



Respiratory system modeling, application to Covid-19

Anita Klein

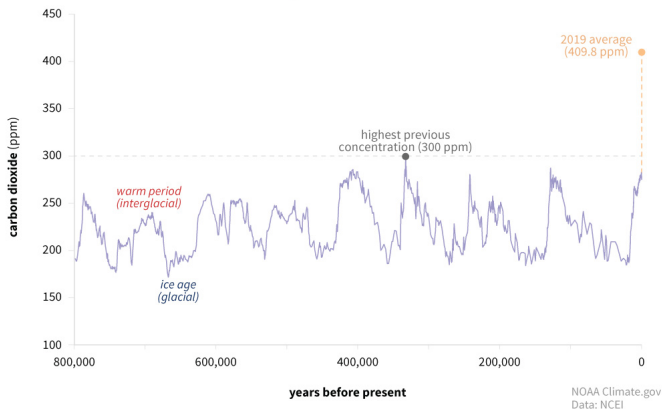
Summer 2021

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The Context

- ▶ The demand for energy is growing.
- ▶ Expansion in carbon dioxide emissions.
- ▶ Global warming, melting of the polar ice caps, rising of sea levels, disturbance of animals' natural habitat...

CARBON DIOXIDE OVER 800,000 YEARS



¹<https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide>



- ▶ 4fastsim-ibat project
- ▶ Reduce and control energy consumption in existing buildings
- ▶ Collaboration between Cemosis and Synapse-Concept



Internship

- ▶ Add a human being to the ibat model.
- ▶ Use of a human simulator: Pulse Physiology engine.
- ▶ Study the effect of the environment on a human, but also the effect of a human on the environment.

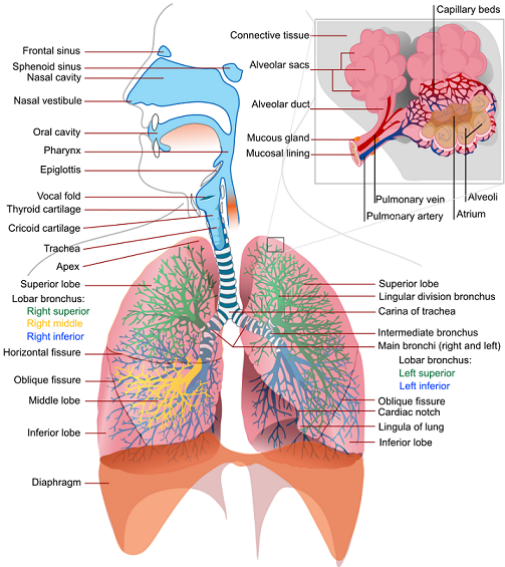
Plan

- ▶ Respiratory model.
- ▶ Simulations.
- ▶ Association with Covid-19.

Respiratory Physiology

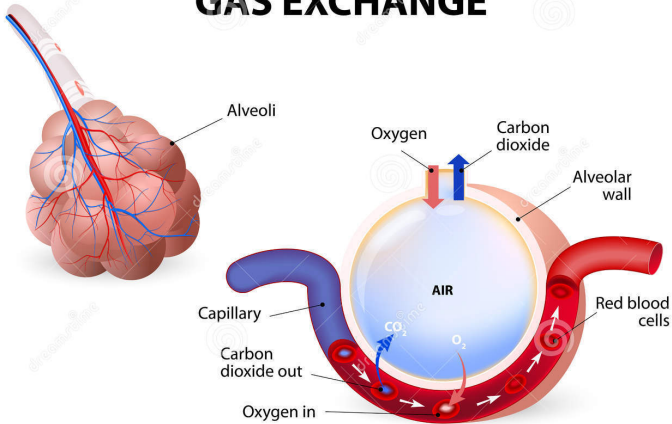
- ▶ 12/20 breaths/min.
- ▶ Inhale oxygen, exhale carbon dioxide.
- ▶ Upper-lower airways, lungs, respiratory muscles.
- ▶ Lower airway: trachea, bronchi, bronchioles and alveoli.

Respiratory system diagram



²<https://pulse.kitware.com/Images/Respiratory/RespiratorySystemDiagram.png>

ALVEOLUS GAS EXCHANGE



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Dreamstime.com

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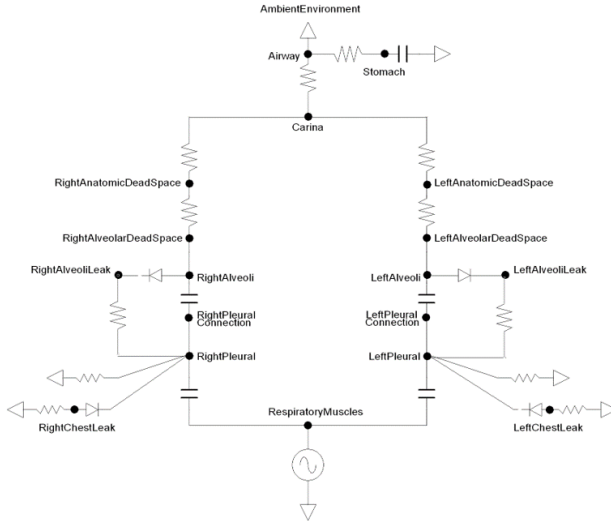
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Respiratory circuit

- ▶ Lumped parameter model of mechanical ventilation.
- ▶ Elastic behavior of the lungs.
- ▶ Flow resistance of the airways.
- ▶ Resistors, capacitors.

Pulse Respiratory circuit



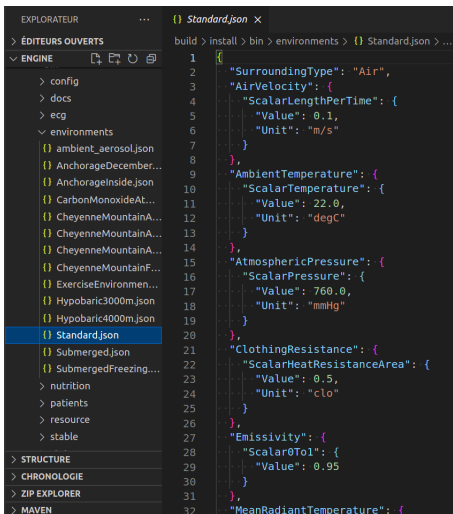
3

³<https://pulse.kitware.com/Images/Respiratory/RespiratoryCircuit.png>

Patient

```
EXPLORATEUR ... {} StandardMale.json X
> Éditeurs ouverts
  build > install > bin > patients > {} StandardMale.json > ...
  ENGINE
  patients
  {} Bradycardic.json
  {} Carol.json
  {} Cynthia.json
  {} DefaultFemale.json
  {} DefaultMale.json
  {} ExtremeFemale.json
  {} ExtremeMale.json
  {} Gus.json
  {} Hassan.json
  {} Jane.json
  {} Jeff.json
  {} Joel.json
  {} Nathan.json
  {} Overweight.json
  {} Rick.json
  {} Soldier.json
  {} StandardFemale.json
  {} StandardMale.json
  {} Tachycardic.json
  {} Underweight.json
  > resource
  > structure
  > CHRONOLOGIE
  > ZIP EXPLORER
  > MAVEN
1
2 "Name": "StandardMale",
3 "Age": {
4   "ScalarTime": {
5     "Value": 44.0,
6     "Unit": "yr"
7   }
8 },
9 "Weight": {
10  "ScalarMass": {
11    "Value": 170.0,
12    "Unit": "lb"
13  }
14 },
15 "Height": {
16  "ScalarLength": {
17    "Value": 71.0,
18    "Unit": "in"
19  }
20 },
21 "BodyFatFraction": {
22  "Scalar0To1": {
23    "Value": 0.21
24  }
25 },
26 "DiastolicArterialPressureBaseline": {
27  "ScalarPressure": {
28    "Value": 73.5,
29    "Unit": "mmHg"
30  }
31 },
32 "HeartRateBaseline": {
```

Environment



```
1 {
2   "SurroundingType": "Air",
3   "AirVelocity": {
4     "ScalarLengthPerTime": {
5       "Value": 0.1,
6       "Unit": "m/s"
7     }
8   },
9   "AmbientTemperature": {
10    "ScalarTemperature": {
11      "Value": 22.0,
12      "Unit": "degC"
13    }
14  },
15  "AtmosphericPressure": {
16    "ScalarPressure": {
17      "Value": 760.0,
18      "Unit": "mmHg"
19    }
20  },
21  "ClothingResistance": {
22    "ScalarHeatResistanceArea": {
23      "Value": 0.5,
24      "Unit": "clo"
25    }
26  },
27  "Emissivity": {
28    "ScalarTheta1": {
29      "Value": 0.95
30    }
31  },
32  "MeanRadiantTemperature": {
```

Output parameters

- ▶ heart rate
- ▶ arterial pressure
- ▶ respiration rate
- ▶ lung volume
- ▶ inspiratory flow
- ▶ expiratory flow

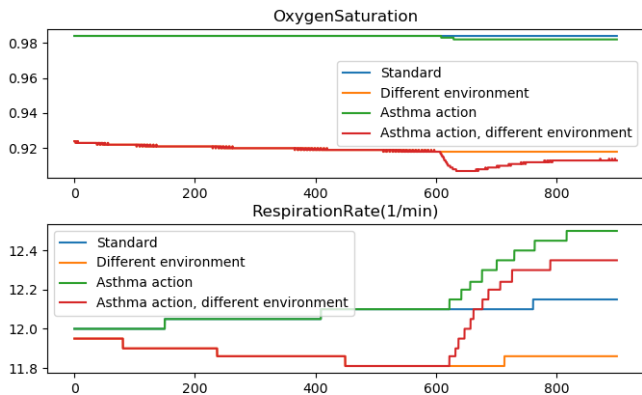
```
1 Time(s),HeartRate(1/min),ArterialPressure(mmHg),SystolicArterialPressure(mmHg),DiastolicArterialPressure(mmHg),MeanArterialPr
2 0.02,75.00,108.6,114,73.8,95.1,0.0569,0.1875,12.00,33.2,77014.328369,11365.409508,2480.462899,1120.687,2.46,824.9781,-824.9781
3 0.04,75.00,110.7,114,73.8,95.1,0.0569,0.1875,12.00,33.2,77015.698089,11365.425413,2480.093561,1120.687,2.42,839.3466,-839.3466
4 0.06,75.00,112.1,114,73.8,95.1,0.0569,0.1875,12.00,33.2,77016.812141,11365.382590,2479.809397,1120.687,2.43,852.1437,-852.1437
5 0.08,75.00,113.1,114,73.8,95.1,0.0569,0.1875,12.00,33.2,77017.662084,11365.398384,2479.609878,1120.687,2.45,863.5638,-863.5638
6 0.10,75.00,113.6,114,73.8,95.1,0.0569,0.1875,12.00,33.2,77018.260131,11365.356085,2479.491196,1120.687,2.47,873.7628,-873.7628
7 0.12,75.00,113.7,114,73.8,95.1,0.0569,0.1875,12.00,33.2,77018.615480,11365.370103,2479.448180,1120.687,2.49,882.8651,-882.8651
8 0.14,75.00,113.5,114,73.8,95.1,0.0569,0.1875,12.00,33.2,77018.741718,11365.320762,2479.477664,1120.687,2.50,890.9698,-890.9698
9 0.16,75.00,112.8,114,73.8,95.1,0.0569,0.1875,12.00,33.2,77018.634899,11365.339845,2479.585227,1120.687,2.52,898.1556,-898.1556
```

- ▶ 30 minutes of simulation
- ▶ Approximately 6 minutes of computing time
- ▶ CSV file
- ▶ A solution every 0.02 second

A different simulation

- ▶ Medical conditions or actions.
- ▶ An asthma attack.
- ▶ Nitrogen $0.75 \rightarrow 0.85$.
- ▶ Oxygen $0.21 \rightarrow 0.11$.

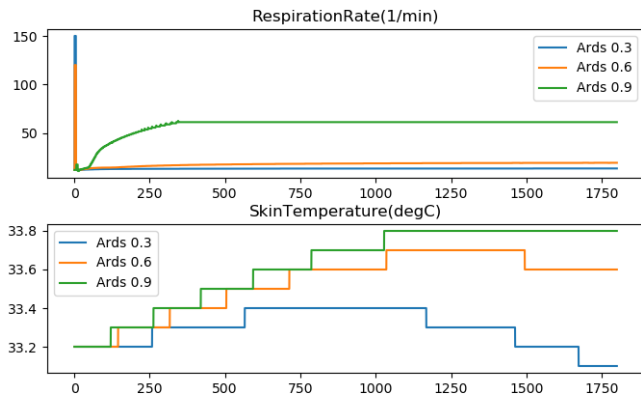
Some graphs



Coronavirus patient

- ▶ Patients sharing a ventilator.
- ▶ Covid pneumonia.
- ▶ ARDS.

ARDS



Particles

- ▶ Airborne transmission of the virus.
- ▶ Particles we exhale.
- ▶ Viral load.
- ▶ ADR equation.

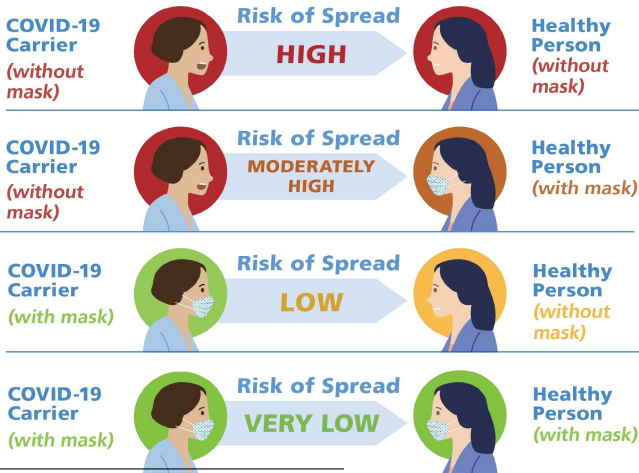
Infectious person state	Particles/s
Breathing	0.5
Talking	5
Breathing with mask	0.25
Talking with mask	2.5

4

⁴<https://arxiv.org/pdf/2012.12267.pdf>

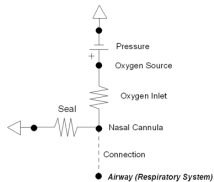
WEAR A FACE COVERING TO PROTECT YOURSELF AND OTHERS

Help prevent the spread of COVID-19!

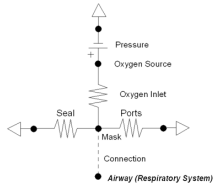


Oxygen supply

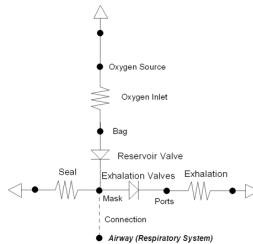
Nasal Cannula



Simple Mask



Nonbreather Mask



Tools

- ▶ VS Code
- ▶ Pulse Physiology engine
- ▶ Gmsh
- ▶ Atlas
- ▶ Docker
- ▶ Feel++