

Cardiovascular JSim Models

Ported from Vincent C. Rideout's
“Mathematical Computer Modeling
Of Physiological Systems” (1991)

By Dan Hoory, Physiome Project Volunteer

Compartmental Models (Chapter 3)

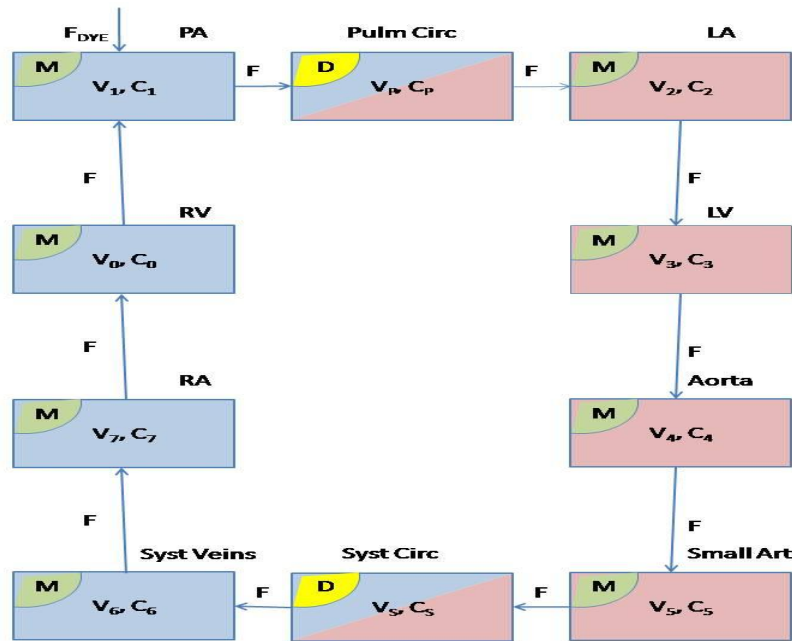
- Rideout IndicatorDilution: Compartmental CV indicator dilution with pulmonary flow used as constant reference
- Rideout IndicatorDilution Modified: Compartmental CV indicator dilution with systemic flow used as constant reference

Pressure-Flow Models (Chapter 4)

- [Rideout PressureFlowLH](#): Left heart and systemic arteries
- [Rideout PressureFlow0](#): Uncontrolled CV loop
- [Rideout PressureFlow1](#): Uncontrolled CV loop
- [Rideout PressureFlowReg](#): CV loop with baroreceptor regulation
- [Rideout PressureFlowNP](#): CV loop nonpulsatile model

Rideout_IndicatorDilution

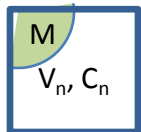
Mode 1: Healthy Heart (Closed Loop)



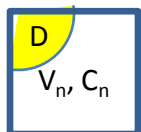
Legend:



Compartment: volume V_n , concentration C_n



Perfect Mixing Compartment

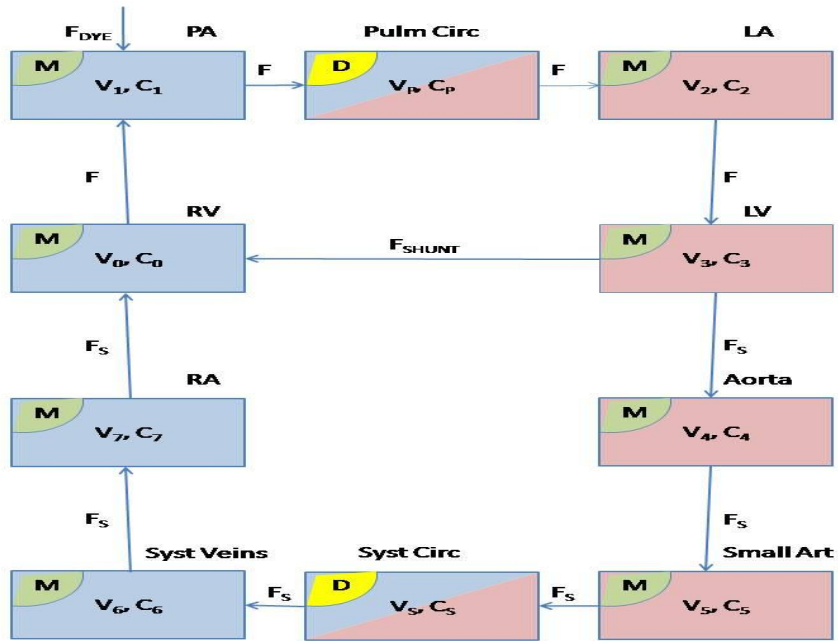


Delay Compartment

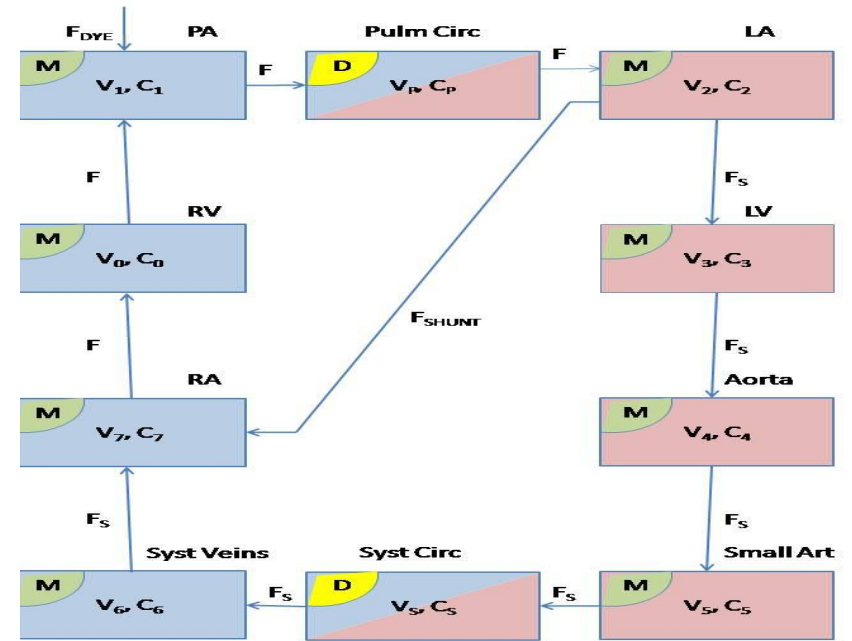
Compartment Characteristics:

| | Anatomy Represented | Volume [ml] | Time Constant [sec] (for $F = 100$ ml/s) |
|---|-----------------------|-------------|--|
| 0 | Right Ventricle | 125 | 1.25 |
| 1 | Pulmonary Artery | 250 | 2.50 |
| P | Pulmonary Circulation | 500 | 5.00 |
| 2 | Left Atrium | 125 | 1.25 |
| 3 | Left Ventricle | 125 | 1.25 |
| 4 | Aorta, Large Arteries | 750 | 7.50 |
| 5 | Small Arteries | 200 | 2.00 |
| S | Systemic Circulation | 800 | 8.00 |
| 6 | Systemic Veins | 1000 | 10.00 |
| 7 | Right Atrium | 125 | 1.25 |
| | Total: | 4000 [ml] | 40 [sec] |

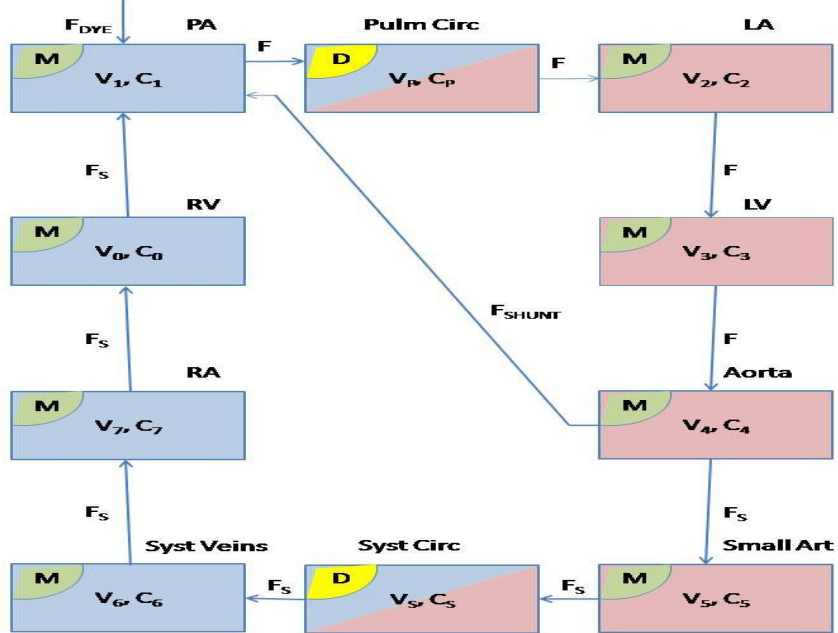
Mode 2: Ventricular Septal Defect (VSD)



Mode 3: Atrial Septal Defect (ASD)



Mode 4: Patent Ductus Arteriosus (PDA)



Mode 5: Open Loop (no recirculation)

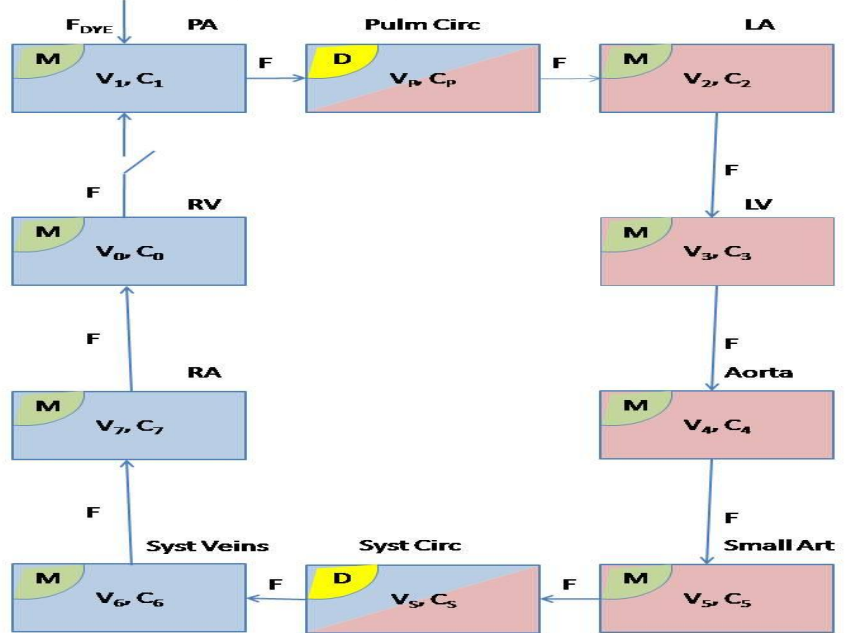


Figure 1 - Indicator Concentrations in a Healthy Heart

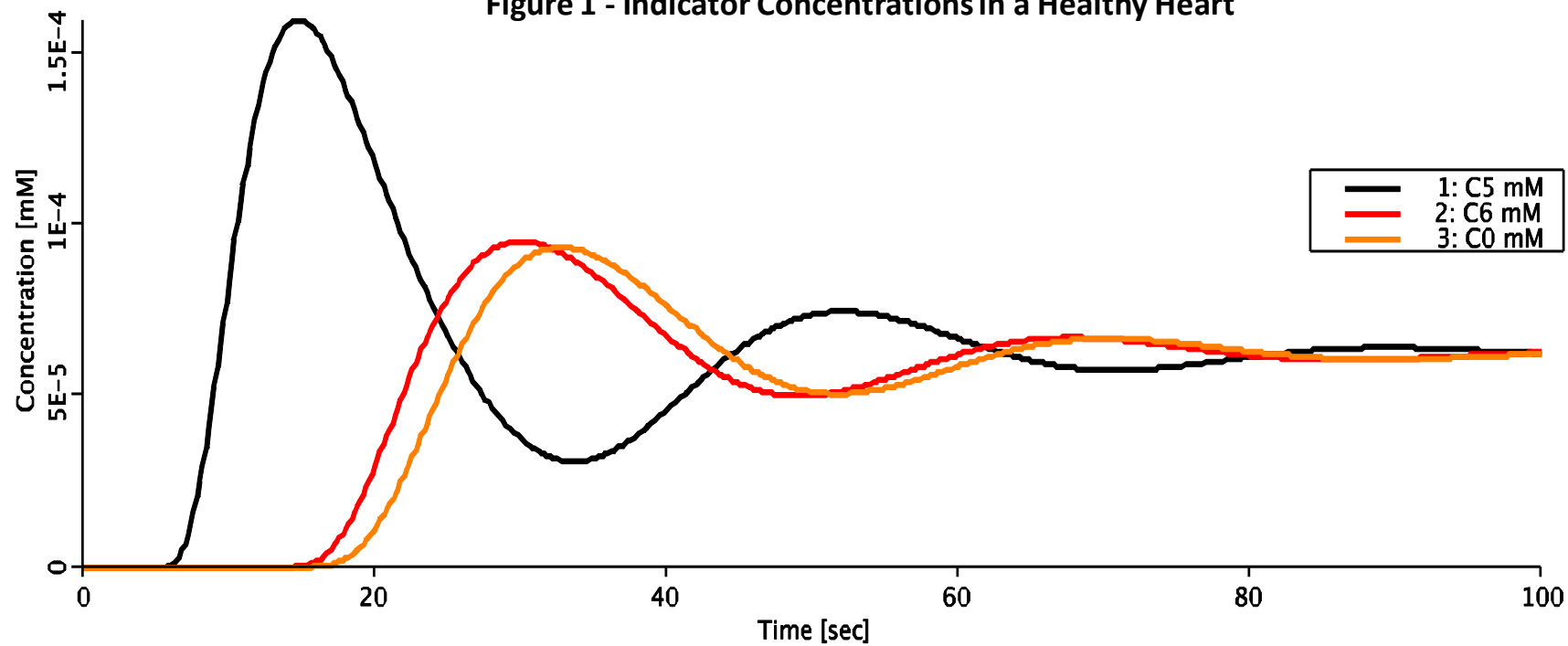
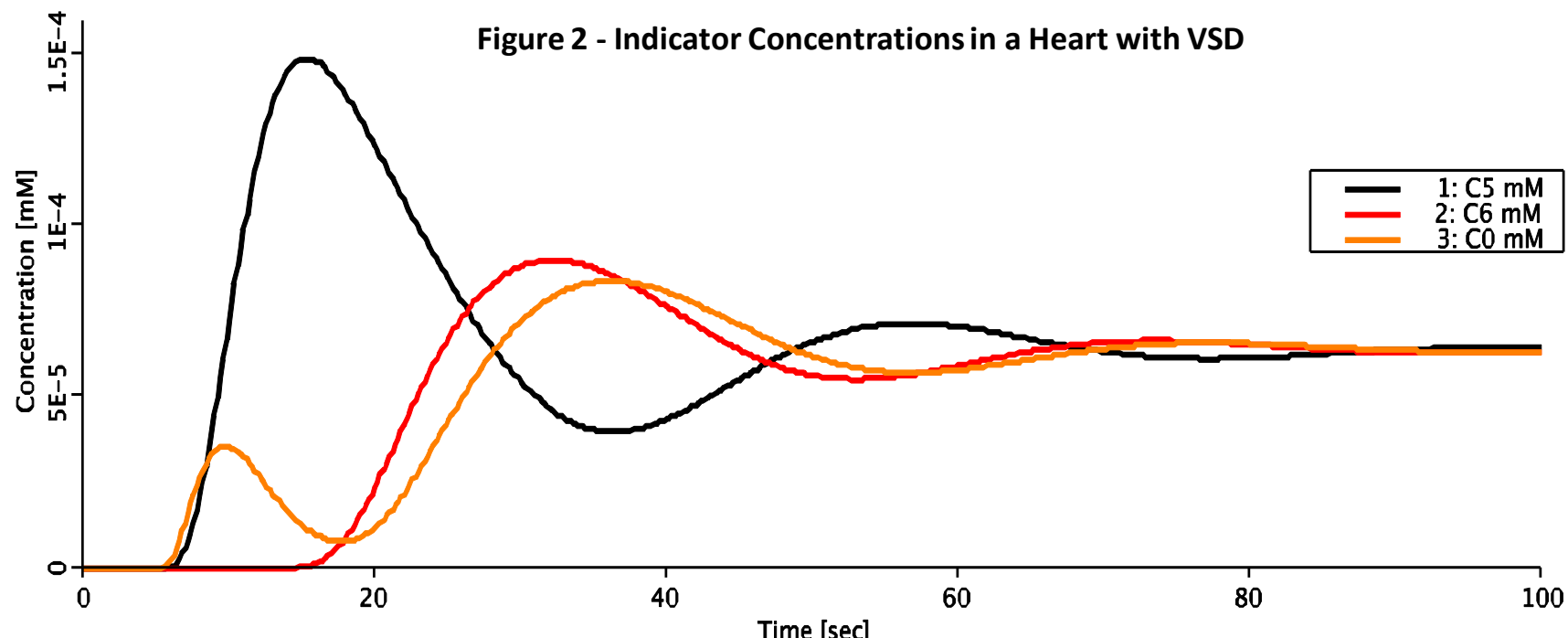
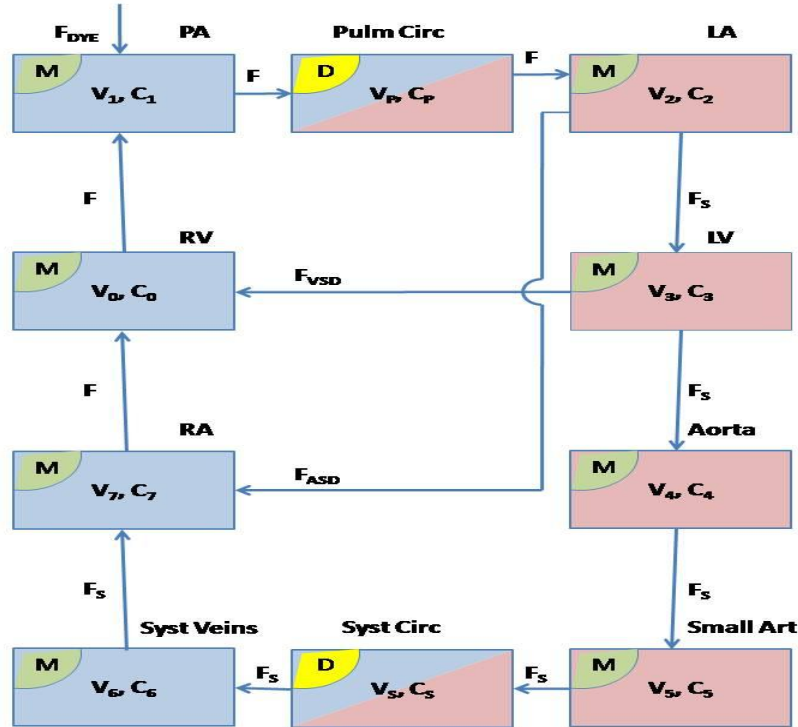


Figure 2 - Indicator Concentrations in a Heart with VSD

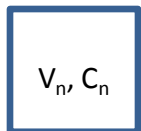


Rideout_IndicatorDilution_Modified

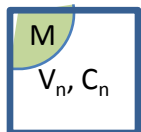
Block Diagram:



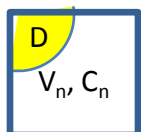
Legend:



Compartment: volume V_n , concentration C_n



Perfect Mixing Compartment

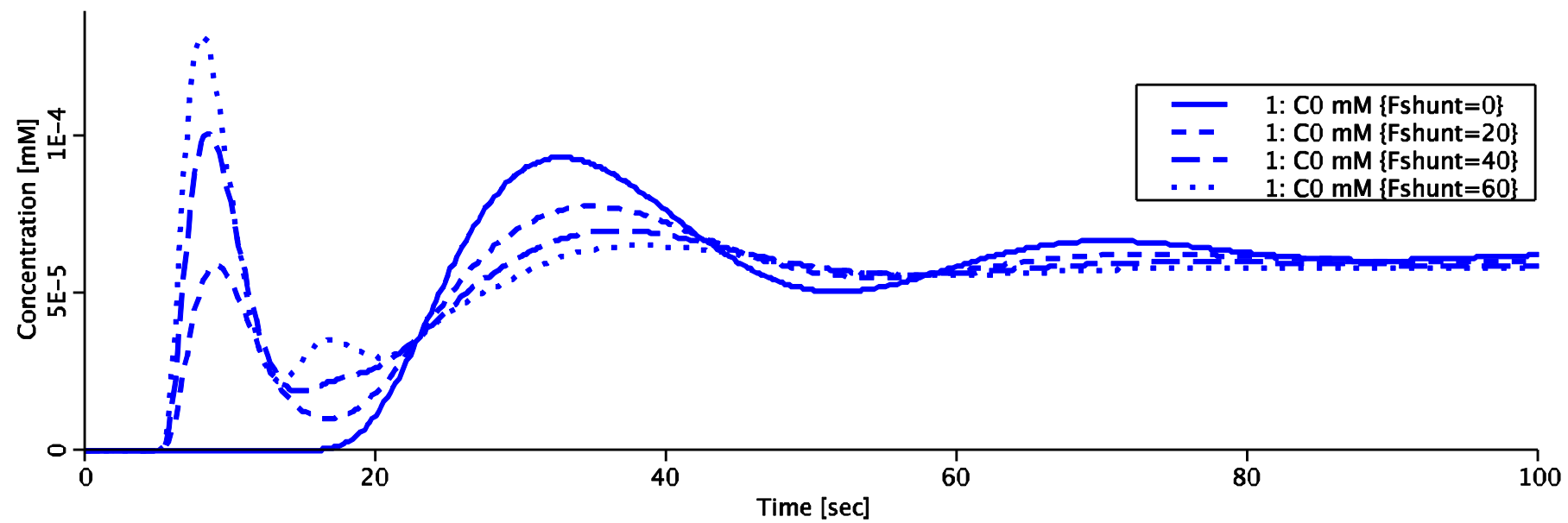


Delay Compartment

Compartment Characteristics:

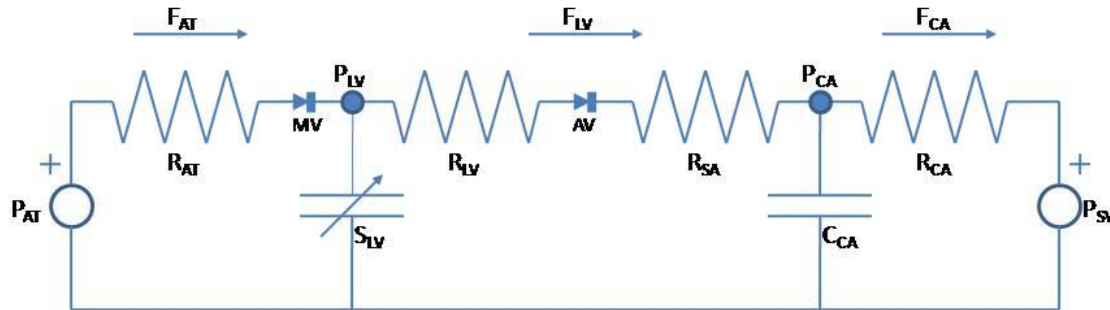
| | Anatomy Represented | Volume [ml] | Time Constant [sec] (for F = 100 ml/s) |
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| 1 | Pulmonary Artery | 250 | 2.50 |
| P | Pulmonary Circulation | 500 | 5.00 |
| 2 | Left Atrium | 125 | 1.25 |
| 3 | Left Ventricle | 125 | 1.25 |
| 4 | Aorta, Large Arteries | 750 | 7.50 |
| 5 | Small Arteries | 200 | 2.00 |
| S | Systemic Circulation | 800 | 8.00 |
| 6 | Systemic Veins | 1000 | 10.00 |
| 7 | Right Atrium | 125 | 1.25 |
| | Total: | 4000 [ml] | 40 [sec] |

Figure 1 - Indicator Dilution Concentration C0 with VSD Shunt Aperture Sweep

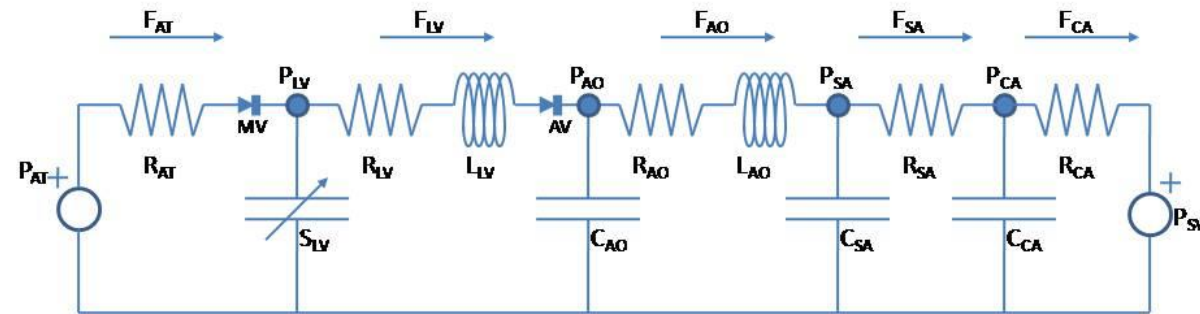


Rideout_PressureFlowLH

BASIC CIRCUIT (LH-PF-1 and LH-PF-2)



IMPROVED CIRCUIT (LH-PF-3)



Legend:

| | |
|----|---|
| F | Flow [ml/sec] |
| P | Pressure [mmHg] |
| Q | Volume [ml] |
| R | Resistance [g/cm ⁴ /sec] |
| C | Compliance [cm ⁴ ·sec ² /g] |
| S | Stiffness (S=1/C) |
| L | Inertance [g/cm ⁴] |
| MV | Mitral Valve |
| AV | Aortic Valve |
| | Constant Pressure |
| | Valve |
| | Resistance |
| | Variable Compliance |
| | Compliance |
| | Inertance |
| | Direction of Flow |

| Suffix | Anatomy | LH-PF-1 , LH-PF-2 | | LH-PF-3 | | |
|--------|--------------------|-------------------|---------------------|---------|-----|---------------------|
| | | R | C · 10 ⁶ | R | L | C · 10 ⁶ |
| AT | Atrium | 5 | | 5 | | |
| LV | Left Ventricle | 5 | Variable | 5 | 0.5 | Variable |
| AO | Aorta | 5 | | 5 | 0.5 | 150 |
| SA | Systemic Arteries | 80 | | 50 | | 300 |
| CA | Capillary Arteries | 1250 | 2200 | 1150 | | 2200 |
| SV | Systemic Veins | | | | | |

Figure 1 – LH-PF-3 Ventricular Stiffness, S_{LV}

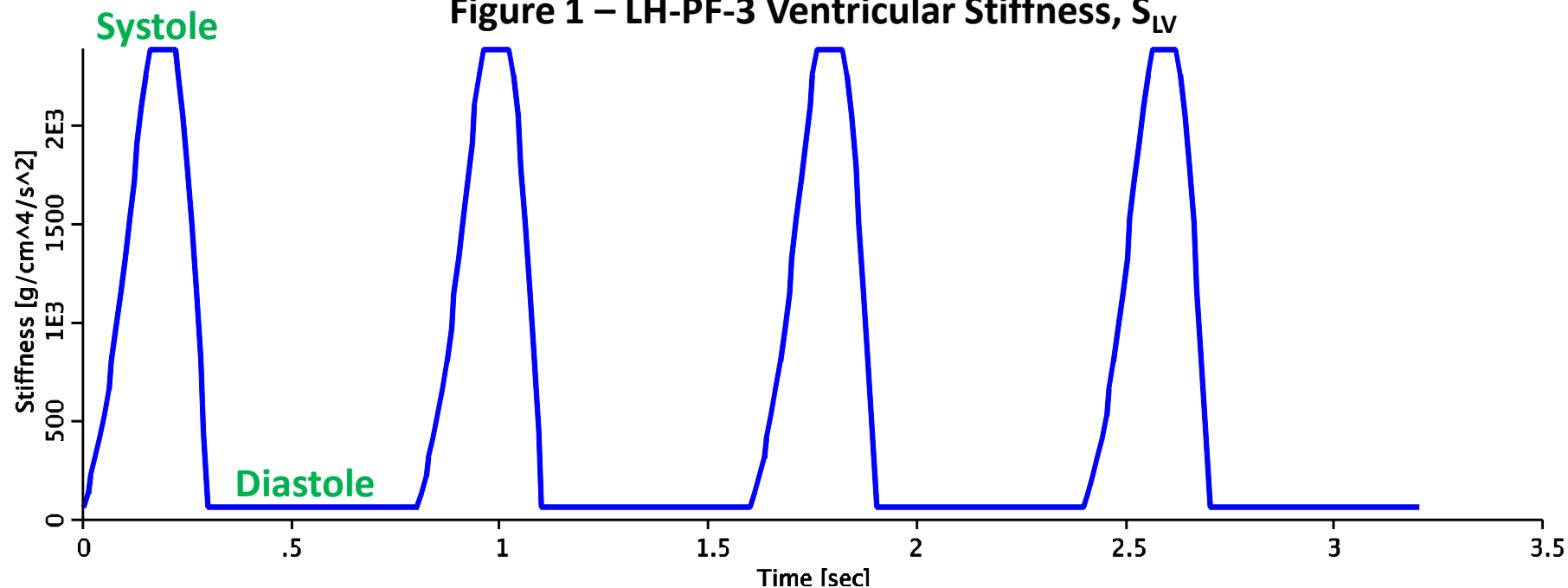


Figure 2 – LH-PF-3 Locus on the P_{LV} vs. Q_{LV} Plane

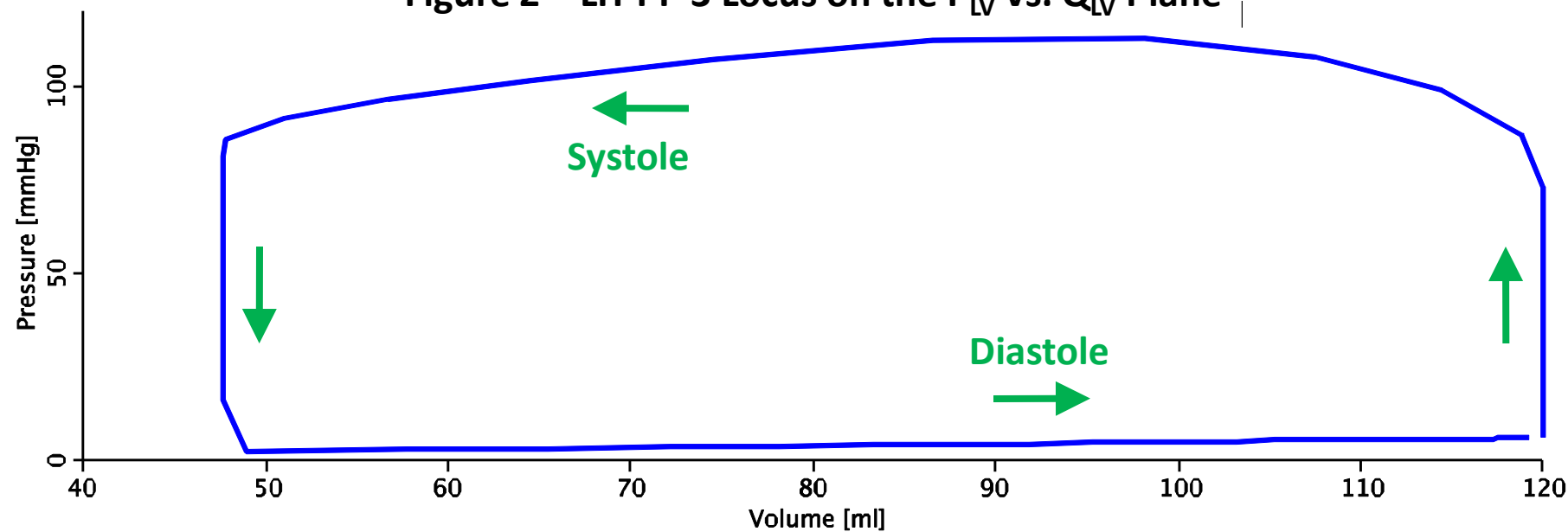


Figure 3 – Flows in LH-PF-3

Diastolic Inflow, F_{AT} ; Systolic Outflow, F_{LV} ; Aortic F_{AO} ; Systemic Arterial, F_{SA} ; Load F_{CA}

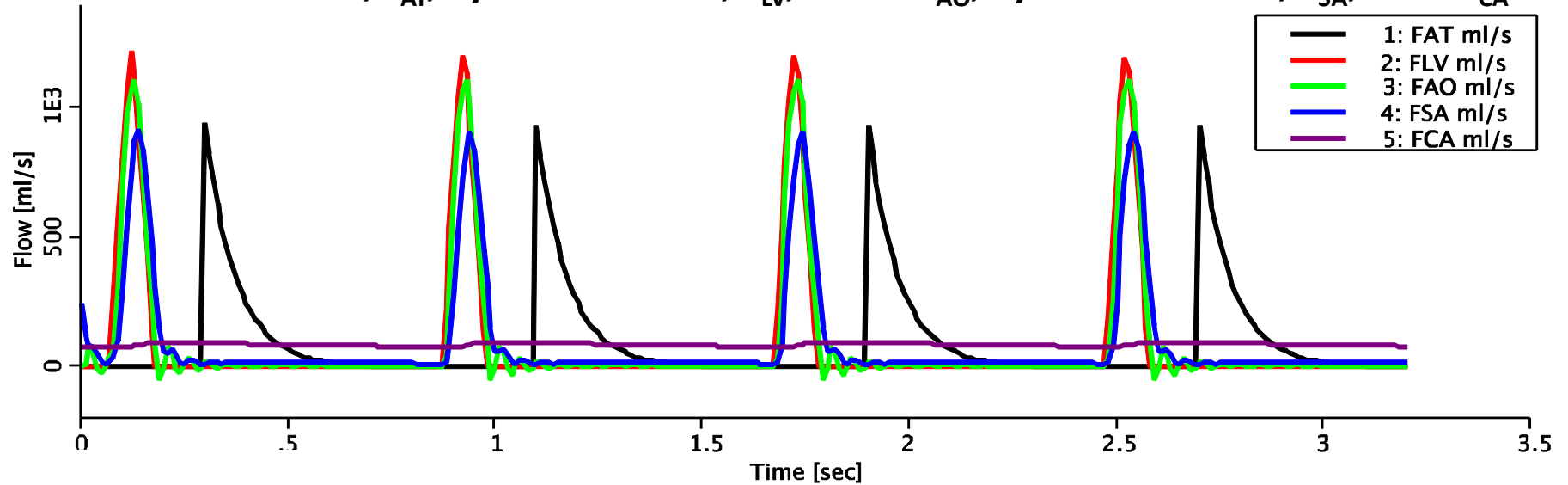
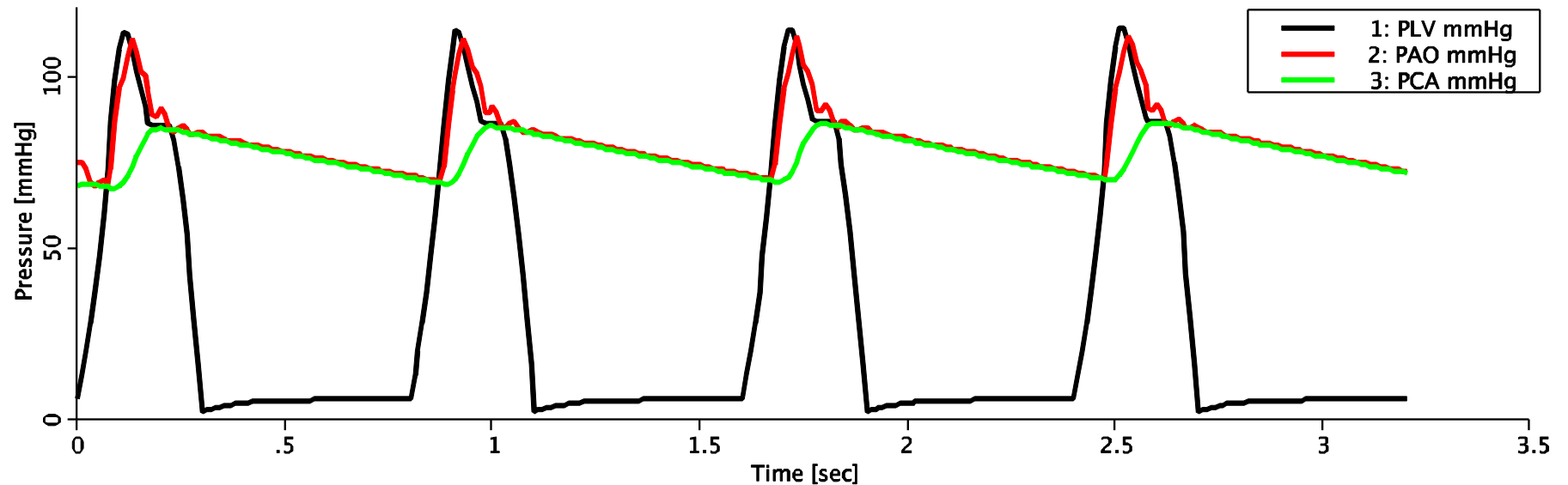


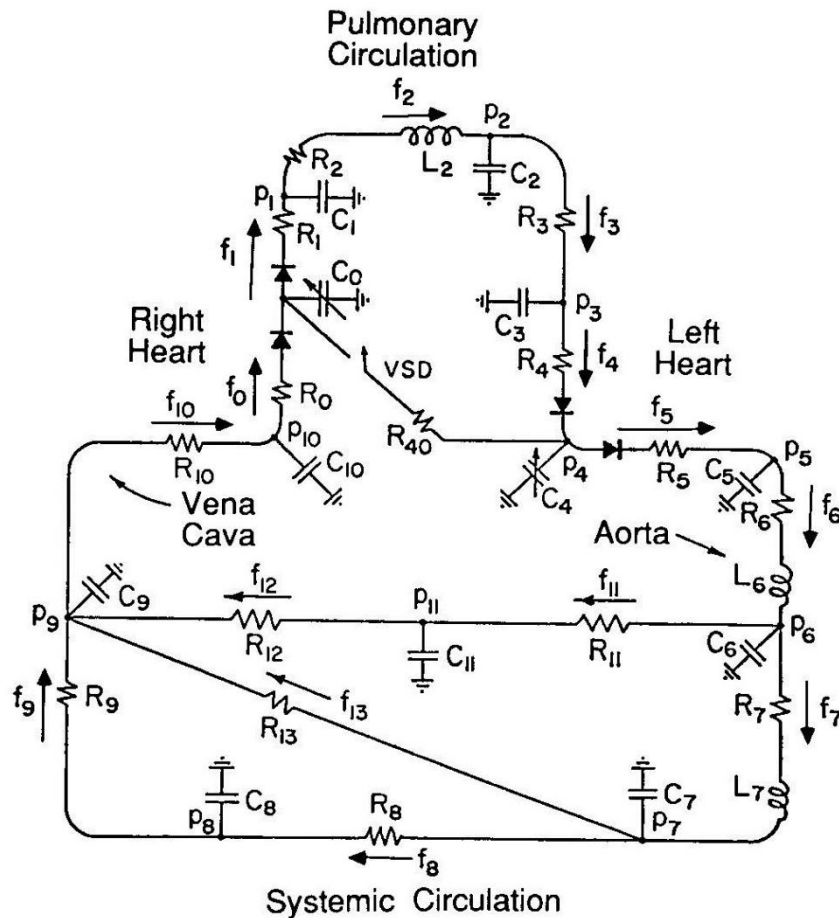
Figure 4 – Pressures in LH-PF-3

Ventricular Pressure, P_{LV} ; Aortic Pressure, P_{AO} ; Load Pressure, P_{CA}



Rideout_PressureFlow0

Rideout's Complete CV Loop Model, PF-0

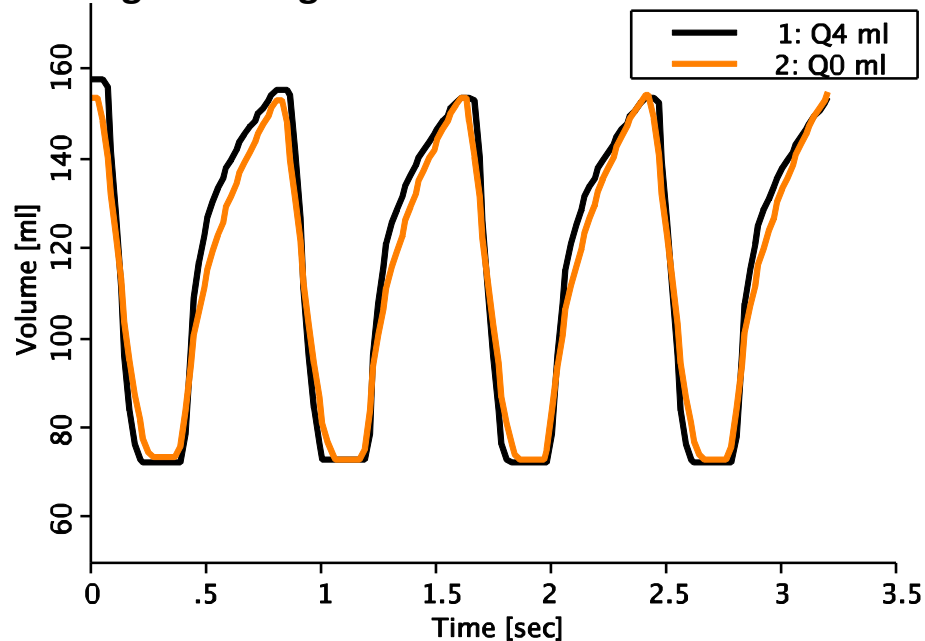
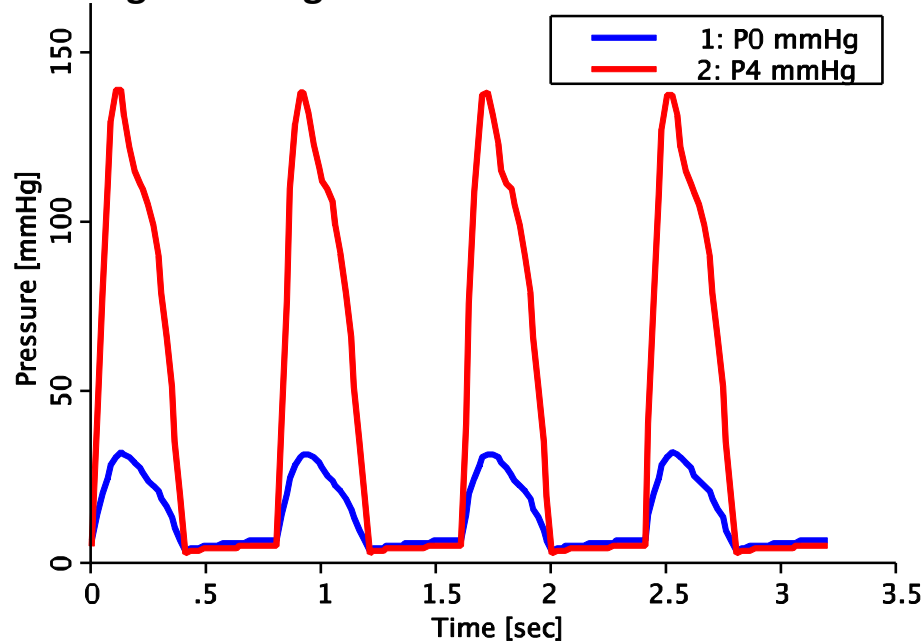
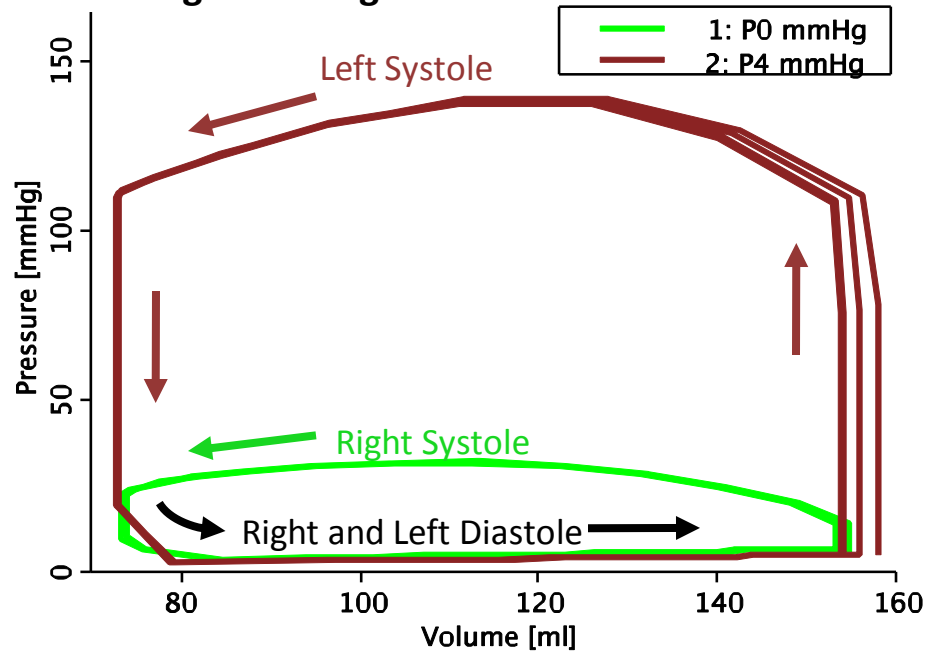
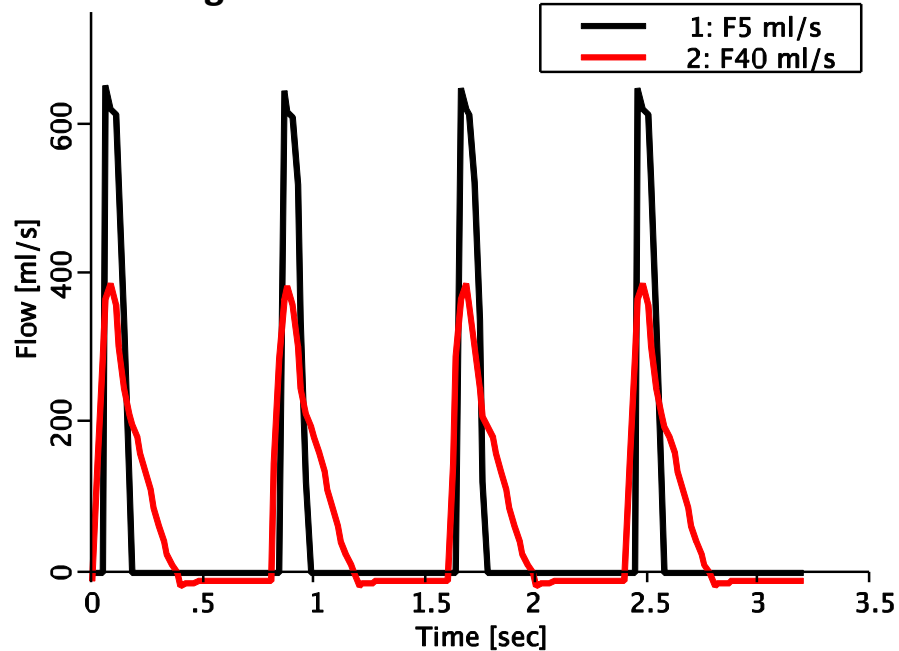


Legend:

| | |
|-----------------|--|
| $f \rightarrow$ | Flow [ml/sec] |
| R | Resistance [$\text{g}/\text{cm}^4/\text{sec}$] |
| C | Compliance [$\text{cm}^4 \cdot \text{sec}^2/\text{g}$] |
| L | Inertance [g/cm^4] |
| | Valve |

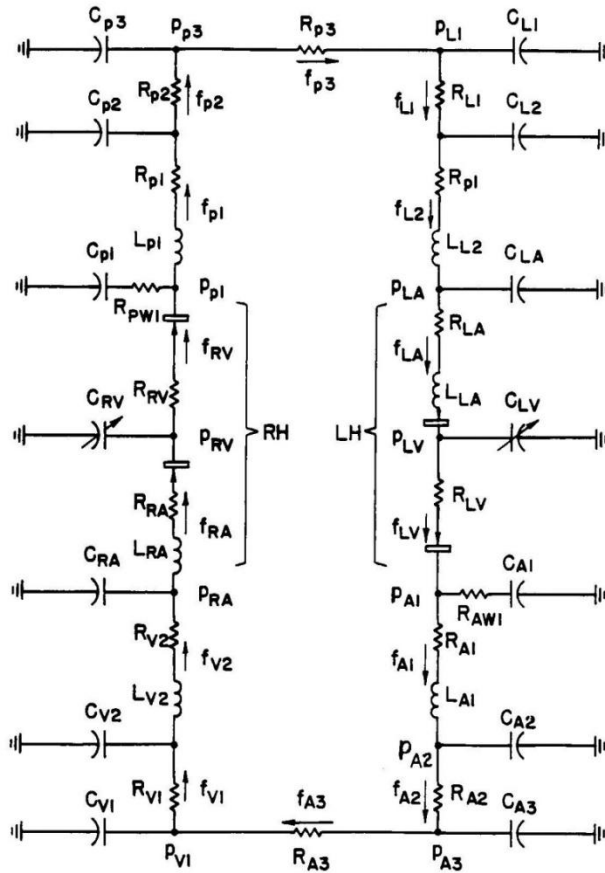
Parameter Values

| | Anatomy | R | L | $C \cdot 10^6$ |
|----|----------------------|------|-------|----------------|
| 0 | Right Ventricle | 10 | | Variable |
| 1 | Pulmonary Artery | 10 | | 1001 |
| 2 | Pulmonary Artery 2 | 27 | 1.332 | 3003 |
| 3 | Lung Capillaries | 150 | | 5005 |
| 4 | Left Ventricle | 10 | | Variable |
| 5 | Ascending Aorta | 13 | | 501 |
| 6 | Descending Aorta | 7 | 1.332 | 1001 |
| 7 | Abdominal Aorta | 27 | 1.332 | 1336 |
| 8 | Leg Arteries | 5328 | | 8314 |
| 9 | Leg Veins | 13 | | 1001 |
| 10 | Vena Cava | 13 | | 5005 |
| 11 | Upper Body Arteries | 1332 | | 2002 |
| 12 | Upper Body Veins | 1332 | | |
| 13 | Internal Organ Veins | 5328 | | |
| 40 | VSD | 250 | | |

Figure 1 - Right and Left Ventricular Volumes**Figure 2 - Right and Left Ventricular Pressures****Figure 3 - Right and Left Ventricle Loci****Figure 4 - VSD: Aortic and VSD flows**

Rideout_PressureFlow1

Rideout's Complete CV Loop Model, PF-1



Legend:

| | |
|-----------------|---|
| $f \rightarrow$ | Flow [ml/sec] |
| R | Resistance [g/cm ⁴ /sec] |
| C | Compliance [cm ⁴ ·sec ² /g] |
| L | Inertance [g/cm ⁴] |
| Valve | Valve |

Parameter Values

| Suffix | Anatomy | R | L | C · 10 ⁶ |
|--------|--------------------|------|---|---------------------|
| P1 | Pulmonary Artery 1 | 10 | 1 | 100 |
| P2 | Pulmonary Artery 2 | 40 | | 300 |
| P3 | Pulmonary Artery 3 | 80 | | 2700 |
| L1 | Pulmonary Veins 1 | 30 | | 1000 |
| L2 | Pulmonary Veins 2 | 10 | 1 | 1000 |
| LA | Left Atrium | 5 | 1 | 11760 |
| LV | Left Ventricle | 5 | 1 | Variable |
| A1 | Aorta 1 | 10 | 1 | 180 |
| A2 | Aorta 2 | 160 | | 230 |
| A3 | Aorta 3 | 1000 | | 1820 |
| V1 | Systemic Veins 1 | 90 | | 21000 |
| V2 | Systemic Veins 2 | 10 | 1 | 45000 |
| RA | Right Atrium | 5 | 1 | 45000 |
| RV | Right Ventricle | 5 | 1 | Variable |

Figure 1 - Right and Left Ventricular Volumes

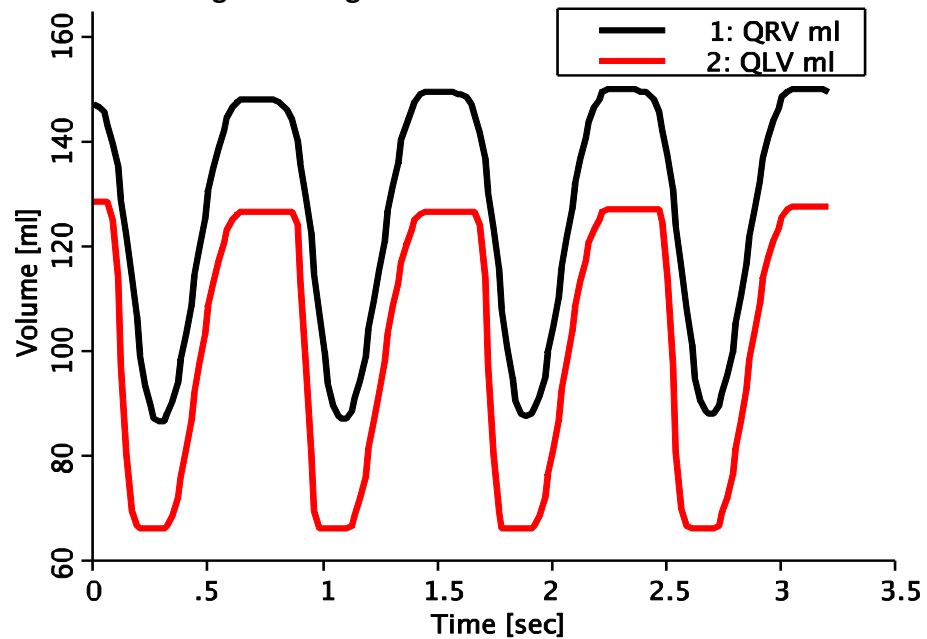


Figure 2 - Left Ventricular Locus

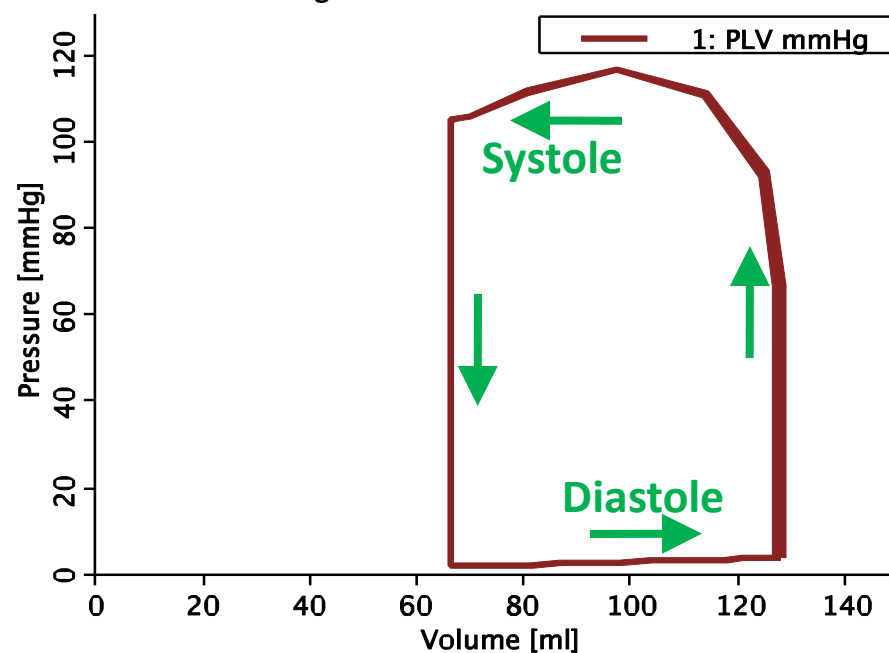


Figure 3 - Right Ventricular and Pulm. Artery Pressures

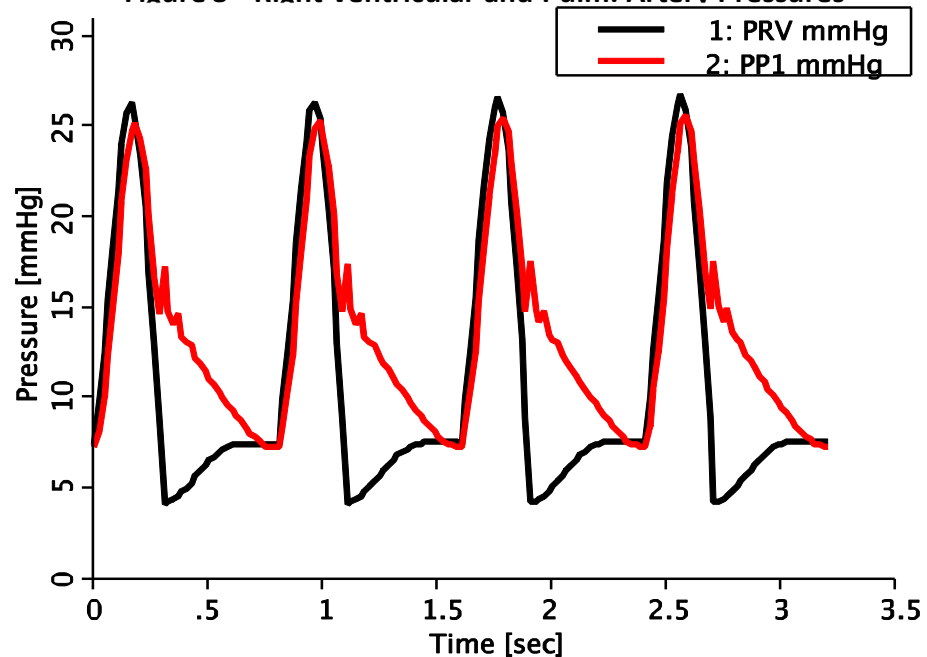


Figure 4 - Left Ventricular and Aortic Pressures

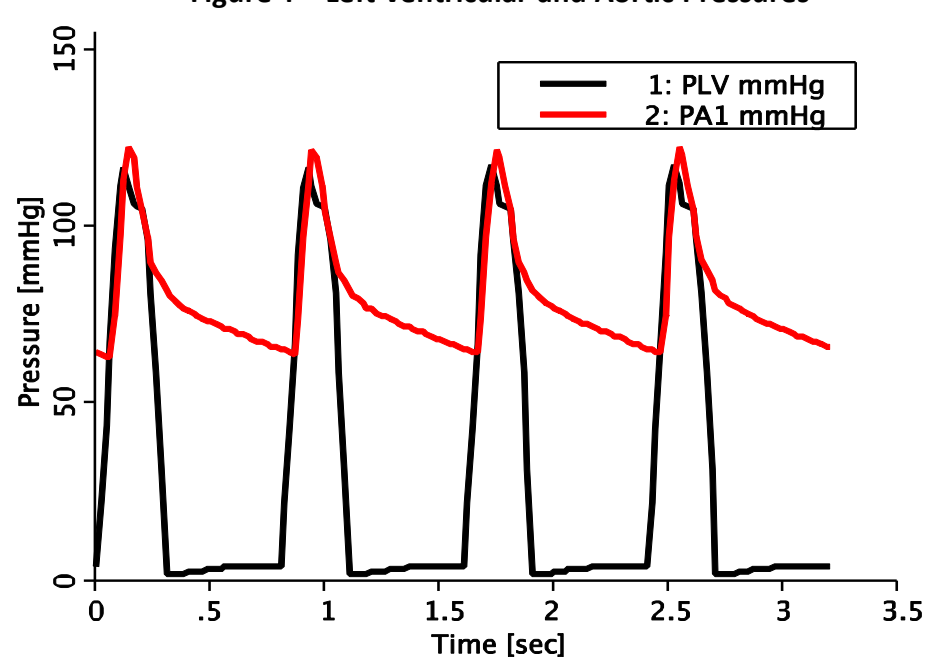


Figure 5 - Aortic and Left Atrial Flows

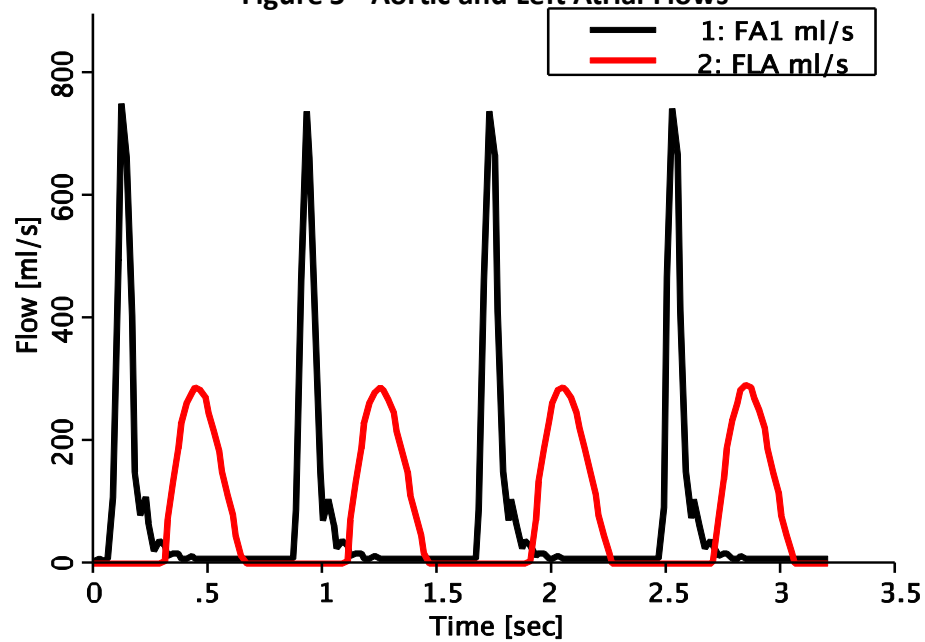


Figure 6 - Myocardial Infarction: Right Stiffness

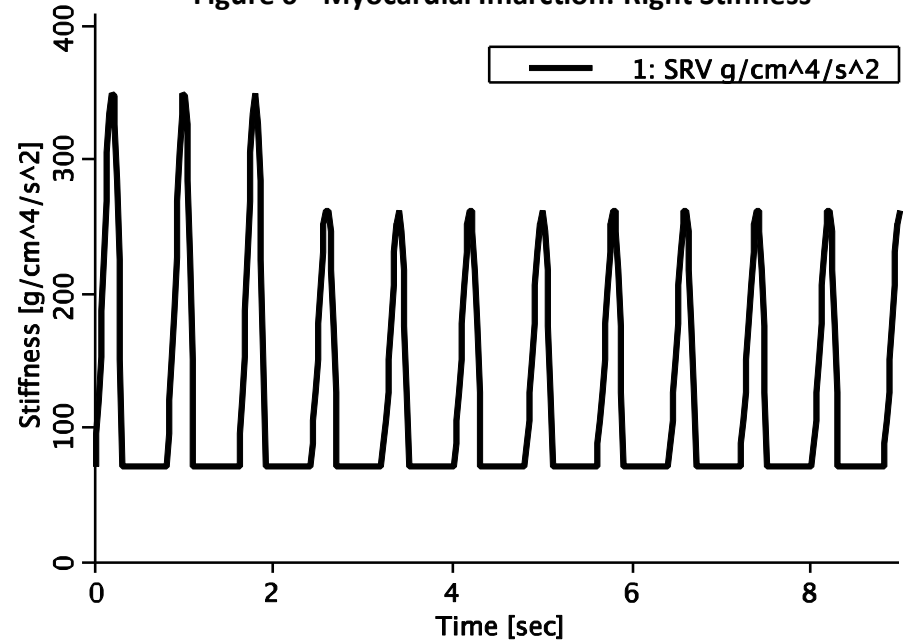


Figure 7 - Myocardial Infarction: Left Stiffness

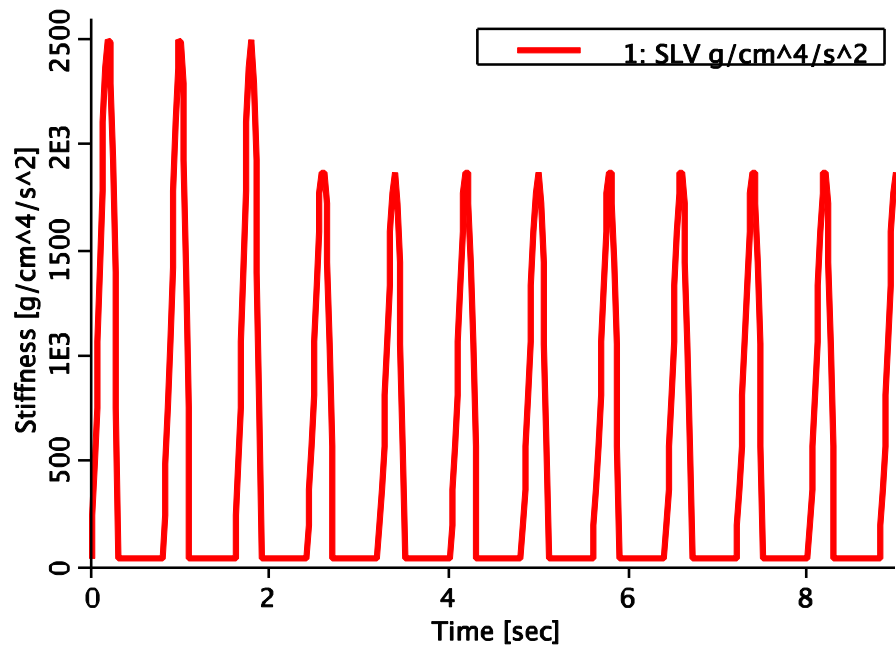
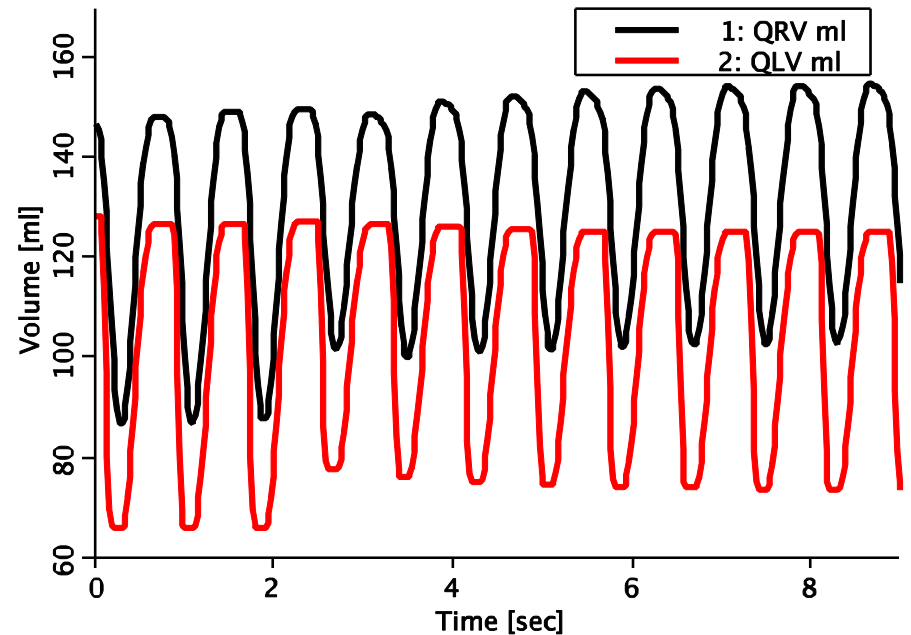
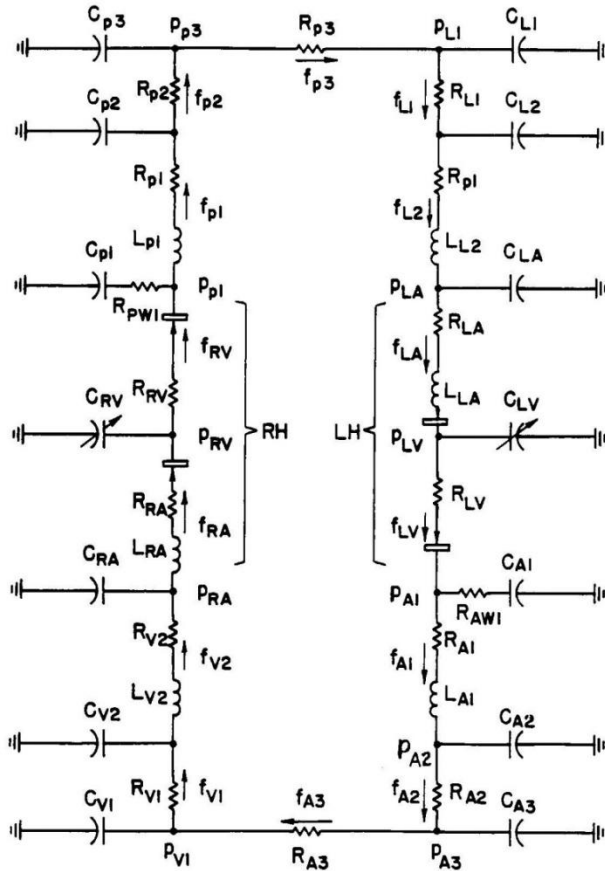


Figure 8 - Myocardial Infarction: Ventricular Volumes



Rideout_PressureFlowReg

Rideout's Regulated CV Loop Model, PF-1-REG



Legend:

| | |
|-----------------|---|
| $f \rightarrow$ | Flow [ml/sec] |
| R | Resistance [g/cm ⁴ /sec] |
| C | Compliance [cm ⁴ ·sec ² /g] |
| L | Inertance [g/cm ⁴] |
| | Valve |

Parameter Values

| Suffix | Anatomy | R | L | C · 10 ⁶ |
|--------|--------------------|------|---|---------------------|
| P1 | Pulmonary Artery 1 | 10 | 1 | 200 |
| P2 | Pulmonary Artery 2 | 40 | | 400 |
| P3 | Pulmonary Artery 3 | 80 | | 2700 |
| L1 | Pulmonary Veins 1 | 30 | | 1000 |
| L2 | Pulmonary Veins 2 | 10 | 1 | 1000 |
| LA | Left Atrium | 5 | 1 | 11760 |
| LV | Left Ventricle | 5 | 1 | Variable |
| A1 | Aorta 1 | 10 | 1 | 180 |
| A2 | Aorta 2 | 160 | | 230 |
| A3 | Carotid (Aorta 3) | 1000 | | 1820 |
| V1 | Systemic Veins 1 | 90 | | 21000 |
| V2 | Systemic Veins 2 | 10 | 1 | 45000 |
| RA | Right Atrium | 5 | 1 | 45000 |
| RV | Right Ventricle | 5 | 1 | Variable |

Feedback Loop Diagram

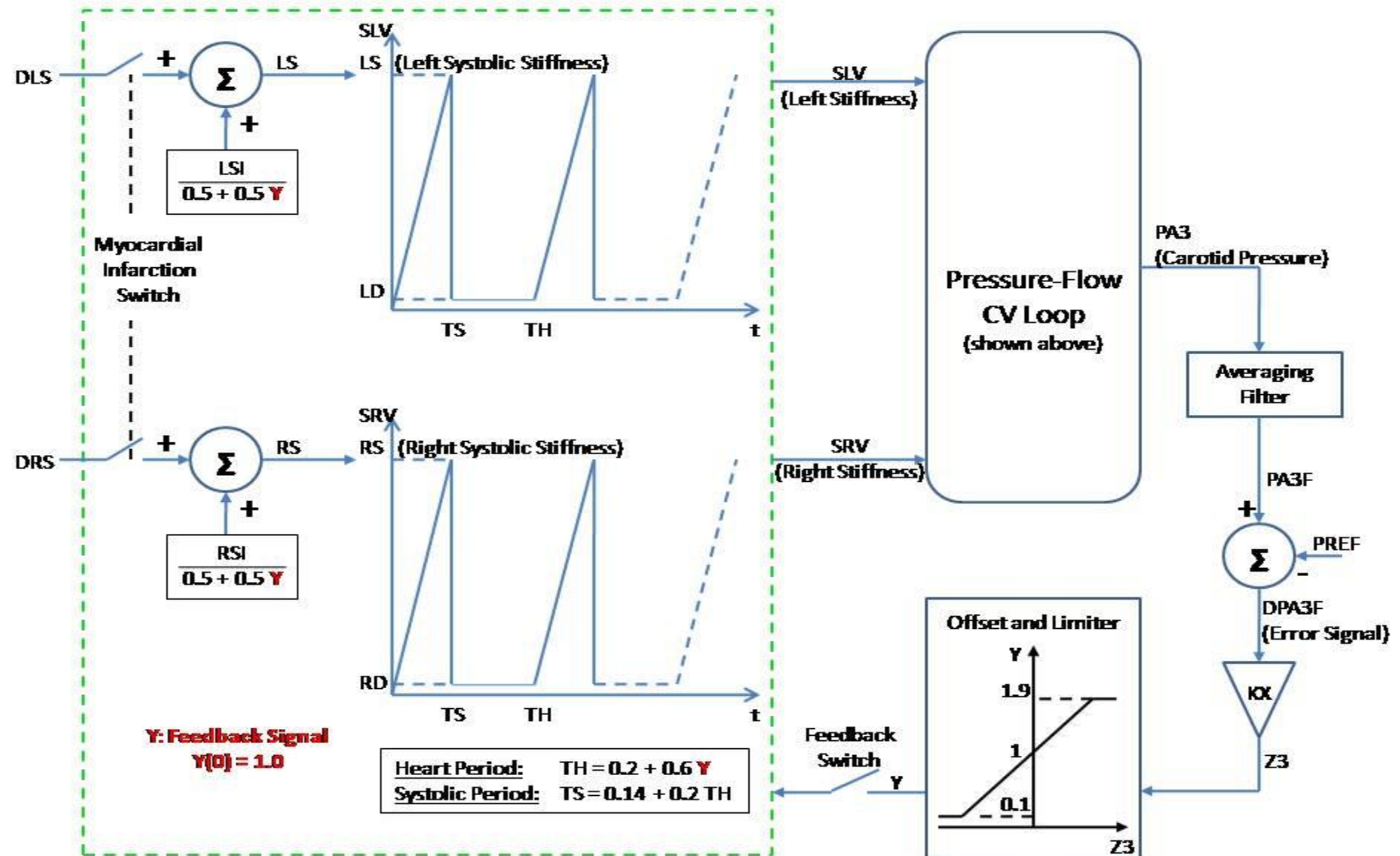


Figure 1 – Open-Loop: Left and Right Ventricular Volumes

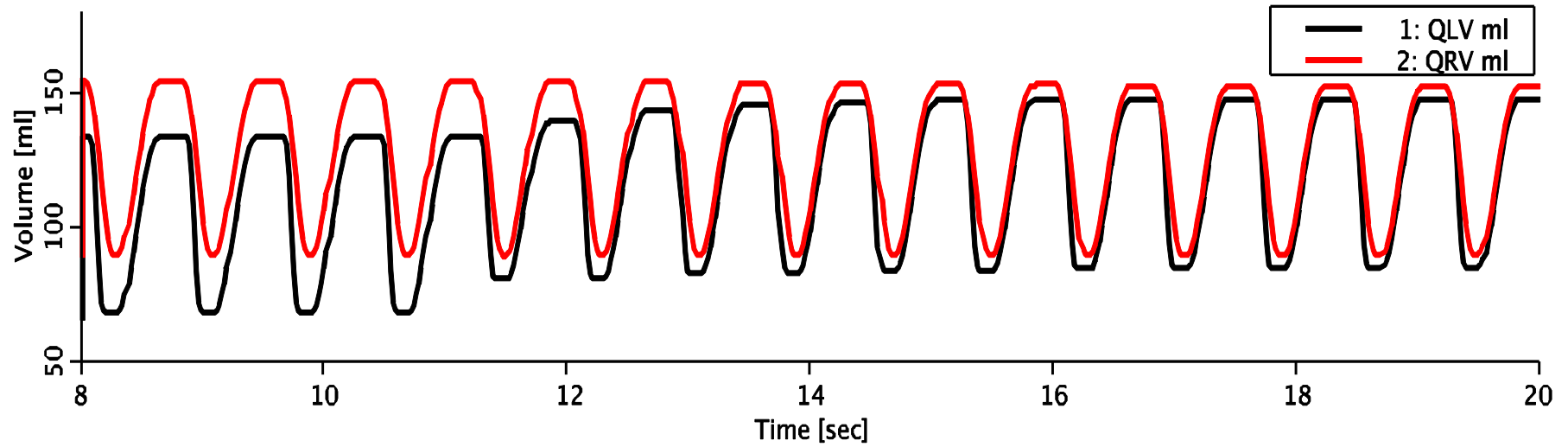


Figure 2 – Open-Loop: Filtered Carotid Pressure

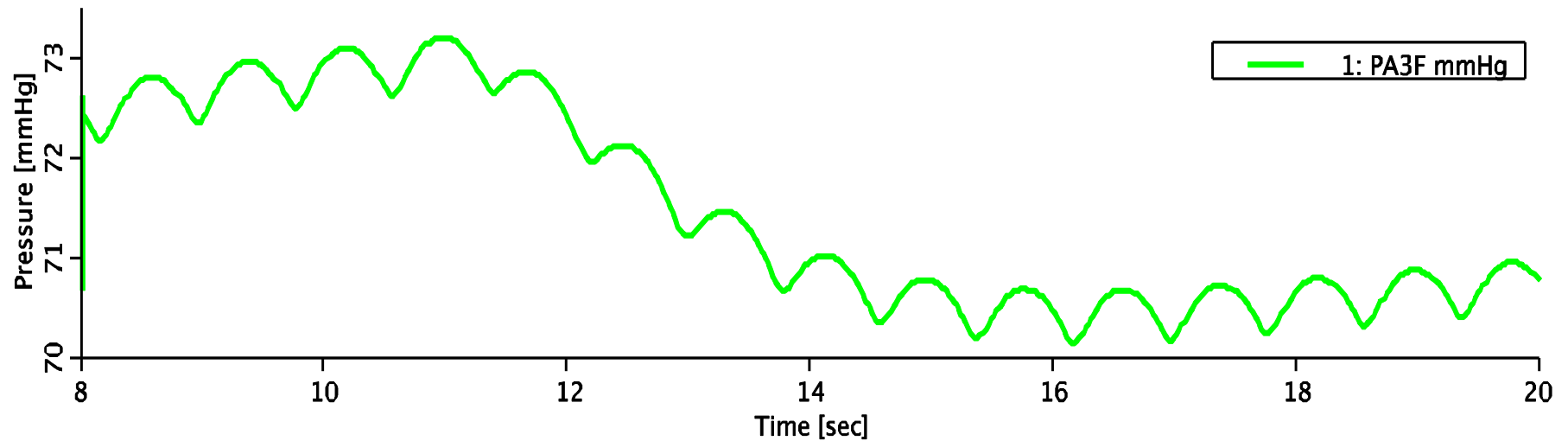


Figure 3 – Closed-Loop: Feedback Signal Y

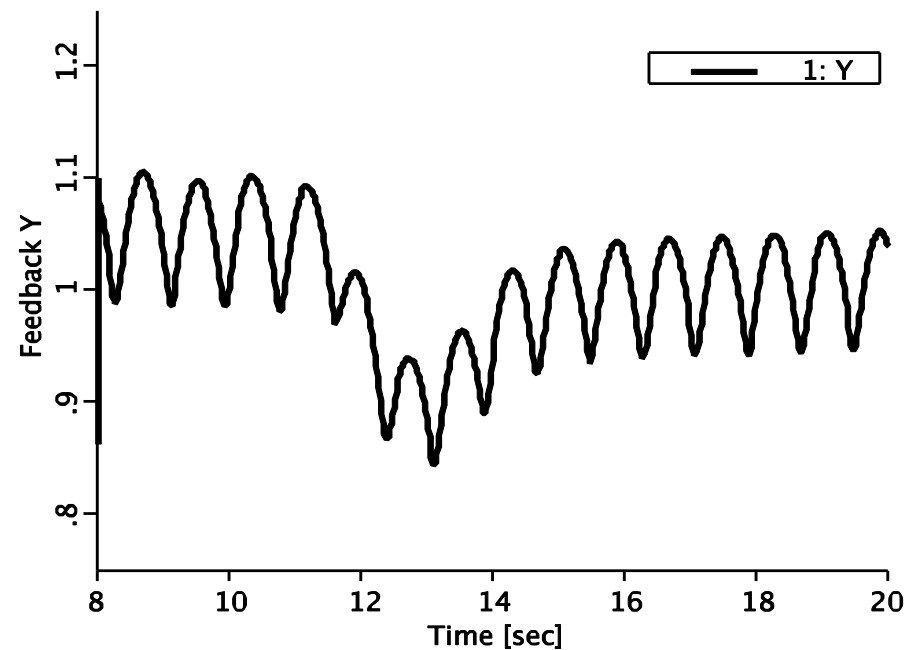


Figure 4 – Closed-Loop: Heart Period TH

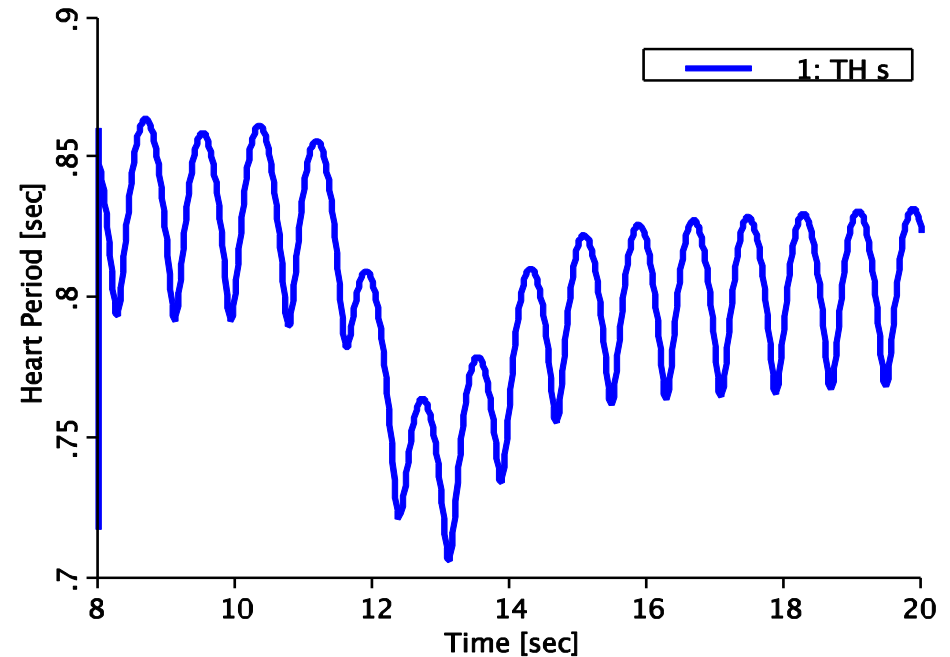


Figure 5 – Closed-Loop: Left Ventricle Stiffness LS

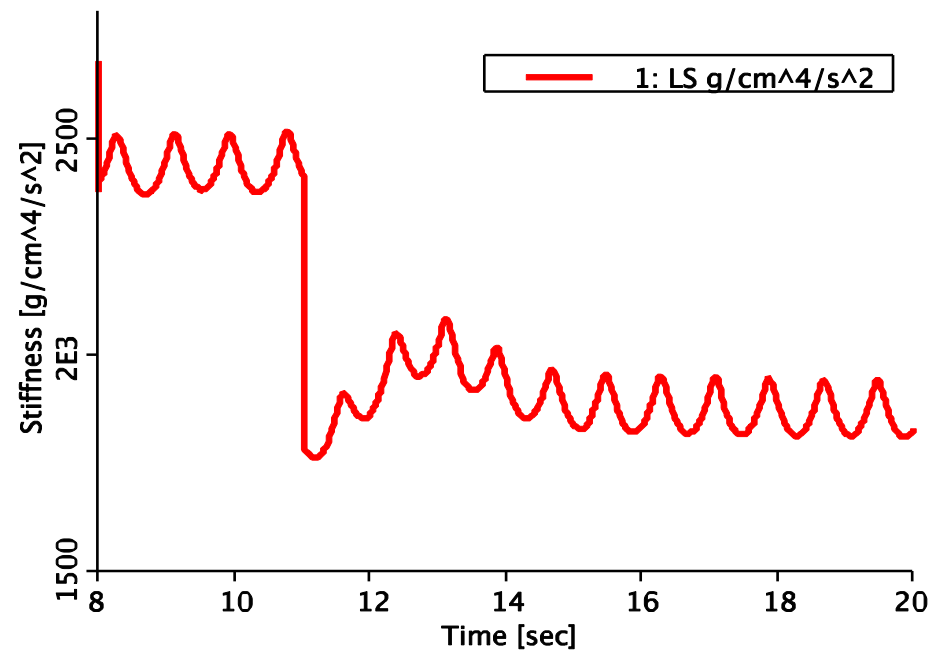


Figure 6 - Closed-Loop: Right Ventricle Stiffness RS

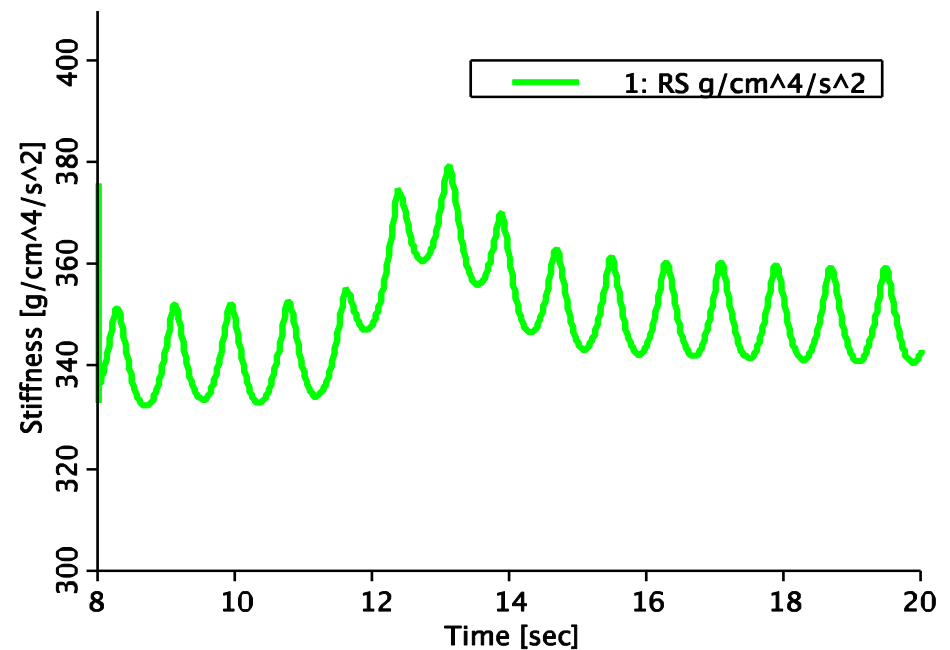


Figure 7 – Closed-Loop: Left and Right Ventricular Volumes

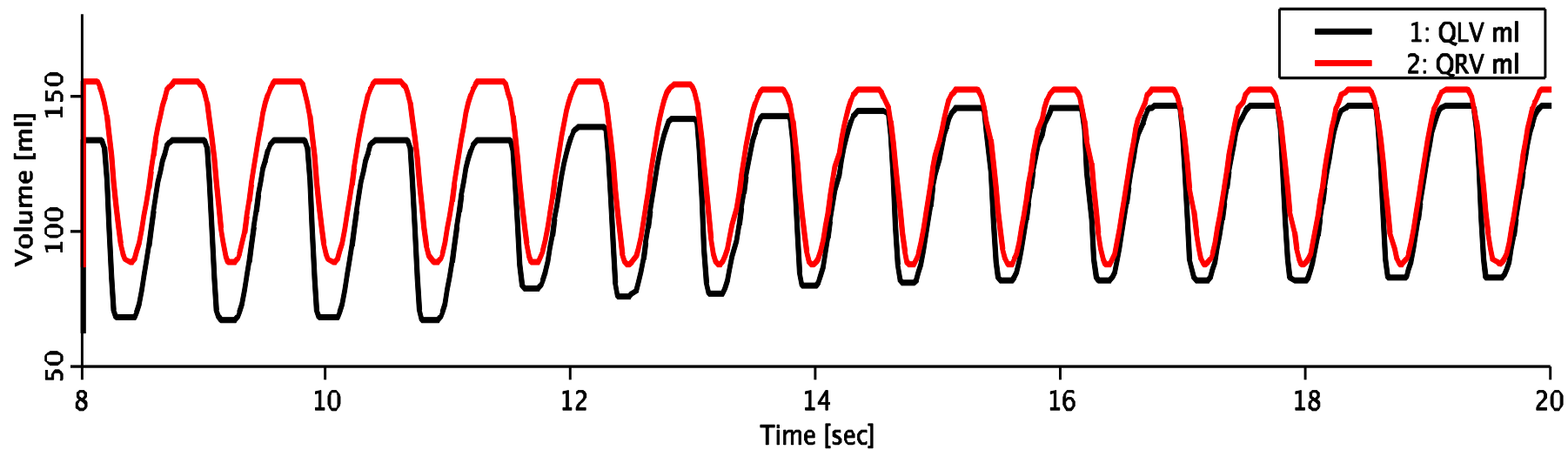
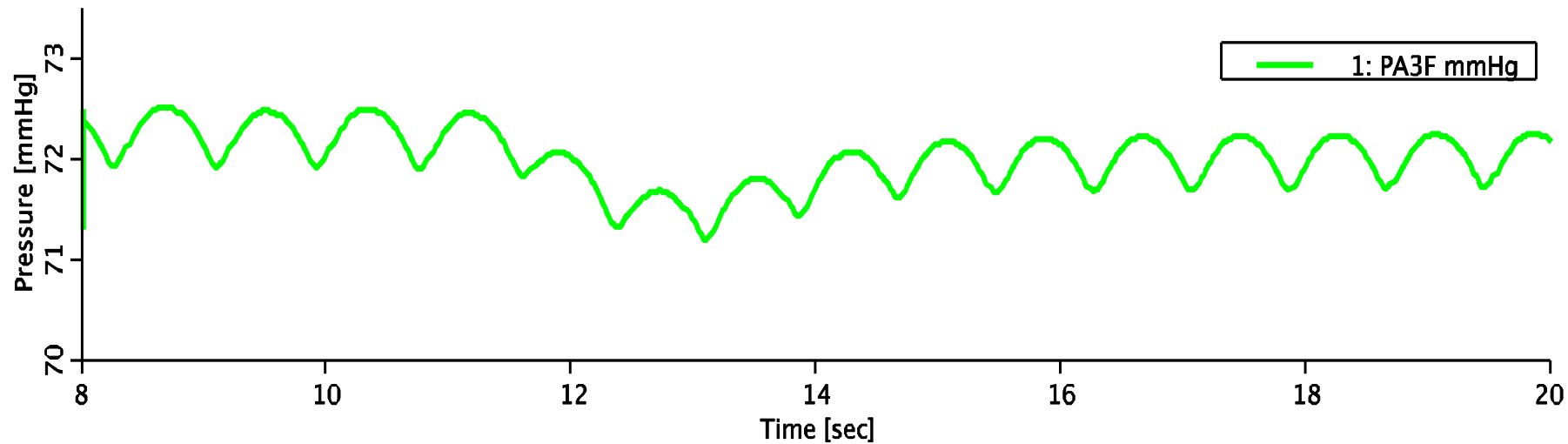
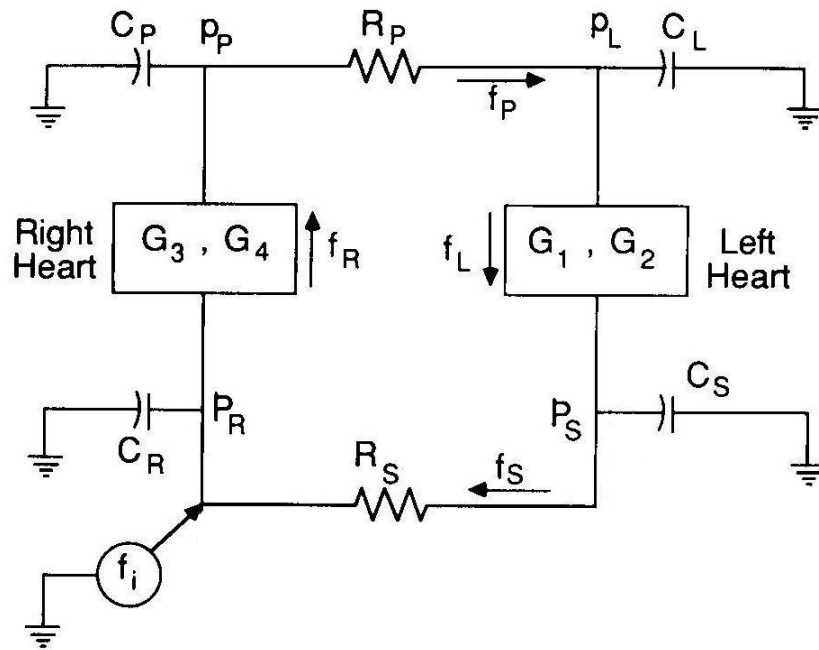


Figure 8 – Closed-Loop: Filtered Carotid Pressure



Rideout_PressureFlowNP

Rideout's Nonpulsatile CV Model, PF-NP



Legend:

| | |
|---------------------|---------------------------|
| $f \longrightarrow$ | Flow [ml/sec] |
| R — — — | Resistance [mmHg·sec/ml] |
| G □ | Conductance [ml/mmHg/sec] |
| C — — — | Compliance [ml/mmHg] |

Parameter Values

| Suffix | Anatomy | R | C |
|--------|--------------------|---------|--------|
| S | Systemic Arteries | 1.0111 | 2.6316 |
| R | Systemic Veins | | 225 |
| P | Pulmonary Arteries | 0.12222 | 6.9444 |
| L | Pulmonary Veins | | 42.857 |

Preload/Afterload Conductances

| Suffix | Anatomy | G |
|--------|---------------------------|-------|
| 1 | Left Ventricle Preload | 24 |
| 2 | Left Ventricle Afterload | 0.821 |
| 3 | Right Ventricle Preload | 40 |
| 4 | Right Ventricle Afterload | 3.889 |

Figure 1 – Blood Infusion Flow Pulse F_i

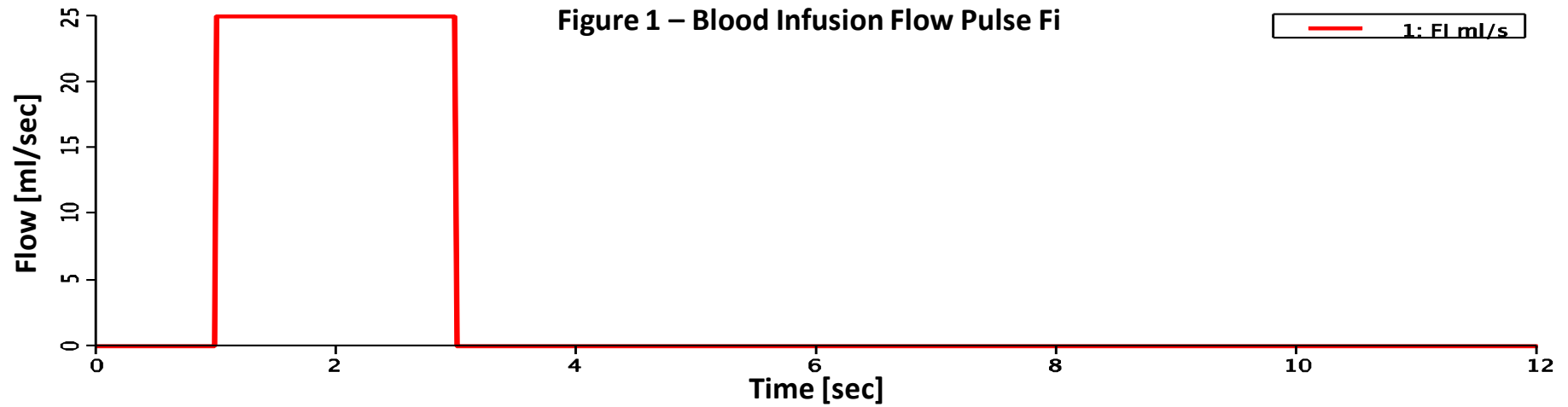


Figure 2 – Total Blood Volume

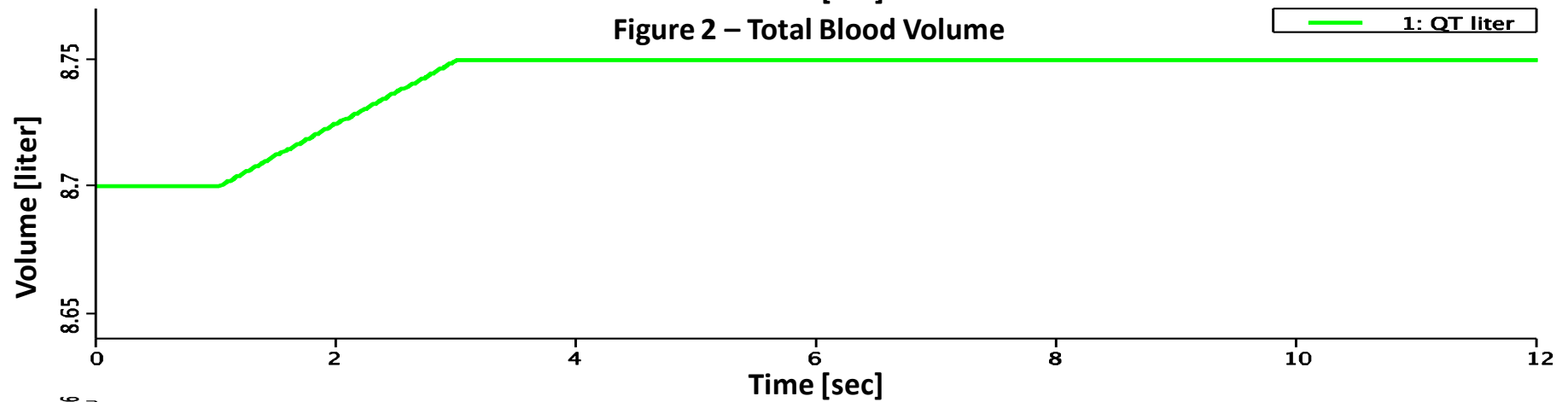


Figure 3 – Infusion: Flows F_R , F_P , F_L , F_S

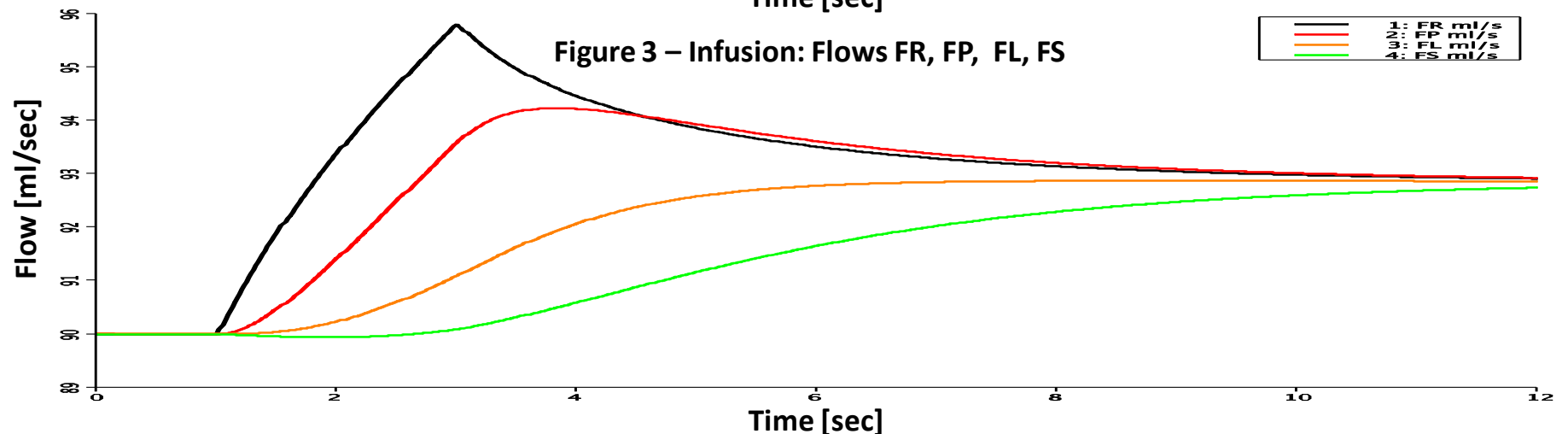


Figure 4 – Infusion: Systemic Arterial Volume QS

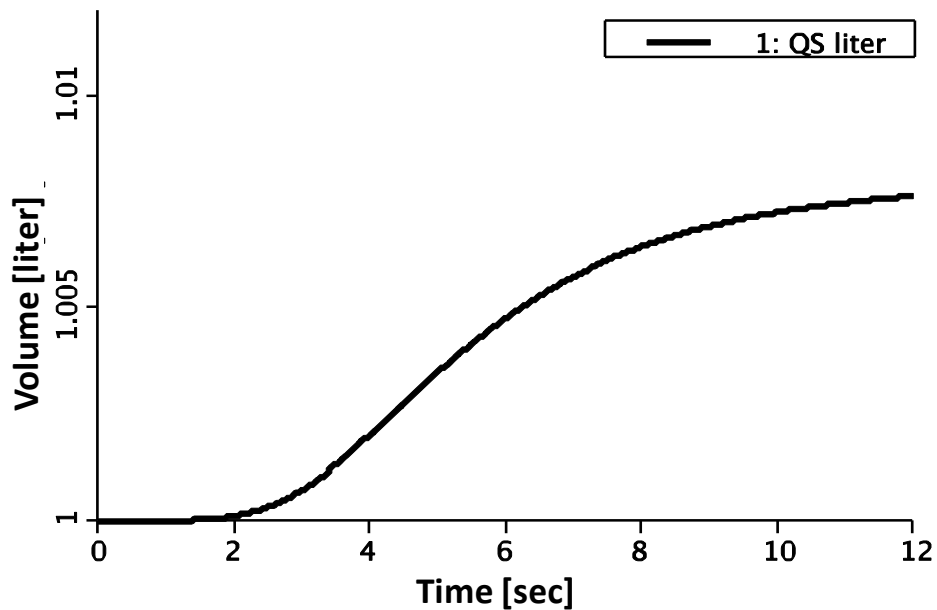


Figure 5 – Infusion: Systemic Venous Volume QR

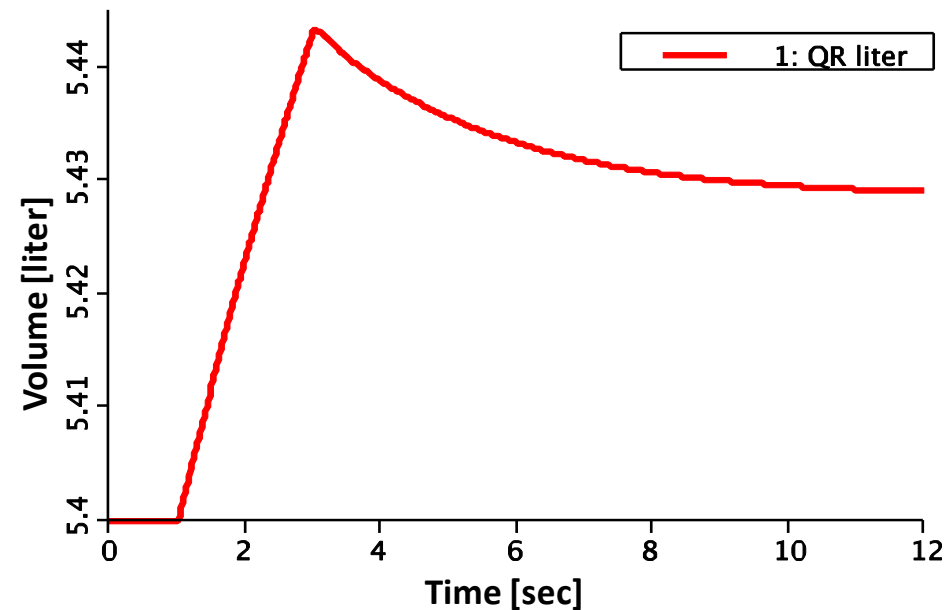


Figure 6 – Infusion: Pulmonary Arterial Volume QP

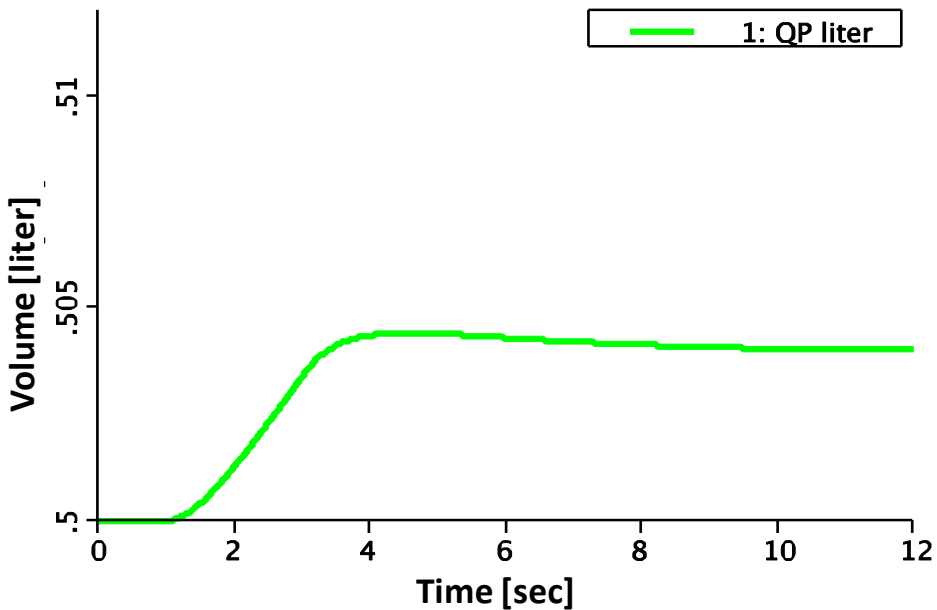


Figure 7 - Infusion: Pulmonary Venous Volume QL

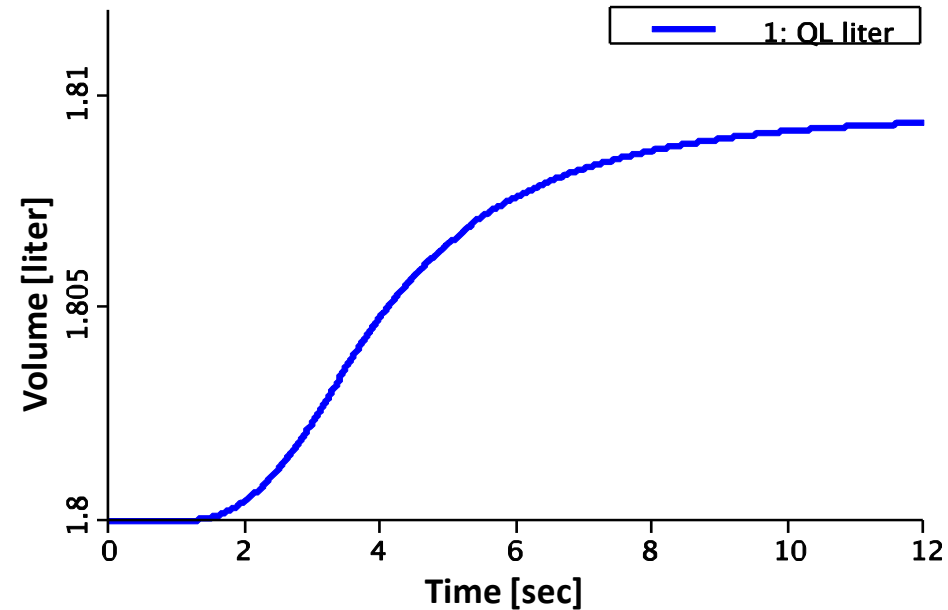


Figure 8 – Infusion: Systemic Arterial Pressure PS

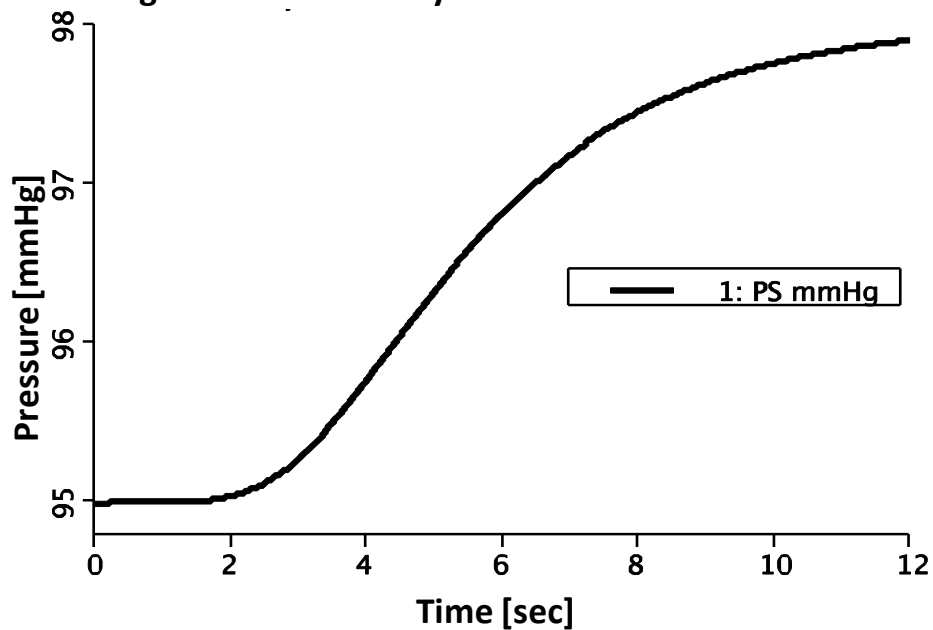


Figure 9 – Infusion: Systemic Venous Pressure PR

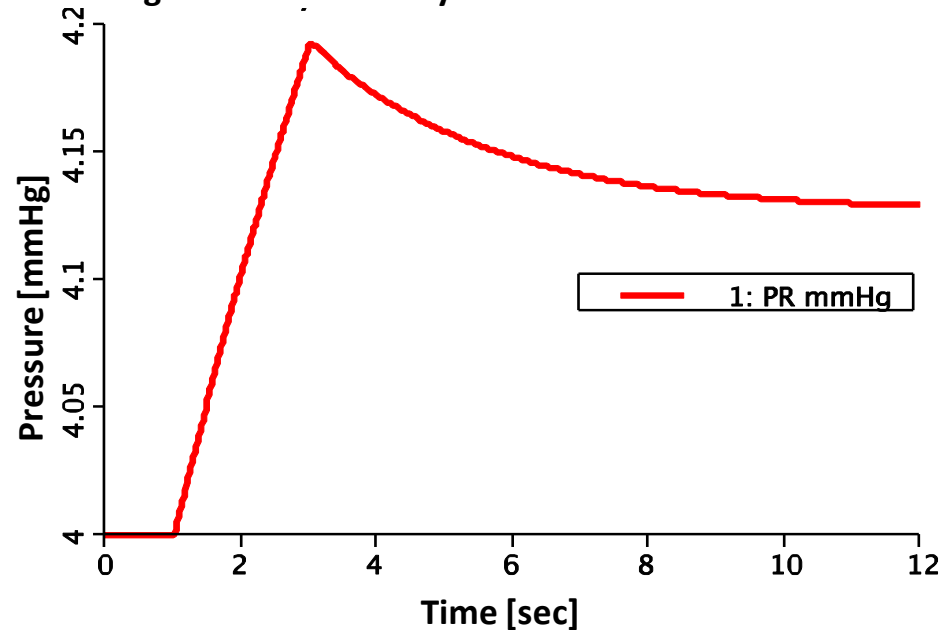


Figure 10 – Infusion: Pulmonary Arterial Pressure PP

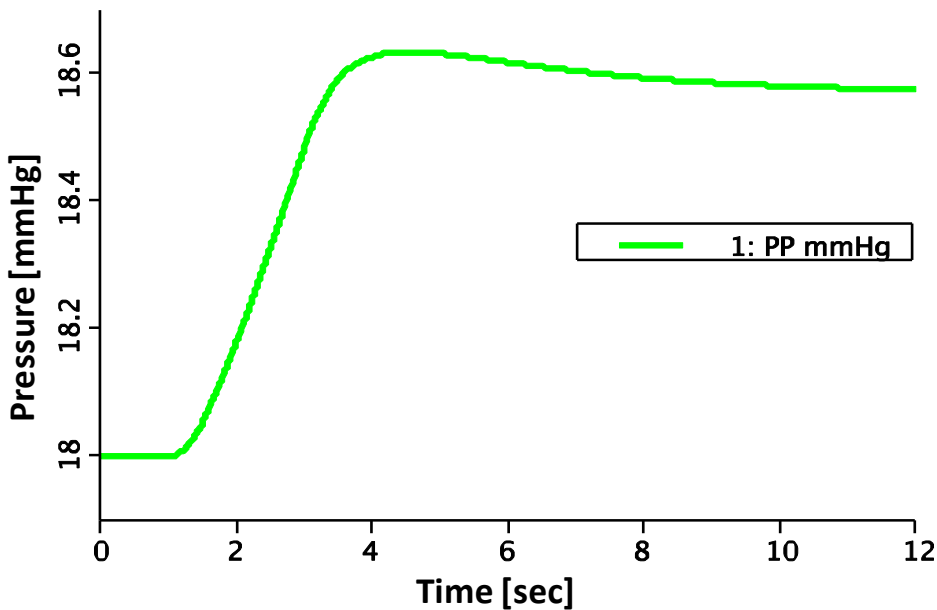


Figure 11 - Infusion: Pulmonary Venous Pressure PL

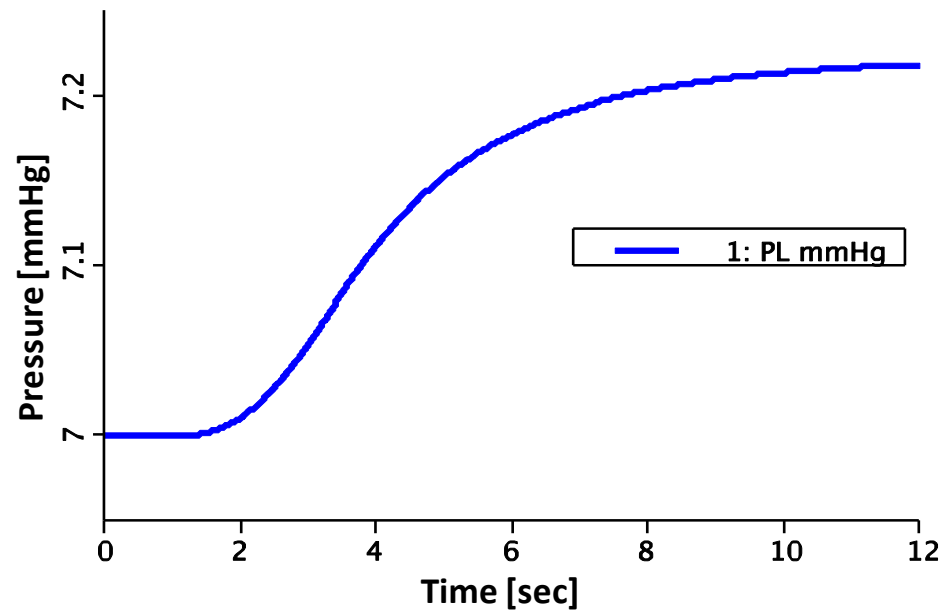


Figure 12 – G2 Decrease: Flows FR, FP, FL, FS

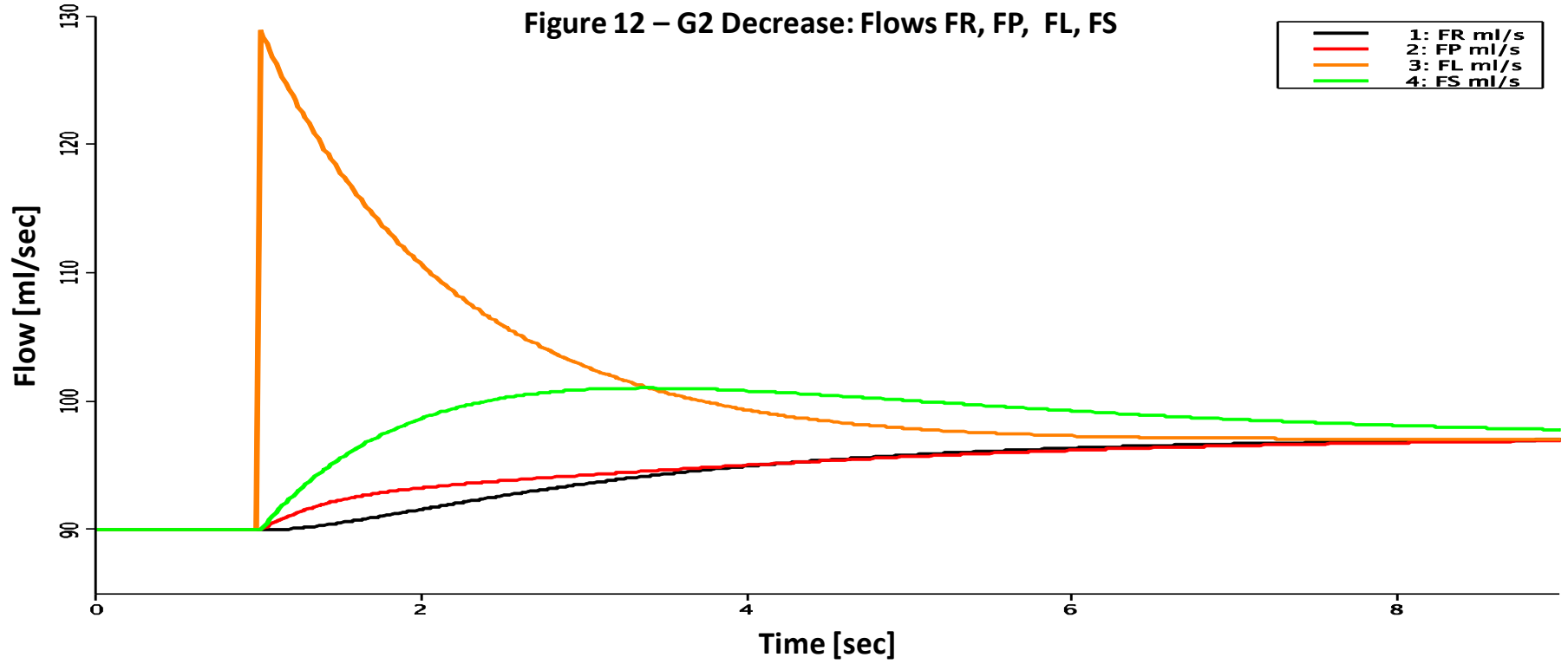


Figure 13 – G2 Decrease: Systemic Arterial Pressure PS

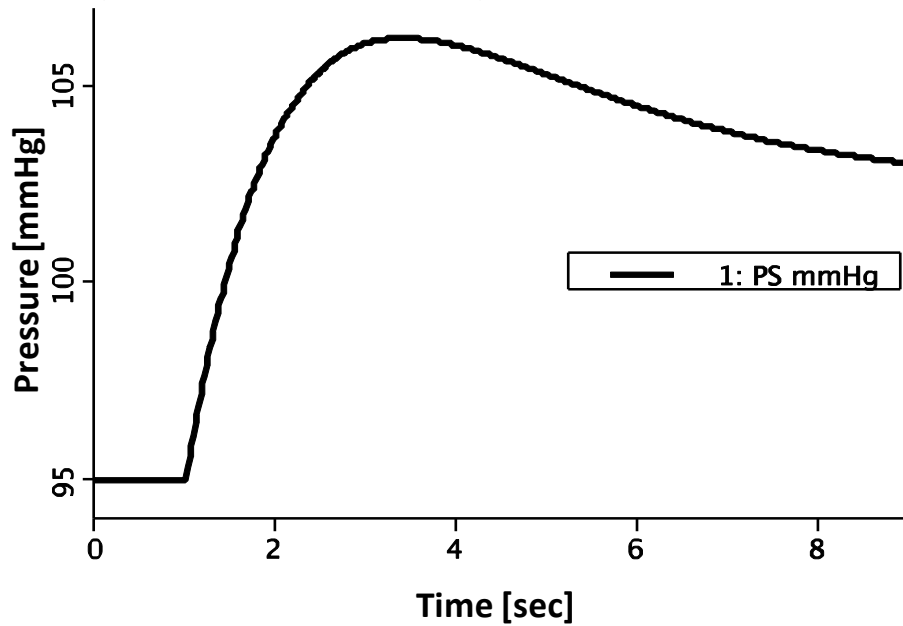


Figure 14 – G2 Decrease: Systemic Venous Pressure PR

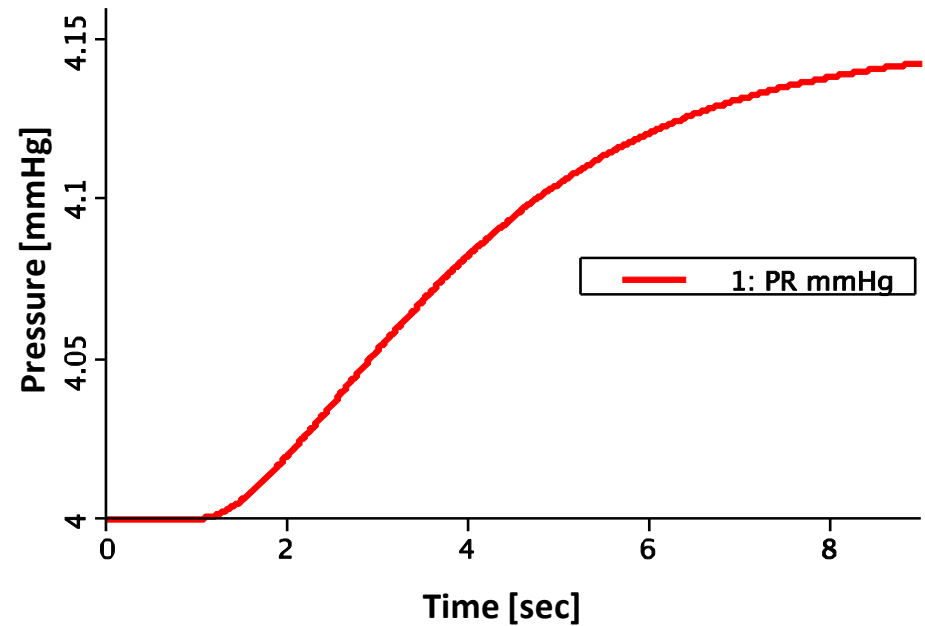


Figure 15 – G2 Decrease: Pulmonary Arterial Pressure PP

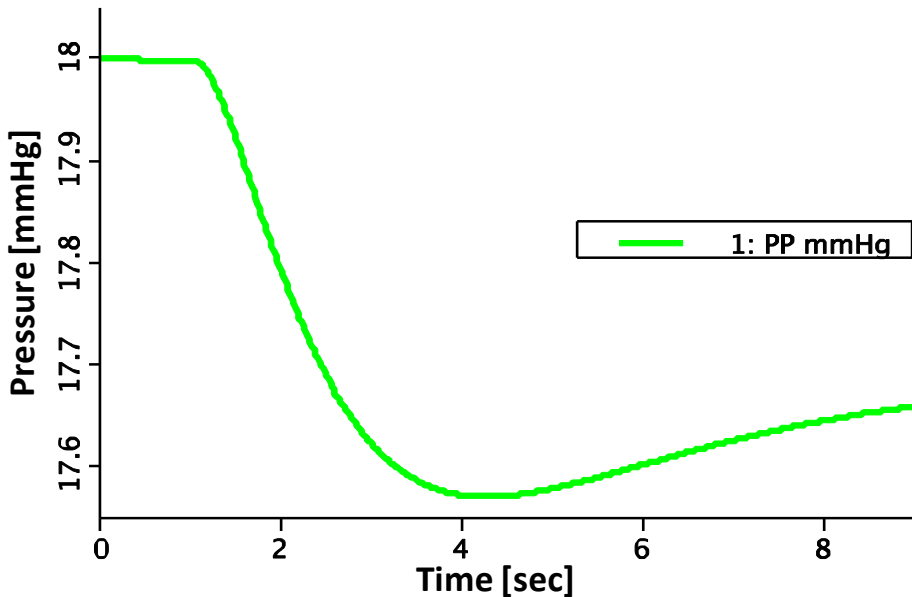


Figure 16 - G2 Decrease : Pulmonary Venous Pressure PL

