Summary

Preview

- Ferrari to support IIT to design and simulate a ventilator for sub-intensive patient use in emergency situation
- Simulink model have been created from scratck which includes:
    1. Matematical model of human lungs → *from Computer-Controlled Mechanical Simulation of the Artifically Ventilated Human Respiratory System (2003)*
    2. Air/Oxigen mixture device (manual tuning to reach O2 target %)
    3. Pressure regulator to allow inlet valve to operate in controlled inlet pressure condition
    4. Main flow line with controlled valves, safety check valves, quick disconnect, pipes (capacitive and resistive).
- Main outcome from the model will be to validate hardware layout in terms of valve selection and operting pressure level across the entire system.

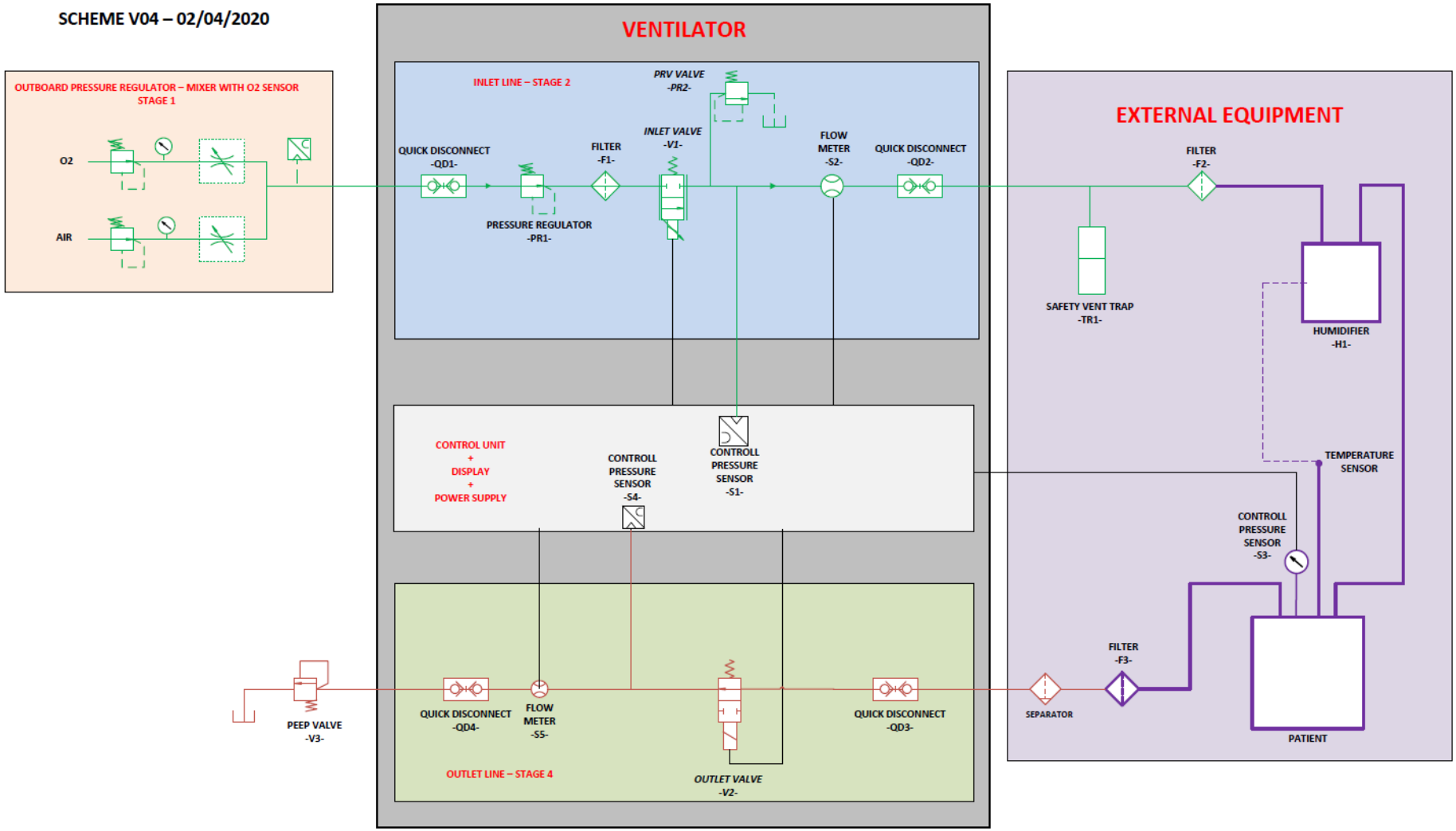
Main results

- Set of possible PR1 pressure level have been produced together with ideal valves characteristics. Pressure level will be defined once Camozzi will have a feedback on maximum permeability valve (lower spring preload). Selected valve is **AP taglia 22 DN 2.4mm orifice**.
- ON/OFF valve **CFB DN 6mm** seems sufficient to evaquate air flow from lungs without blocking them.
- Pressure changes using helmet instead of mask (+8L) lead to a **100cc of tidal volume lost. Increasing V1** command **current by 4-5%** is possible to recover entirely lungs tidal volume matching mask-like pressure dynamics.
- Assuming the water bottle vent valve to be fitted and with a dP char of **5mabr dP @ 10lpm** will be sufficient to limit Mouth maximum pressure to **50mbar** even with inlet valve fully open (due to an issue on control or mechanical) with inlet flowrate rund 40lpm.
- Without fitting water bottle vent valve and still condiering V1 fully open, mouth pressure will be around 5_8mbar lower than PR2 valve cranking pressure (could be setted to 70mbar).

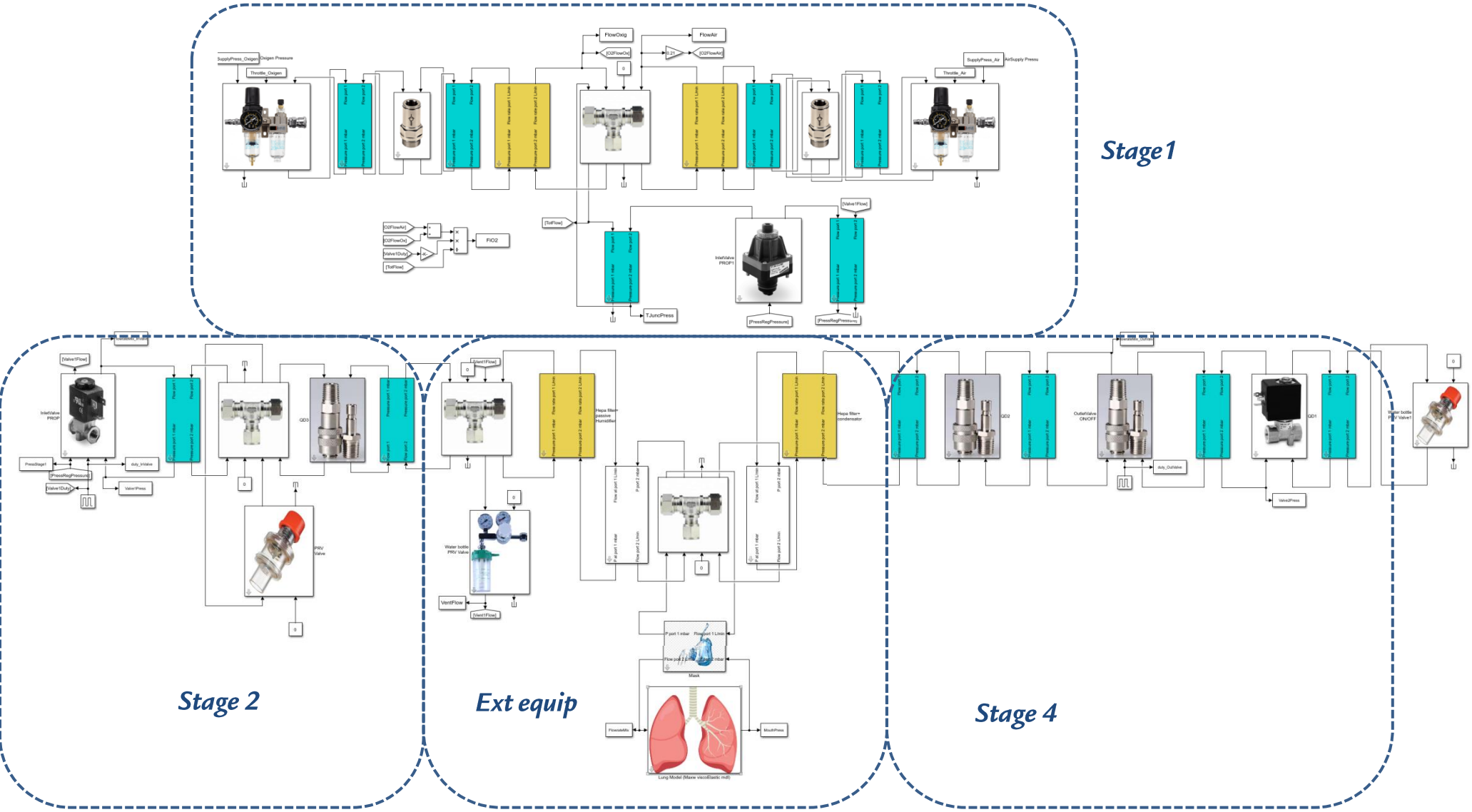
Next *Step*

- To use a pressure characterization of normal lung (actual one comes from a patient with fibrosis!)
- CO2 concentration inside helmet case
- Add mouth pressure target and control the proportional valve in closed loop
- Any others?

Pneumatic scheme



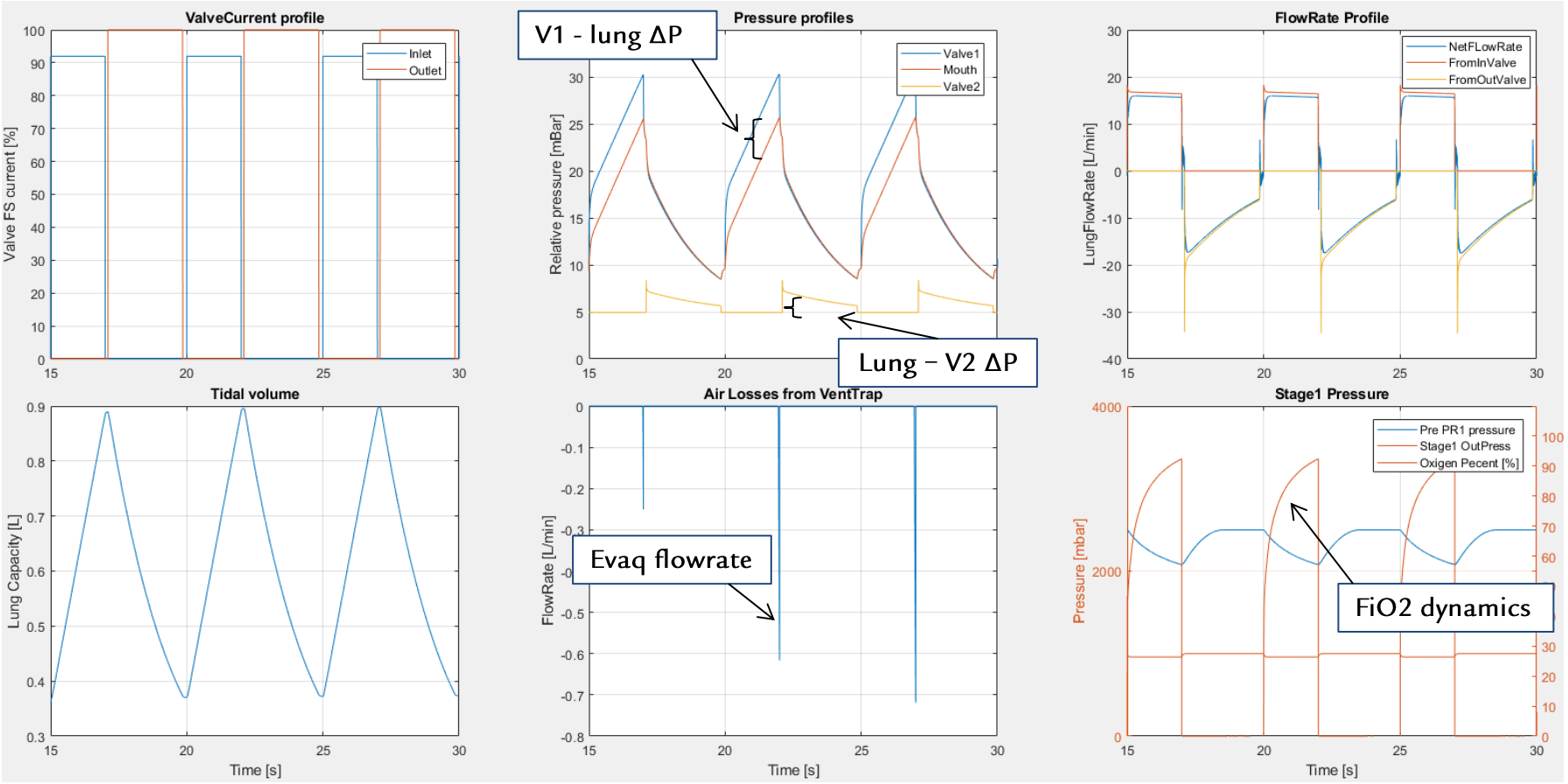
Simulink model scheme



Simulation list

- Stage 1 pressure regulator operating level and V1 valve permeability scan
- Effect on pressure dynamics using «helmet» instead of mask
- Permeability threshold of ON/OFF V2 valve
- CO2 accumulation in case of Helmet usage
- Failure conditions

Results general outlook



Stage 1: pressure regulator operating level and V1 valve permeability

The lower the pressure level of PR1 (pressure regulator 1) the lower the amount of air flow rate must be evacuated in order to protect patient lungs in case of components failure. Camozzi's max permeability valve (*AP series taglia 22 ugello 2.4mm – bottom rhight picture*) is tight to guaranteed target flowrate already at 1.5 bar of inlet pressure; There is the possibility to reduce internal spring preload to increase valve permeability.
Desired valve must satify target air flow rate (*25mbar mouth pressure*) at 50% of it's FS current.

PR1 @1500 mbar

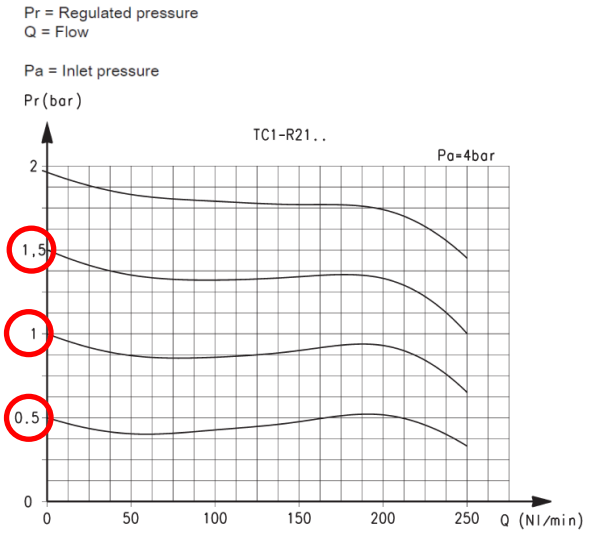
- the minimum %FS current to satify required flow rate is **75%.**
- In order to provide sufficient margin to the usage of this valve characheristics from catalogue will be **offsetted back by 25% of FS current.**

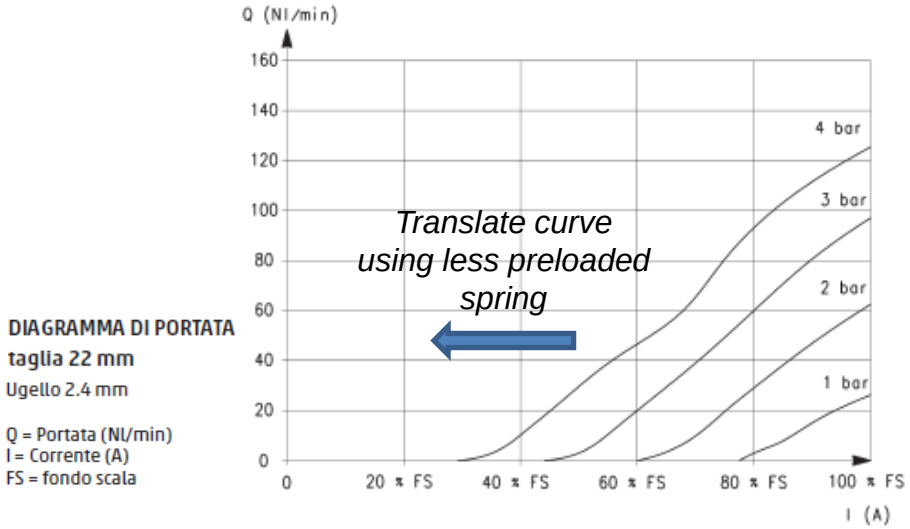
PR1 @1000 mbar

- With 1 bar of inlet pressure the minimum %FS current to satify target flow rate is **90%.**
- Curves from catalogue needs to be **offsetted by 40% of FS current** to provide enough margin of the usage with this pressure level.

PR1 @500 mbar

- Valve 1 from catalogue is **not able to satirfy the target flow rate**.
- Curves from catalogue needs to **be offsetted at least by 60% of FS current** to provide enough margin of the usage of this pressure.

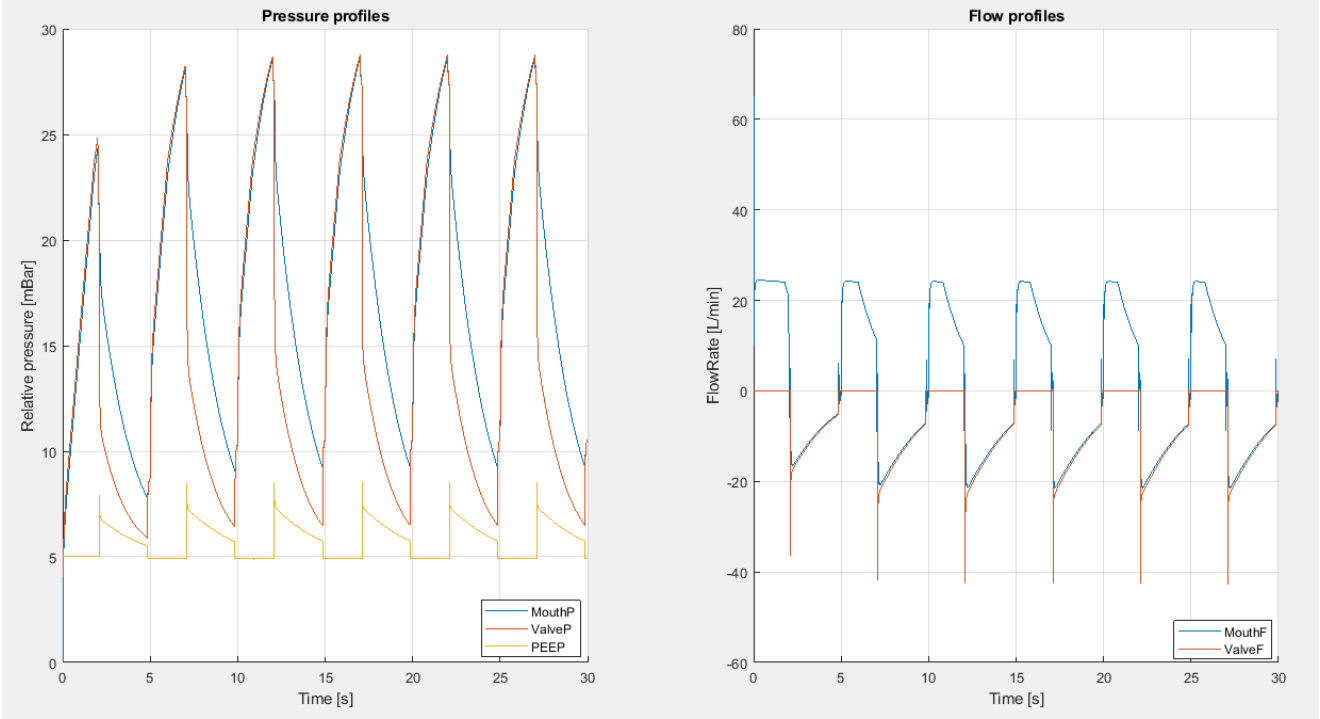




Stage 4: Outlet vale V2 valve permeability

The valve permeability used in the model up to now is equivalent to Kv = 0.5. The 6mm valve available in the camozzi catalogue has a Kv of 0.6 so it should be enough. That said, an highr margine would be nice to have.

Here below you can find the pressure profiles of the 6mm valve:



K v defines the flow rate of water (between 5° and 40°), expressed in l/ min, through a valve with a differential pressure (pressure drop) of 1 bar

$$Q = K_V \sqrt{P2 - P1}$$

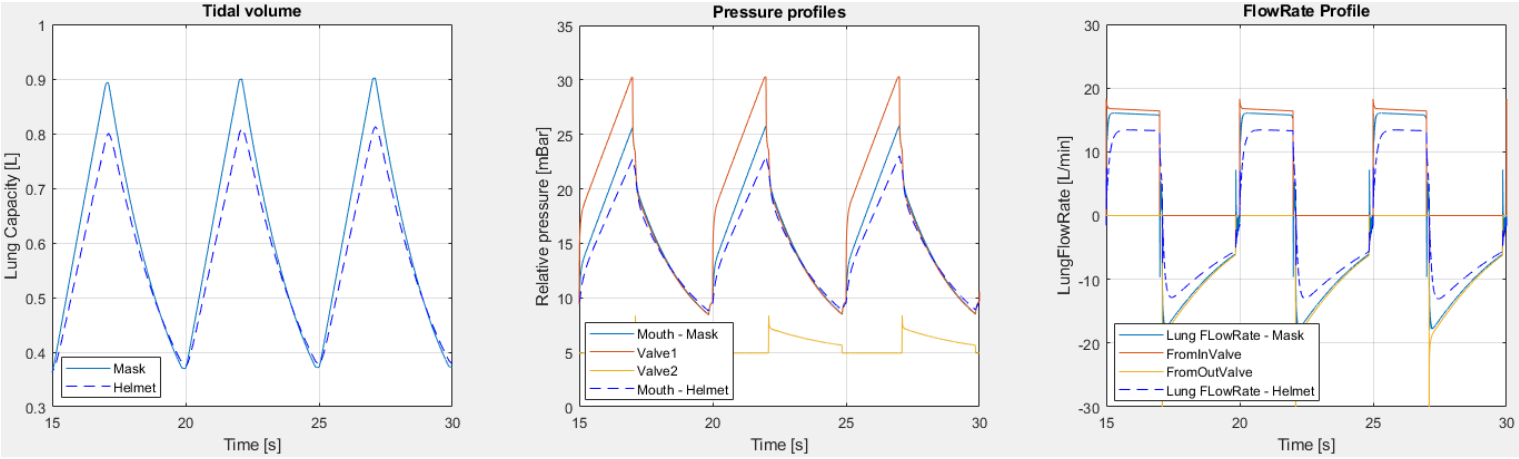
If Kv is expressed in m3/h vs bar, Kv has to be multiplied by 15.05 to have L/min vs mbar (with 1.225 kg/m3 air density, 16.7 considering 1)

Effect on pressure dynamics helmet VS mask

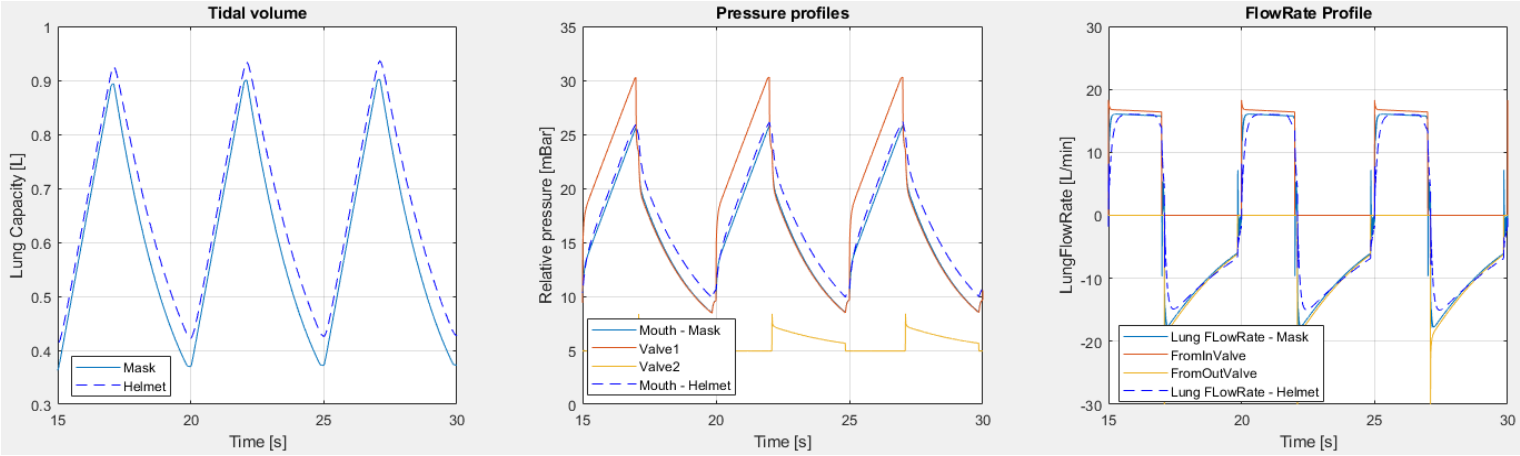
A volume of 0.2L for mask and **8L for helmet** have been considered for this calculation; please note that no air leakage have been modeled in helmet case (although probably there is). Dotted line in following graph represent case with helmet.

With almost +8L volume before patient muth pressure dynamics changes a significantly.

100cc of tidal volume will be lost due to the reduction of either 3 mbar mouth pressure and 4l/min of lungs inflation flowrate.



Increasing V1 command current by 4-5% is possible to recover entirely lungs tidal volume matching mask-like pressure dynamics.
Expiration phase is driven by lungs dynamics and cannot be replicated using helmet.

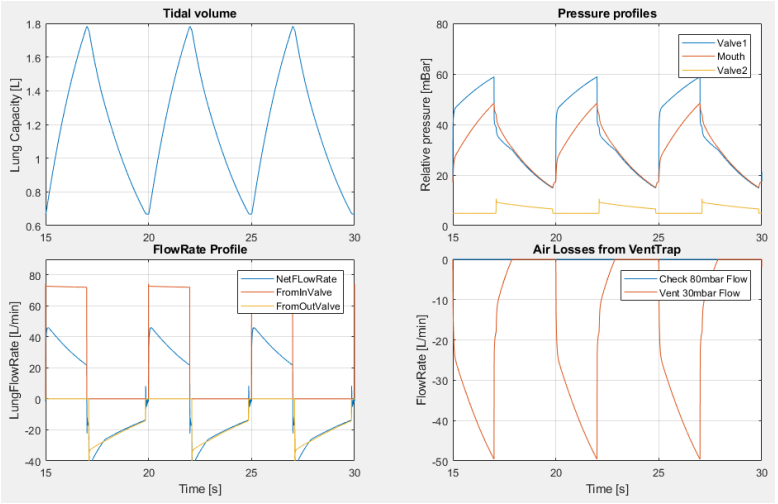


Overpressure conditions

Three mechanical valve are fitted between hospital supply line and patient mouth: PR1 (1000 mbar), V1 fully open and PR2 (80mbar).
We assume the bottle vent valve to be fitted and always working due to it's simplicity and the overpressure to be generted by either control issue or mechanical failure.

Case 1 – PR1 1000 mbar, V1 100% Duty, VentValve fitted

- Assuming a bottle vent valve with **5mabr dP with 10lpm** is sufficient to not trigger 80 mbar check valve even with V1 fully open. Mouth maximum pressure will be close to 50mbar and inlet flowrate will be from 42 to 20lpm due to the vent valve flow cut.
- if needed to reach 40lpm as target flowrate, water height in bottle vent valve **must ovbiusly be higher than 30cm** in order to not spread out air flow.



Case 2 – PR1 1000 mbar, V1 100% Duty, VentValve not fitted

- Assuming the bottle vent valve **not fitted** 80 mbar mechanical check valve can evaquate all excess of air flow but mouth pressure reaches value close to 80mbar. Will be safer to set the mechanical valve cranking pressure to 70mbar in order to limit to 65mbar the mouth max pressure.
- In this extreme case scenario a flowrate between 67 and 22 lpm is providet to the patient