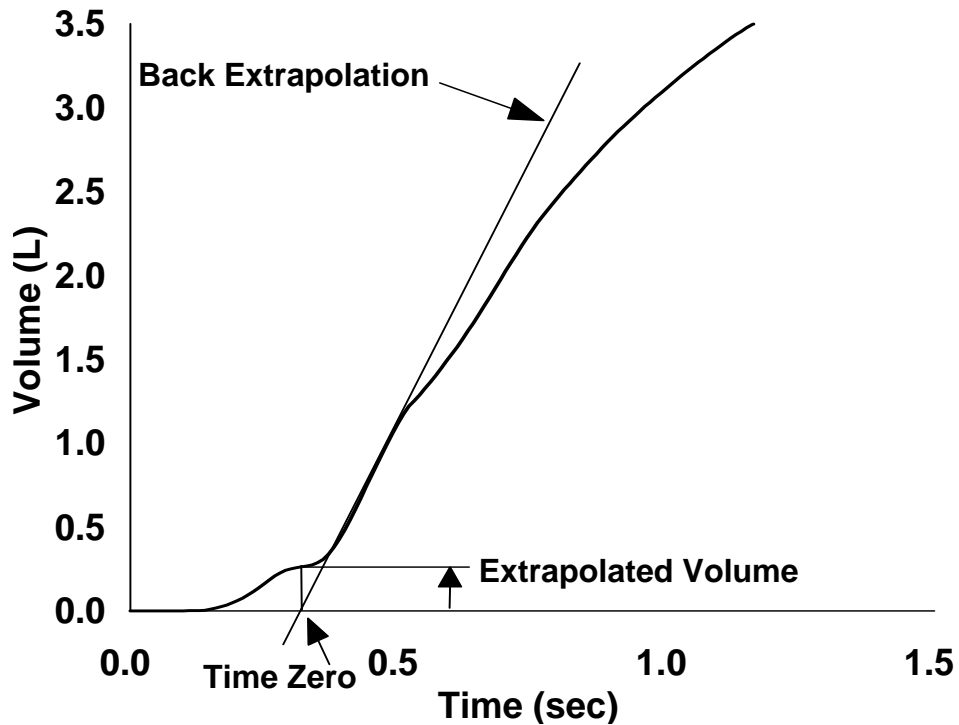
To find if the extrapolated volume is greater than 5% (use for FVCs greater than 3 liters):

1. Follow steps 1 and 2 above. (In Figure 5-14, the extrapolated volume is 0.329 L. or 329 ml.)
2. Divide the extrapolated volume by the FVC. (In Figure 5-14, the FVC is 3.34 L.;  $.329/3.34 = .0985$ .)
3. Multiply the answer by 100 to find the percentage of the difference. (In Figure 5-14,  $0.0985 \times 100 = 9.9\%$ . Clearly there is excessive extrapolated volume and this would not be an acceptable tracing.)
4. (Optional) Another way to determine if the extrapolated volume is greater than 5%, is to multiply the FVC by 0.05 and check that the extrapolated volume in liters does not exceed this amount. (In Figure 5-14, the FVC is 3.34 L.  $0.05 \times 3.34 = 0.167$  liters. Since the extrapolated volume is 0.329 liters, this is not an acceptable tracing.)

**FIGURE 5-11. EXAMPLE OF EXTRAPOLATED VOLUME**



**FIGURE 5-12. EXAMPLE OF EXTRAPOLATED VOLUME**



**FIGURE 5-13. VOLUME TIME CURVE  
MEASURE EXTRAPOLATED VOLUME (VEXT)**

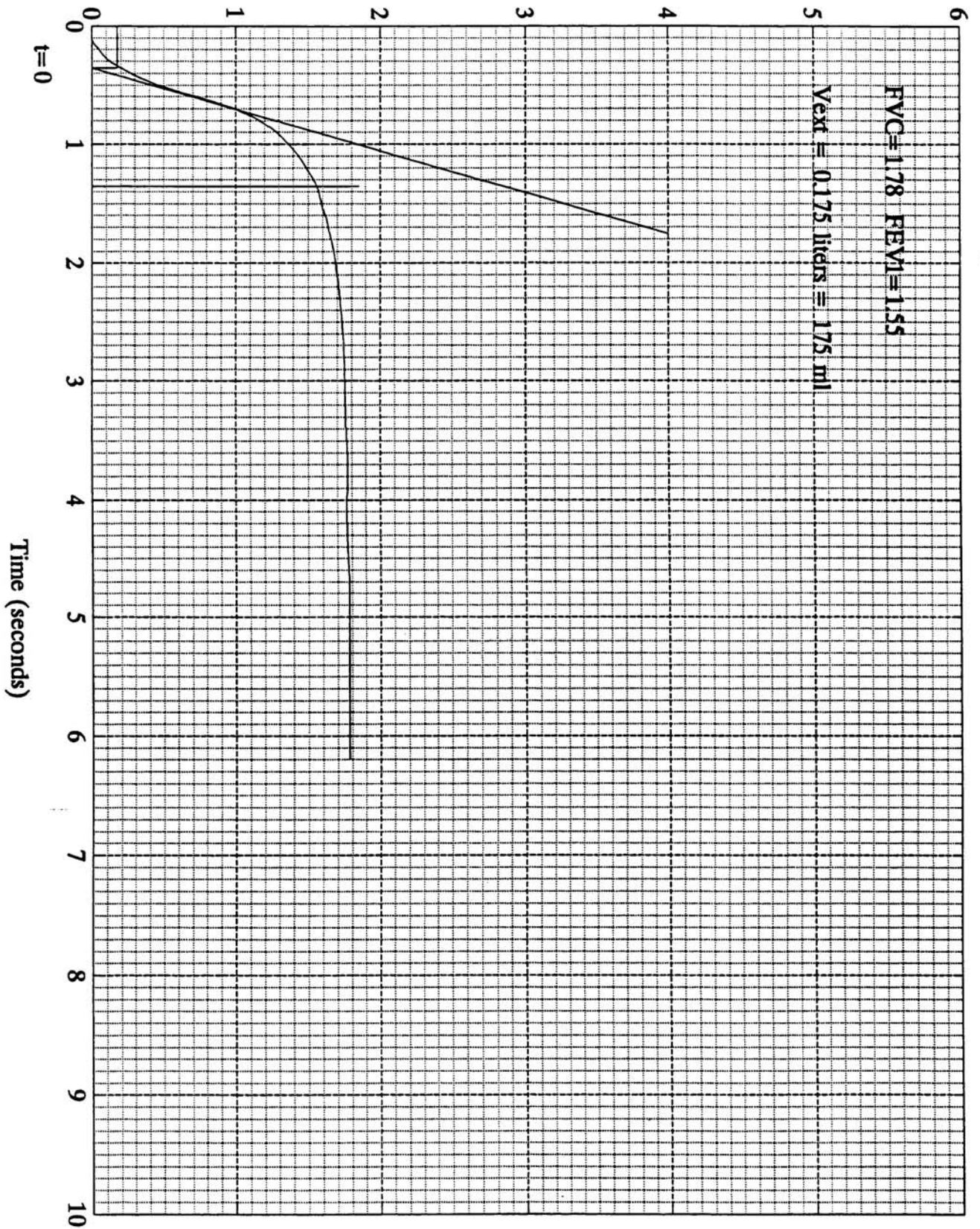
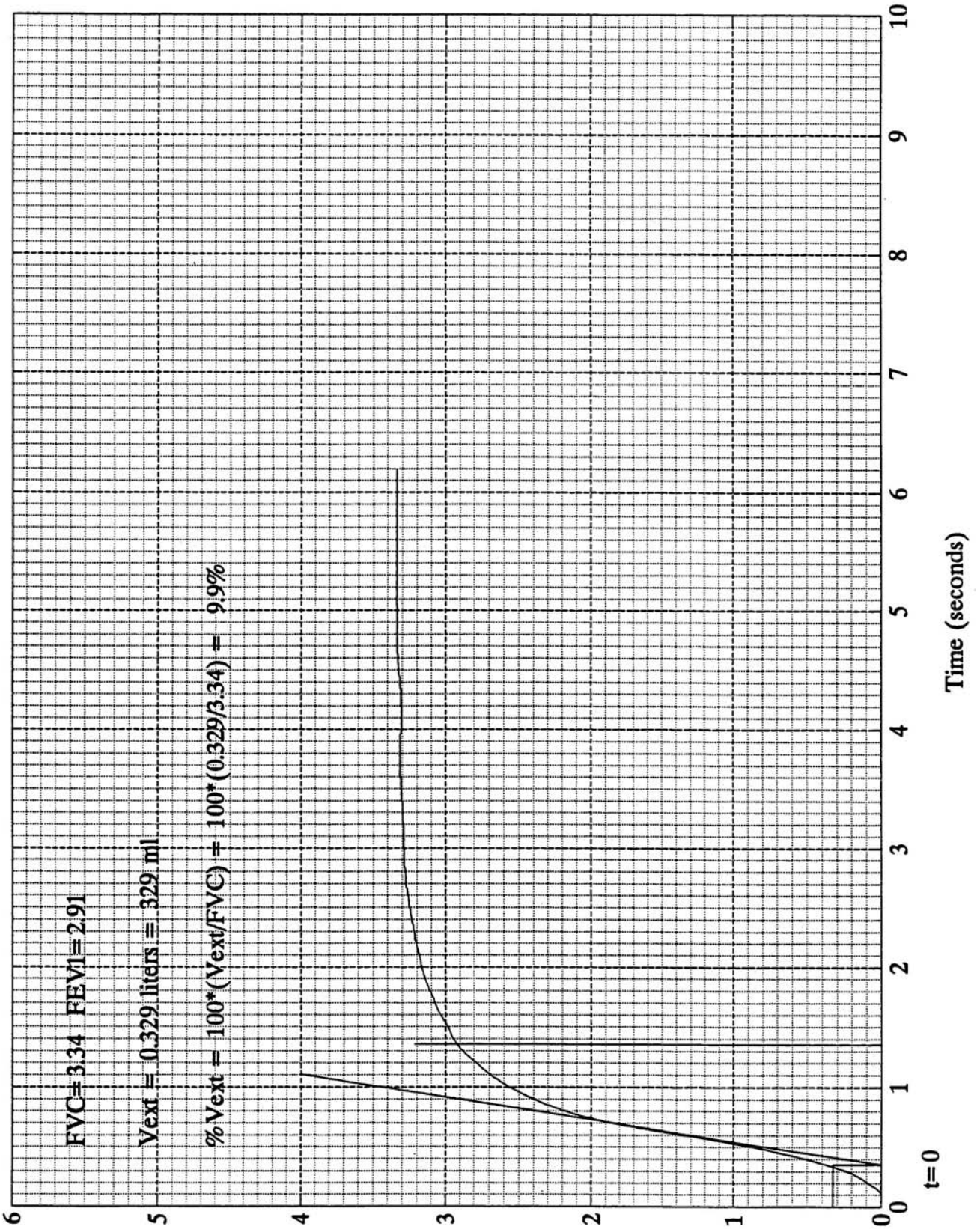


Figure 5-13. Volume Time Curve - Measure Extrapolated Volume (Vext)



**FIGURE 5-14. VOLUME TIME CURVE  
MEASURE EXTRAPOLATED VOLUME (Vext)**

**Figure 5-14. Volume Time Curve - Measure Extrapolated Volume (Vext)**



**EXERCISE:** Using the curve in Figure 5-15 (which is the same as Figure 5-9), determine whether there is excessive extrapolated volume.

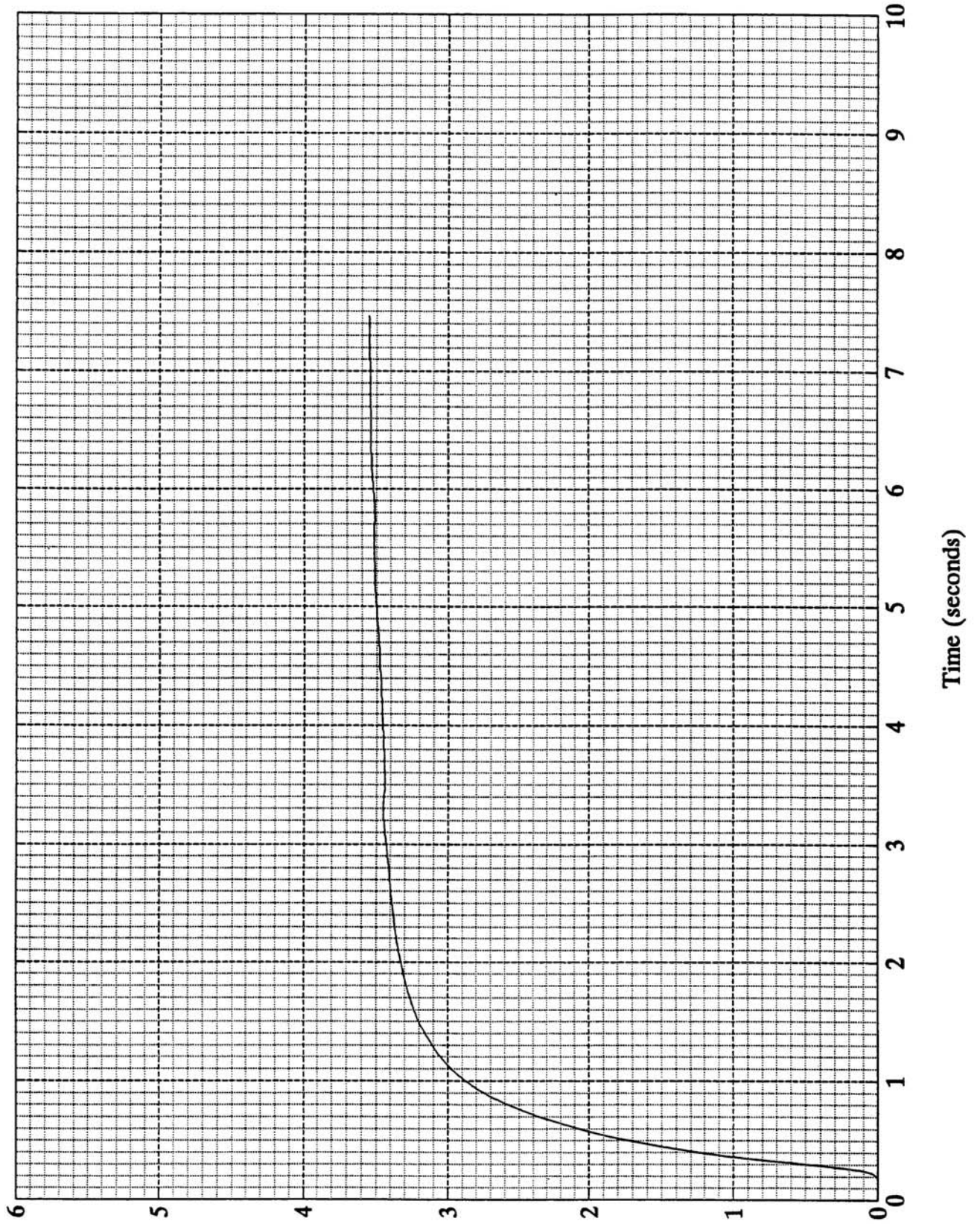
**FEEDBACK:** No excessive extrapolated volume. Extrapolated volume = 0.07 L.

$$\text{FVC} = 3.55 \text{ L.}$$

$$(0.07/3.55) 100 = 2\%$$

FIGURE 5-15. VOLUME TIME CURVE – EXERCISE

Figure 5-15. Volume Time Curve - Exercise



**EXERCISE:** Using the curve in Figure 5-16 (which is the same as Figure 5-10), determine whether there is excessive extrapolated volume.

**FEEDBACK:** Excessive extrapolated volume. Extrapolated volume = 0.13 L.

$$\text{FVC} = 2.25 \text{ L.}$$

$$(0.13/2.25) 100 = 5.7\%$$

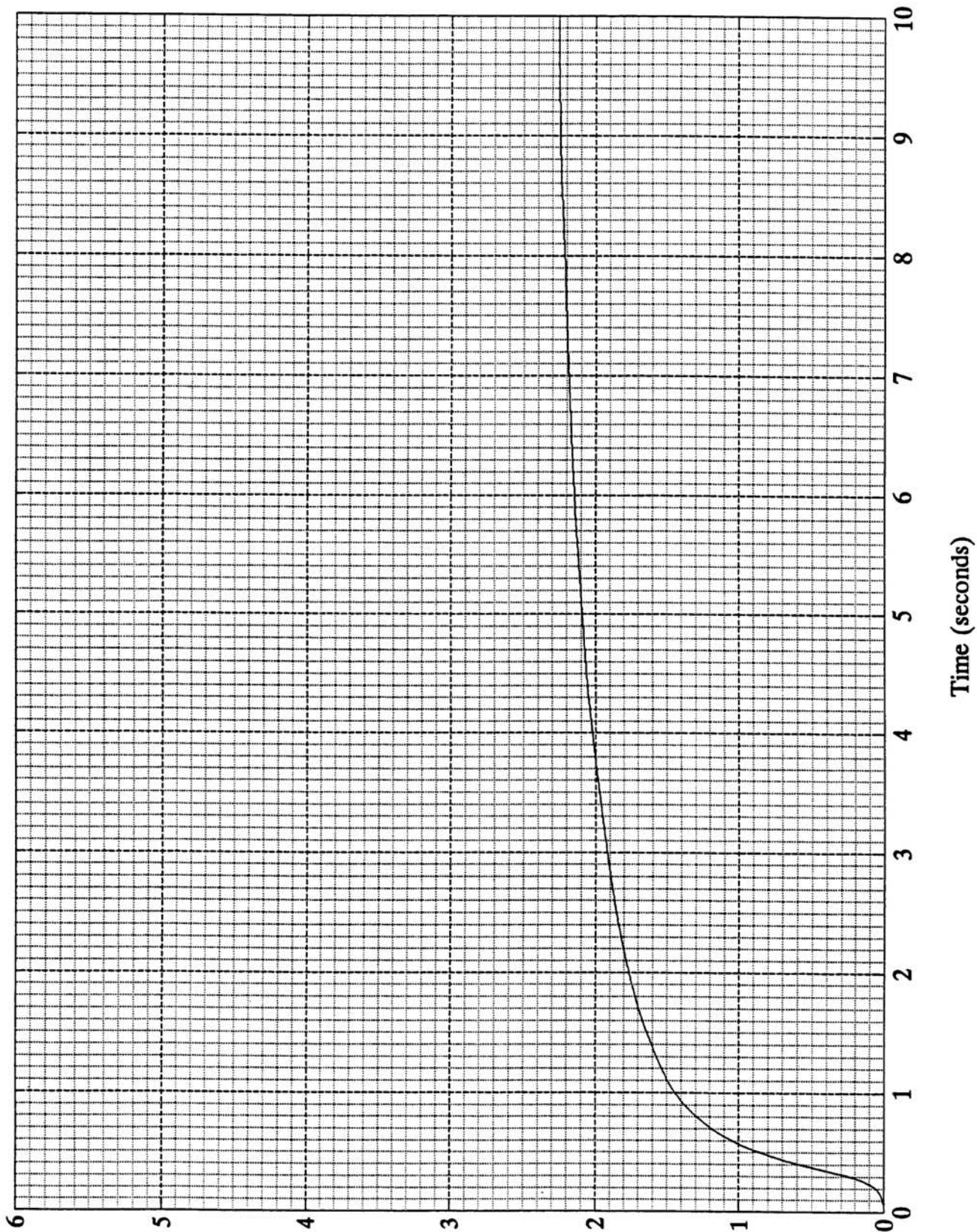
**POINTS TO REMEMBER:**

1. 1 liter = 1000 milliliters (ml)
2. Use 150 ml for FVCs of 3 liters or less. Use 5% for FVCs greater than 3 liters.



FIGURE 5-16. VOLUME TIME CURVE – EXERCISE

Figure 5-16. Volume Time Curve - Exercise



## **G. FEV<sub>1</sub> as a Percentage of FVC (FEV<sub>1</sub>/FVC)**

### **DEFINITION:**

The percent of the total observed FVC that is exhaled in the first second (FEV<sub>1</sub>). This calculation is useful for detecting obstructive disease. A person with healthy lungs can exhale 70-80% of the FVC in the first second, while a person with airways obstruction may be able to exhale 60% or less of the FVC in the first second.

### **HOW TO CALCULATE:**

1. Calculate the largest acceptable FVC and FEV<sub>1</sub>, even if they are not from the same tracing.
2. Divide the FEV<sub>1</sub> by the FVC.
3. Multiply the answer by 100 to obtain the percentage.

**EXAMPLE:** (See Figure 5-17. Volume Time Curve - Calculation of FEV<sub>1</sub>/FVC%):

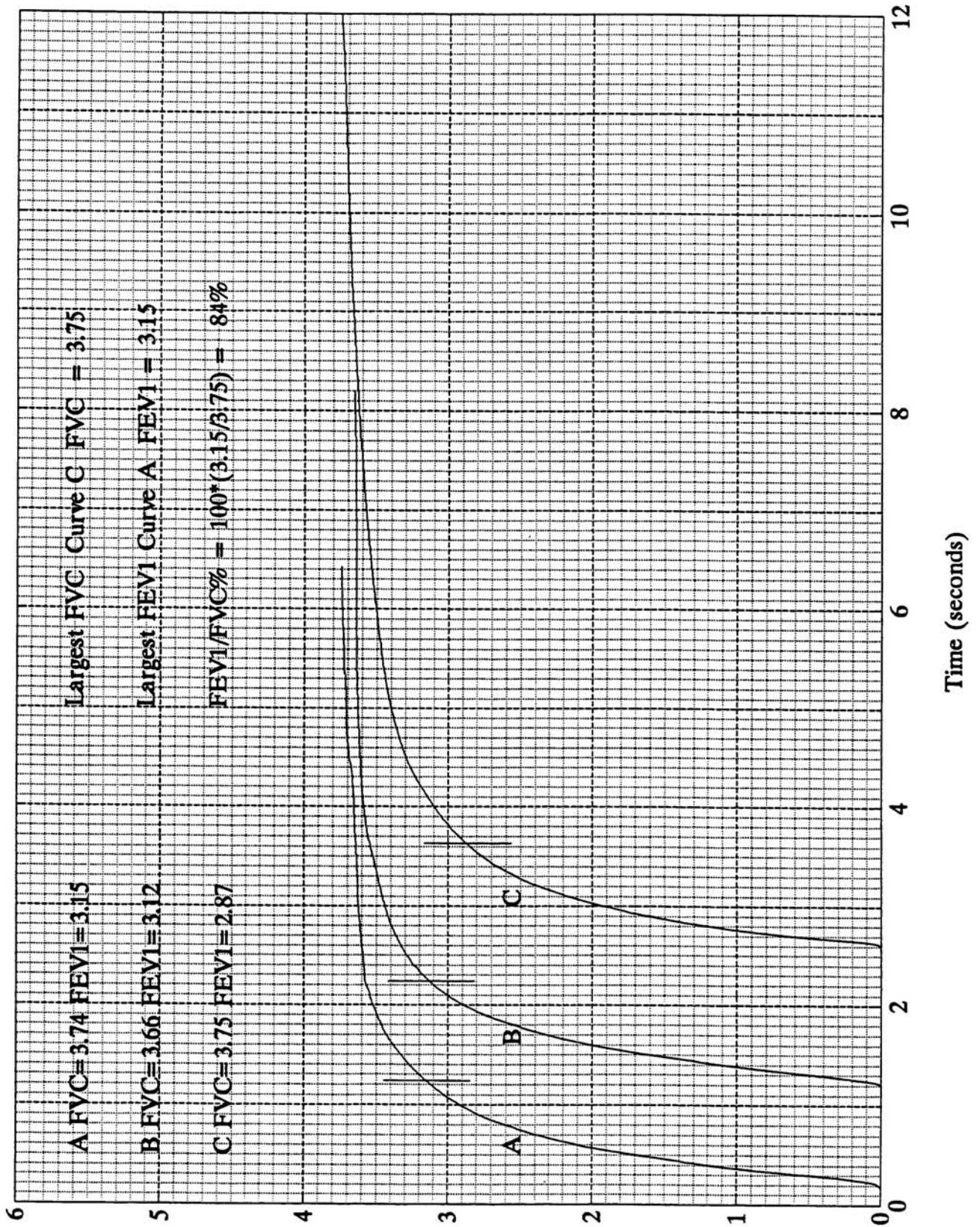
The largest acceptable FVC is 3.75 L. (from Curve C).

The largest acceptable FEV<sub>1</sub> is 3.15 L. (from Curve A).

$$(3.15/3.75) \times 100 = 84\%$$

FIGURE 5-17. VOLUME TIME CURVE - CALCULATION OF FEV<sub>1</sub>/FVC%

Figure 5-17. Volume Time Curve - Calculation of FEV<sub>1</sub>/FVC%



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**EXERCISE:** Using the information in Figure 5-18, calculate the FEV<sub>1</sub>/FVC%. Before doing so, check to be sure that reproducibility criteria are met for the FVC and the FEV<sub>1</sub>.

It should be noted that a larger paper size would have been needed to use a time scale meeting ATS standards. (See **Unit Eight: Overview of Standards for Spirometric Equipment.**) However, larger paper was not possible to use in this guide due to reproduction constraints. These curves were included as a reminder that many individuals, especially those with obstructive patterns, need longer than 10 seconds to complete a forced expiratory maneuver.

**FEEDBACK:** FVC variability = 1.1%

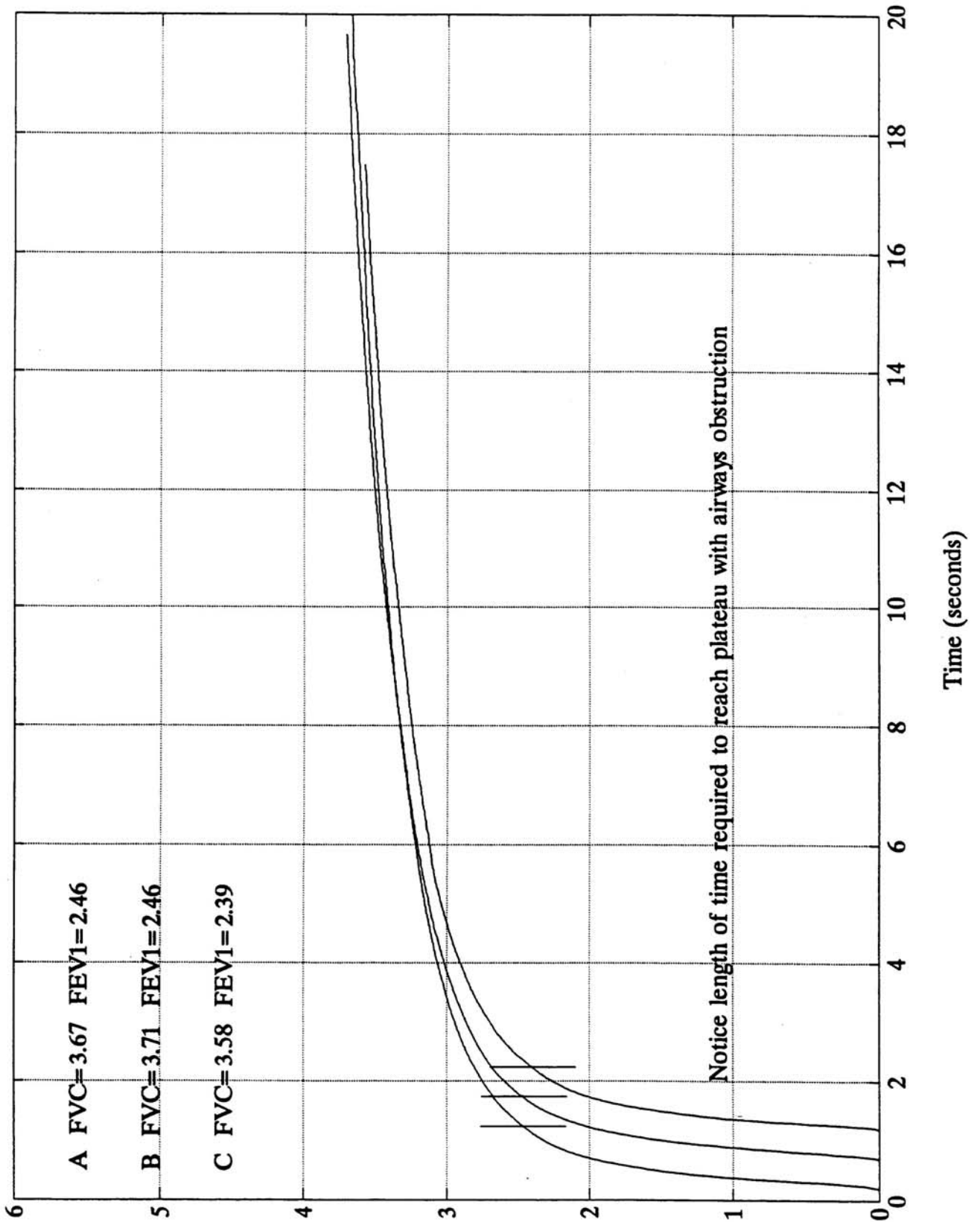
FEV<sub>1</sub> variability = 0

FEV<sub>1</sub>/FVC% = 66.3%



**FIGURE 5-18. VOLUME TIME CURVE - CALCULATION OF FEV<sub>1</sub>/FVC%**

**Figure 5-18. Volume Time Curve - Calculation of FEV<sub>1</sub>/FVC%**



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**EXERCISE:** Three acceptable and reproducible curves yielded the following results:

Curve A:      FVC = 3.65 L.  
                  FEV<sub>1</sub> = 3.01 L.

Curve B:      FVC = 3.52 L.  
                  FEV<sub>1</sub> = 3.01 L.

Curve C:      FVC = 3.53 L.  
                  FEV<sub>1</sub> = 3.07 L.

Calculate the FEV<sub>1</sub>/FVC%

**FEEDBACK:** 84.1%

Did you remember to use the largest FEV<sub>1</sub> and FVC, regardless of which curve?

**POINTS TO REMEMBER:**

1. The percentage is given rounded to one decimal place (e.g., 85.4%).
2. The FEV<sub>1</sub> and the FVC may come from different tracings for this calculation.

## H. Forced Mid -Expiratory Flow (FEF<sub>25-75%</sub>) (OPTIONAL)

### DEFINITION:

The mean forced expiratory flow during the middle half of the FVC (previously known as the mid-expiratory flow rate or MMEF). Although it may be more sensitive than the FEV<sub>1</sub>, it has considerably more variability than the FVC and FEV<sub>1</sub>. Therefore, the ATS (1) recommends that the FEF<sub>25-75%</sub> only be considered after determining the presence and clinical severity of impairment and should not be used to diagnose disease in individual patients.

### HOW TO CALCULATE AND EXAMPLE:

1. Using an acceptable tracing, identify the "best curve", the one with the largest sum of the FEV<sub>1</sub> and the FVC. In most cases, the best curve will have the largest FVC. To do this, for each curve, add together the FEV<sub>1</sub> and the FVC. (See Figure 5-19. In this case, the best curve is curve A.)
2. Using the best curve, calculate 25% and 75% of the FVC curve.  
25% of FVC = 0.25 x FVC  
75% of FVC = 0.75 x FVC  
Note: The FVC is given in liters, therefore the answers will also be in liters.  
(For curve A, 25% of the FVC is 0.94 L. and 75% is 2.81 L.)
3. Mark the answers on the FVC curve. (See Figure 5-20.)
4. Having found the two points which represent 25% and 75% of FVC, draw a straight line through them. (See the line drawn through these points for Figure 5-20.)
5. This line should intersect some of the time bars on the graph paper. To do the next calculation, use any two adjacent time bars that are one second apart and intersect the line that you have drawn. Read off the volumes for each of these time bars at the point where they intersect the line. (See Figure 5-20, Point A (1.70) and Point B (5.05). Other points could have been selected on the line, as long as they were 1 second apart.)
6. Find the difference between these two volumes. Subtract the volume at the 1st time bar intersection from the volume at the 2nd time bar intersection to get the difference.) (See Figure 5-20.  $5.05 - 1.70 = 3.35$  L.)
7. Convert the answer to BTPS. For instructions, see the next section.
8. The answer is given in liters per second. This is because you have calculated a change in volume over a one second interval.

**FIGURE 5-19. VOLUME TIME CURVE - FEF<sub>25-75%</sub> BEST CURVE**

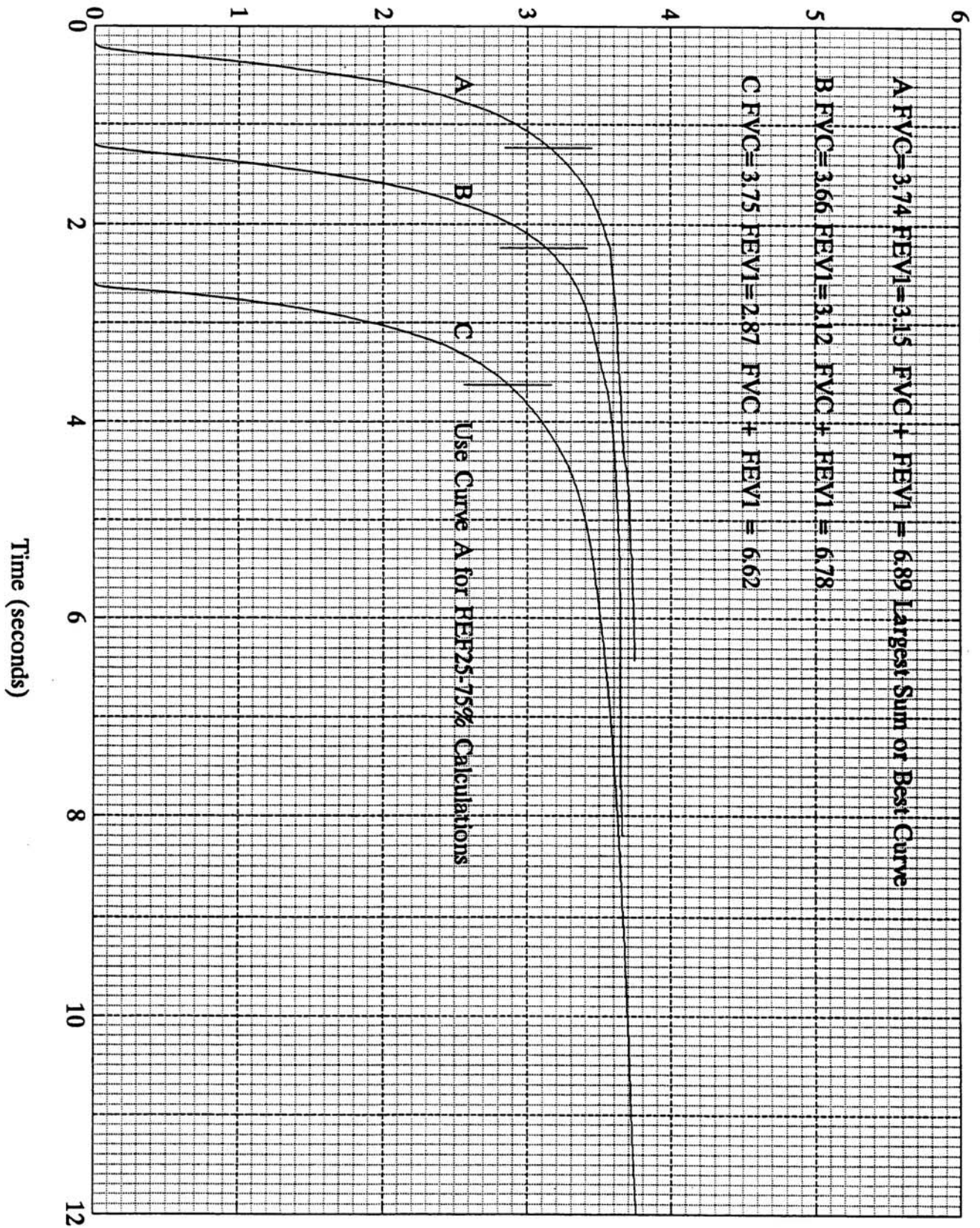
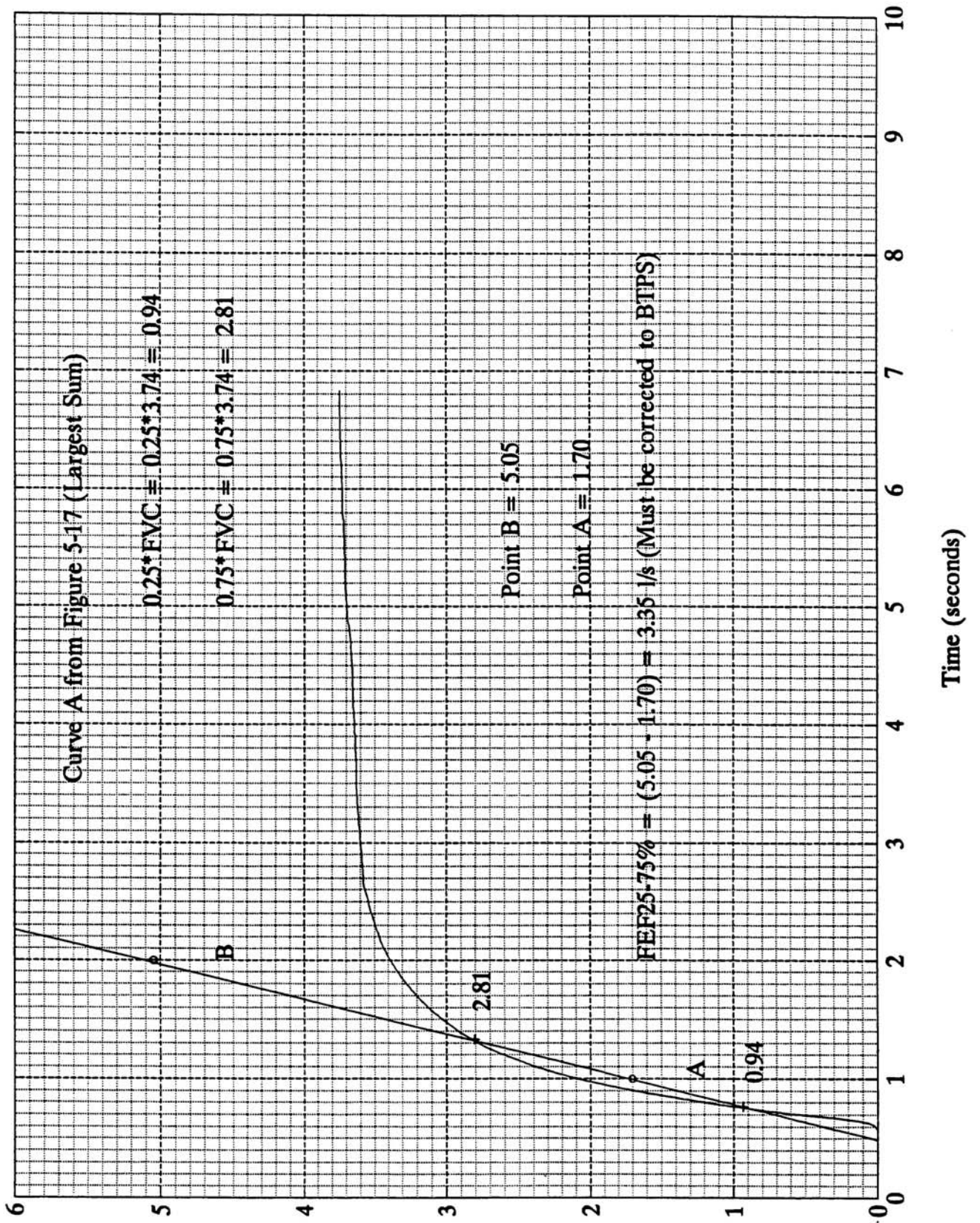


Figure 5-19. Volume Time Curve - FEF<sub>25-75%</sub> Best Curve

FIGURE 5-20. VOLUME TIME CURVE - FEF<sub>25-75%</sub>

Figure 5-20. Volume Time Curve - FEF<sub>25-75%</sub>



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**EXERCISE:** Using the curves in Figure 5-21, identify the best curve (the best curve is defined as that which has the largest sum of FEV<sub>1</sub> and FVC).

**FEEDBACK:**

Curve B is the best curve.

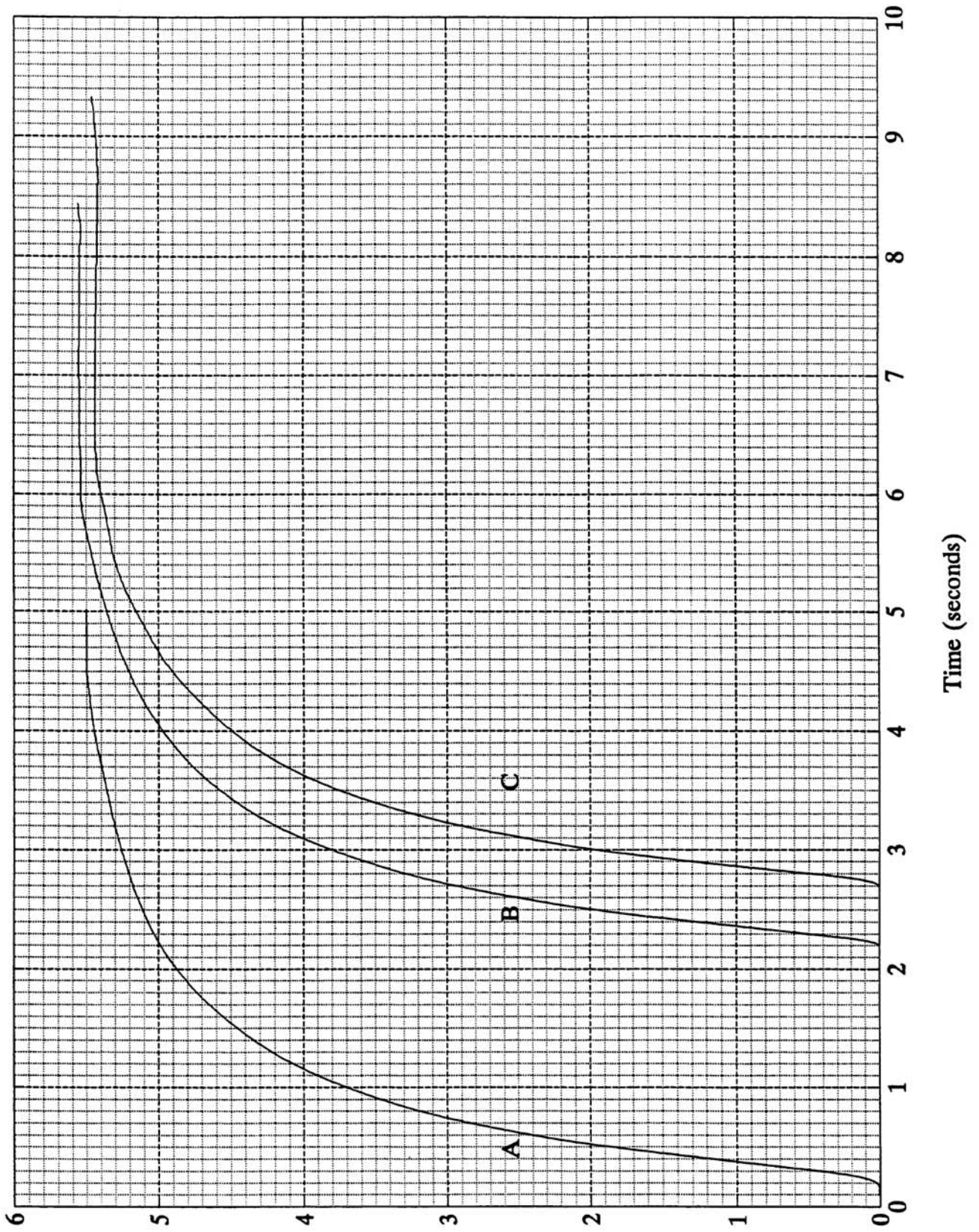
FEV<sub>1</sub> = 4.22 L    FVC = 5.55 L

Total of FEV<sub>1</sub> + FVC = 4.22 L + 5.55 L = 9.77 L



FIGURE 5-21. VOLUME TIME CURVE - FEF<sub>25-75%</sub>

Figure 5-21. Volume Time Curve - Exercise FEF<sub>25-75%</sub>



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**EXERCISE:** Using the curve in Figure 5-22, calculate the  $FEF_{25-75\%}$ .

**FEEDBACK:** The  $FEF_{25-75\%} = 3.75$  L/sec.

25% of the FVC (5.55 L) = 1.39 L

75% of the FVC (5.55 L) = 4.16 L

Draw a straight line at any 2 adjacent time lines and read the volumes at the intersection of the slope and 2 adjacent time lines (5.60 L and 1.85 L). Calculate the difference between these 2 numbers (5.65 L - 1.85 L = 3.75 L/sec.)

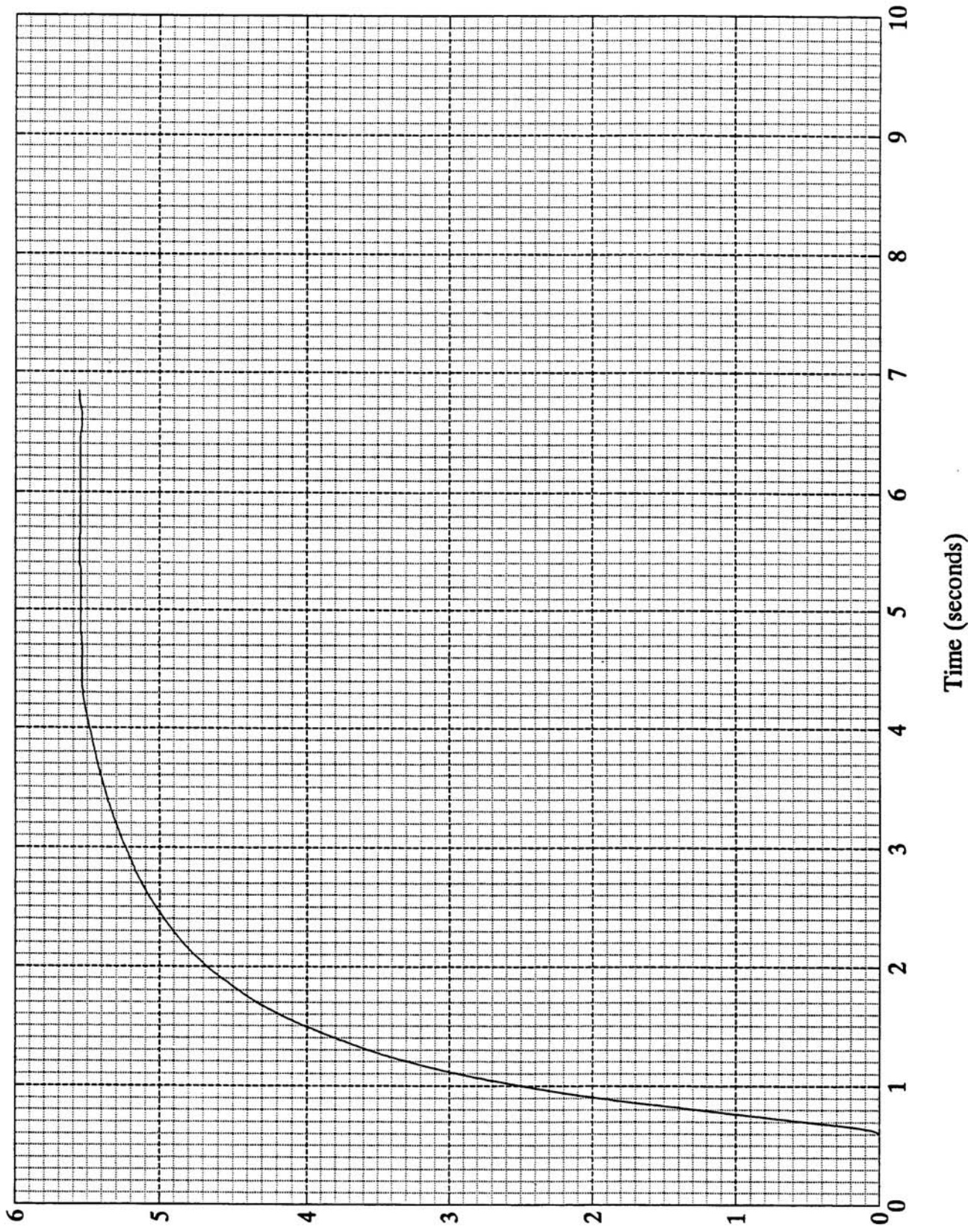
**POINTS TO REMEMBER:**

A number of problems have precluded widespread use of the  $FEF_{25-75\%}$  in industrial screening programs. Although less dependent on voluntary effort than  $FEV_1$ , the  $FEF_{25-75\%}$  is also less reproducible. The amount of variability in the same person may be as great as 20%, compared with 3% for the  $FEV_1$ . Isolated abnormalities in the  $FEF_{25-75\%}$  are relatively common, particularly in asymptomatic asthmatics and young cigarette smokers. Hence, there is a danger that an abnormal  $FEF_{25-75\%}$  may become reason for employment rejection or job transfer in such individuals. Although clearly not justifiable, such misapplication of screening data occurs all too frequently in the occupational setting (6). To prevent this from happening, the  $FEF_{25-75\%}$  should only be interpreted by a physician experienced in its use.



FIGURE 5-22. VOLUME TIME CURVE - FEF<sub>25-75%</sub>

Figure 5-22. Volume Time Curve - Exercise FEF<sub>25-75%</sub>



## I. Conversion to BTPS

### DEFINITION:

Gas (air) at:

- ...Body Temperature (37°C)
- ...Ambient Pressure (surrounding air pressure)
- ...Saturated with water vapor (relative humidity = 100% as is the case in the lungs).

Air is at body temperature in the lungs and is saturated with water vapor. The ambient temperature is usually much cooler and dryer, thus exhaled air contracts as it leaves the lungs and enters a spirometer. The volume of air as recorded by most spirometers is usually 6-10% less than the actual volume of air exhaled by the test subject. The BTPS correction adjusts the measured result obtained in the spirometer to what the volume originally was in the lungs. In most volume spirometers, recorded volumes that have not been converted are indicated as **ATPS** (ambient temperature and pressure saturated with water vapor).

### Spirometric Tests Requiring Conversion to BTPS:

1. FVC, FEV<sub>1</sub>, and FEF<sub>25-75%</sub> all represent volumes (or volumes per unit of time). Therefore these tests must be converted to BTPS.
2. FEV<sub>1</sub>/FVC (%) is a ratio of volumes. It does not have to be converted to BTPS since the same conversion factor would appear in both the numerator and the denominator and therefore it would cancel out.

### HOW TO CALCULATE:

1. Convert the ambient, room air, or spirometer temperature to Centigrade if needed.

$$^{\circ}\text{C} = \frac{5}{9} (^{\circ}\text{F} - 32)$$

2. Locate the ambient, room, or spirometer temperature on the **BTPS Conversion Chart**.
3. Look across the table to find the corresponding conversion factor.
4. Multiply the volume of gas recorded by the spirometer (FVC, FEV<sub>1</sub>, or FEF<sub>25-75%</sub>) by the correct conversion factor to obtain the volume at BTPS.

## BTPS CONVERSION CHART

### FACTORS FOR CONVERTING VOLUMES FROM AMBIENT OR SPIROMETER TEMPERATURE TO BTPS

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Gas Temperature		Conversion
°F	°C	Factor
64	18	1.114
<b>66</b>	<b>19</b>	<b>1.111</b>
68	20	1.102
<b>70</b>	<b>21</b>	<b>1.096</b>
72	22	1.091
<b>73</b>	<b>23</b>	<b>1.085</b>
75	24	1.080
<b>77</b>	<b>25</b>	<b>1.075</b>
79	26	1.068
<b>81</b>	<b>27</b>	<b>1.063</b>
82	28	1.057
<b>84</b>	<b>29</b>	<b>1.051</b>
86	30	1.045
<b>88</b>	<b>31</b>	<b>1.039</b>
90	32	1.032
<b>91</b>	<b>33</b>	<b>1.026</b>
93	34	1.020
<b>95</b>	<b>35</b>	<b>1.014</b>
97	36	1.007
<b>99</b>	<b>37</b>	<b>1.000</b>

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**EXAMPLE:** A subject's FVC as recorded by the spirometer reads 5 liters (volume of gas) at an ambient temperature of 21°C (ATPS).

The conversion factor that corresponds to 21°C is 1.096.

5 liters x 1.096 = 5.48 liters BTPS.

Therefore, the recorded FVC of 5 liters at 21° C (ATPS), actually represents a volume of 5.48 liters (BTPS) in the subject's lungs at body temperature.

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**EXERCISES:** Convert the following data for several individuals from ATPS to BTPS:

FVC = 6.71 L. (ambient temperature = 75°F)

FEV<sub>1</sub> = 5.02 L. (ambient temperature = 26°C)

FEF<sub>25-75%</sub> = 4.01 L/s (ambient temperature = 82°F)

**FEEDBACK:** FVC = 7.25 L. BTPS

FEV<sub>1</sub> = 5.36 L. BTPS

FEF<sub>25-75%</sub> = 4.24 L/s BTPS

**POINTS TO REMEMBER:**

1. Temperature: ATS makes the following recommendations:
  - a. Ambient temperature should be accurately recorded to within 1°C.
  - b. Spirometric testing should only be done with ambient temperatures between 17°-40°C.

- c. Recent studies have shown that at ambient temperatures lower than 23°C, the BTPS correction factor may cause errors in FEV<sub>1</sub> readings when using volume spirometers. BTPS factors are based on the assumption that the subject's exhaled breath cools immediately upon entering the spirometer. However, it has been found that expired breath takes longer than previously thought to reach equilibrium with the ambient temperature. Therefore, the BTPS correction factor falsely raises the FEV<sub>1</sub> and peak flow, and as the ambient temperature drops, the rate of error increases. For example, Hankinson and Viola found an error range from 7.7% at 3°C to 2.1% at 23°C for FEV<sub>1</sub> and 14.1% at 3°C to 4.6% at 23°C for peak flow (27). FVC readings typically are not affected because the exhaled breath usually reaches equilibrium by the time the forced expiratory maneuver is completed.

The BTPS error caused by low ambient temperature is of concern during longitudinal and pre- and post-shift studies. If testing is done at different temperatures, statistically significant changes in the FEV<sub>1</sub> and peak flow could be caused by ambient temperature alone.

*"For example, during a recent study at a cotton-processing facility, the temperature was 10 °C during the pre-shift examinations. After 6 h of exposure, the spirometric examinations were repeated on the same subjects. However, the ambient temperature after the work shift was approximately 25 or 15 °C higher.*

*Upon analysis of these data, an average decrease in FEV<sub>1</sub> of approximately 4% over the work shift was observed. Not only was a decrease observed for the exposed workers but also for the technicians who were conducting the examinations. This decrease was thought to be explained by the increase in ambient temperature over the work shift. With low temperatures, the BTPS correction factor was falsely elevated, resulting in falsely elevated FEV<sub>1</sub>s. After the work shift, the FEV<sub>1</sub>s were less in error because of a higher temperature, and therefore statistically significant drops over the work shift were observed. The cotton dust standard defines a worker as a possible "reactor" if he has a 5% or greater drop in FEV<sub>1</sub> over the work shift" (28).*

Until the BTPS correction factor is modified and new correction tables are developed, the simplest solution to this problem is to keep the ambient temperature constant with a range of no more than 3°C (23). Or keep the ambient temperature at 23°C, ± 1.5°C (28).

Since ambient temperature is difficult to control in field studies, the problem should be brought to the attention of the medical surveillance physician so that it can be considered during the interpretation of results. It is also best if the temperature sensor is located inside the spirometer and ambient (spirometer) temperature is recorded at each testing session.

2. Other Factors to Consider: Three other factors may need consideration when calculating BTPS: ambient pressure, instrument or bell factor, and the use of graph paper in BTPS units. See **Appendix K. Other Factors to Consider When Calculating BTPS** for further information.