

# Waveform Analysis for the MIT Emergency Ventilator

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## 1 Introduction

In this analysis report, waveforms for a set of test settings are obtained via both a model-based approach where the breathing circuit, the lung and the flow profiles are modeled; and via a data-driven approach where response data is collected using an ASL 5000 breathing simulator connected to the ventilator.

### 1.1 ISO 80601-2-79:2018

The test settings used are inspired by ISO 80601-2-79:2018 (<https://www.iso.org/standard/68843.html>). The following table shows the test settings used throughout the report where the first 8 rows are directly from ISO 80601-2-79:2018.

Of particular interest is understanding:

- the shape of the pressure signal
- the flow signal and its peak values
- the delivered tidal volume signal
- the settings for which the pressure exceeds 40 cm H<sub>2</sub>O

Additional general requirements from ISO 80601-2-79:2018 are: for volume-controlled breath types, during the testing, the error of:

- i. the delivered volume of individual breaths shall not deviate by more than 35 %.
- ii. the delivered volume averaged over a one-minute interval shall not deviate by more than 25 %.

We use cm H<sub>2</sub>O for pressure instead of hPa in generating the data and for test settings where 1cm H<sub>2</sub>O is within 2% accuracy of 1 hPa (1cm H<sub>2</sub>O = 0.980665 hPa).

Test Num.	Test Lung Parameters		Ventilatory Support Equipment Settings			
	Compliance (ml/hPa) ±10%	Linear Resistance (hPa/(L/s)) ±10%	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (hPa)
1	50	5	500	20	1	5
2	50	20	500	12	1	10
3	20	5	500	20	1	5
4	20	20	500	20	1	10
5	20	20	300	20	1	5
6	20	50	300	12	1	10
7	10	50	300	20	1	10
8	10	20	200	20	1	5
9	10	20	200	25	1	5
10	10	20	200	30	1	5

## 1.2 Flow Profiles

In the report, data due to a constant flow profile and due to a triangular profile are discussed.

### 1.2.1 Constant flow

In volume control ventilation, a common approach is to supply volume at a constant flow during the inspiratory time. This requires a short rise time and short fall time to approximate a square wave as closely as possible. The peak inspiratory pressure (PIP) for a constant flow profile is expected at the end of the inhale duration when maximum pressure due to compliance is added to the constant pressure due to the constant flow flowing through the airway resistance. Ideally, a perfect constant flow achieves a minimum peak flow needed to deliver a specified tidal volume.

### 1.2.2 Triangular flow

A triangular flow covering the same area (delivered tidal volume) as a constant flow would require a peak flow that is twice that from a constant flow profile.

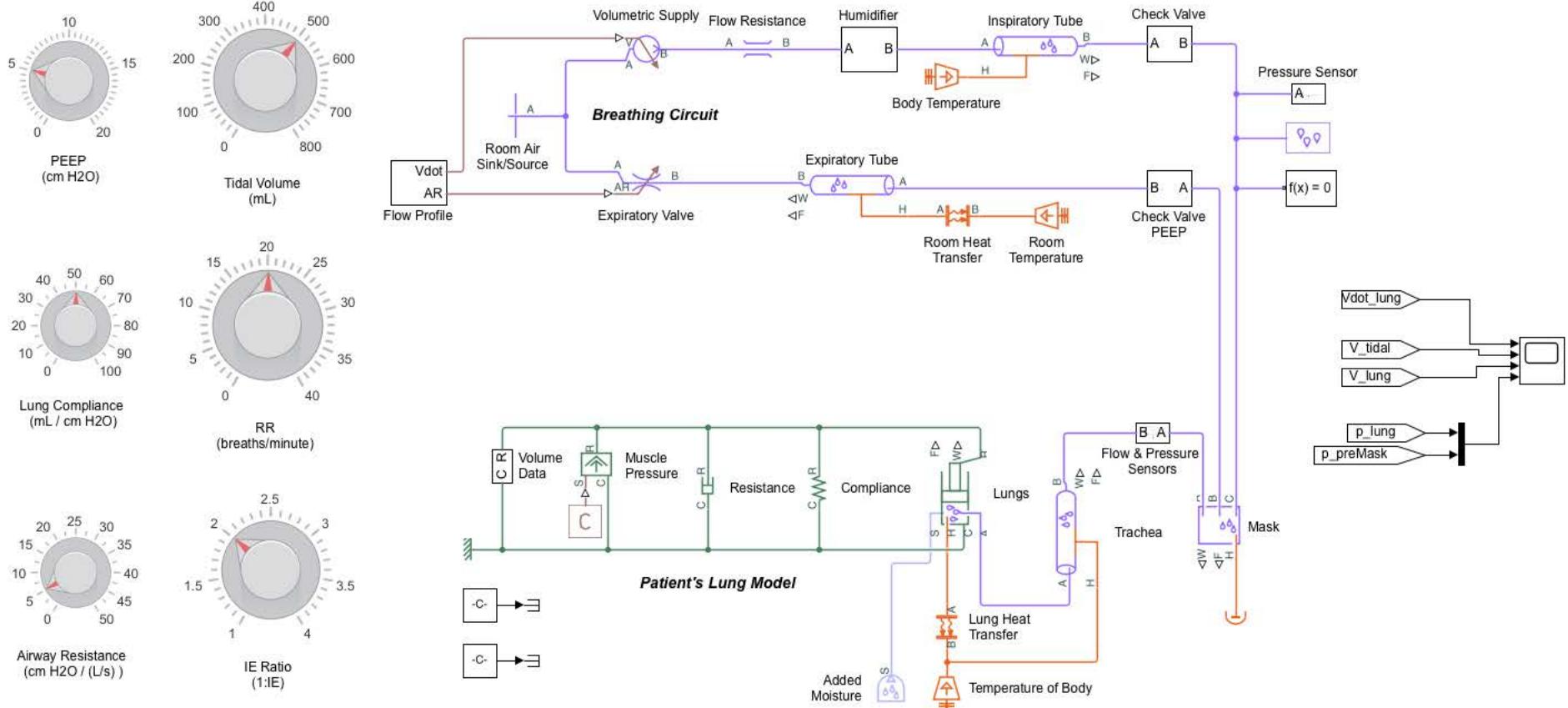
In cases where a short rise and fall times cannot be achieved, a triangular flow is possible.

## 2 Model-Based Waveforms for MIT Emergency Ventilator

In this section, a model is used to simulate the behavior. According to these model-based simulations, Tests #4 and #7 exceed 40 cm H<sub>2</sub>O when a constant flow is used, while Tests #4, #6, and #7 exceed 40 cm H<sub>2</sub>O when a triangular flow profile is used. Moreover, and for the constant flow case, some preliminary calculations are also provided to characterize the model-based responses observed.

## 2.1 Ventilator Modeling in Simulink

The following Simulink model is utilized to generate the expected waveforms for the flow profile of interest. For more about such models, see MathWorks demo: <https://www.mathworks.com/help/physmod/simscape/examples/medical-ventilator-with-lung-model.html>

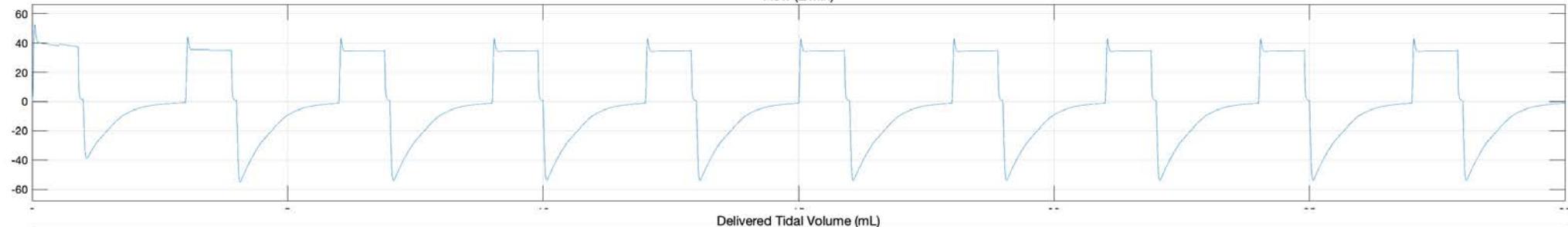


## 2.2 Model-Based Responses

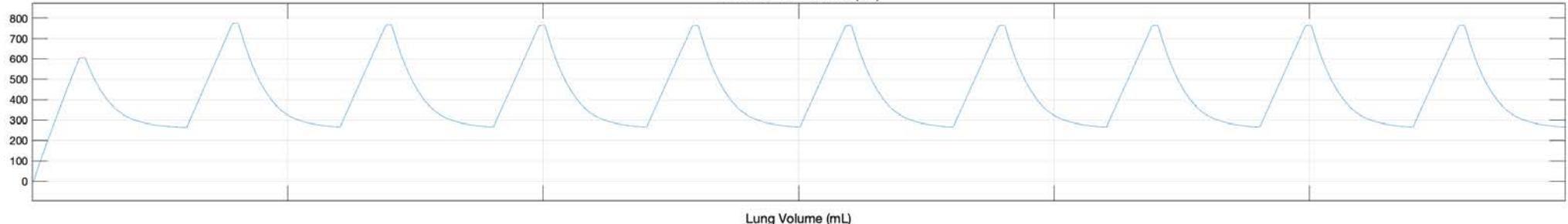
Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
1	50	5	500	20	1 I/E = 1:2	5

### Constant Flow Profile

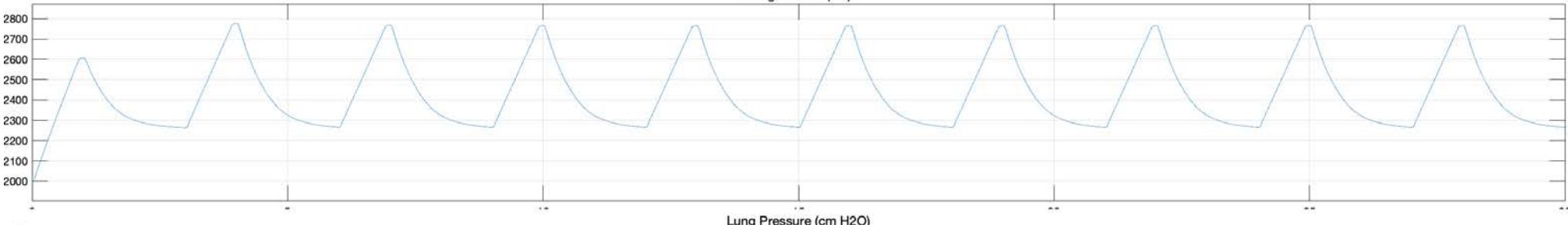
Flow (L/min)



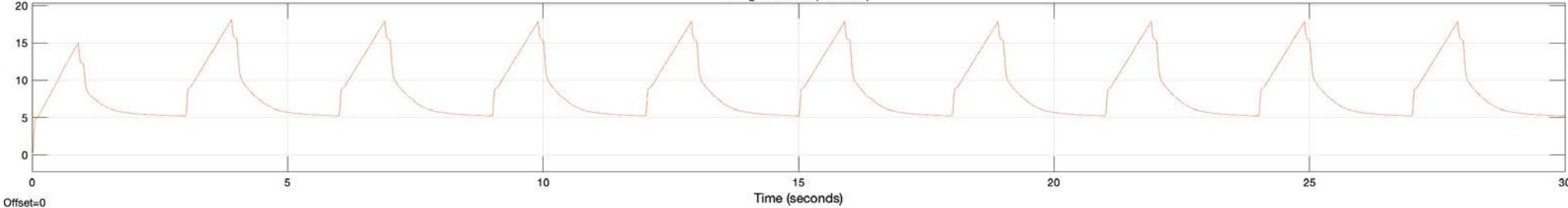
Delivered Tidal Volume (mL)



Lung Volume (mL)



Lung Pressure (cm H<sub>2</sub>O)



Time (seconds)

Offset=0

PIP[1]

$$= \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = (0.5 / 0.90) * 5 + 605 / 50 = 2.78 + 12.1 = 14.88 \text{ cm H}_2\text{O}$$

PIP[2]

$$= \text{PEEP} + \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = 5 + (0.5 / 0.90) * 5 + (776 - 265) / 50 = 5 + 2.78 + 10.22 = 18.00 \text{ cm H}_2\text{O}$$

Delivered V<sub>T</sub>

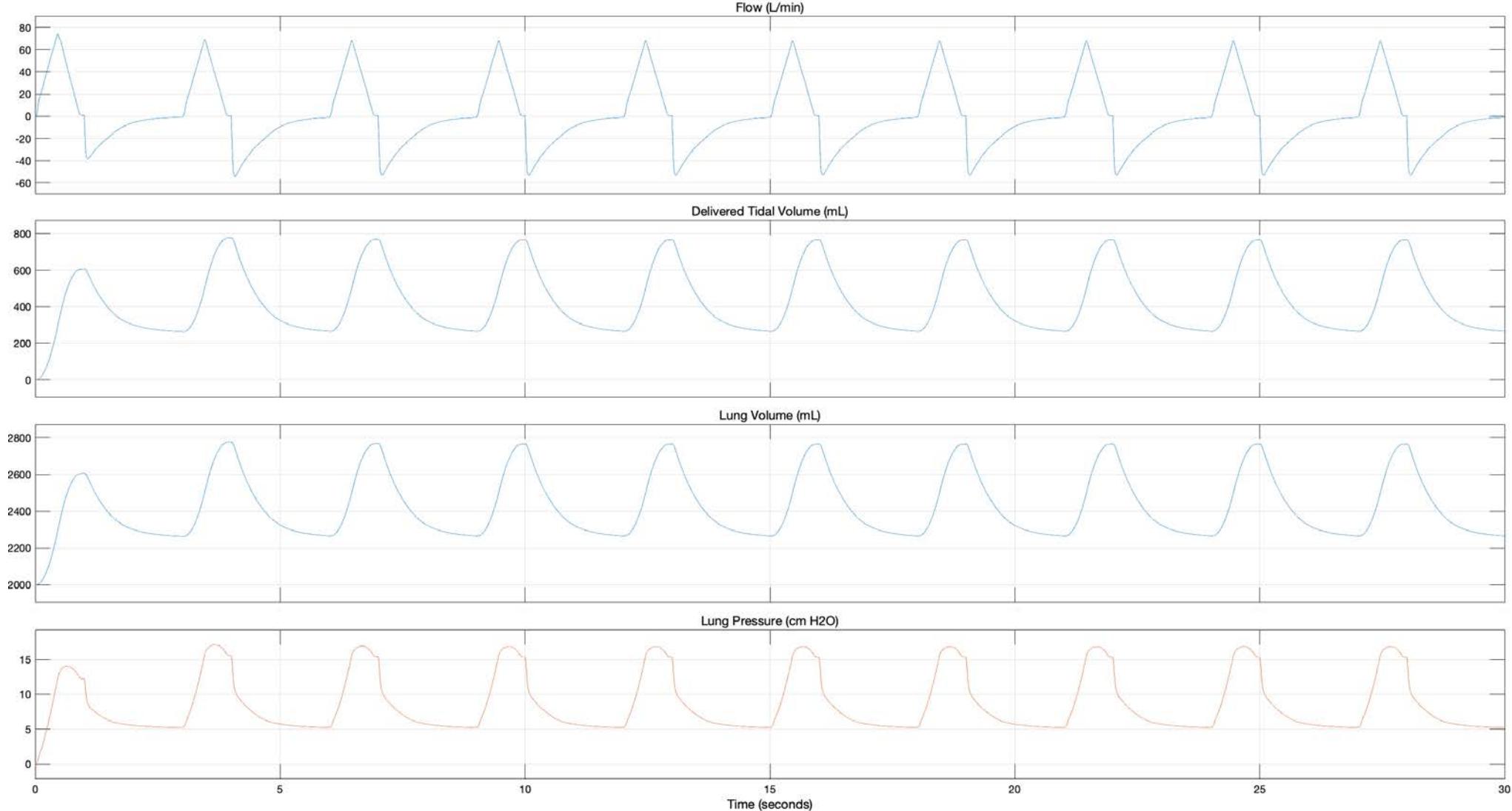
$$= V_T - (\text{PIP} - \text{PEEP}) * \text{compressible volume ratio} = 500 - (18 - 5) * 0.0 = 500 \text{ mL}$$

End-expiratory lung volume

$$= \text{FRC} + \text{PEEP} * \text{Compliance} = 2000 \text{ mL} + 250 \text{ mL} = 2250 \text{ mL}$$

Note that T<sub>inhale</sub> = 0.9s, T<sub>Hold</sub>=0.1s and T<sub>inhale</sub> + T<sub>Hold</sub> = 1s. Flow = V<sub>T</sub>/T<sub>inhale</sub>.

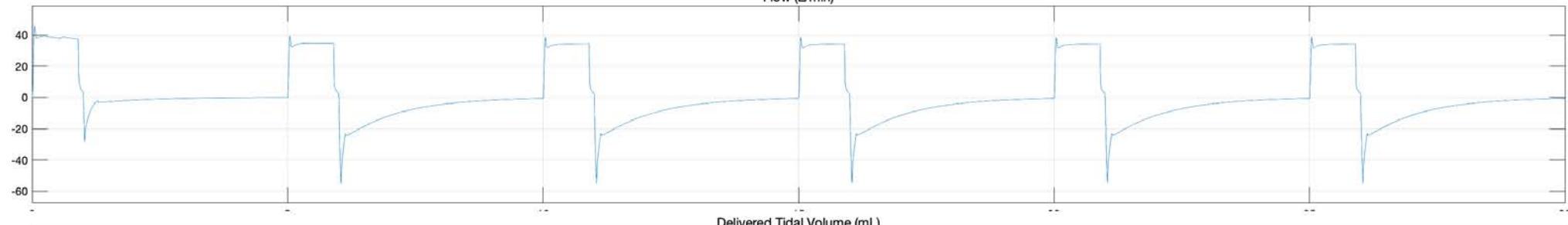
### Triangular Flow Profile (Accelerating-Decelerating)



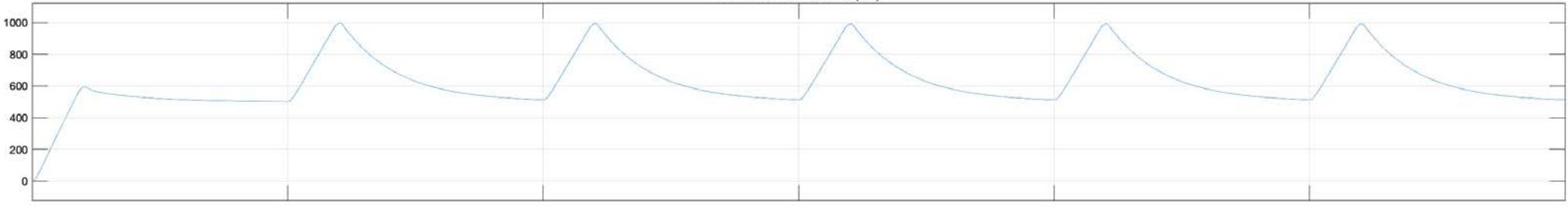
Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
2	50	20	500	12	1 I/E = 1:4	10

### Constant Flow Profile

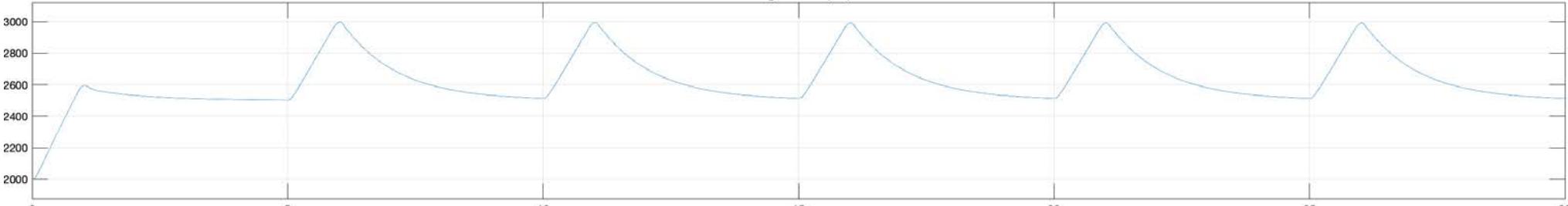
Flow (L/min)



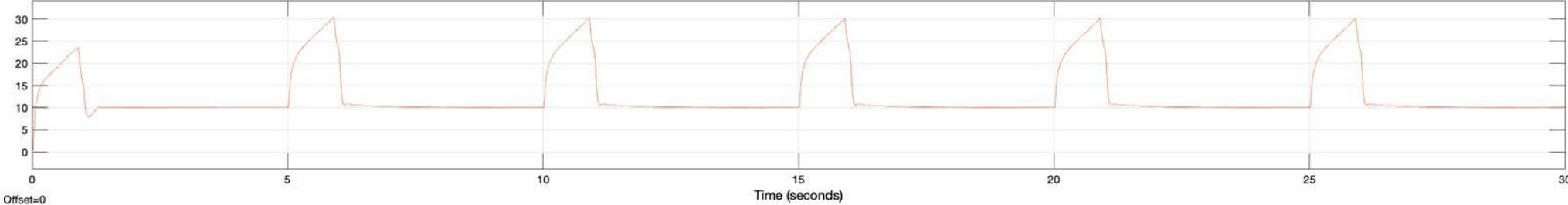
Delivered Tidal Volume (mL)



Lung Volume (mL)



Lung Pressure (cm H<sub>2</sub>O)



Time (seconds)

Offset=0

PIP[1]

$$= \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = (0.5 / 0.90) * 20 + 595 / 50 = 11.11 + 11.90 = 23.01 \text{ cm H}_2\text{O}$$

PIP[2]

$$= \text{PEEP} + \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = 10 + (0.5 / 0.90) * 20 + (1000 - 500) / 50 = 10 + 11.11 + 10 = 31.11 \text{ cm H}_2\text{O}$$

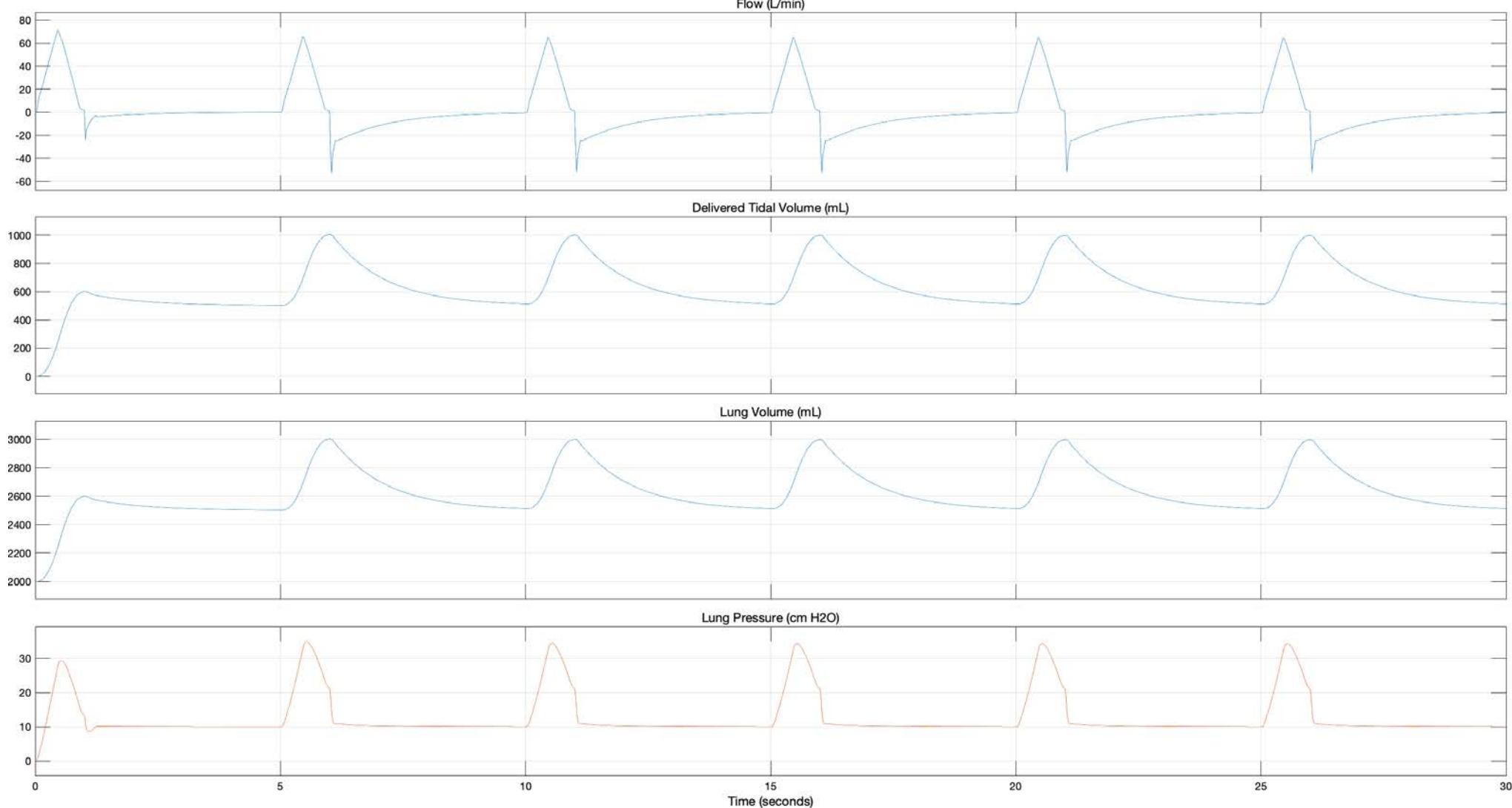
Delivered V<sub>T</sub>

$$= V_T - (\text{PIP} - \text{PEEP}) * \text{compressible volume ratio} = 500 - (31.11 - 10) * 0.0 = 500 \text{ mL}$$

End-expiratory lung volume

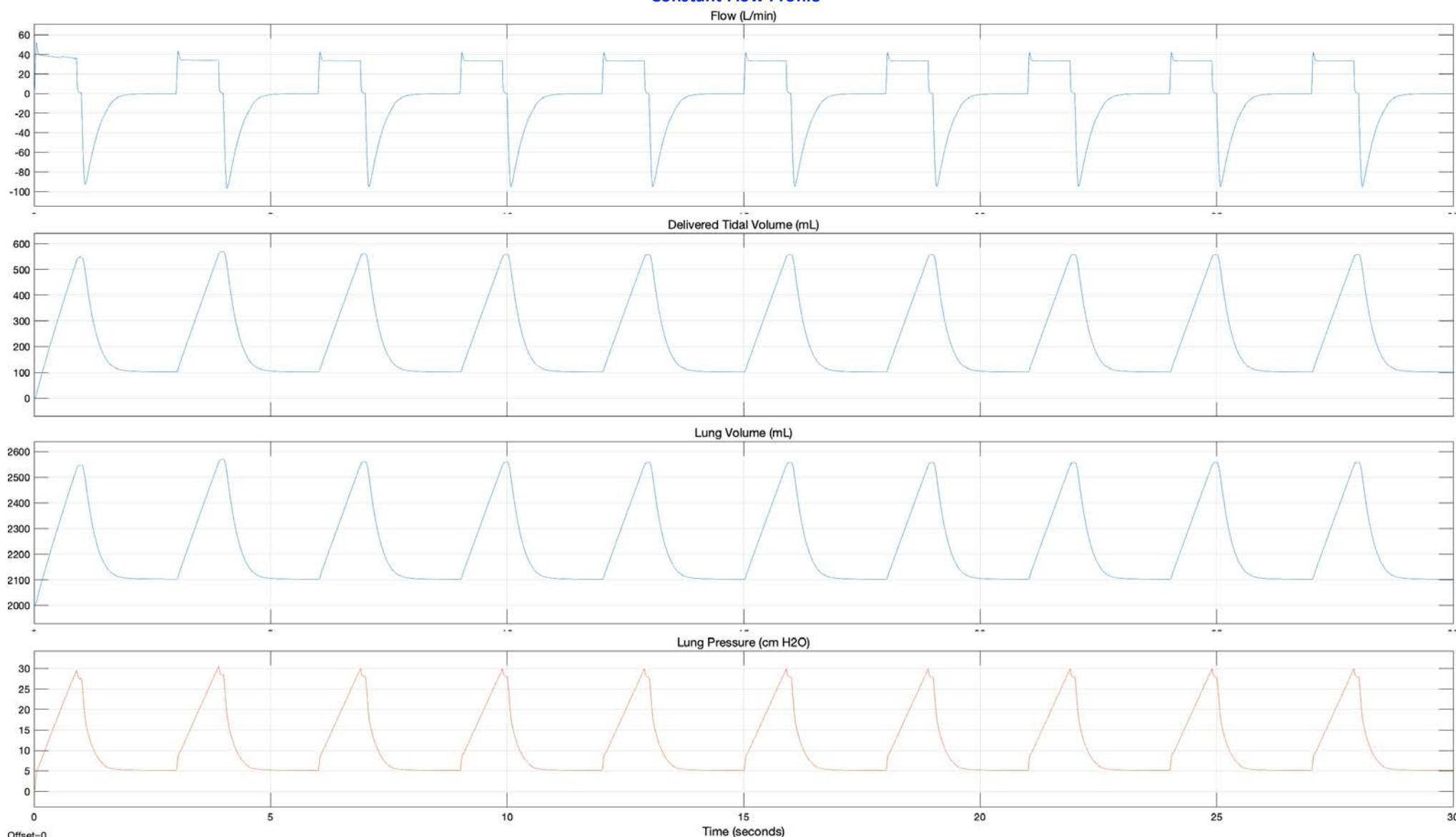
$$= \text{FRC} + \text{PEEP} * \text{Compliance} = 2000 \text{ mL} + 500 \text{ mL} = 2500 \text{ mL}$$

### Triangular Flow Profile (Accelerating-Decelerating)



Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
3	20	5	500	20	1 I/E = 1:2	5

### Constant Flow Profile



Offset=0

PIP[1]

$$= \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = (0.5 / 0.90) * 5 + 548 / 20 = 2.78 + 27.4 = 30.18 \text{ cm H}_2\text{O}$$

PIP[2]

$$= \text{PEEP} + \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = 5 + (0.5 / 0.90) * 5 + (569 - 100) / 20 = 5 + 2.78 + 23.45 = 31.23 \text{ cm H}_2\text{O}$$

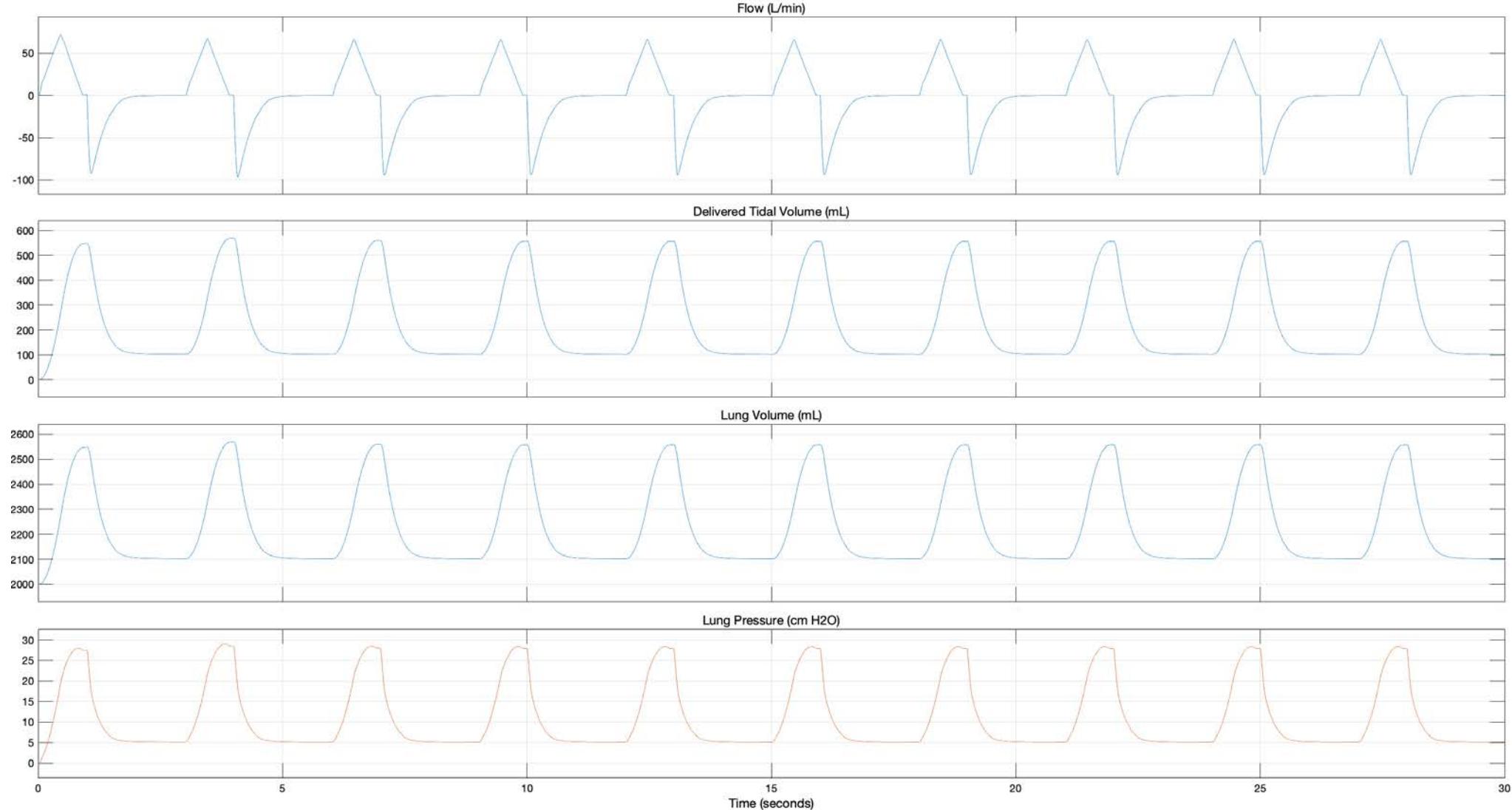
Delivered V<sub>T</sub>

$$= V_T - (\text{PIP} - \text{PEEP}) * \text{compressible volume ratio} = 500 - (31.23 - 5) * 1.154 = 469.73 \text{ mL}$$

End-expiratory lung volume

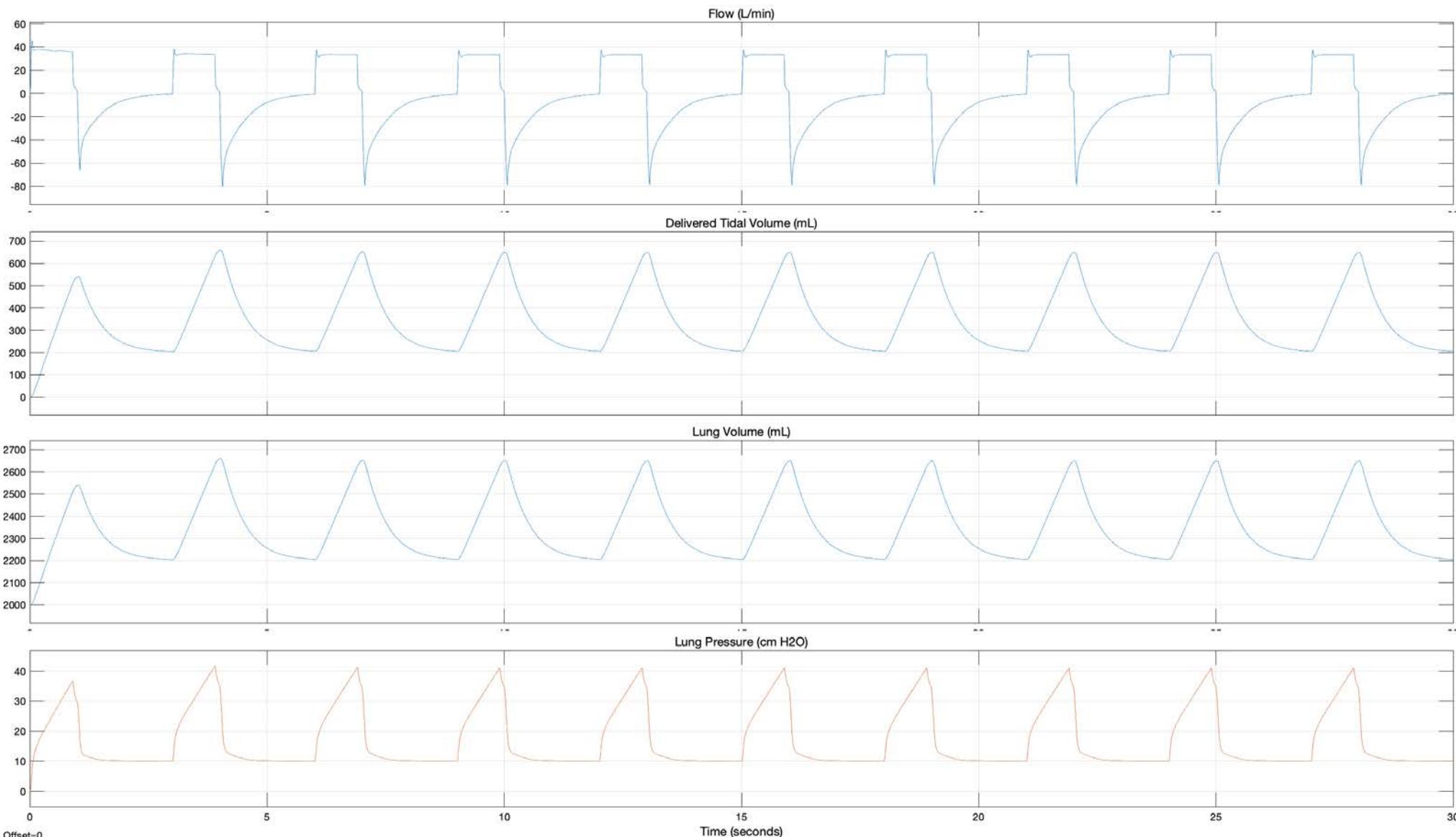
$$= \text{FRC} + \text{PEEP} * \text{Compliance} = 2000 \text{ mL} + 100 \text{ mL} = 2100 \text{ mL}$$

### Triangular Flow Profile (Accelerating-Decelerating)



Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
4	20	20	500	20	1 I/E = 1:2	10

### Constant Flow Profile



Offset=0

PIP[1]

$$= \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = (0.5 / 0.90) * 20 + 540 / 20 = 11.11 + 27 = 38.11 \text{ cm H}_2\text{O}$$

PIP[2]

$$= \text{PEEP} + \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = 10 + (0.5 / 0.90) * 20 + (660 - 200) / 20 = 10 + 11.11 + 23 = 44.11 \text{ cm H}_2\text{O}$$

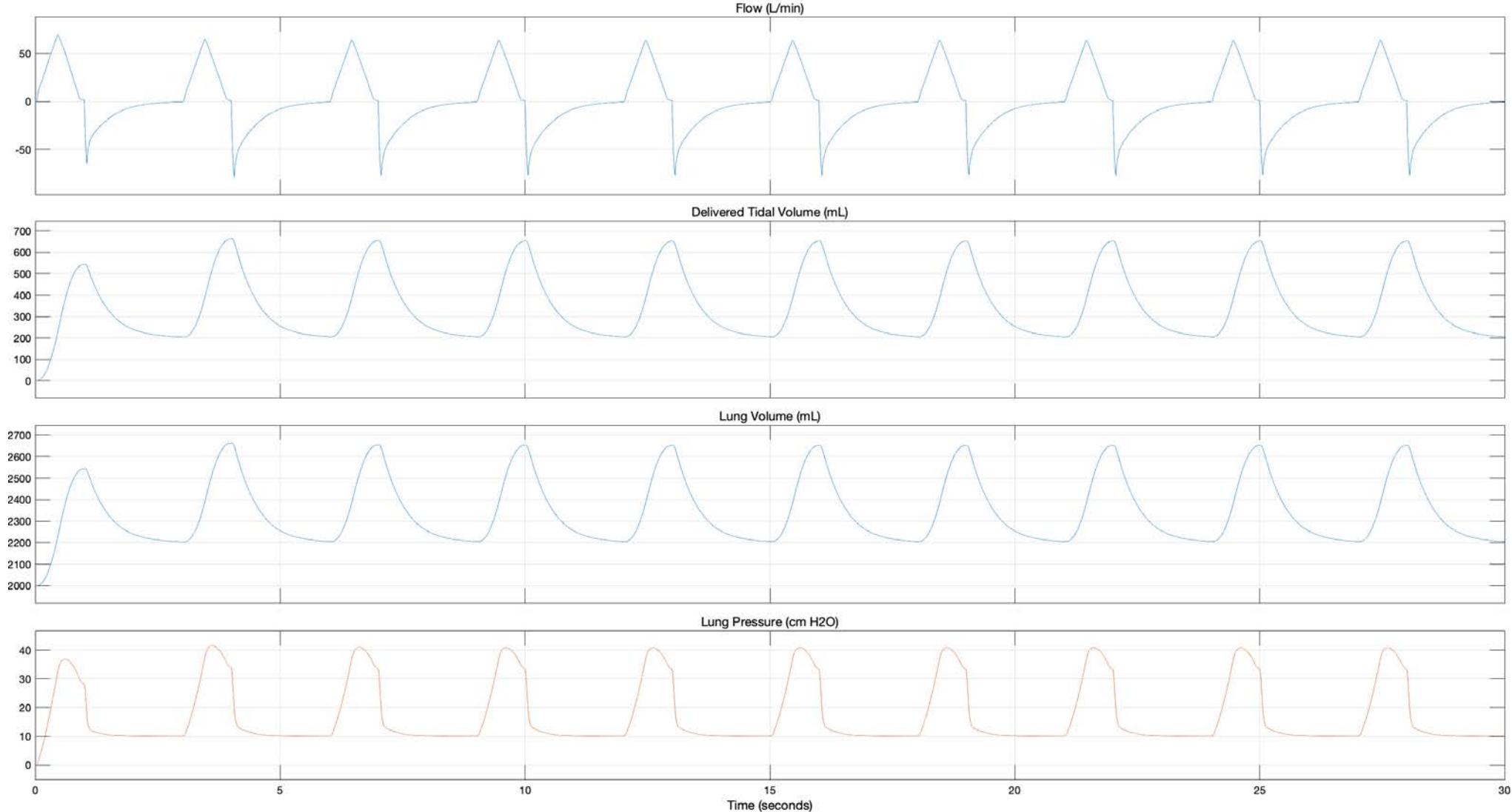
Delivered V<sub>T</sub>

$$= V_T - (\text{PIP} - \text{PEEP}) * \text{compressible volume ratio} = 500 - (44.11 - 10) * 1.154 = 460.64 \text{ mL}$$

End-expiratory lung volume

$$= \text{FRC} + \text{PEEP} * \text{Compliance} = 2000 \text{ mL} + 200 \text{ mL} = 2200 \text{ mL}$$

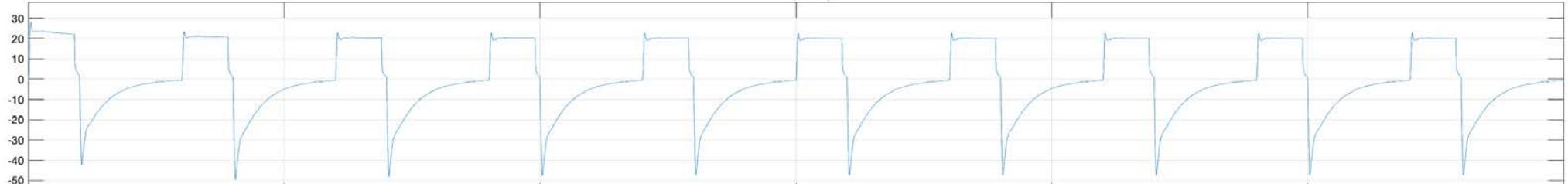
### Triangular Flow Profile (Accelerating-Decelerating)



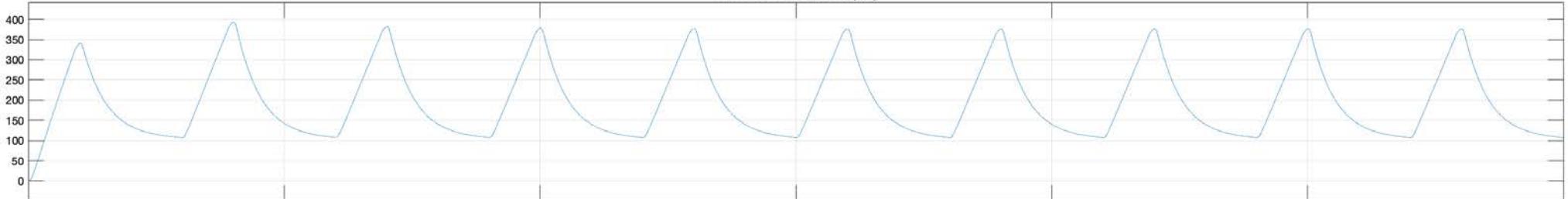
Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
5	20	20	300	20	1 I/E = 1:2	5

### Constant Flow Profile

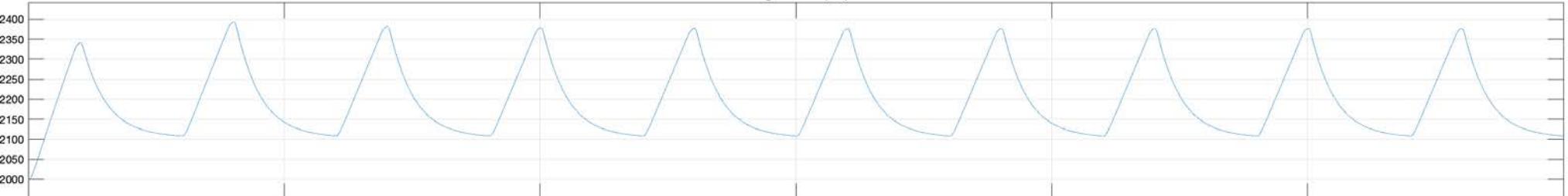
Flow (L/min)



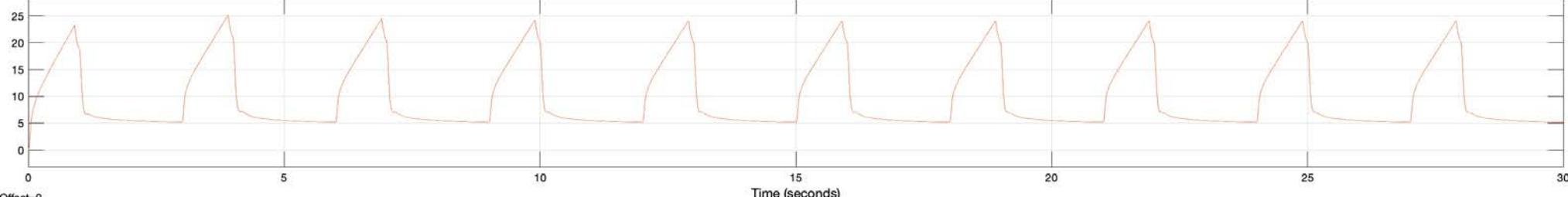
Delivered Tidal Volume (mL)



Lung Volume (mL)



Lung Pressure (cm H<sub>2</sub>O)



Offset=0

PIP[1]

$$= \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = (0.3 / 0.90) * 20 + 340 / 20 = 6.67 + 17 = 23.67 \text{ cm H}_2\text{O}$$

PIP[2]

$$= \text{PEEP} + \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = 5 + (0.3 / 0.90) * 20 + (393 - 108) / 20 = 5 + 6.67 + 14.25 = 25.92 \text{ cm H}_2\text{O}$$

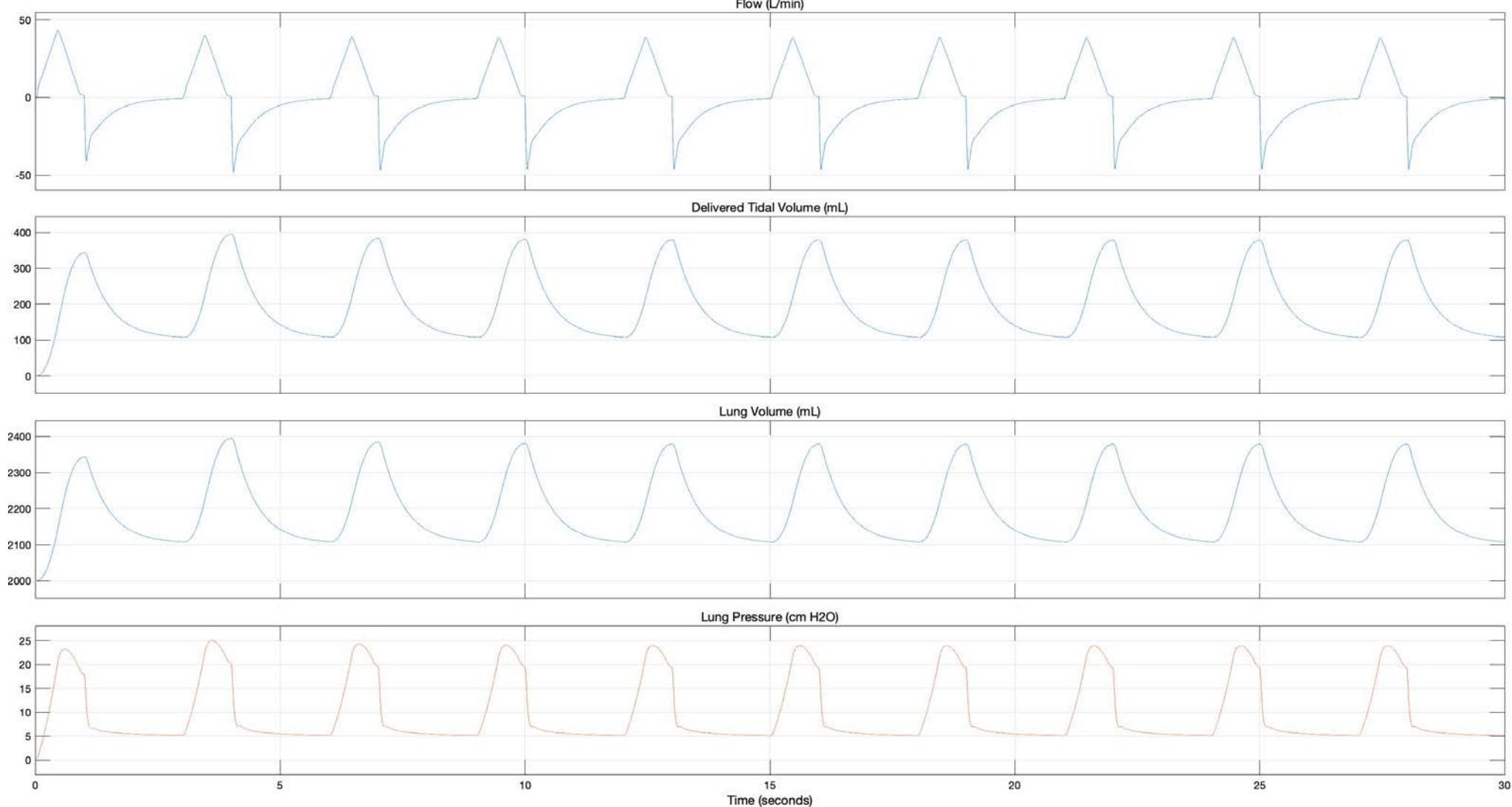
Delivered V<sub>T</sub>

$$= V_T - (\text{PIP} - \text{PEEP}) * \text{compressible volume ratio} = 300 - (25.92 - 5) * 1.154 = 275.86 \text{ mL}$$

End-expiratory lung volume

$$= \text{FRC} + \text{PEEP} * \text{Compliance} = 2000 \text{ mL} + 100 \text{ mL} = 2100 \text{ mL}$$

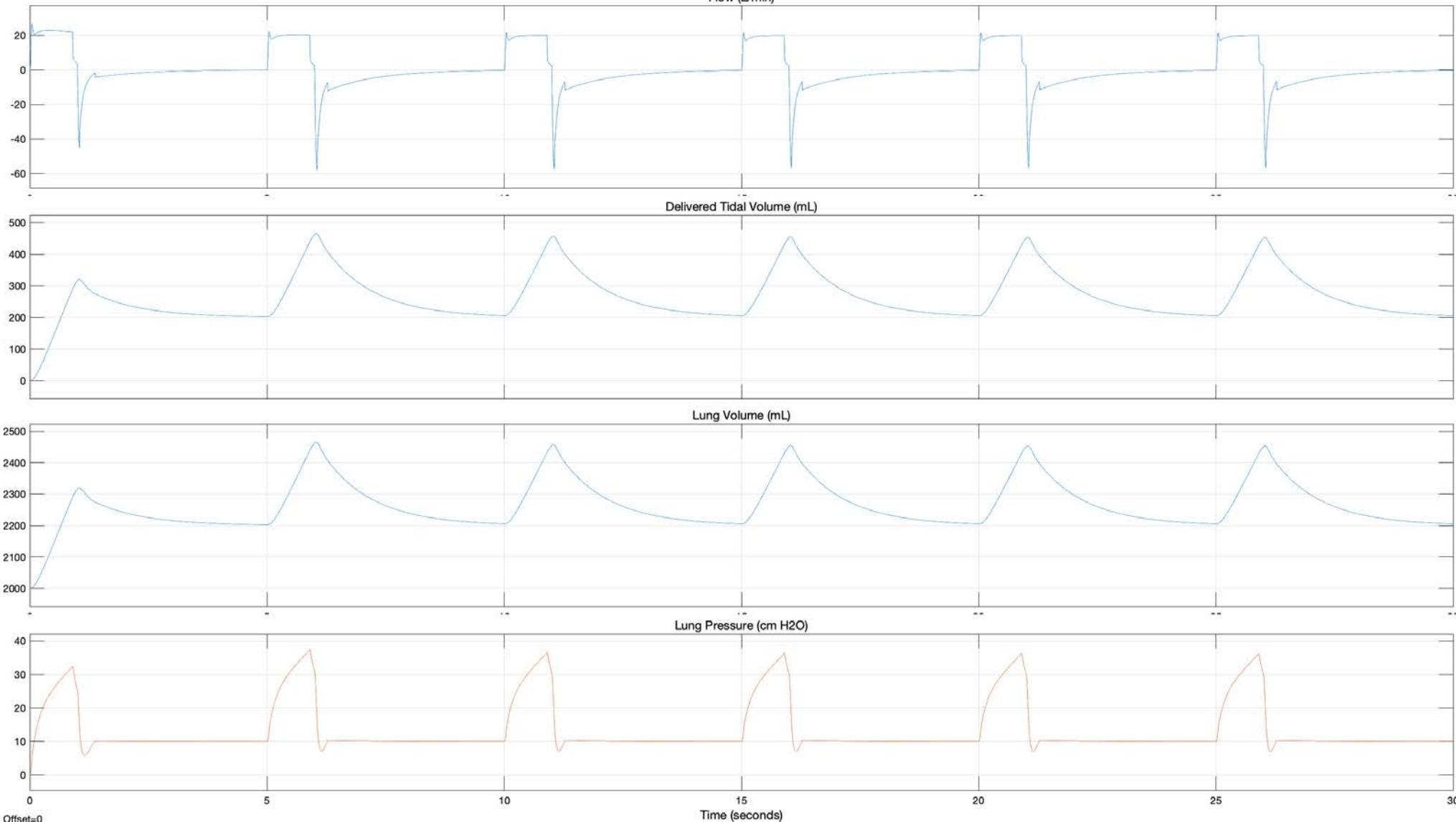
### Triangular Flow Profile (Accelerating-Decelerating)



Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
6	20	50	300	12	1 I/E = 1:4	10

### Constant Flow Profile

Flow (L/min)



Offset=0

PIP[1]

$$= \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = (0.3 / 0.90) * 50 + 320 / 20 = 16.67 + 16 = 32.67 \text{ cm H}_2\text{O}$$

PIP[2]

$$= \text{PEEP} + \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = 10 + (0.3 / 0.90) * 50 + (465 - 202) / 20 = 10 + 16.67 + 13.15 = 39.82 \text{ cm H}_2\text{O}$$

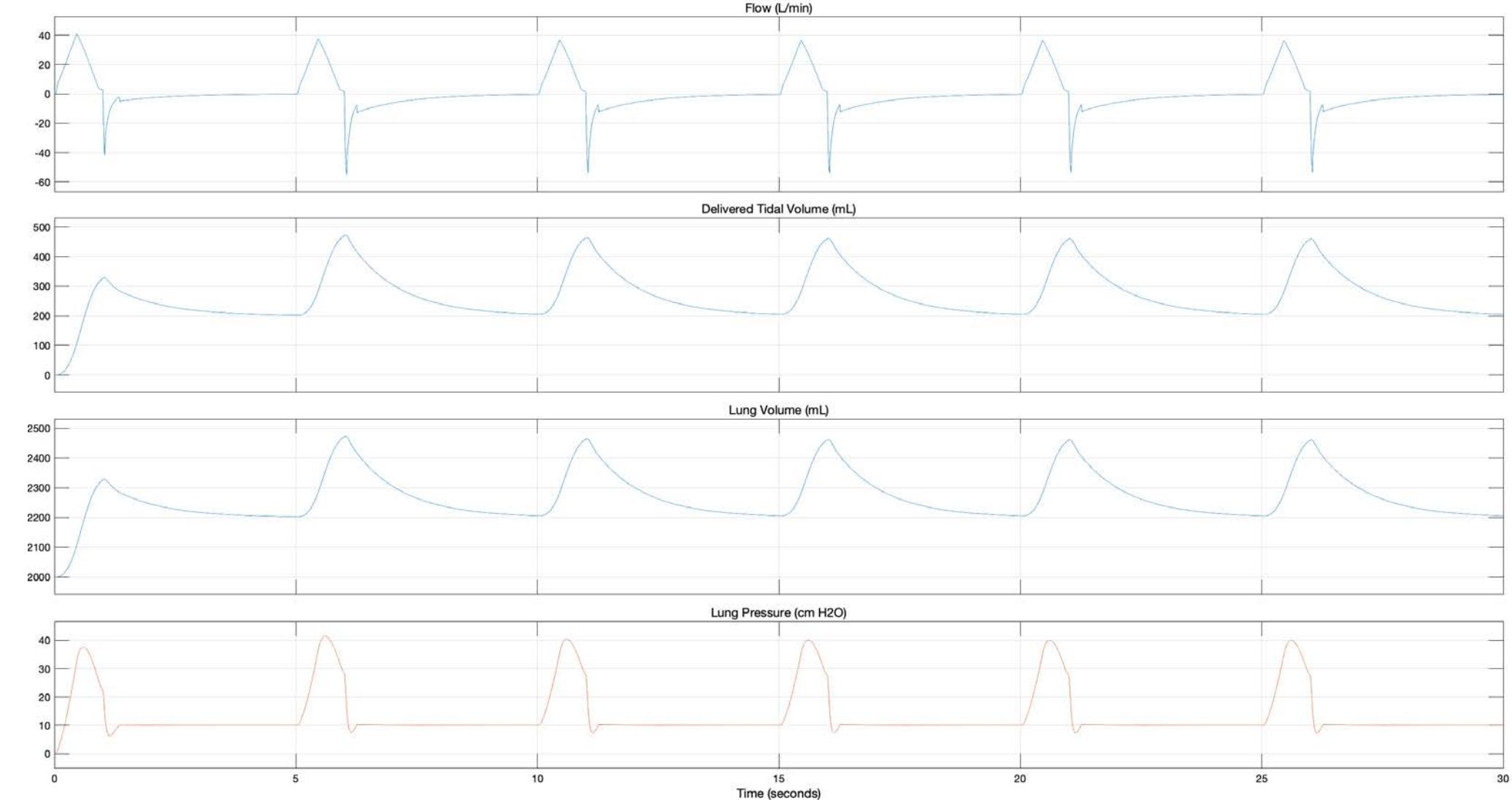
Delivered V<sub>T</sub>

$$= V_T - (\text{PIP} - \text{PEEP}) * \text{compressible volume ratio} = 300 - (39.82 - 10) * 1.154 = 265.59 \text{ mL}$$

End-expiratory lung volume

$$= \text{FRC} + \text{PEEP} * \text{Compliance} = 2000 \text{ mL} + 200 \text{ mL} = 2200 \text{ mL}$$

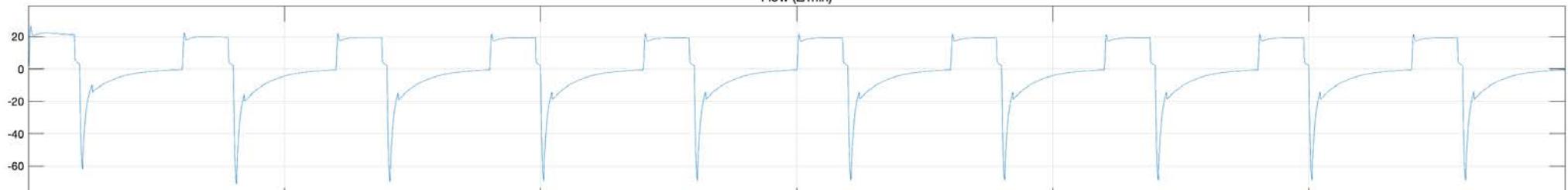
### Triangular Flow Profile (Accelerating-Decelerating)



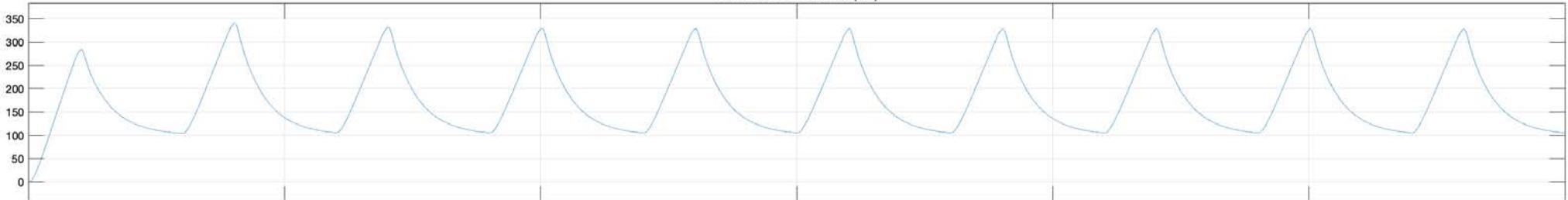
Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
7	10	50	300	20	1 I/E = 1:2	10

### Constant Flow Profile

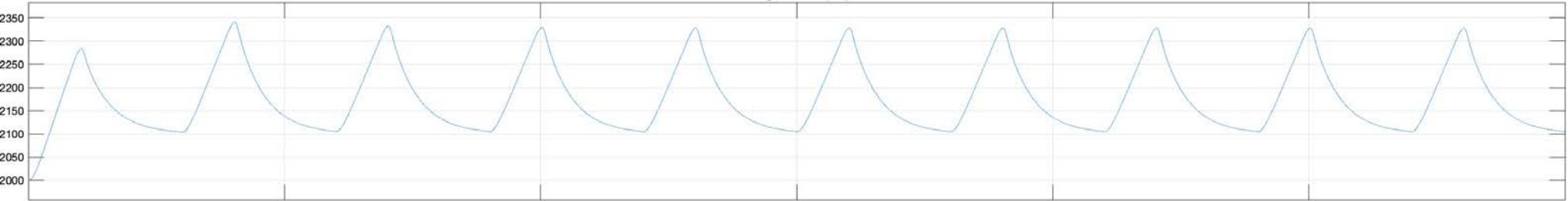
Flow (L/min)



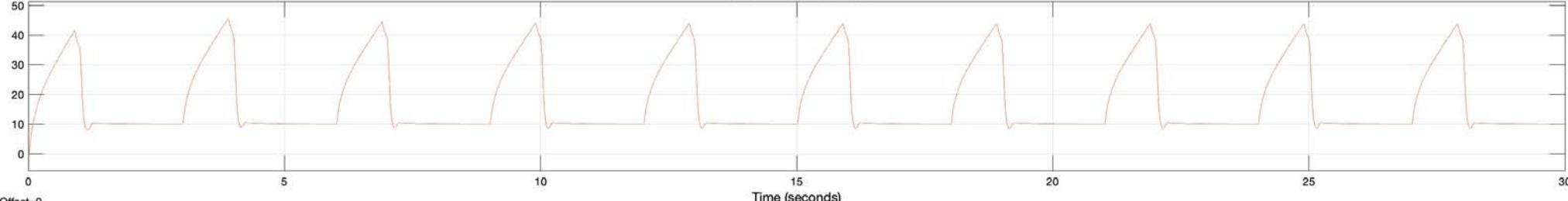
Delivered Tidal Volume (mL)



Lung Volume (mL)



Lung Pressure (cm H<sub>2</sub>O)



Time (seconds)

Offset=0

PIP[1]

$$= \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = (0.3 / 0.90) * 50 + 284 / 10 = 16.67 + 28.4 = 45.06 \text{ cm H}_2\text{O}$$

PIP[2]

$$= \text{PEEP} + \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = 10 + (0.3 / 0.90) * 50 + (341 - 104) / 10 = 10 + 16.67 + 23.7 = 50.37 \text{ cm H}_2\text{O}$$

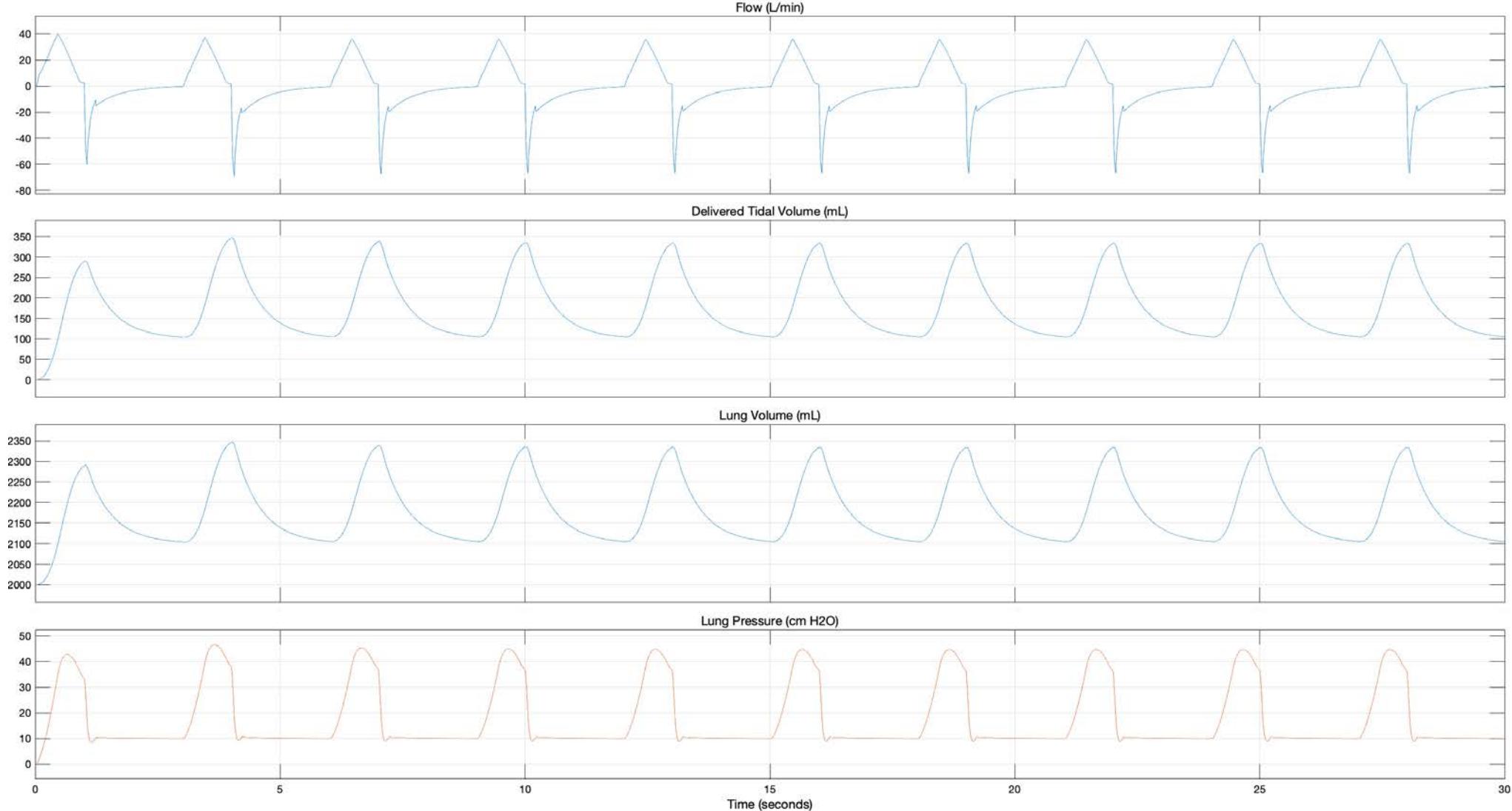
Delivered V<sub>T</sub>

$$= V_T - (\text{PIP} - \text{PEEP}) * \text{compressible volume ratio} = 300 - (50.37 - 10) * 1.154 = 253.41 \text{ mL}$$

End-expiratory lung volume

$$= \text{FRC} + \text{PEEP} * \text{Compliance} = 2000 \text{ mL} + 100 \text{ mL} = 2100 \text{ mL}$$

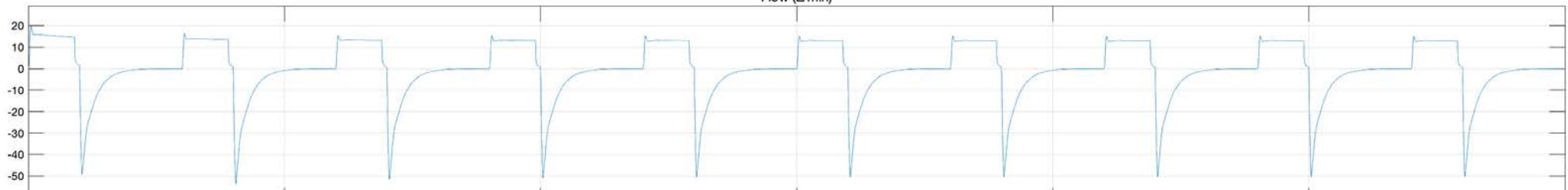
### Triangular Flow Profile (Accelerating-Decelerating)



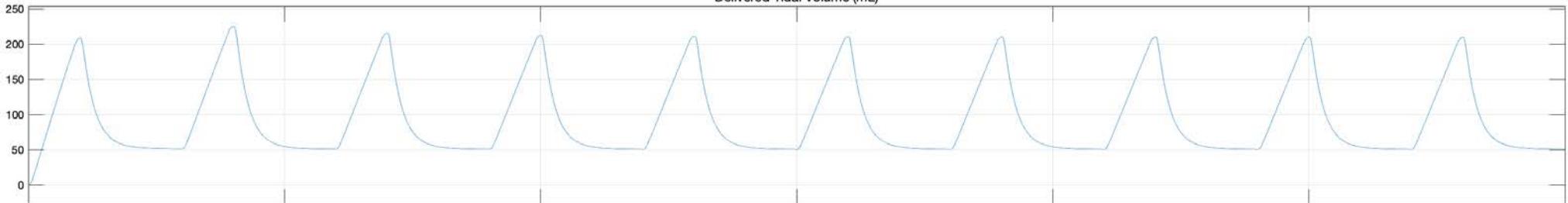
Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
8	10	20	200	20	1 I/E = 1:2	5

### Constant Flow Profile

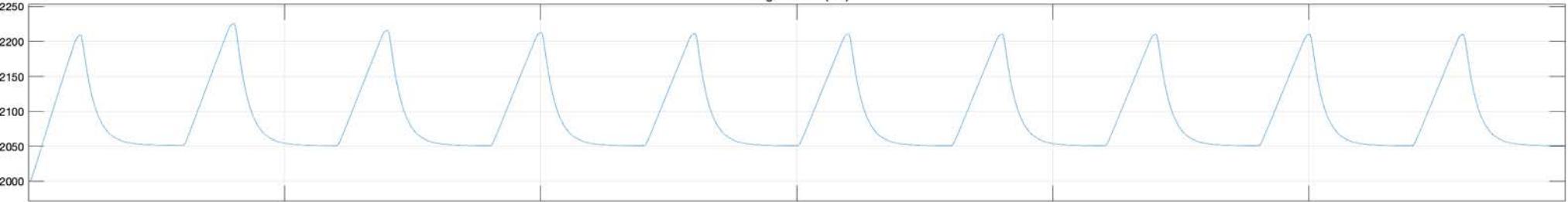
Flow (L/min)



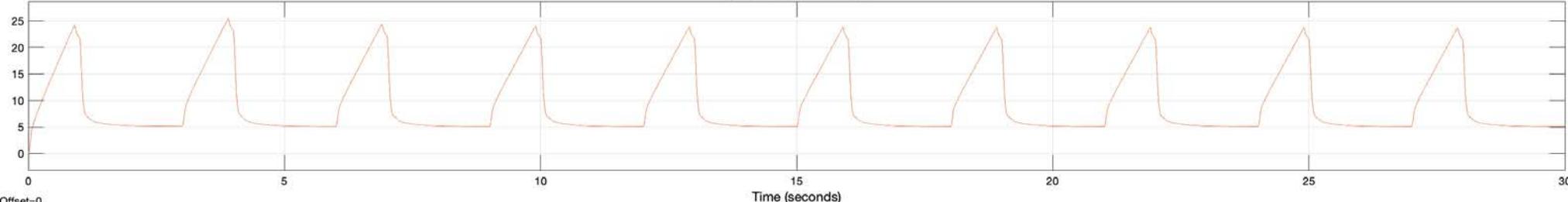
Delivered Tidal Volume (mL)



Lung Volume (mL)



Lung Pressure (cm H<sub>2</sub>O)



Offset=0

PIP[1]

$$= \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = (0.2 / 0.90) * 20 + 209 / 10 = 4.44 + 20.9 = 25.34 \text{ cm H}_2\text{O}$$

PIP[2]

$$= \text{PEEP} + \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = 5 + (0.2 / 0.90) * 20 + (226 - 51) / 10 = 5 + 4.44 + 17.5 = 26.94 \text{ cm H}_2\text{O}$$

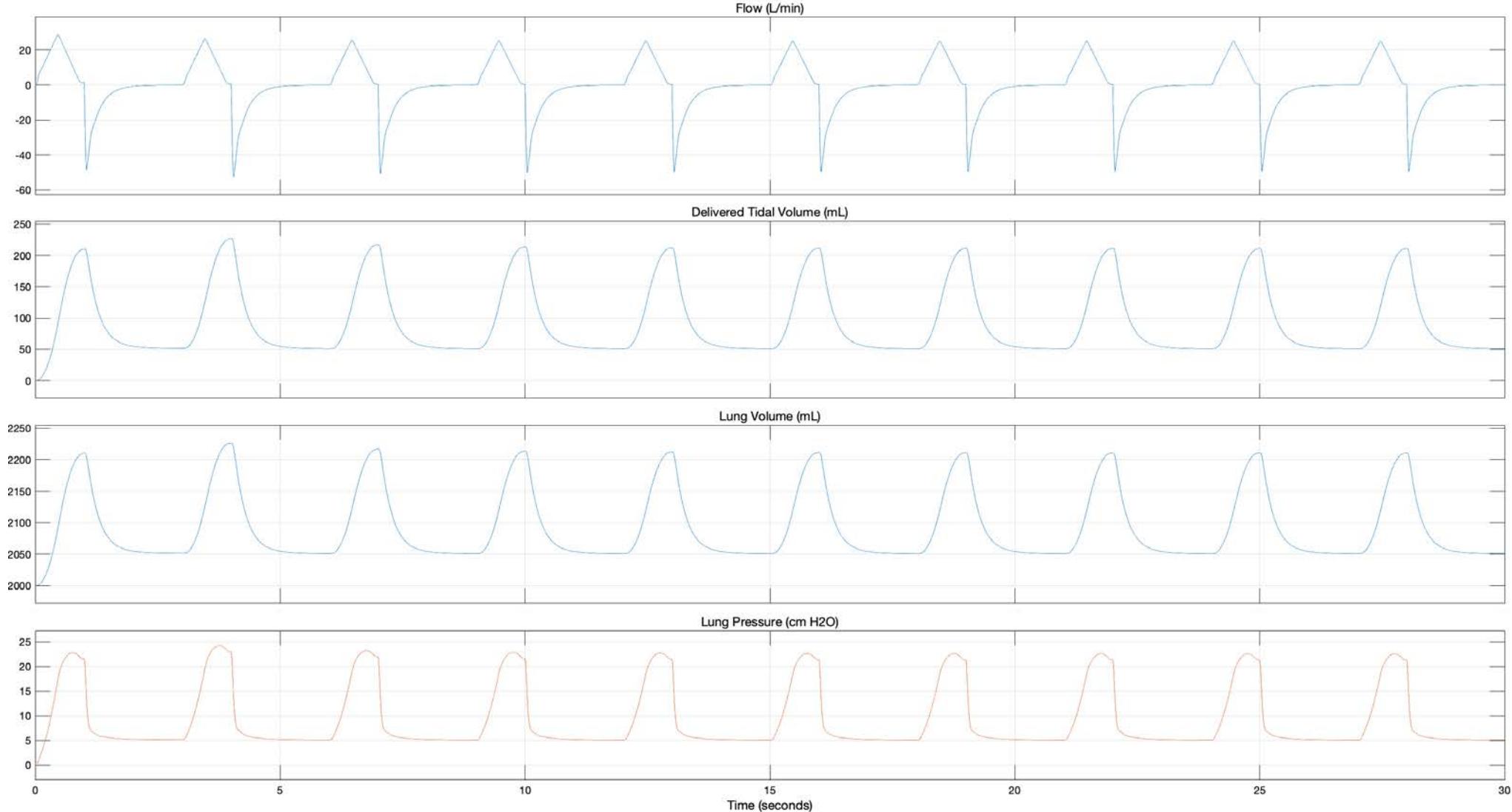
Delivered V<sub>T</sub>

$$= V_T - (\text{PIP} - \text{PEEP}) * \text{compressible volume ratio} = 200 - (26.94 - 5) * 1.154 = 174.68 \text{ mL}$$

End-expiratory lung volume

$$= \text{FRC} + \text{PEEP} * \text{Compliance} = 2000 \text{ mL} + 50 \text{ mL} = 2050 \text{ mL}$$

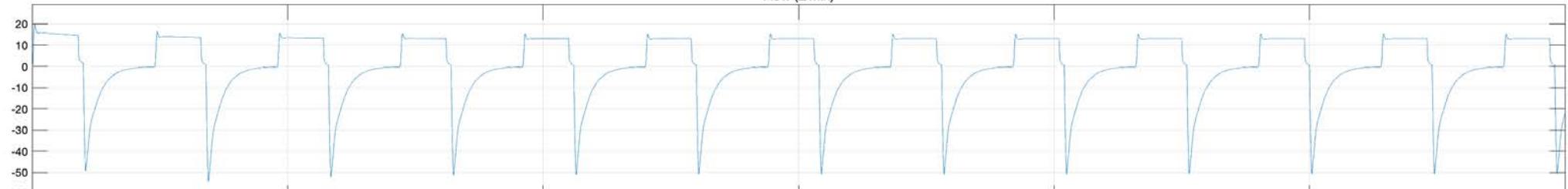
### Triangular Flow Profile (Accelerating-Decelerating)



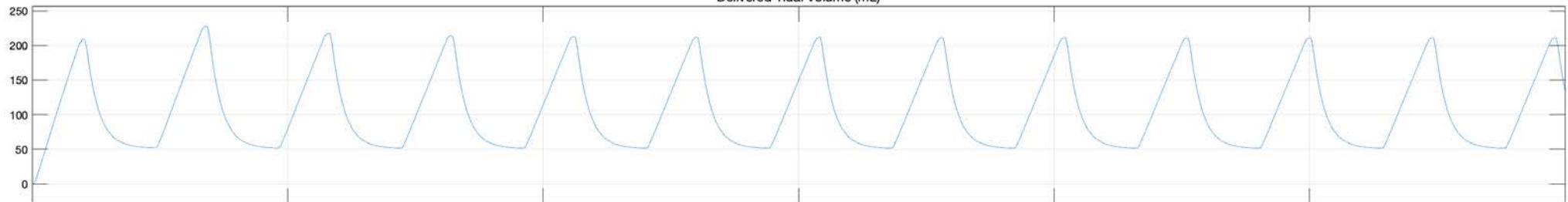
Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
9	10	20	200	25	1 I/E = 1:1.4	5

### Constant Flow Profile

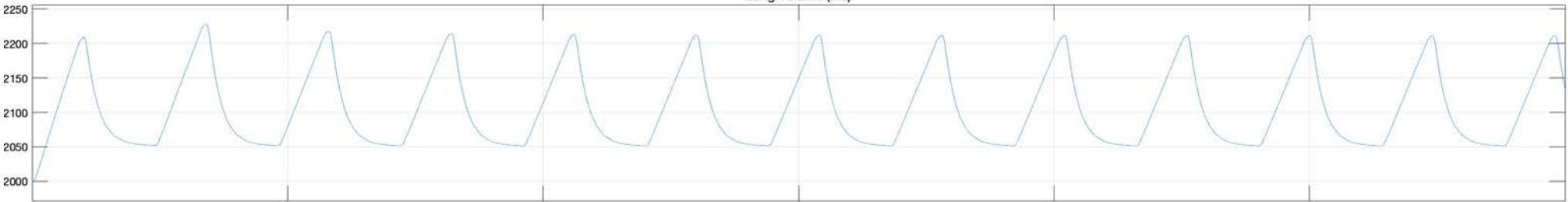
Flow (L/min)



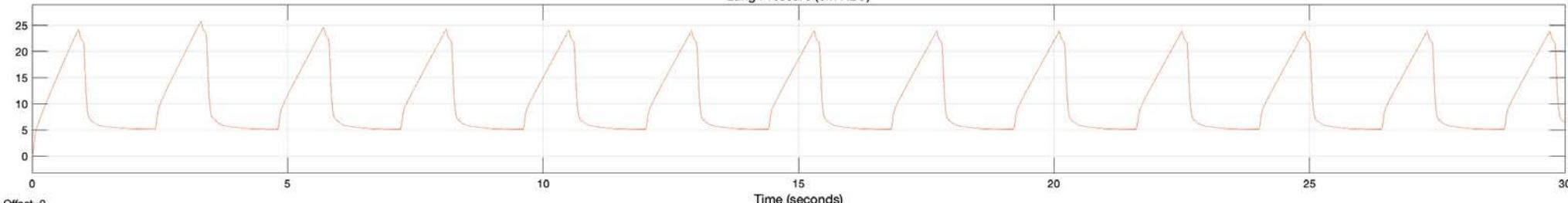
Delivered Tidal Volume (mL)



Lung Volume (mL)



Lung Pressure (cm H<sub>2</sub>O)



Offset=0

PIP[1]

$$= \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = (0.2 / 0.90) * 20 + 209 / 10 = 4.44 + 20.9 = 25.34 \text{ cm H}_2\text{O}$$

PIP[2]

$$= \text{PEEP} + \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = 5 + (0.2 / 0.90) * 20 + (228 - 52) / 10 = 5 + 4.44 + 17.6 = 27.04 \text{ cm H}_2\text{O}$$

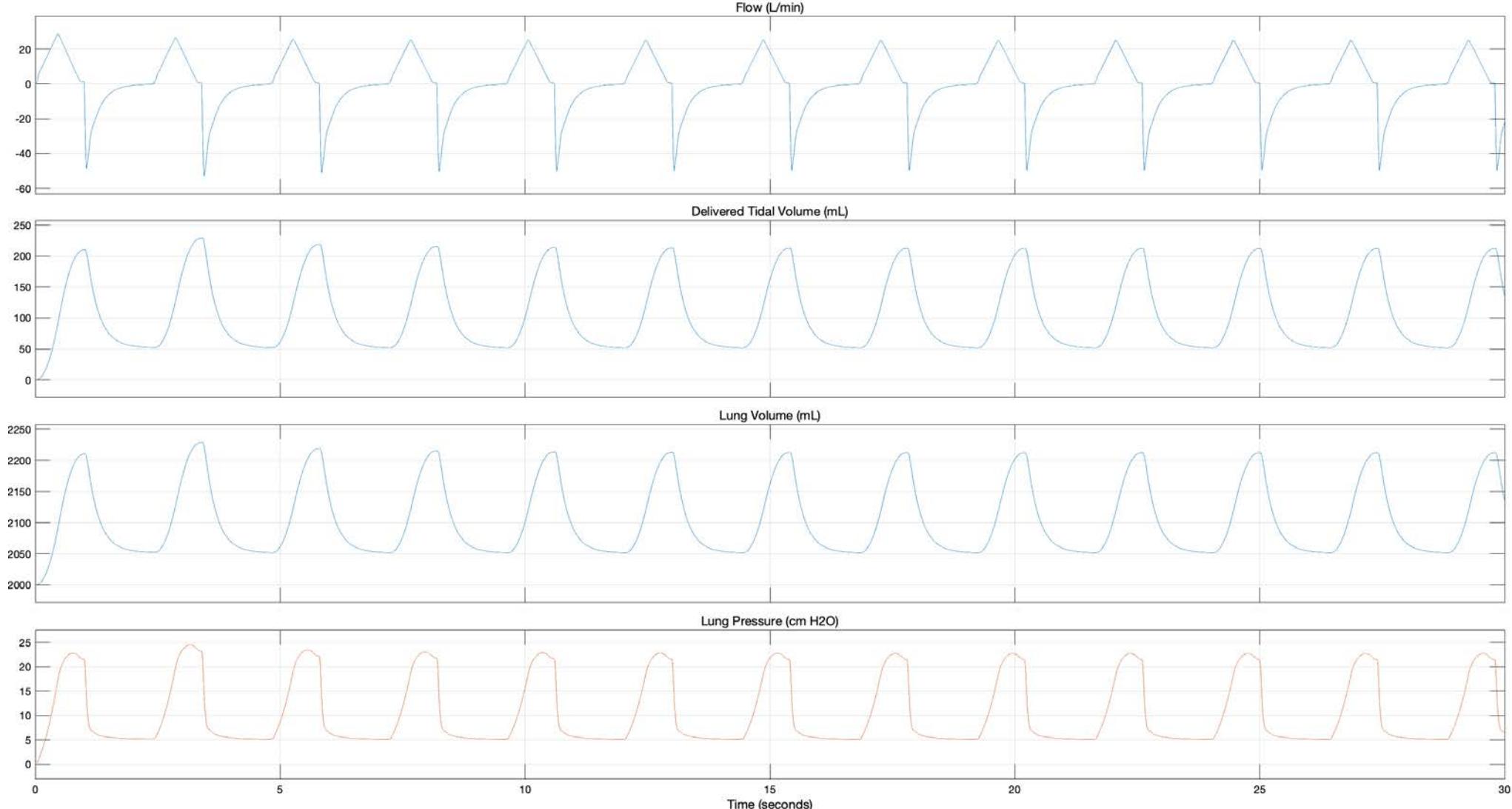
Delivered V<sub>T</sub>

$$= V_T - (\text{PIP} - \text{PEEP}) * \text{compressible volume ratio} = 200 - (27.04 - 5) * 1.154 = 174.57 \text{ mL}$$

End-expiratory lung volume

$$= \text{FRC} + \text{PEEP} * \text{Compliance} = 2000 \text{ mL} + 50 \text{ mL} = 2050 \text{ mL}$$

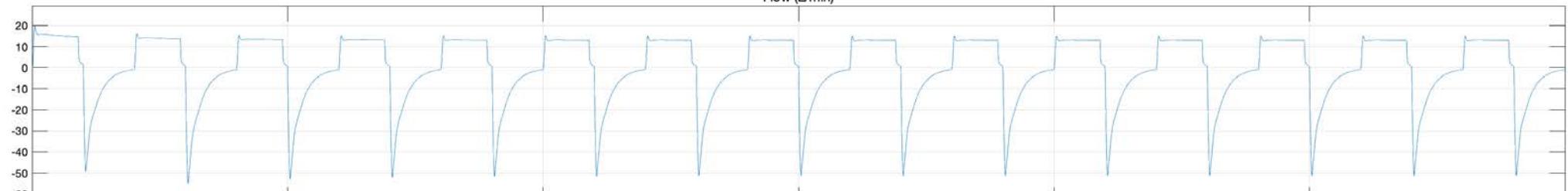
### Triangular Flow Profile (Accelerating-Decelerating)



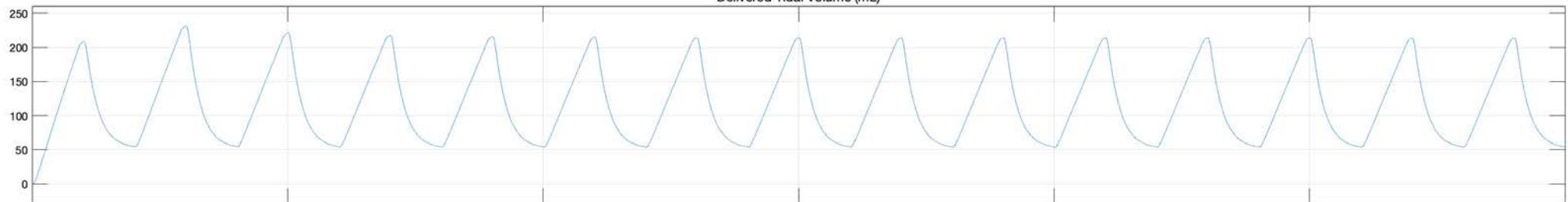
Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
10	10	20	200	30	1 I/E = 1:1	5

### Constant Flow Profile

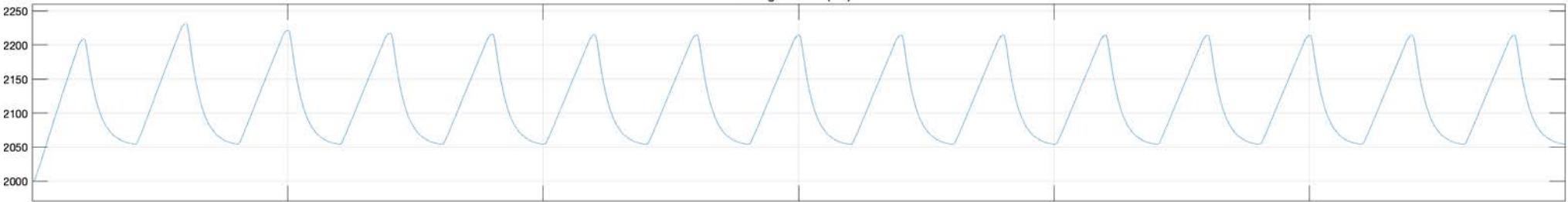
Flow (L/min)



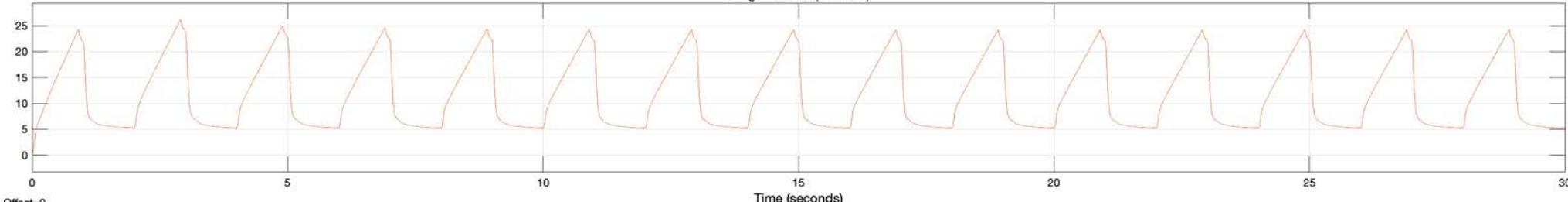
Delivered Tidal Volume (mL)



Lung Volume (mL)



Lung Pressure (cm H<sub>2</sub>O)



Offset=0

PIP[1]

$$= \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = (0.2 / 0.90) * 20 + 209 / 10 = 4.44 + 20.9 = 25.34 \text{ cm H}_2\text{O}$$

PIP[2]

$$= \text{PEEP} + \text{Flow} * \text{Resistance} + \text{Delivered } V_T / \text{Compliance} = 5 + (0.2 / 0.90) * 20 + (232 - 54) / 10 = 5 + 4.44 + 17.8 = 27.24 \text{ cm H}_2\text{O}$$

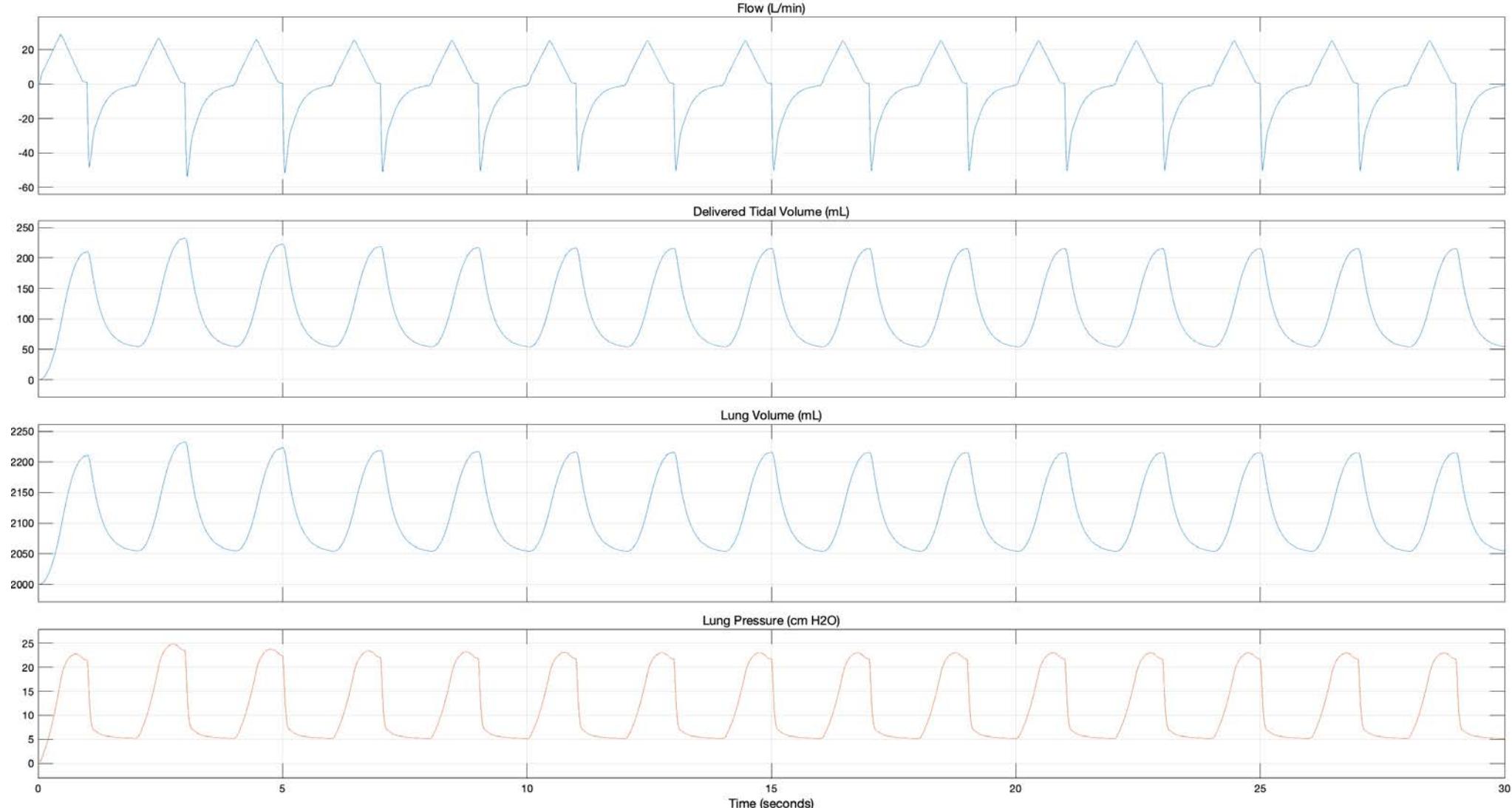
Delivered V<sub>T</sub>

$$= V_T - (\text{PIP} - \text{PEEP}) * \text{compressible volume ratio} = 200 - (27.24 - 5) * 1.154 = 174.34 \text{ mL}$$

End-expiratory lung volume

$$= \text{FRC} + \text{PEEP} * \text{Compliance} = 2000 \text{ mL} + 50 \text{ mL} = 2050 \text{ mL}$$

### Triangular Flow Profile (Accelerating-Decelerating)



### 3 ASL 5000 Simulator Waveforms for MIT Emergency Ventilator

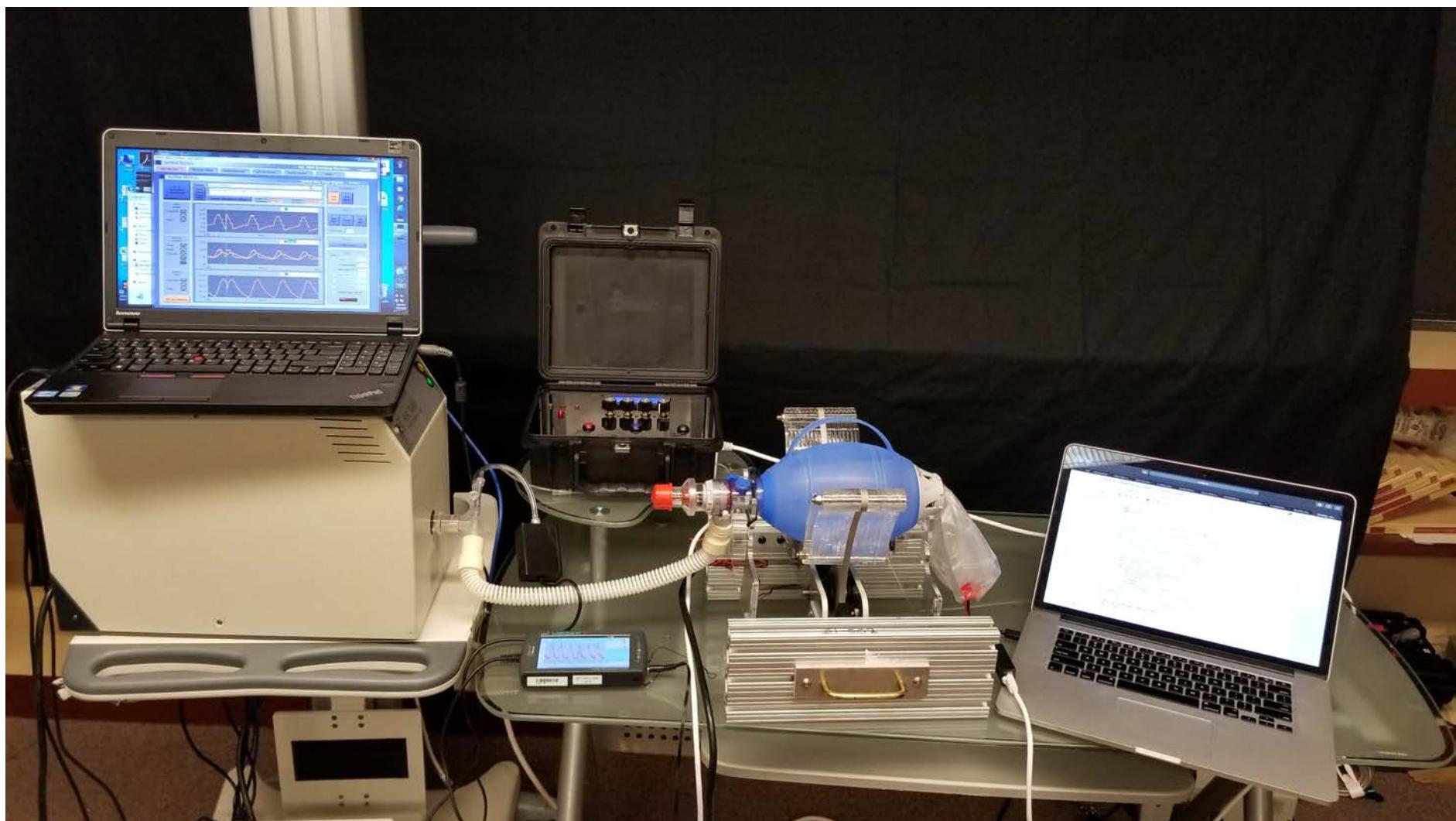
In this section, data is recorded when an ASL 5000 breathing simulation (<https://www.ingmarmmed.com/product/asl-5000-breathing-simulator/>) is connected to the MIT Emergency Ventilator.

During the runs, we did not use a popoff valve intentionally to records maximum pressures.

Based on the collected data, Tests #4, #6, and #7 exceed 40 cm H<sub>2</sub>O. This is consistent with the model-based observations from Section 2 where the triangular flow profile also resulted in a pressure build up exceeding 40 cm H<sub>2</sub>O for Tests #4, #6, and #7.

As expected, the peak flow is consistent with the model-based simulations and is twice what a constant flow requires. Despite that, the PIP-Plateau pressure remains close to that in the constant flow profile because the maximum pressure due to compliance and resistance do not line up in a triangular flow, unlike the case in the constant flow.

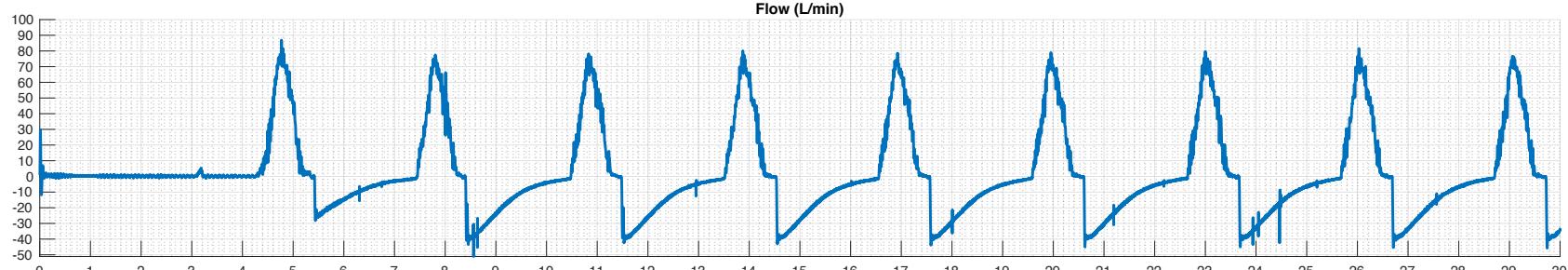
### 3.1 ASL 5000 Simulator Setup



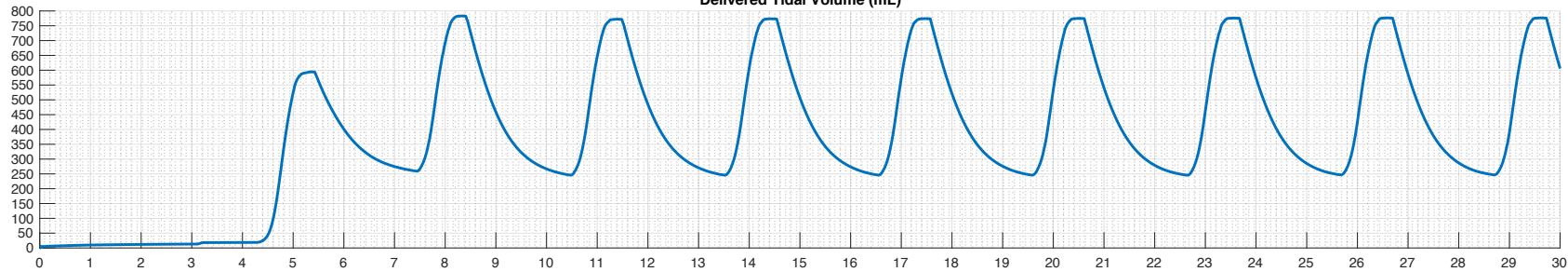
### 3.2 Breathing Data

Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
1	50	5	500	20	1 I/E =1:2	5

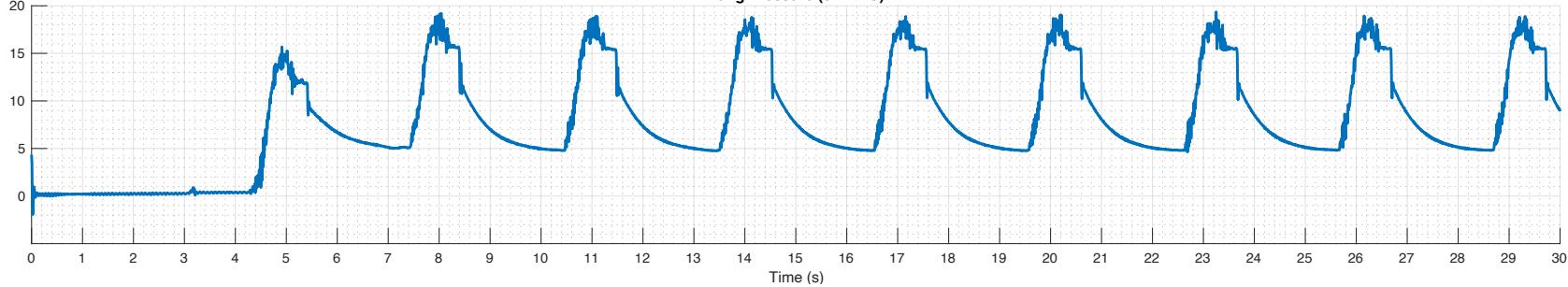
**Triangular Flow Profile (Accelerating-Decelerating)**



Delivered Tidal Volume (mL)



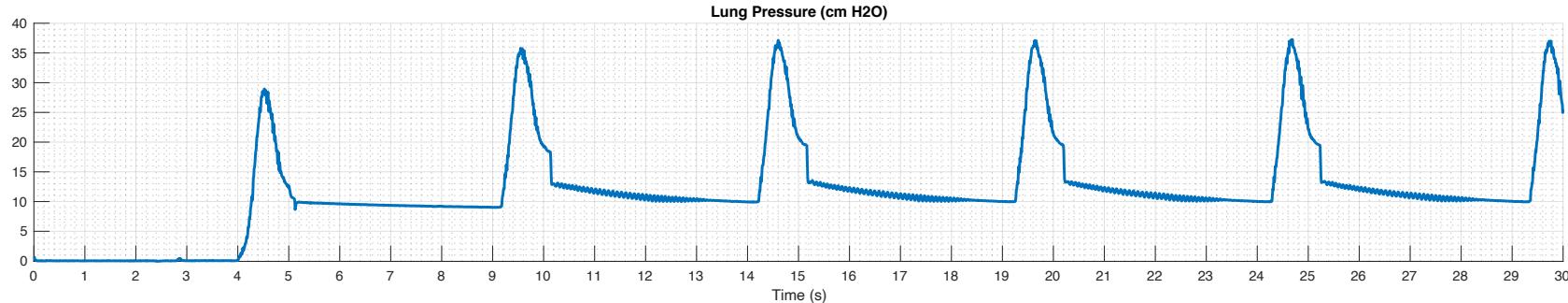
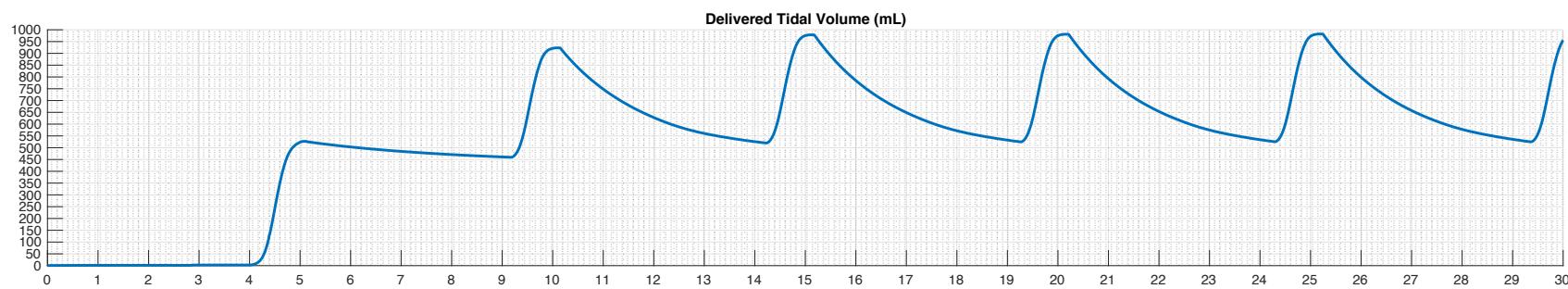
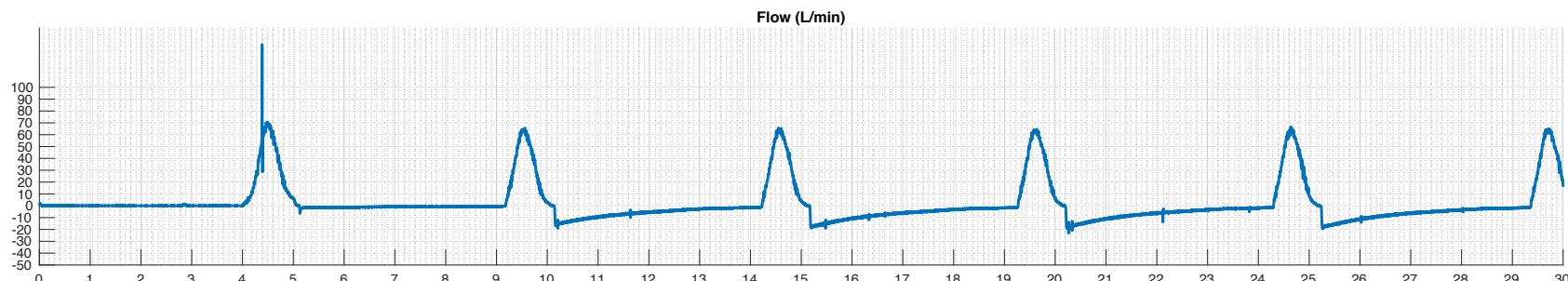
Lung Pressure (cm H<sub>2</sub>O)



Breath Rate (BPM)	19.756	P_peak (cmH <sub>2</sub> O)	18.238
I/E	0.415	P_pause (cmH <sub>2</sub> O)	15.889
Pause Time (s)	0.221	PEEP (cmH <sub>2</sub> O)	4.866
I Time (s)	0.891	Patient Insp Vt (mL)	547.819

Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
2	50	20	500	12	1 I/E =1:4	10

**Triangular Flow Profile (Accelerating-Decelerating)**

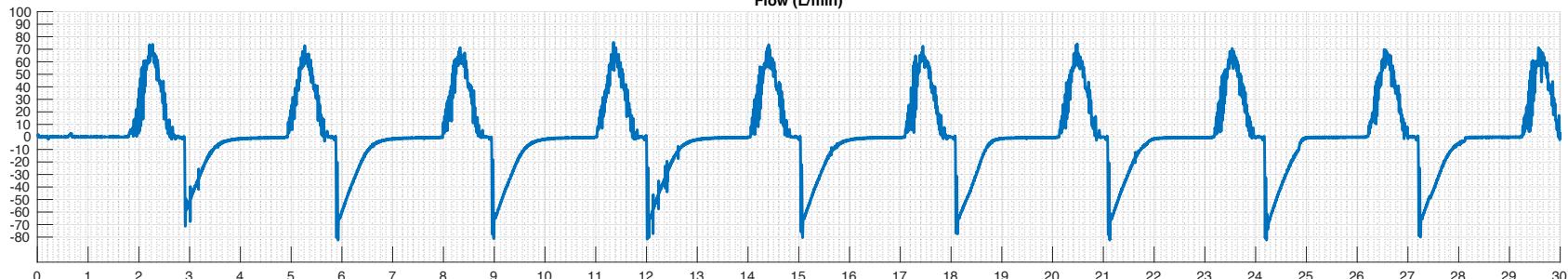


Breath Rate (BPM)	11.889	P_peak (cmH <sub>2</sub> O)	36.365
I/E	0.204	P_pause (cmH <sub>2</sub> O)	22.865
Pause Time (s)	0.186	PEEP (cmH <sub>2</sub> O)	9.877
I Time (s)	0.855	Patient Insp Vt (mL)	465.335

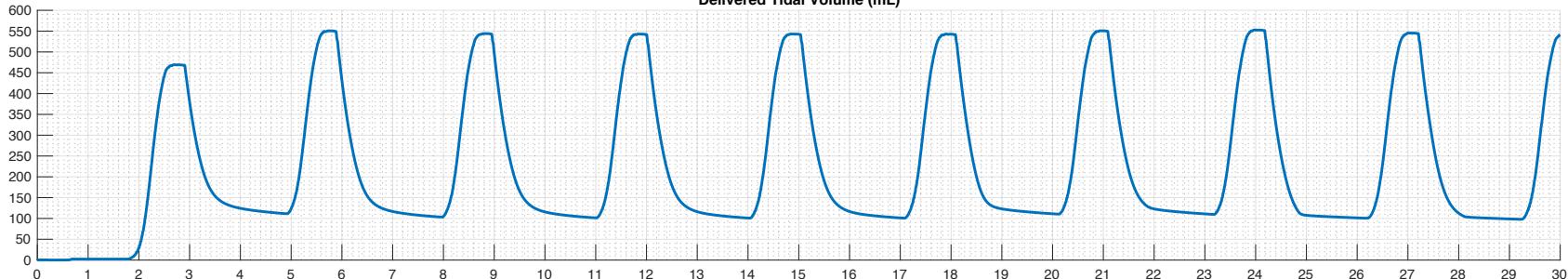
Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
3	20	5	500	20	1 I/E =1:2	5

### Triangular Flow Profile (Accelerating-Decelerating)

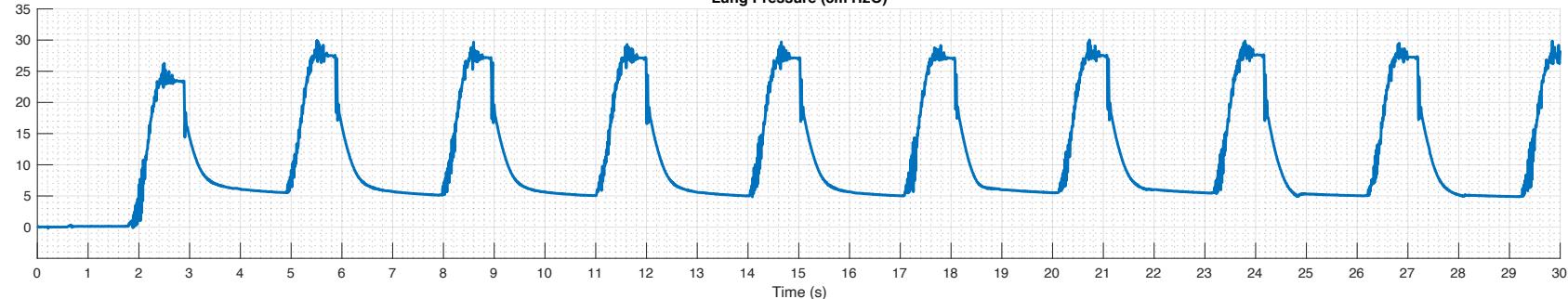
Flow (L/min)



### Delivered Tidal Volume (mL)



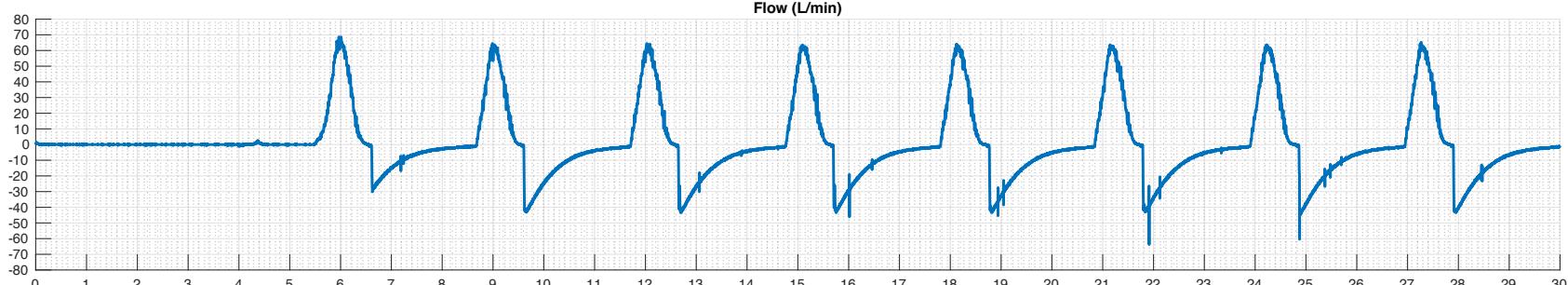
### Lung Pressure (cm H<sub>2</sub>O)



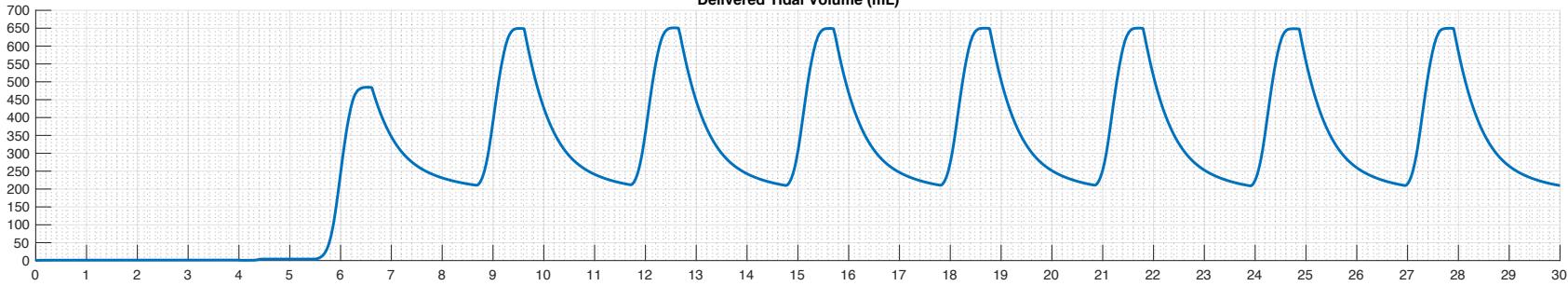
Breath Rate (BPM)	19.832	P_peak (cmH2O)	29.074
I/E	0.407	P_pause (cmH2O)	27.526
Pause Time (s)	0.246	PEEP (cmH2O)	5.082
I Time (s)	0.875	Patient Insp Vt (mL)	472.493

Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
4	20	20	500	20	1 I/E =1:2	10

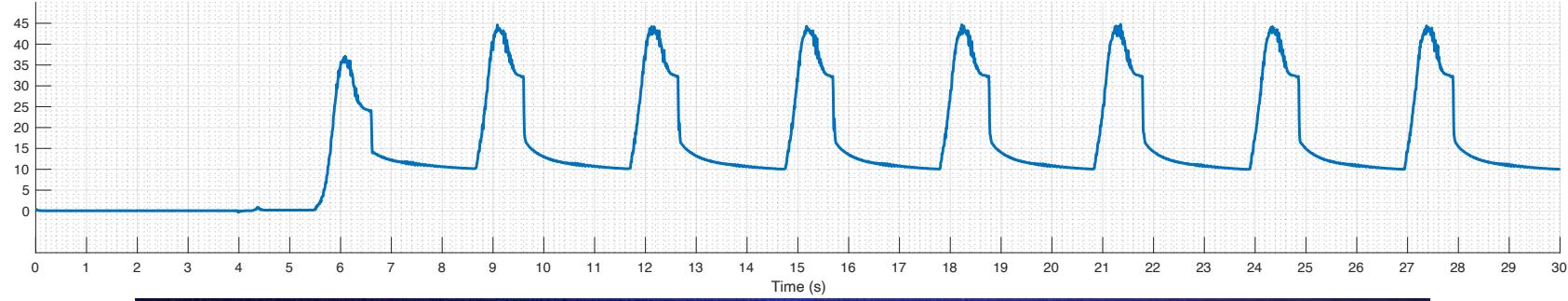
### Triangular Flow Profile (Accelerating-Decelerating)



### Delivered Tidal Volume (mL)



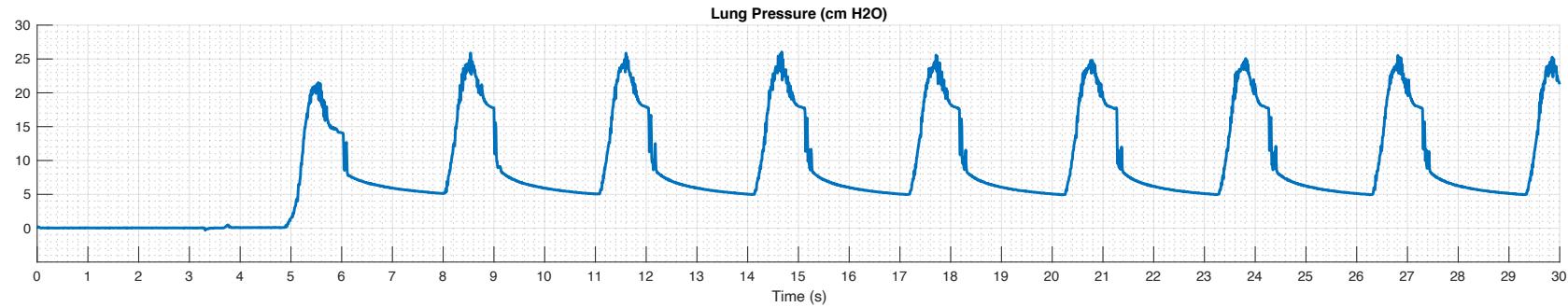
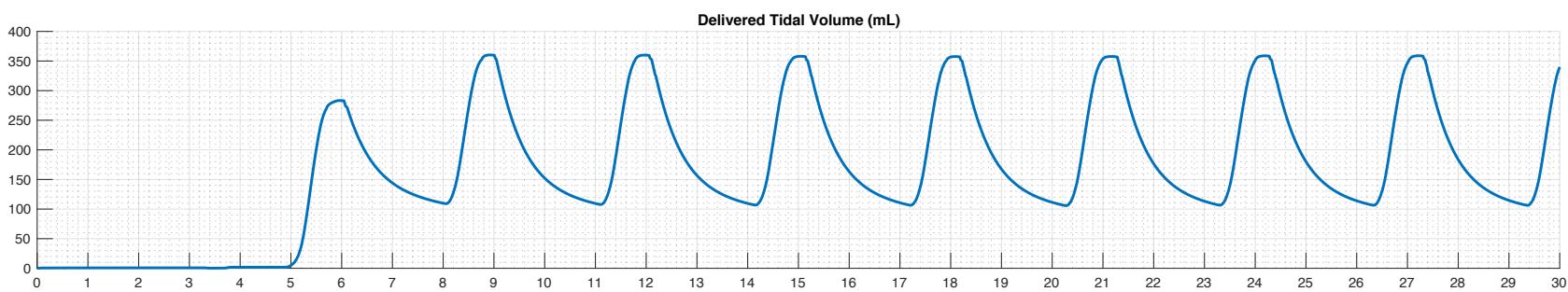
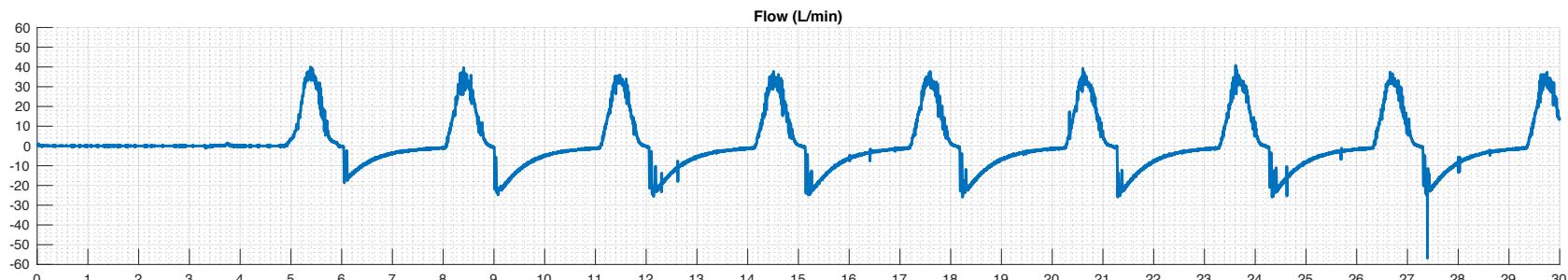
### Lung Pressure (cm H<sub>2</sub>O)



Breath Rate (BPM)	19.756	P_peak (cmH2O)	43.842
I/E	0.369	P_pause (cmH2O)	35.105
Pause Time (s)	0.164	PEEP (cmH2O)	10.020
I Time (s)	0.818	Patient Insp Vt (mL)	473.139

Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
5	20	20	300	20	1 I/E =1:2	5

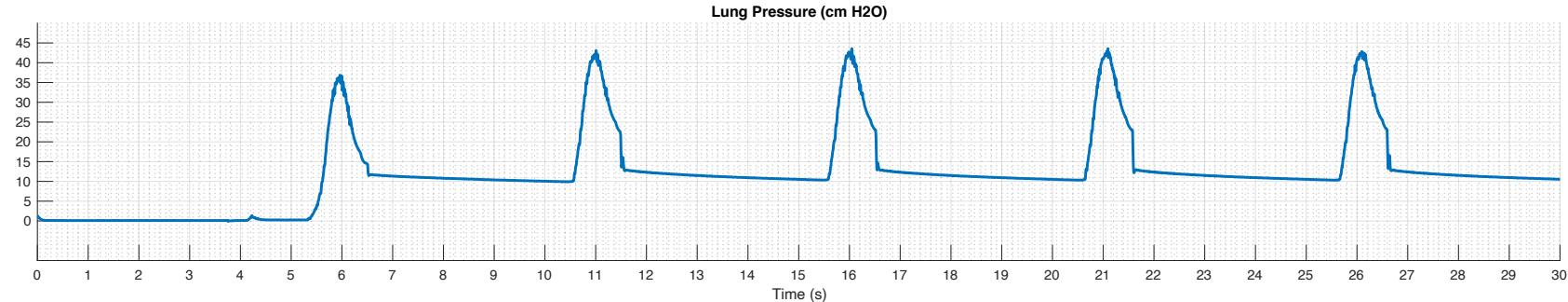
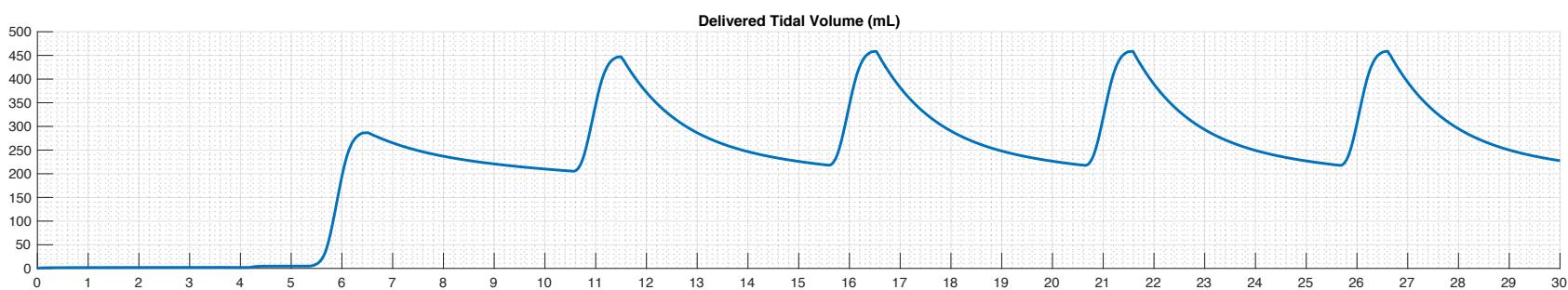
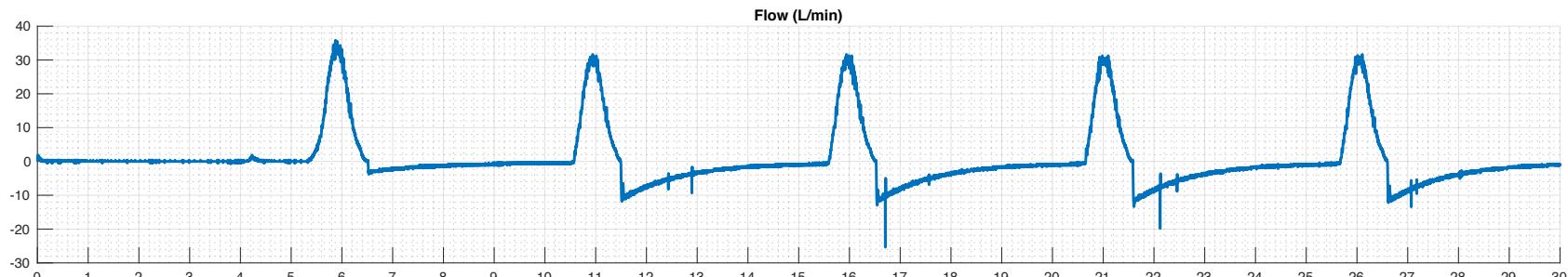
**Triangular Flow Profile (Accelerating-Decelerating)**



Breath Rate (BPM)	19.642	P_peak (cmH <sub>2</sub> O)	24.484
I/E	0.408	P_pause (cmH <sub>2</sub> O)	19.285
Pause Time (s)	0.203	PEEP (cmH <sub>2</sub> O)	4.983
I Time (s)	0.885	Patient Insp Vt (mL)	265.938

Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
6	20	50	300	12	1 I/E =1:4	10

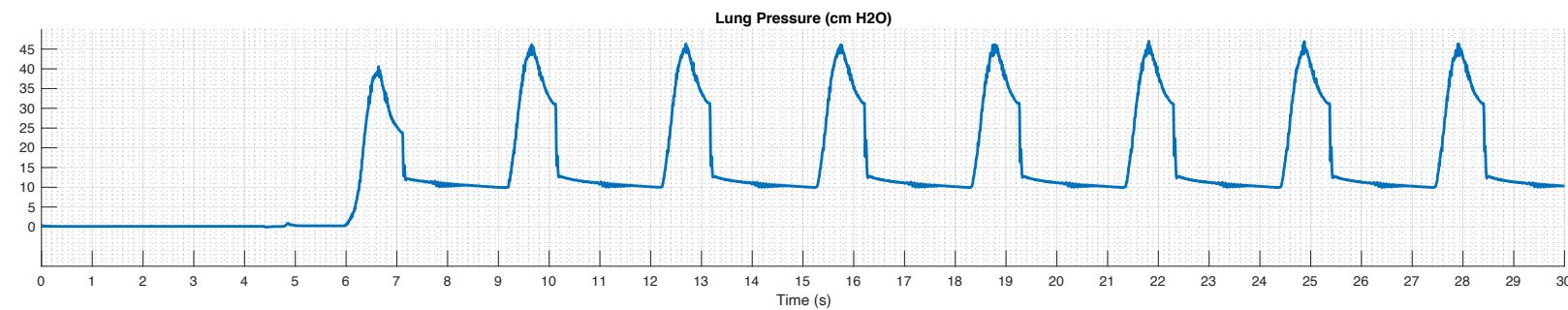
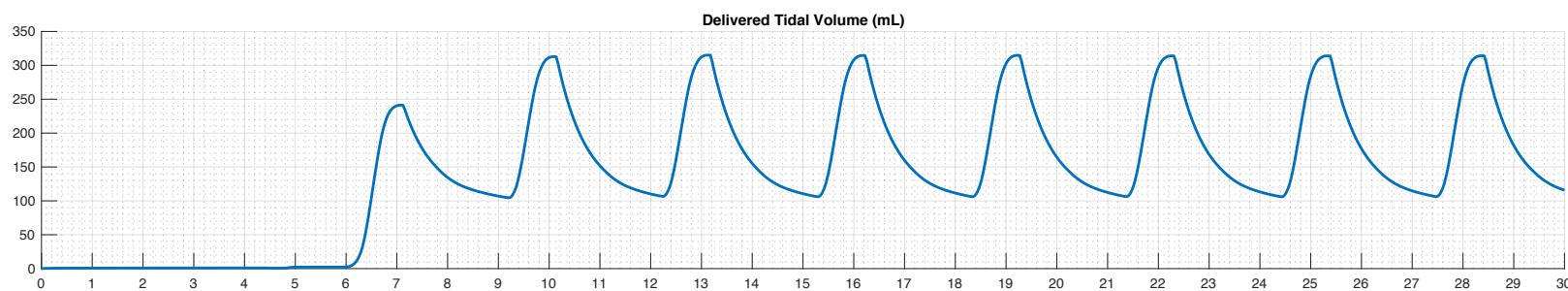
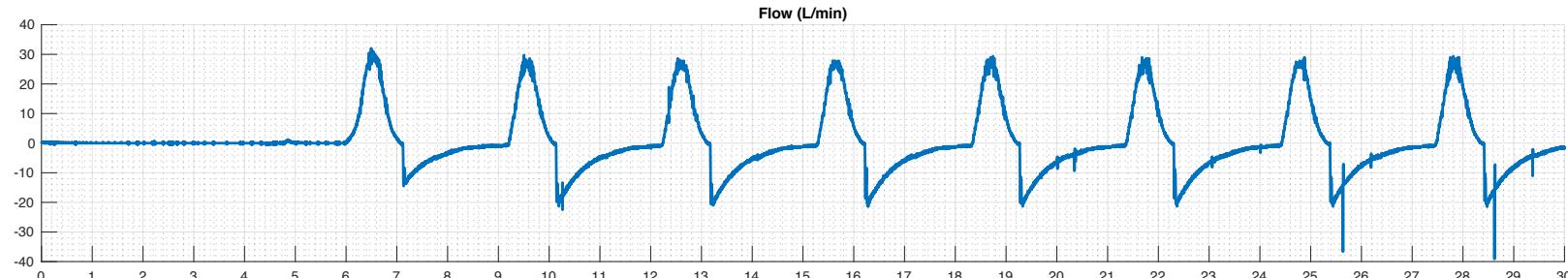
**Triangular Flow Profile (Accelerating-Decelerating)**



Breath Rate (BPM)	11.944	P_peak (cmH <sub>2</sub> O)	42.850
I/E	0.202	P_pause (cmH <sub>2</sub> O)	28.939
Pause Time (s)	0.146	PEEP (cmH <sub>2</sub> O)	10.377
I Time (s)	0.846	Patient Insp Vt (mL)	258.382

Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
7	10	50	300	20	1 I/E =1:2	10

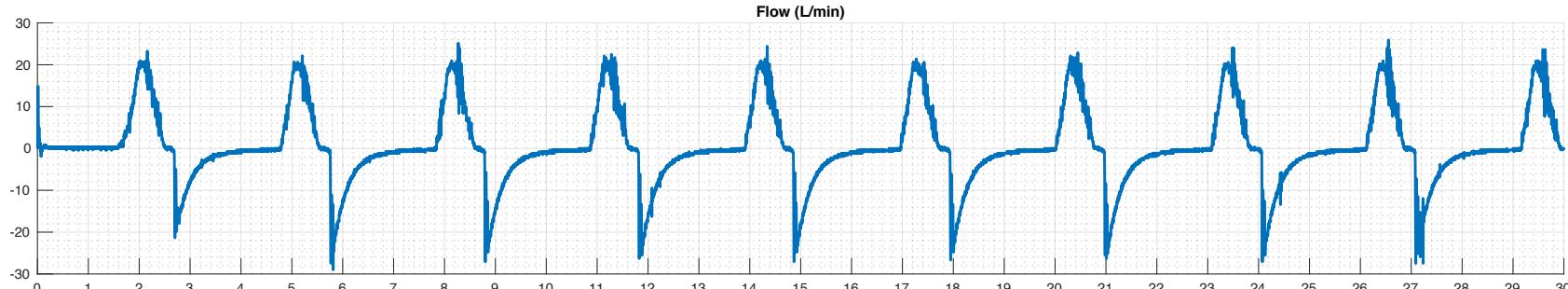
**Triangular Flow Profile (Accelerating-Decelerating)**



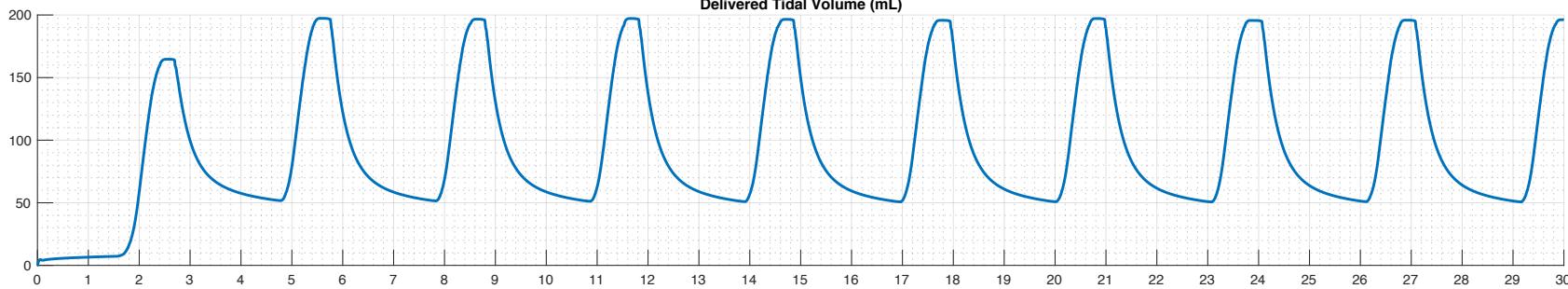
▲ Breath Rate (BPM)	19.896	▲ P_peak (cmH <sub>2</sub> O)	45.429
▲ I/E	0.388	▲ P_pause (cmH <sub>2</sub> O)	35.491
▲ Pause Time (s)	0.152	▲ PEEP (cmH <sub>2</sub> O)	10.035
▲ I Time (s)	0.844	▲ Patient Insp Vt (mL)	232.605

Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
8	10	20	200	20	1 I/E =1:2	5

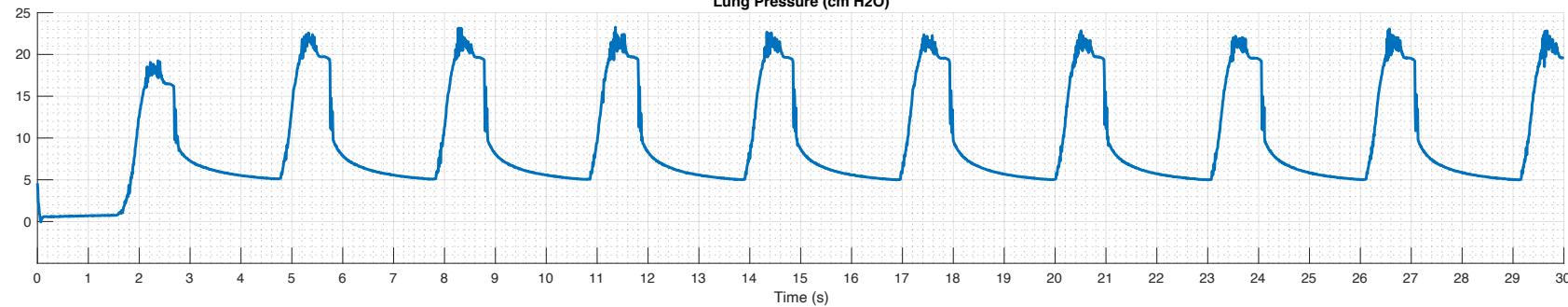
### Triangular Flow Profile (Accelerating-Decelerating)



Delivered Tidal Volume (mL)



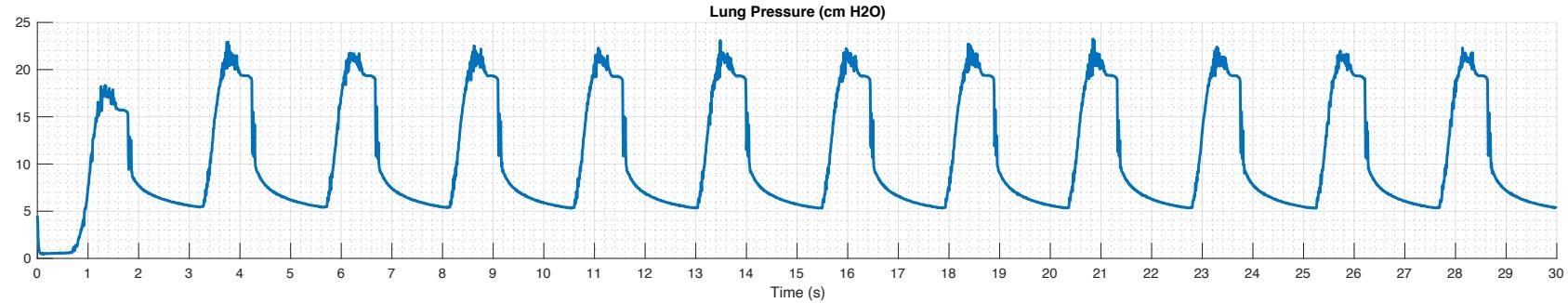
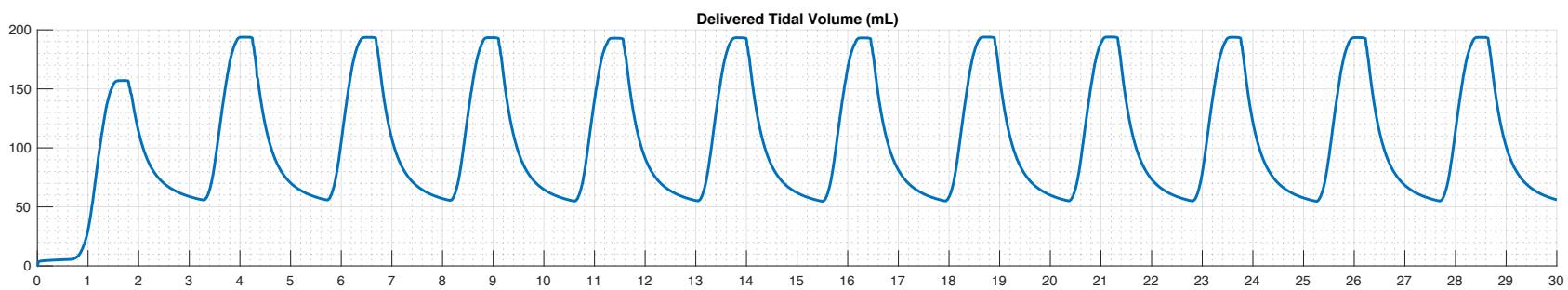
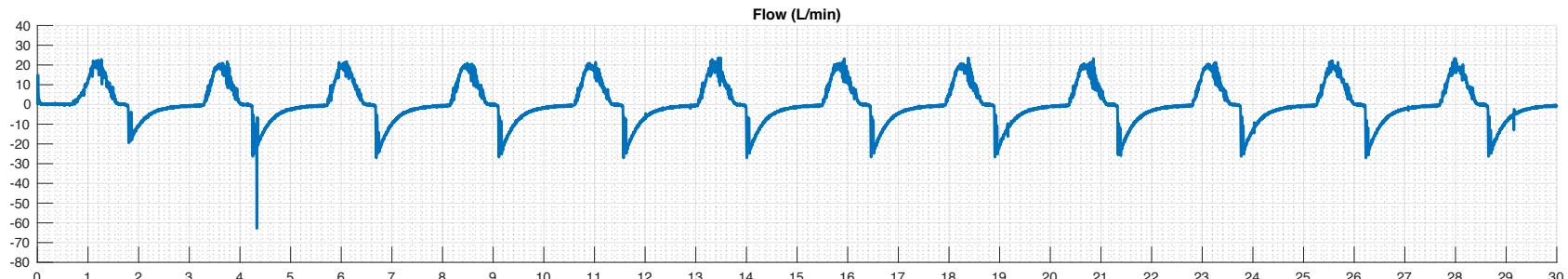
Lung Pressure (cm H<sub>2</sub>O)



▼ Breath Rate (BPM)	19.781	▼ P_peak (cmH <sub>2</sub> O)	21.762
▼ I/E	0.403	▼ P_pause (cmH <sub>2</sub> O)	19.914
▼ Pause Time (s)	0.232	▼ PEEP (cmH <sub>2</sub> O)	5.022
▼ I Time (s)	0.871	▼ Patient Insp Vt (mL)	158.740

Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
9	10	20	200	25	1 I/E =1:1.4	5

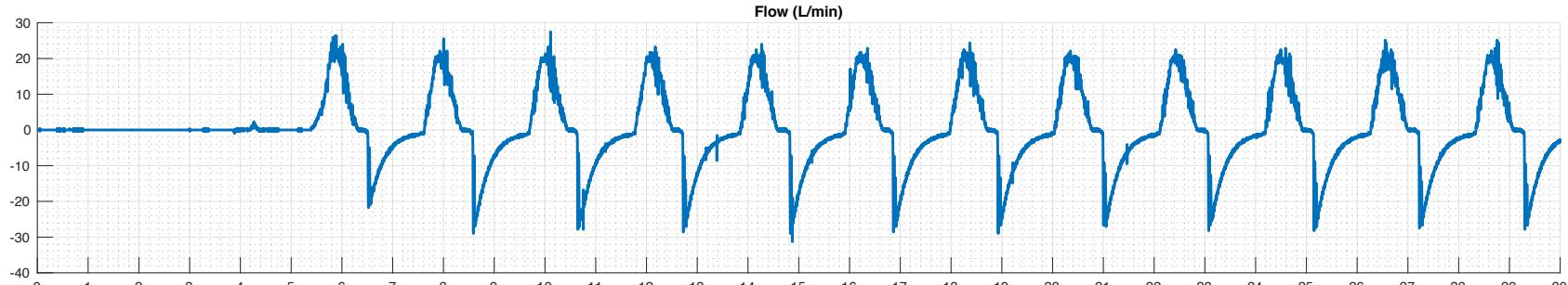
**Triangular Flow Profile (Accelerating-Decelerating)**



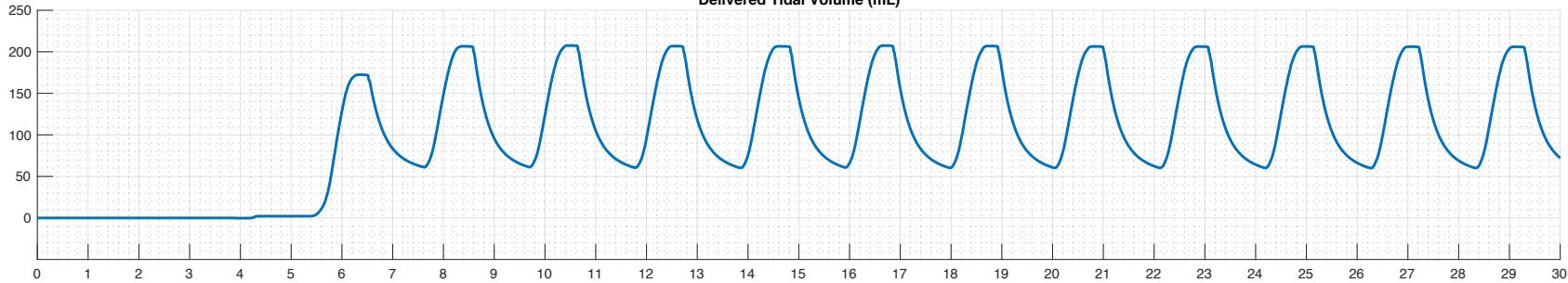
▲ Breath Rate (BPM)	24.478	▲ P_peak (cmH <sub>2</sub> O)	21.578
▲ I/E	0.480	▲ P_pause (cmH <sub>2</sub> O)	20.274
▲ Pause Time (s)	0.213	▲ PEEP (cmH <sub>2</sub> O)	5.343
▲ I Time (s)	0.795	▲ Patient Insp Vt (mL)	151.479

Test Num.	Compliance (ml/cm H <sub>2</sub> O)	Linear Resistance (cm H <sub>2</sub> O/(L/s))	Volume (ml)	Ventilator Frequency <sup>1</sup> (breaths/min)	Inspiratory Time (s)	PEEP (cm H <sub>2</sub> O)
10	10	20	200	30	1 I/E =1:1	5

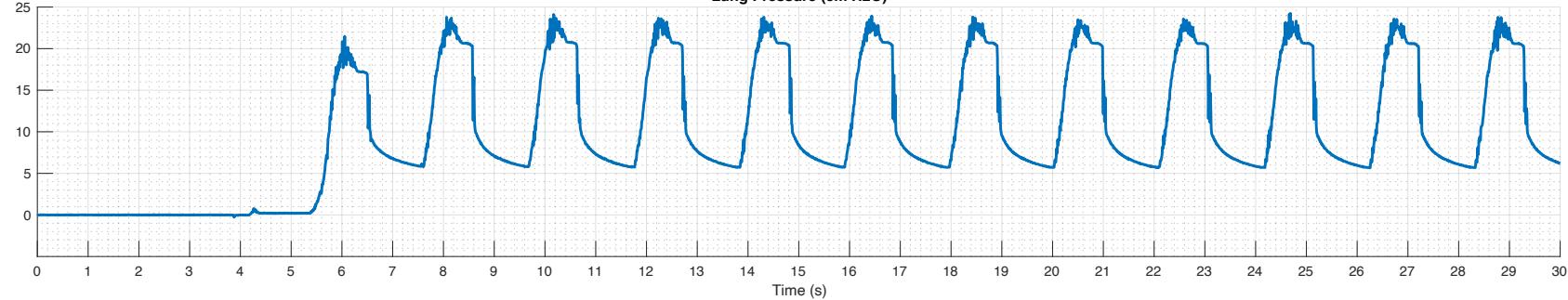
### Triangular Flow Profile (Accelerating-Decelerating)



### Delivered Tidal Volume (mL)



### Lung Pressure (cm H<sub>2</sub>O)



Breath Rate (BPM)	29.009	P_peak (cmH2O)	23.051
I/E	0.629	P_pause (cmH2O)	21.388
Pause Time (s)	0.230	PEEP (cmH2O)	5.682
I Time (s)	0.799	Patient Insp Vt (mL)	159.421