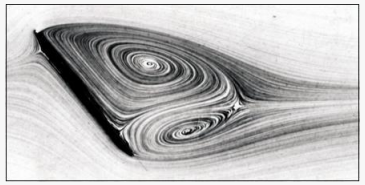
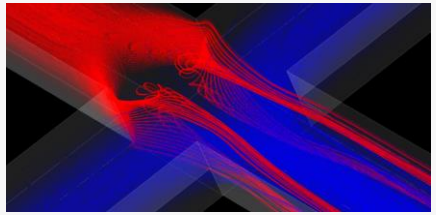
REOROM LABORATORY
UNIVERSITY POLITEHNICA OF BUCHAREST
Corneliu Balan & REOROM Team

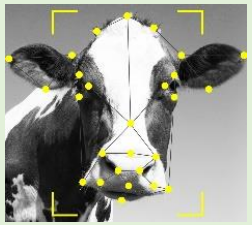
AIR-MUCUS FLOW IN TRACHEA

SCIENTIFIC RESULTS – 2021

PERSPECTIVES - 2022







MUCCA – Multi-disciplinary Use Case for Convergent new Approaches to AI explainability

CHIST-ERA – 19 – XAI – 009 MUCCA project, by the founding of EC and UEFISCDI, grant COFUND-CHIST-ERA

1st meeting, Rome, 11-13 April, 2022

MUCCA – Multi-disciplinary Use Cases for Convergent new Approaches to AI explainability

The MUCCA consortium is formed by 6 partners:

1. **University Sapienza of Rome** (coordinator)
2. **Istituto Nazionale Fisica Nucleare, Rome, Italy**
3. **Medlea S.r.l.s., Rome, Italy**
4. **University of Sofia "St. Kl. Ohridski", Bulgaria**
5. **University Politehnica of Bucharest, Romania**
6. **University of Liverpool, U.K.**

Partner 5 is represented by the

REOROM – Complex Fluids and Microfluidics Laboratory,

a research unit founded and directed since 2000

by Professor Corneliu Balan.

The contributions of the REOROM group are the following:

1. Characterization of the mucus/saliva rheology;
2. Reconstructions of the analyzed respiratory airways – flow visualization and velocity measurements;
3. Comparison between experiments and simulations performed by Medlea software products DigiScan (Partner 3) to optimize the model both at analytical level and by proper numerical treatment;
4. xAI algorithm to predict the global airflow resistances in respiratory conduits.

NAME	POSITION	PERIOD	Role	Responsibilities
Corneliu Balan	Professor	2020-2023	Principal Investigator	Coordinator
Diana Broboana	Professor	2020-2023	Co-investigator	Numerical simulations, administration
Nicoleta Tanase	Asoc. Prof.	2020-2023	Co-investigator	Numerical simulations, modeling, website responsible
Claudiu Patrascu	Ph.D student	2020-2023	researcher	Experiments (responsible), modeling
Eugen Chiriac	Ph.D student	2021-2023	researcher	Numerical simulations contact P2, Experiments
István Magos	Ph.D student	2020-2023	researcher	Experiments (flow visualizations), numerical code
Ciprian Mateescu	Master student	2021-2023	researcher	Experiments (design setup), image processing
Ana-Maria Bratu	Master student	2021-2023	researcher	Experiments (visualizations), contact partners
Sanda Maiduc	Dr. ing.	2020-2023	technician	Administrative

WP – 5
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The main goals of the first stage were the following:

1. To establish the procedure to extract from CT image the test geometry, to reconstruct the test geometry for the experiments, to perform qualitative visualizations and numerical simulations of the air flow in the confined domains (which corresponds to some test geometries).
2. To design the test setup and to make the acquisition of the necessary equipment for the experiments scheduled in the second-year of the project;
3. To find the best sample for the synthetic mucus sample, to characterize its rheology and to establish the material constitutive relation to be implemented in the numerical simulations.

Conclusions

The main targets of the first year related to the Tasks T5.1 and T5.2 of the project were reached:

1) Reconstruction of the test geometry from the CT scan (procedure, geometry, physical test body),
2) Rheological characterization of the synthetic mucus sample,
3) Design and qualitative testing of the experimental setup,
4) Numerical simulations of the air flow in trachea bifurcation using two codes: commercial Ansys and original code Moebius developed by our partner MedLea.

WP – 5
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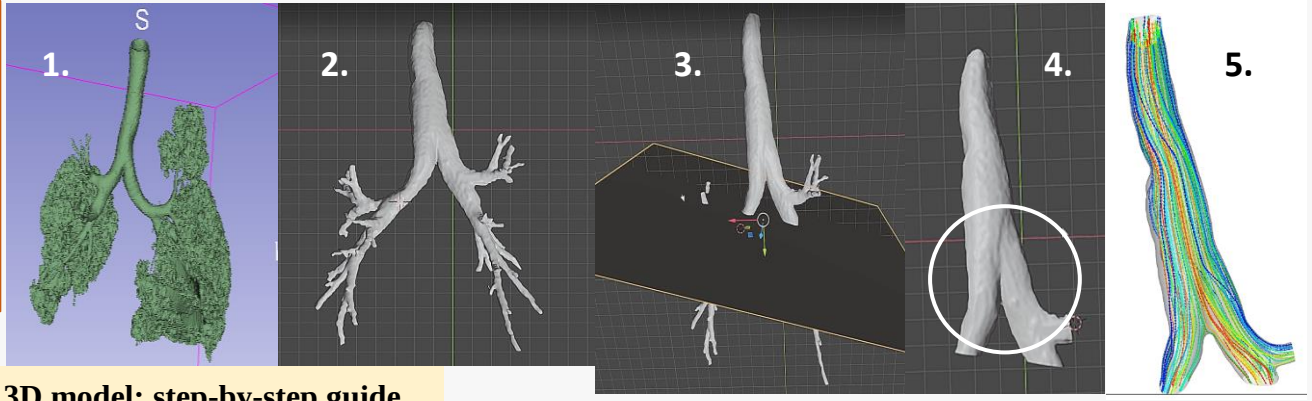
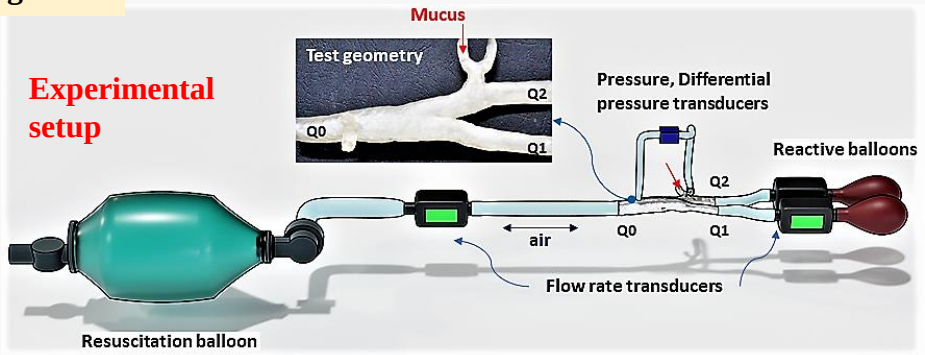
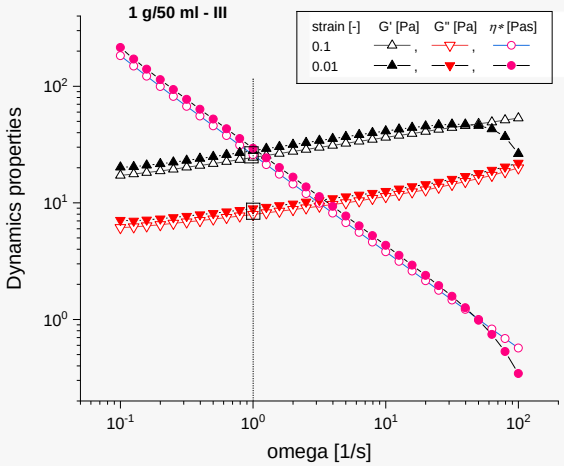
Air-Mucus transport in tracheal model



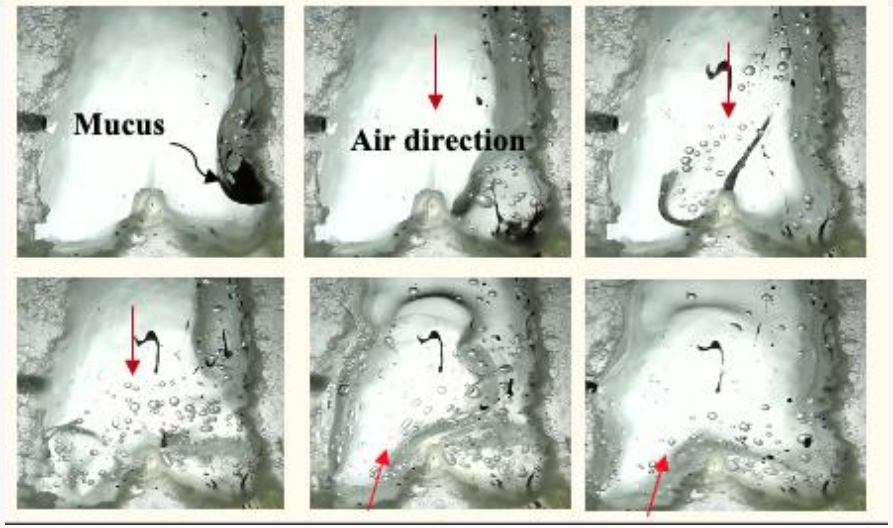
From CT scan to 3D model: step-by-step guide

1. Final model from 3DSlicer;
2. The trachea model in Blender interface;
3. Removed unwanted segments; **4.** Final solid 3D architecture of the trachea and main bronchi (3D printing); **5.** 3D geometry imported in ANSYS Fluent & MOEBIUS; numerical simulations of the air flow (with and without mucus)

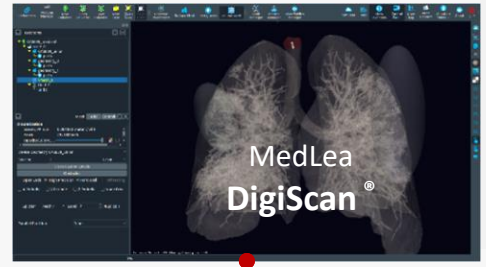




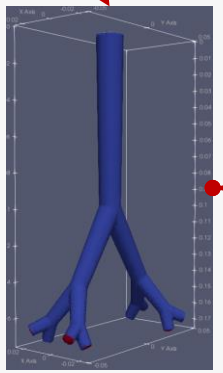
Direct visualization of air-mucus flow in the tracheal bifurcation

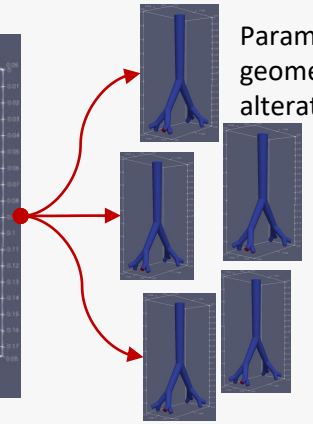


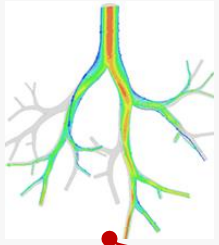
Reconstruction and simulations of multibranched airways



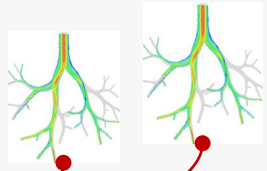
1. CT-derived airways; **2.** Generate many model airways obeying Murray's law over generations; **3.** Gather velocity and pressure over centerlines



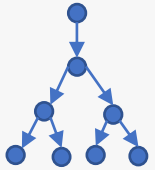




Moebius®
Multiphase viscoelastic fluid (Oldroyd-B model)



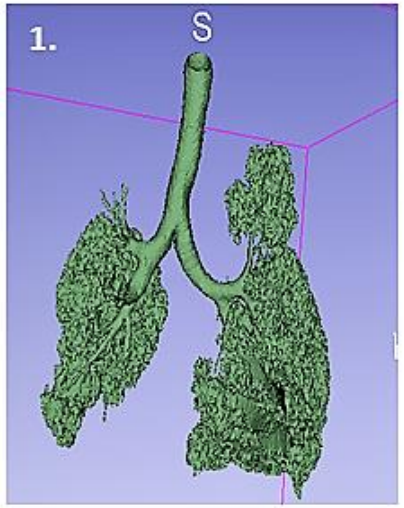
GNN

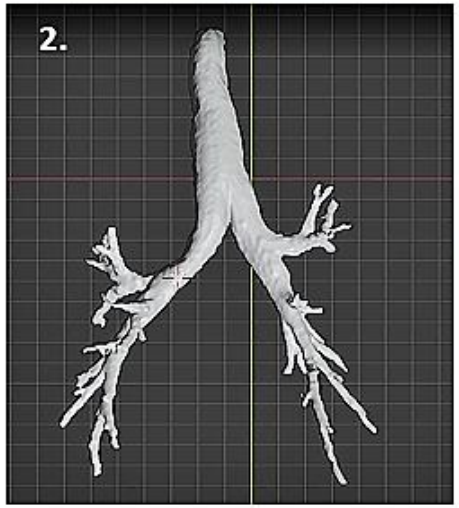


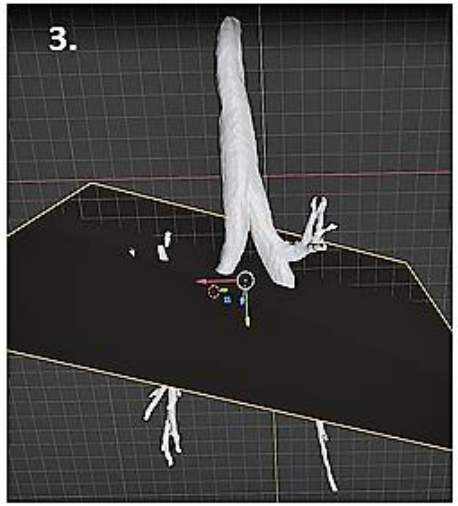
Optimize GNN over information content

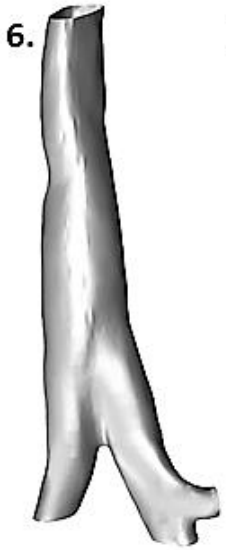
xAI: Iterate over geometric alterations and boundary conditions and interrogate GNN over airflow predictions. Determine input – output correlations.

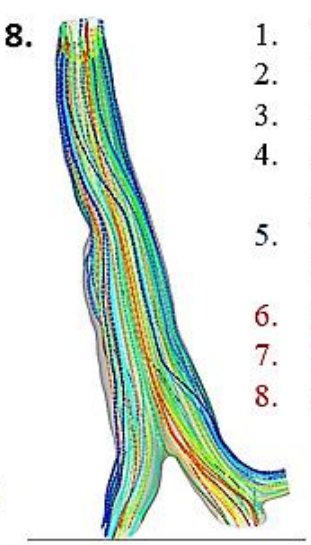
From CT scan to 3D model: step-by-step guide (Annex A.II.1)





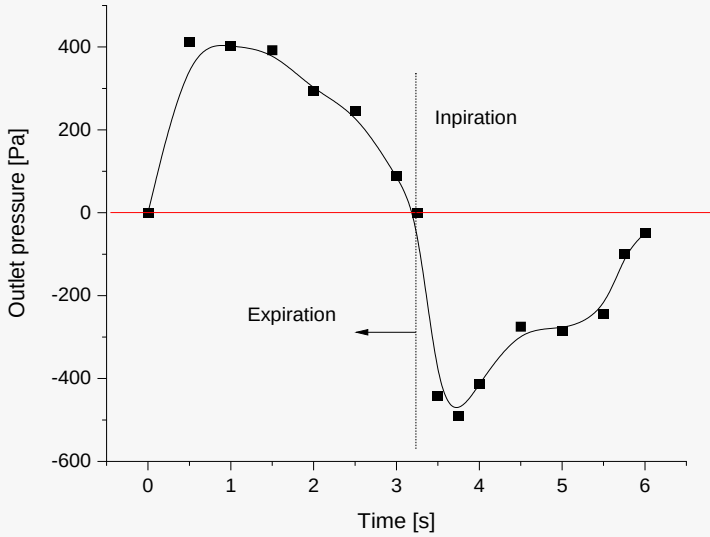


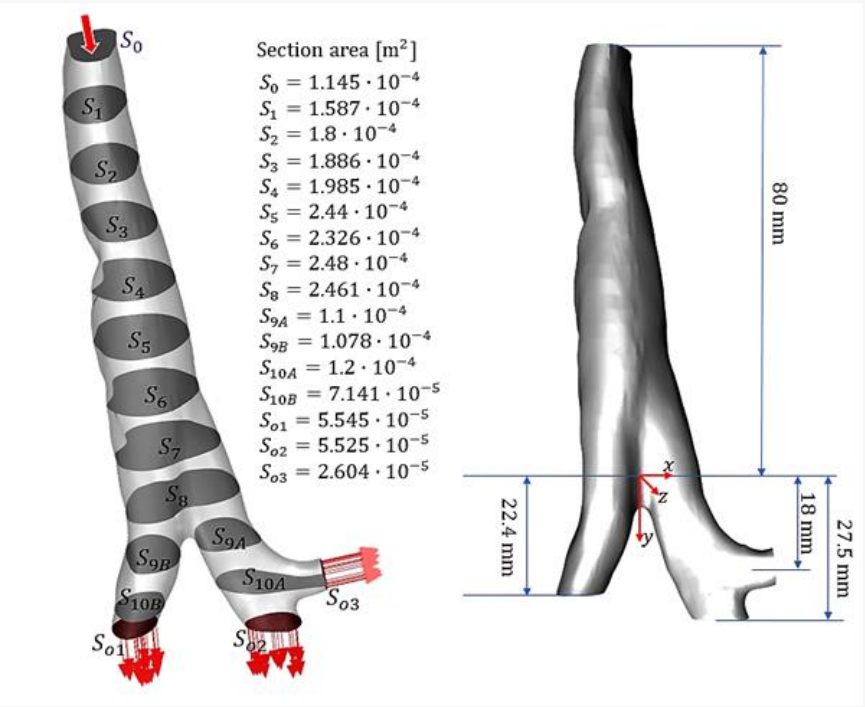




1. Final model from 3DSlicer
2. The trachea model in Blender interface
3. Creating a plane to remove unwanted segments
4. Final Blender model created in Blender and ready to be exported
5. Final solid 3D architecture of the trachea and main bronchi (3D printing)
6. 3D geometry imported in ANSYS Fluent
7. Steady velocity distributions (numerics)
8. Steady path-lines distribution (numerics)

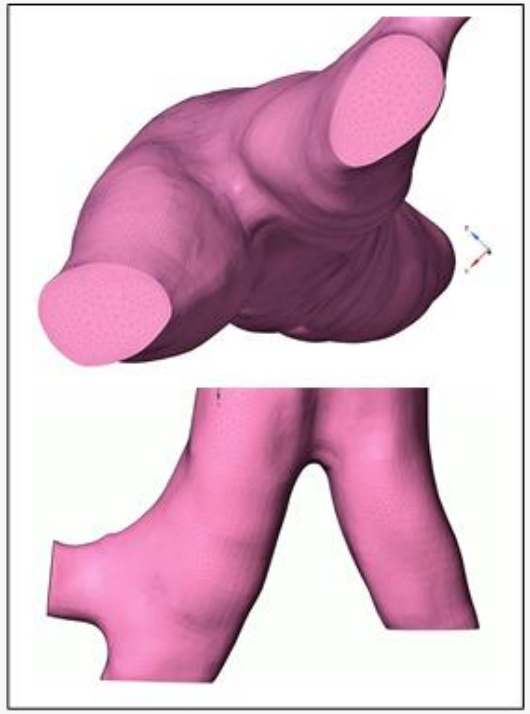
Numerical solutions of the air flow (steady and unsteady)

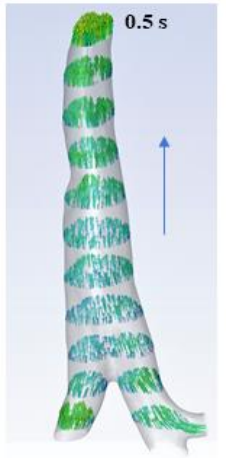


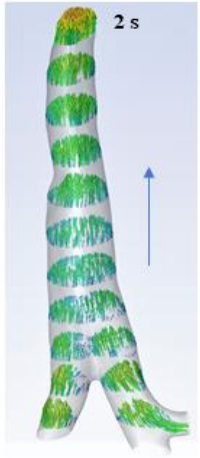


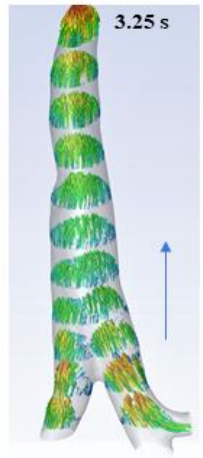
Section area [m²]

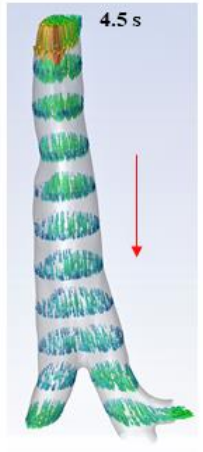
$S_0 = 1.145 \cdot 10^{-4}$
$S_1 = 1.587 \cdot 10^{-4}$
$S_2 = 1.8 \cdot 10^{-4}$
$S_3 = 1.886 \cdot 10^{-4}$
$S_4 = 1.985 \cdot 10^{-4}$
$S_5 = 2.44 \cdot 10^{-4}$
$S_6 = 2.326 \cdot 10^{-4}$
$S_7 = 2.48 \cdot 10^{-4}$
$S_8 = 2.461 \cdot 10^{-4}$
$S_{9A} = 1.1 \cdot 10^{-4}$
$S_{9B} = 1.078 \cdot 10^{-4}$
$S_{10A} = 1.2 \cdot 10^{-4}$
$S_{10B} = 7.141 \cdot 10^{-5}$
$S_{o1} = 5.545 \cdot 10^{-5}$
$S_{o2} = 5.525 \cdot 10^{-5}$
$S_{o3} = 2.604 \cdot 10^{-5}$







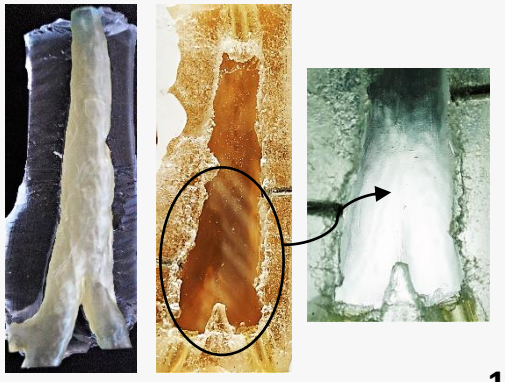




3D test geometry (trachea's first bifurcation), computation flow domain and dimensions. The geometry is obtained from the CT images and the model is fabricated using the 3D printing method

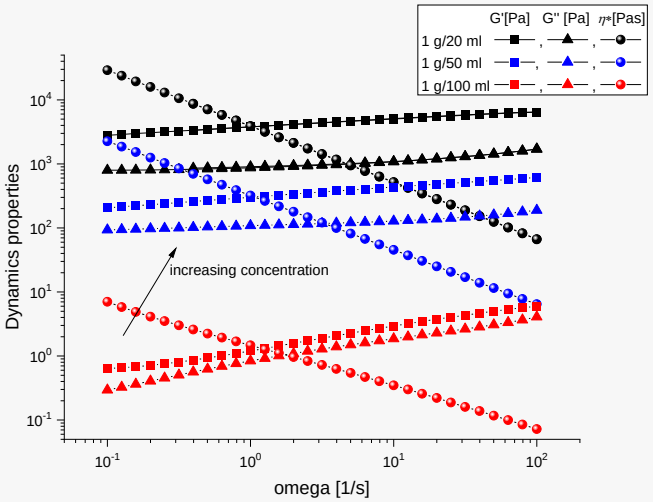
Artificial Mucus

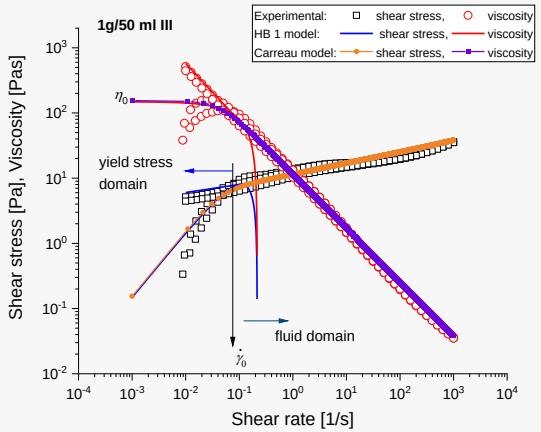
- preparation;
- rheology

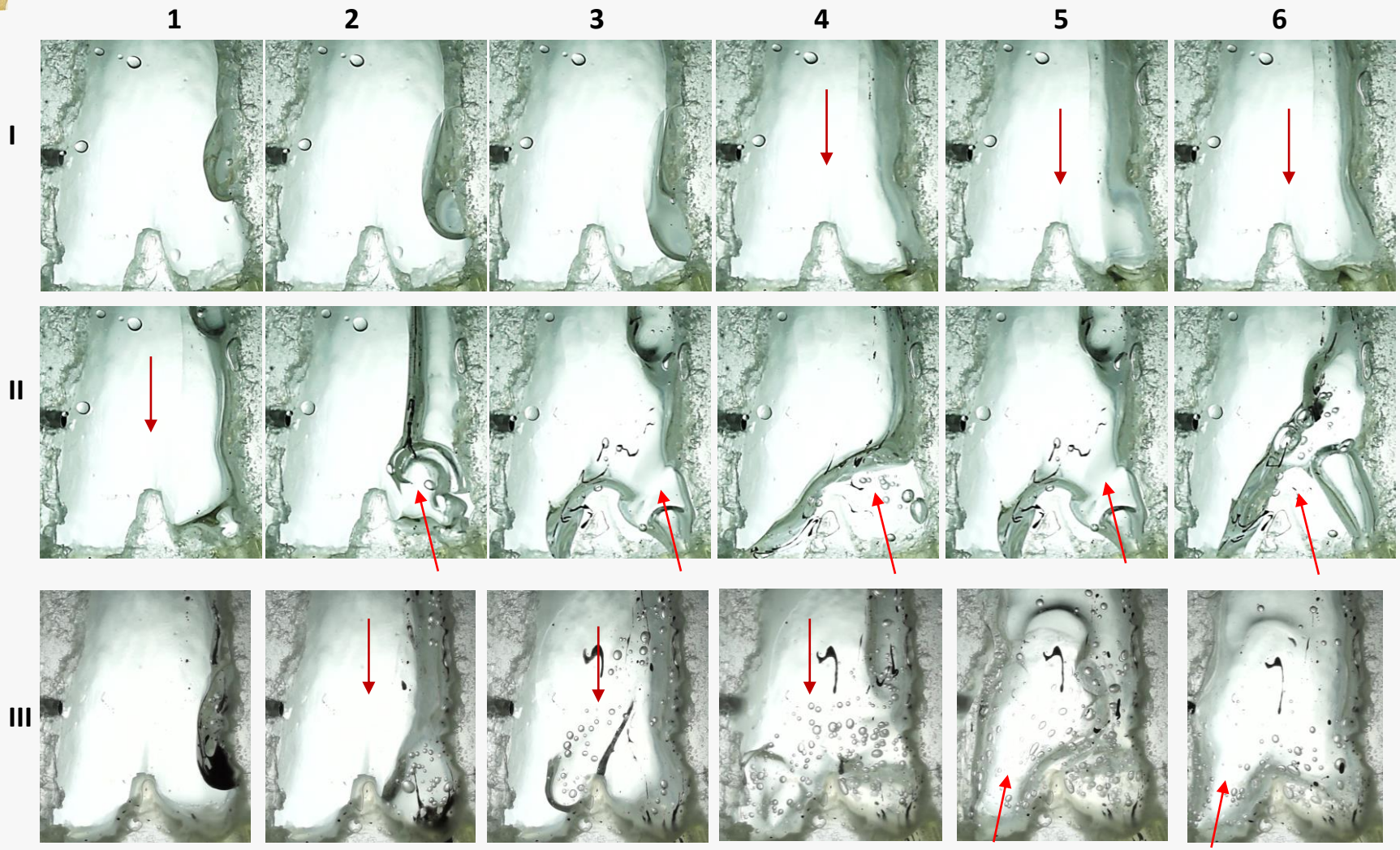


SAM – Sample Artificial Mucus is a solution based on water (as solvent) and the food thickener Fresubin, produced for medical use by Fresenius Kabi company (as solute)

Sample	Newtonian oil	SAM light	SAM with air	SAM gel
Image				





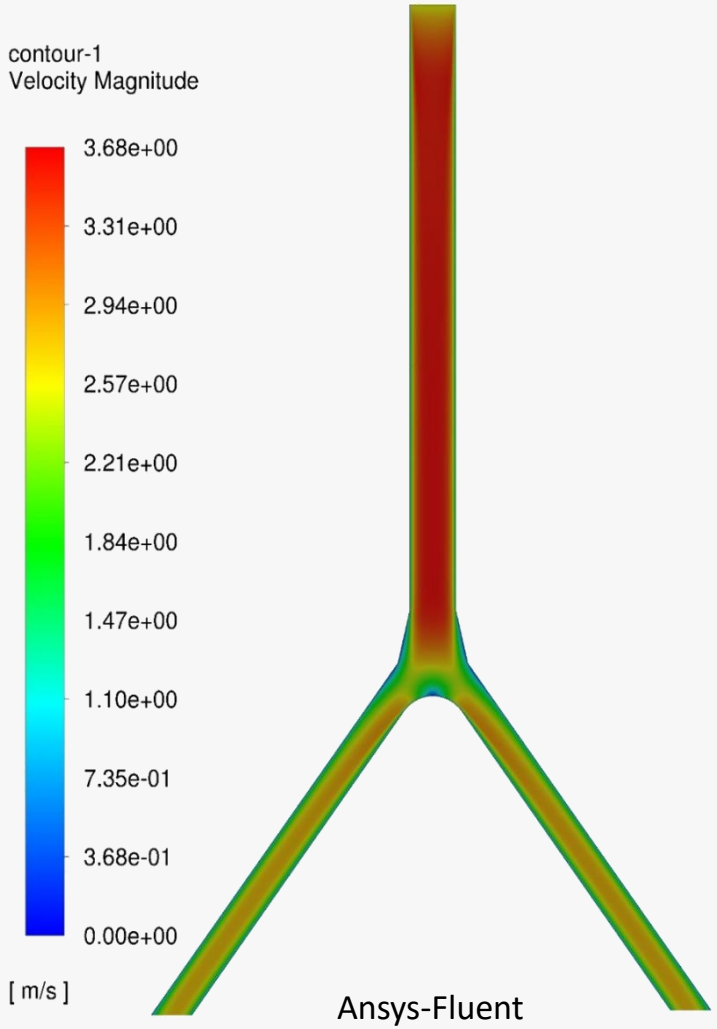


2022

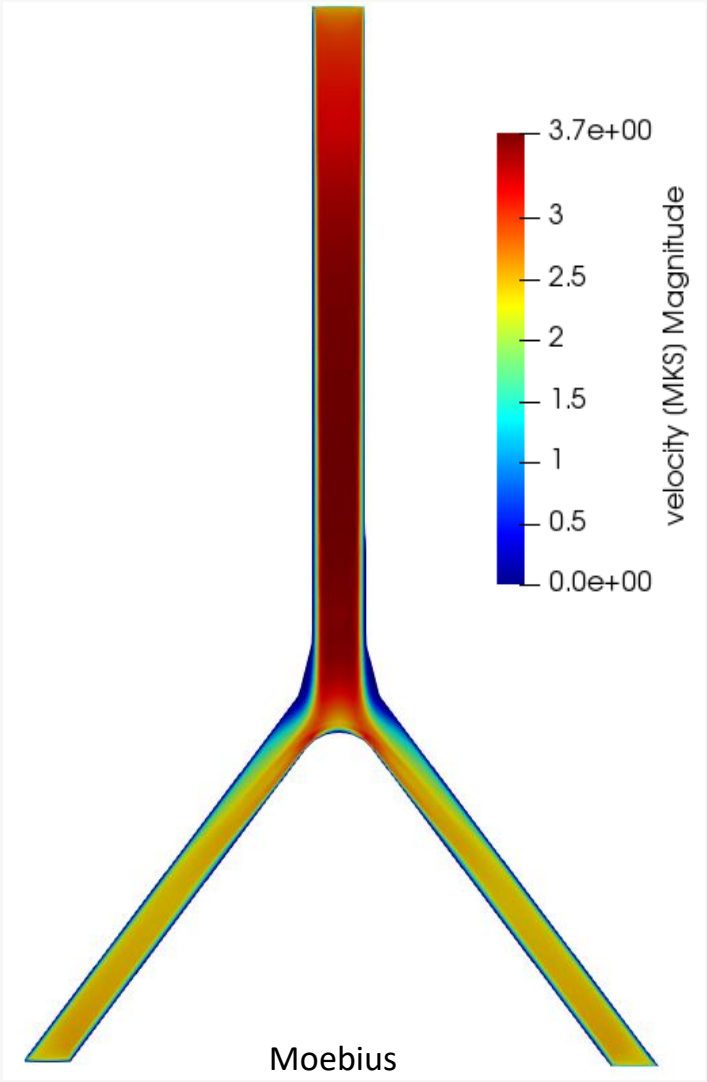
T5.2-3 Experiments and validations of the air-mucus flows in 3D idealized geometries

Boundary conditions:
- inlet: v=2.5 m/s
- outlet: $p = p_0$
- walls: solid wall, no slip

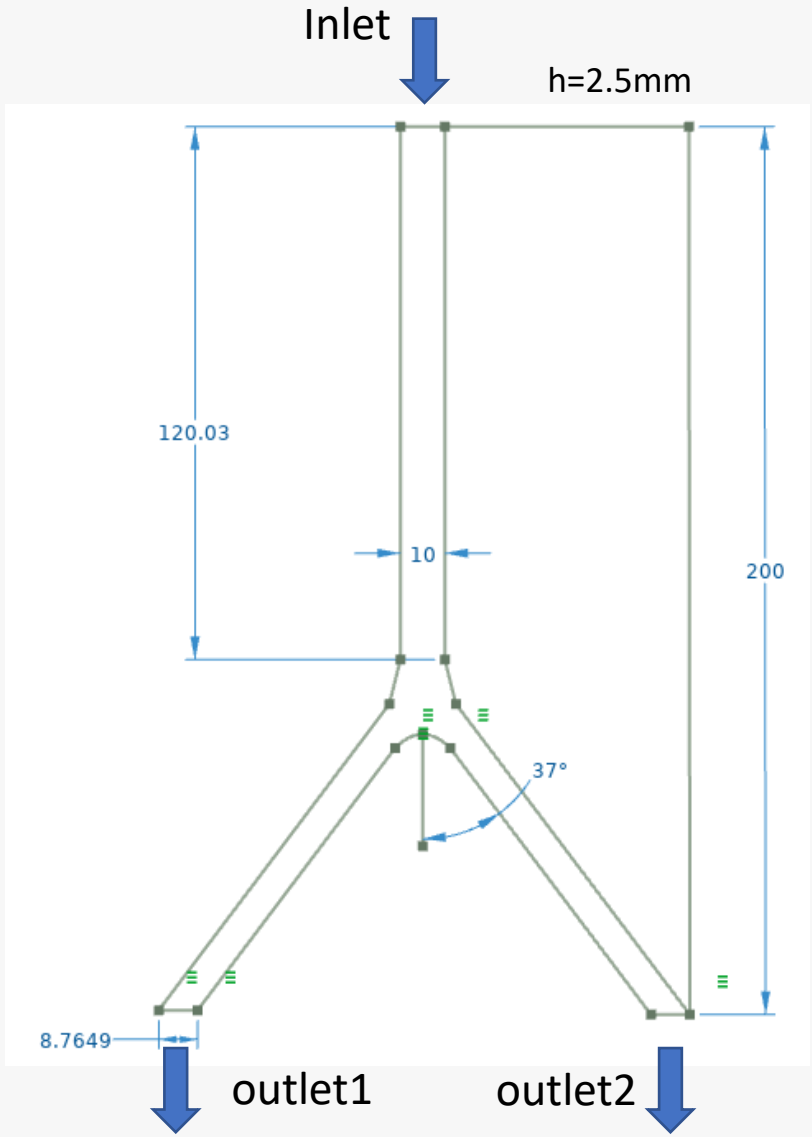
Fluid: air, $\rho = 1.225\ kg/m^3$, $\nu = 1.608 \cdot 10^{-5}\ m^2/s$



Ansys-Fluent



Moebius



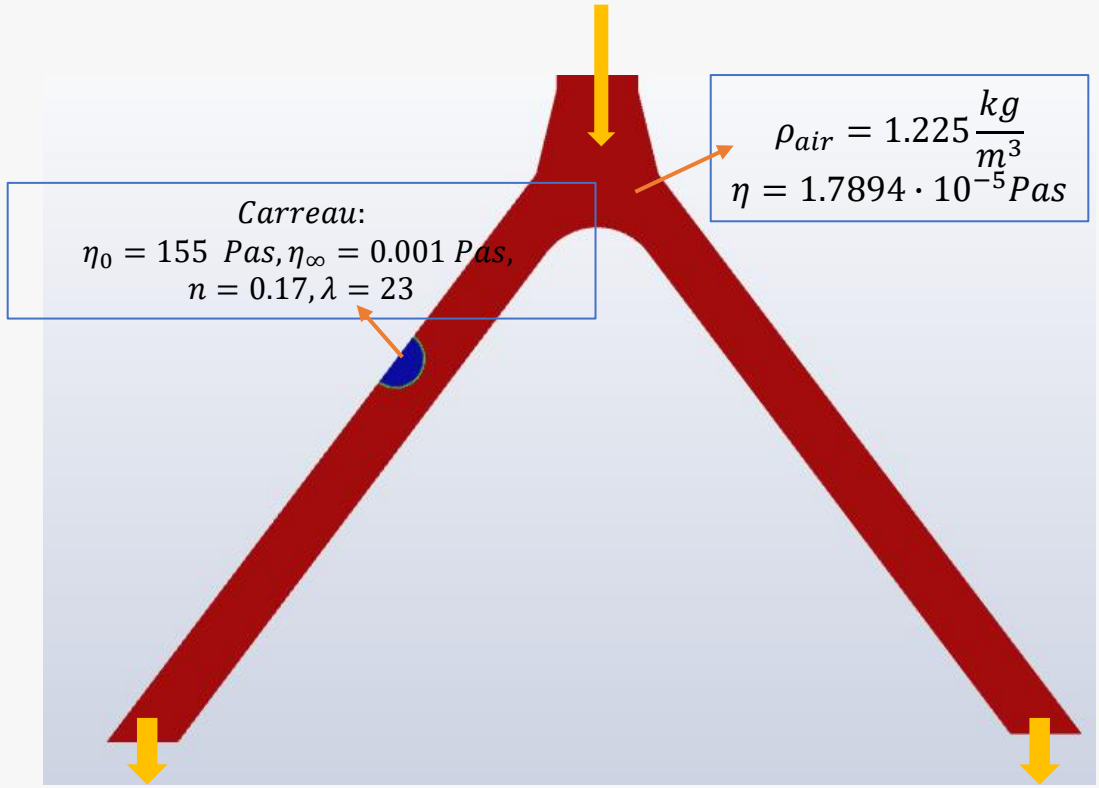
Unsteady air flow in the presence of mucus

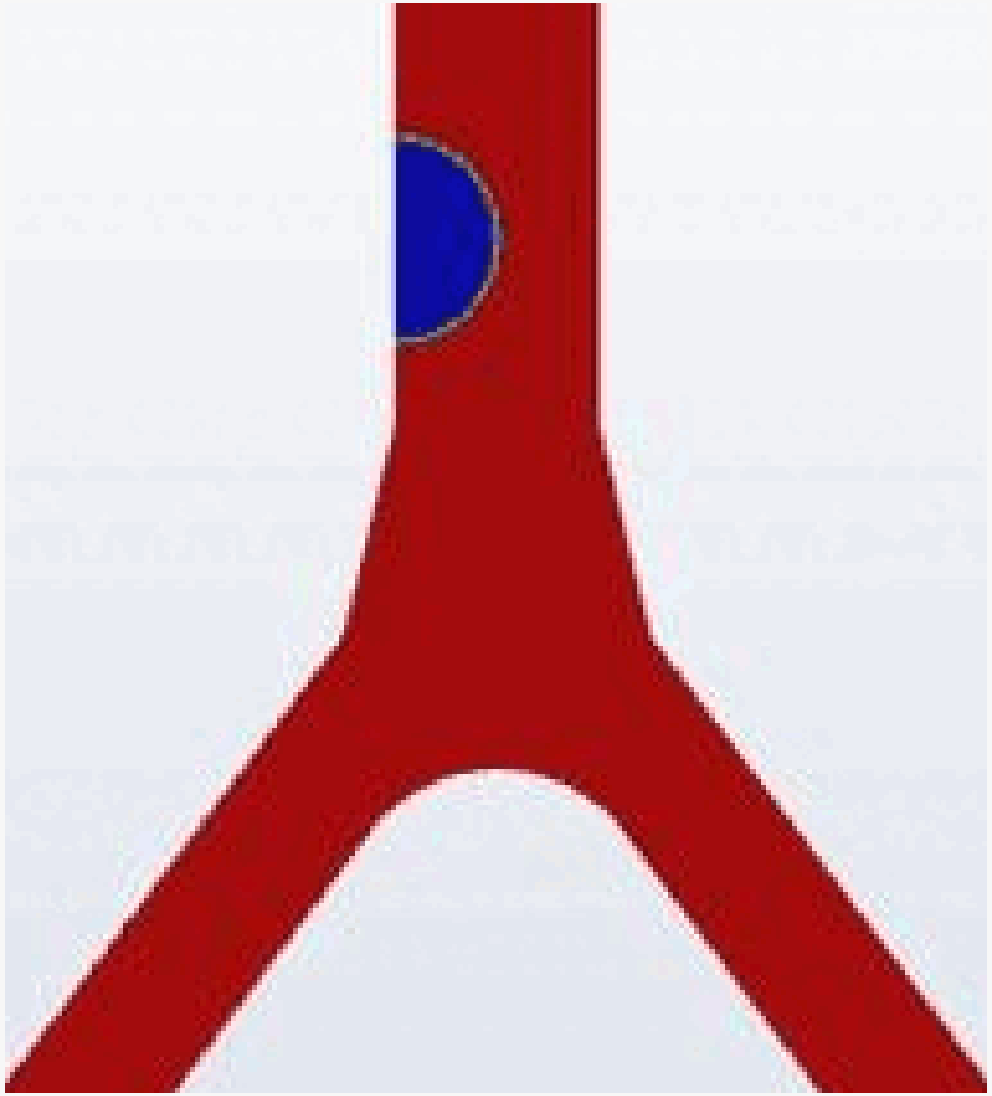
Ansys Workbench 2021 R1

Settings: 3D, double precision, pressure-based, unsteady,
$\Delta t = 10^{-5}\ s, 200\ iterations.time\ steps$
Standard $k-\varepsilon$ turbulence model, VOF (Volume of Fluid):
air – Carreau, surface tension coefficient 0.1 N/m

Boundary conditions:
- inlet: v=7 m/s
- outlet: $p = p_0$
- walls: solid wall, no slip

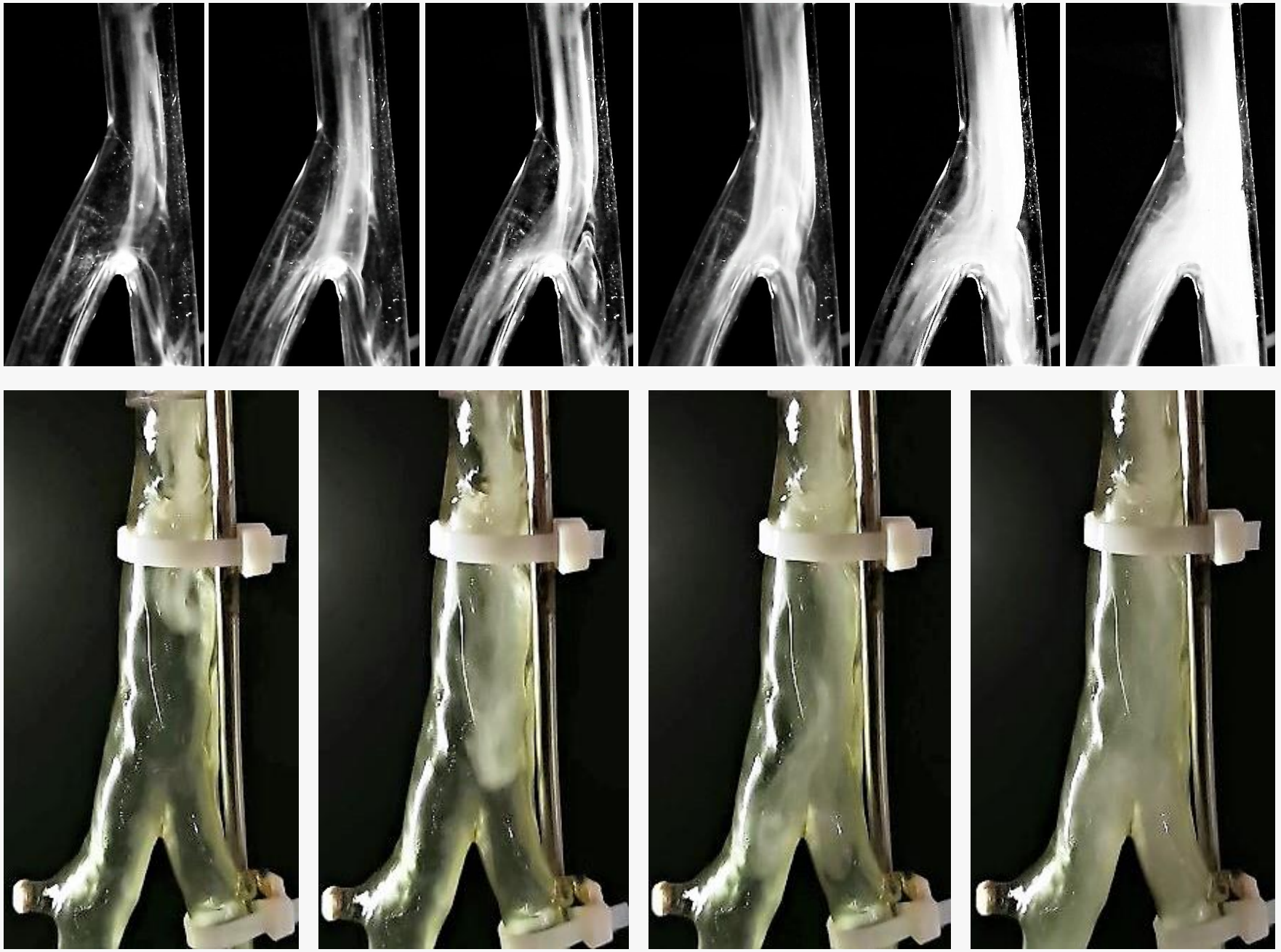
cells	faces	nodes
1255620	3861281	1351644



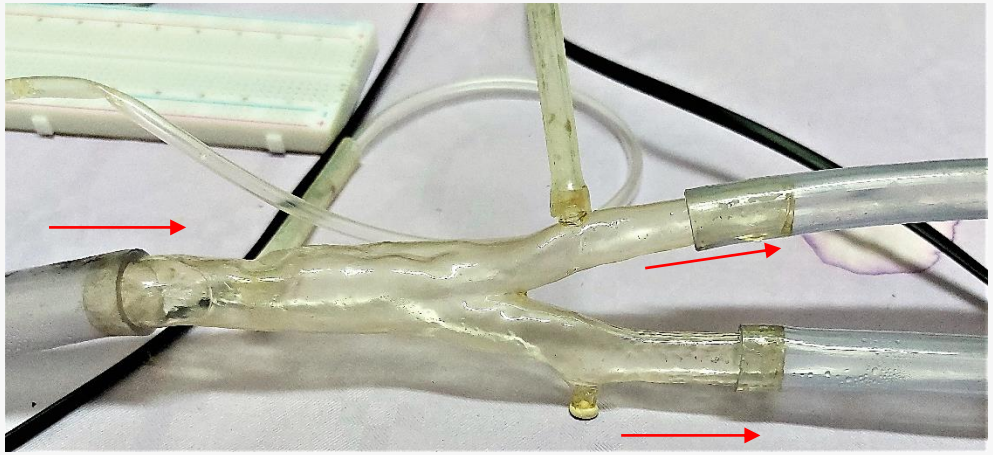


T5.2-3 Experiments and validations of the air-mucus flows in respiratory geometries

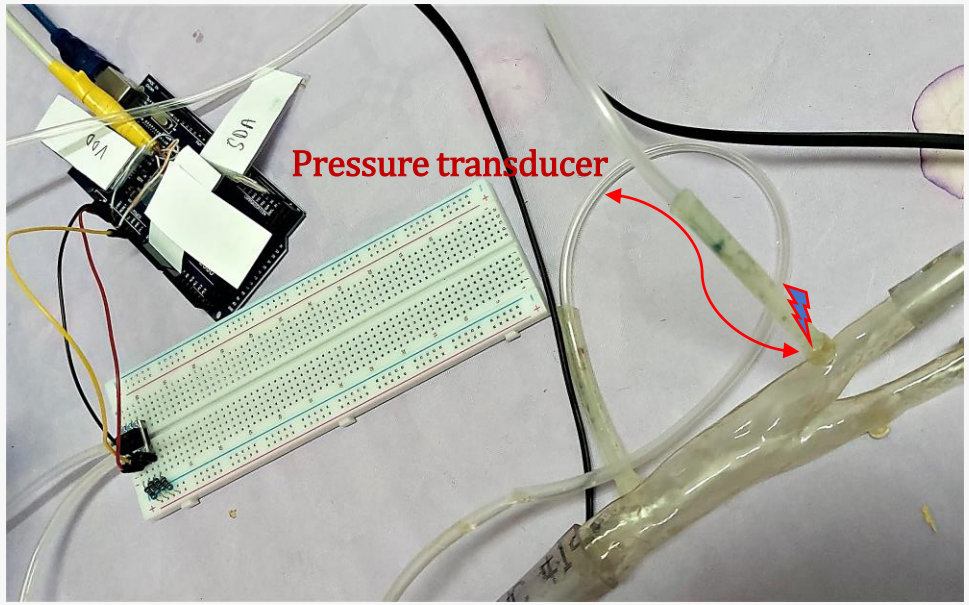
MOVIES

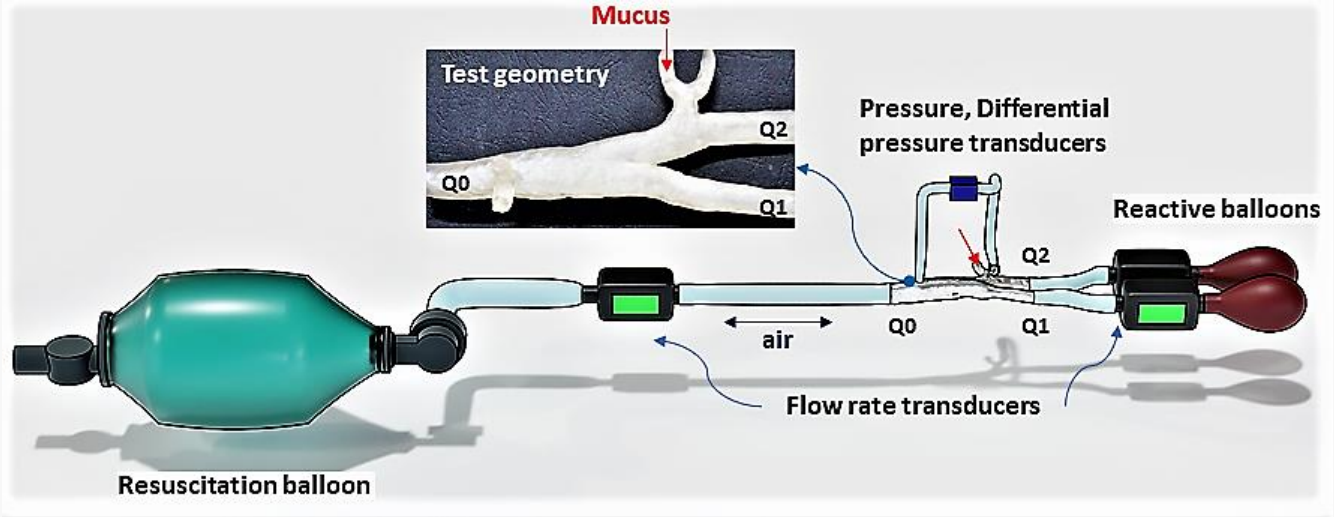


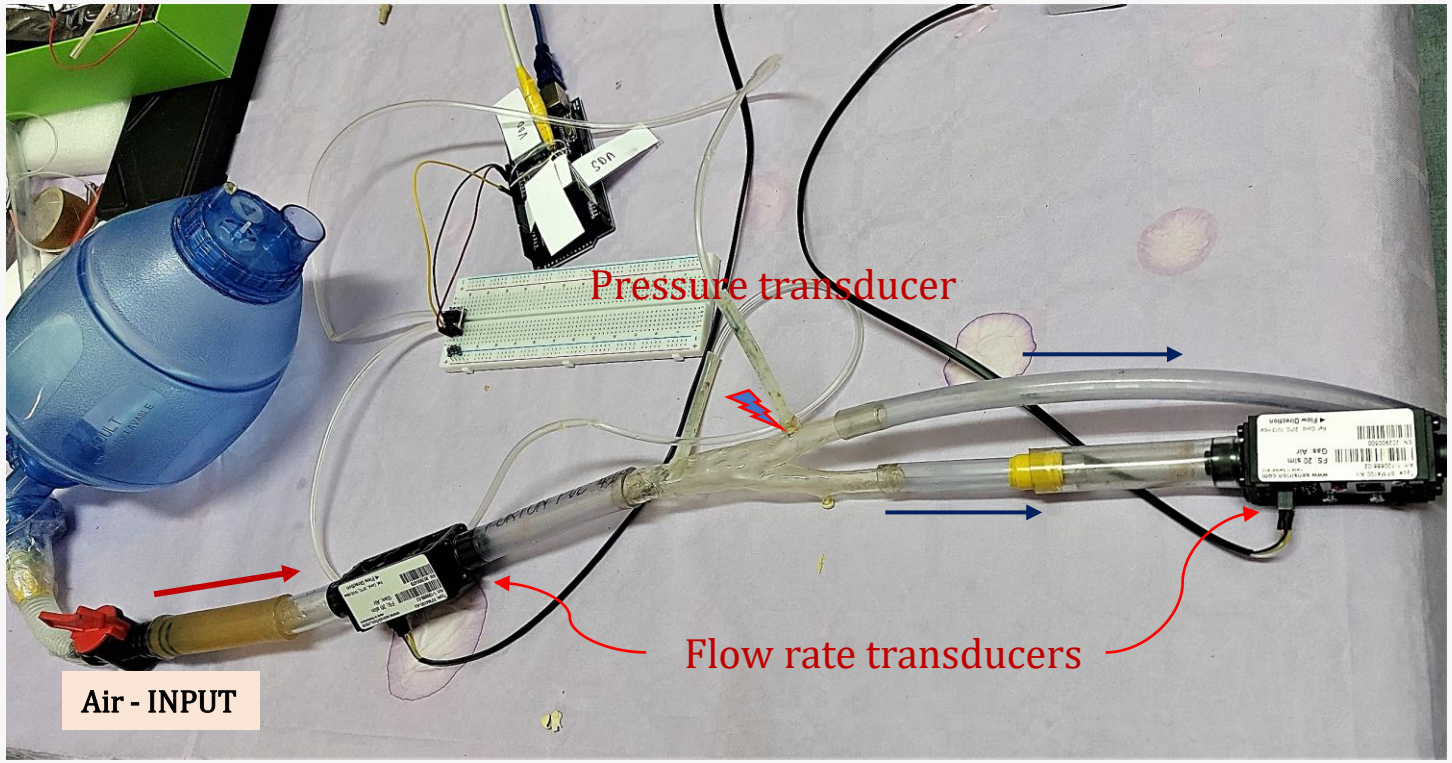
Experimental set-up



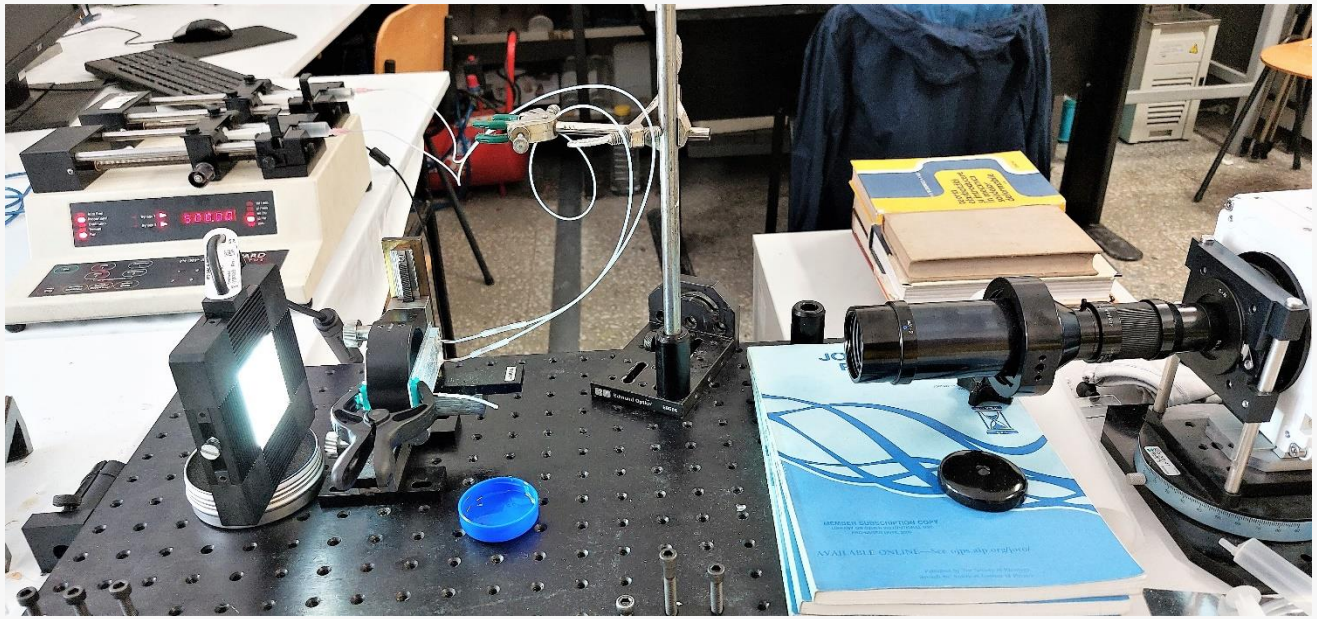
Test bifurcation







Visualizations and PIV measurements



THANK YOU VERY MUCH FOR ATTENTION .....

PS. Part II is folowing ....