flowgy

The power of medical efficiency

Functional CFD Study

Patient Name: [redacted]
Date: 2021.11.26

Introduction

In this report we provide you with the simulation results of the airflow inside the nasal cavity using Computational Fluid Mechanics (CFD) and Virtual Surgery (VS) techniques.

CFD is a field of Physics (Fluid Mechanics) that uses computers to solve problems involving fluid flows. The huge computational power of computers is used by Flowgy to calculate the millions of operations required to solve the interaction of air flow with the complex and unique geometry of the nasal cavity.

CFD and VS techniques are, unlike techniques such as rhinomanometry or acoustic rhinometry, non-invasive and allow you to modify the geometry of the patient's nostrils as many times as you wish, and then analyze and compare the functional results, thus allowing you to optimize and at the same time predict surgical results.

The starting point for CFD and VS analysis is a CT scan or similar of the patient. From this CT scan, an optimized 3D model of the nasal cavity is obtained for the simulation of the airflow inside the nasal cavity and the virtual surgery. After solving the air flow, Flowgy extracts the fields of the fluid variables (pressure, temperature, velocity, humidity, etc.) resulting from the simulation, and presents them in the form of tables, graphs, images, etc. in a way that makes their reading and interpretation an easy task.

How can this report help you?

The results of these simulations will provide you with valuable objective and quantitative information about the real behavior of the air in the nasal cavity, which will help you in your daily clinical practice to accurately detect the different alterations in the upper airway tract of your patients, serving as a support for diagnosis and decision making.

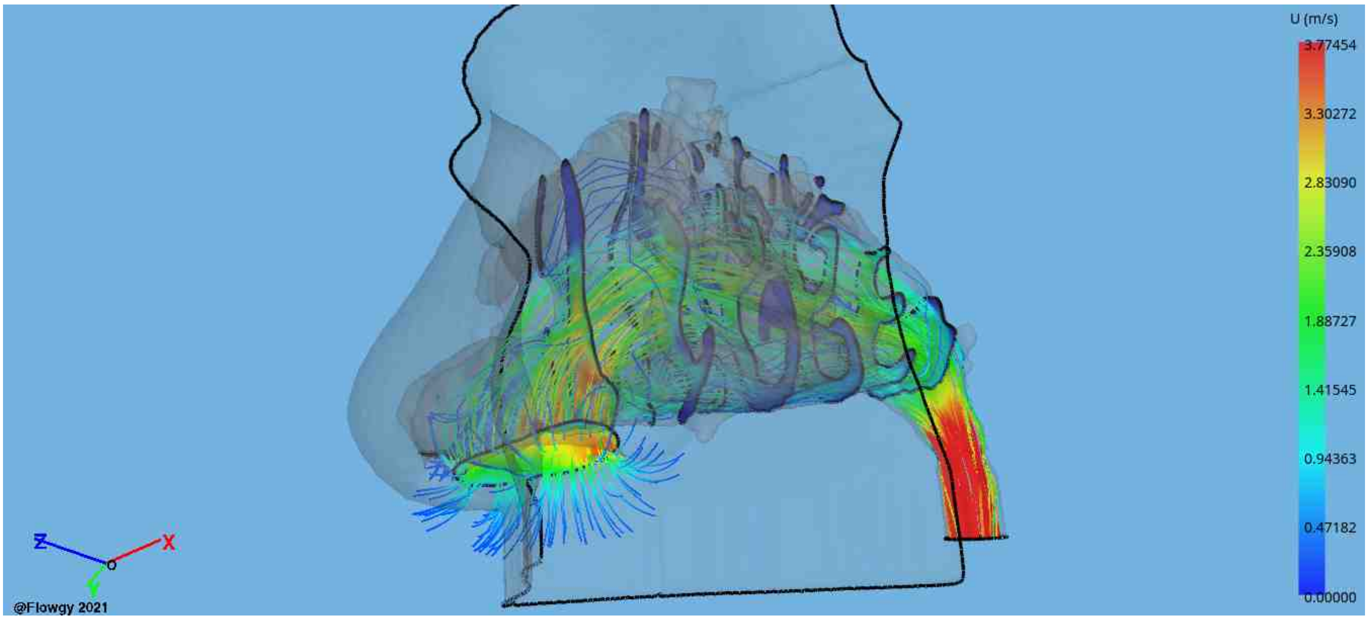

Figure 1: Representation by streamlines of air entry into the nasal cavity. Flow: Inspiration.

OBSERVATIONS - CFD STUDY PRELIMINARY

The flow in inspiration has been solved using computational fluid mechanics techniques (CFD) on the geometry of the nasal cavity of the patient. The geometry was obtained from a CT scan provided by the patient directly. The CFD solution obtained indicates a severe obstruction of the nasal cavity (right nostril). The inspiration flow presents a very high flow asymmetry, with a very high volumetric flow in the left nostril relative to the right nostril.
Resistance is normal, although a very high resistance is seen in the right nostril compared to a very low resistance in the left nostril.

CT Scan

Figure 2: View of the three planes (Coronal, Axial and Sagittal) of the CT Scan.

Comments:

The information contained in the CT Scan provided

"File_Extended_Ext_A.nrrd"

has been analyzed for the resolution of this report.

Information about the patient:

Name: [redacted]
Sex: [redacted]
Age: [redacted]
Nationality:
Comments:

Technical Information about the CT Scan:

File: File_Extended_Ext_A.nrrd
Image Type: scalar
Pixel Type: short
Number of Dimensions: 3
Index: 0, 0, 0
Dimensions: 527, 527, 192
Origin: -105.5, -100.388, -31.75
Spacing: 0.4, 0.4, 0.4

Info before Resample:

CFD Results

For the CFD simulation, a three-dimensional digital model of the patient's nasal cavity will be created from the CT data provided. On the generated three-dimensional model a stationary laminar inspiratory flow is simulated to solve the RANS equations, which will provide us with the CFD analysis values: Flow, Pressure, Nasal Resistance, Temperature, Velocity, etc.

All the resulting data are post-processed for visual representation. Likewise, in order to guarantee its easy interpretation, the engineering terminology is adapted to a medical language.

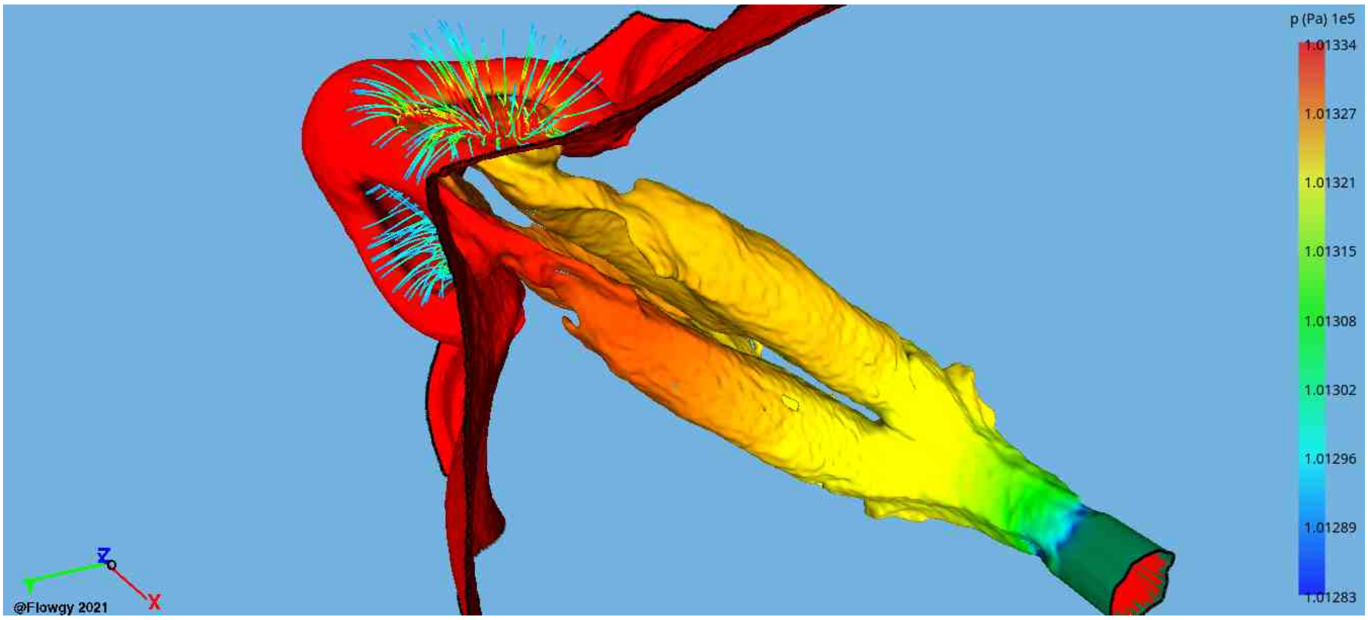

Figure 3: Overview of the outside of the nasal cavity (color map of the pressure field), and streamlines (with color corresponding to the velocity field). Flow: Inspiration.

Comments:

DATA OF THE CFD SOLUTION

Right Area: 114.515 mm^2
Left Area: 107.674 mm^2

Mass Flow: 15.00 L/min
Right Mass Flow: 15.97 % 2.39 L/min)
Left Mass Flow: 84.03 % 12.61 L/min)

Pressure Inlet: 101333.55 Pa
Pressure Choana: 101320.80 Pa (ΔPc = 12.75 Pa)
Pressure Outlet: 101299.99 Pa (ΔP = 33.55 Pa)

Φ: 2.633
R: 5.910

Technical information of the CFD Mesh:

Number of vertices: 359365
Number of faces: 718778
Number of 3D vertices: 1052221
Number of 3D cells: 5466161
Number of 3D faces: 11291711

Information of the CFD Solver:

Summary of the flow conditions that have been simulated in the three-dimensional model of the patient's nasal cavity.

Mass Flow: 15 L/min
Outside temperature: 21 C
Wall temperature: 36.5 C
Type of flow: Inspiration
Humidity:
HR ext.: 100
HR wall: 20

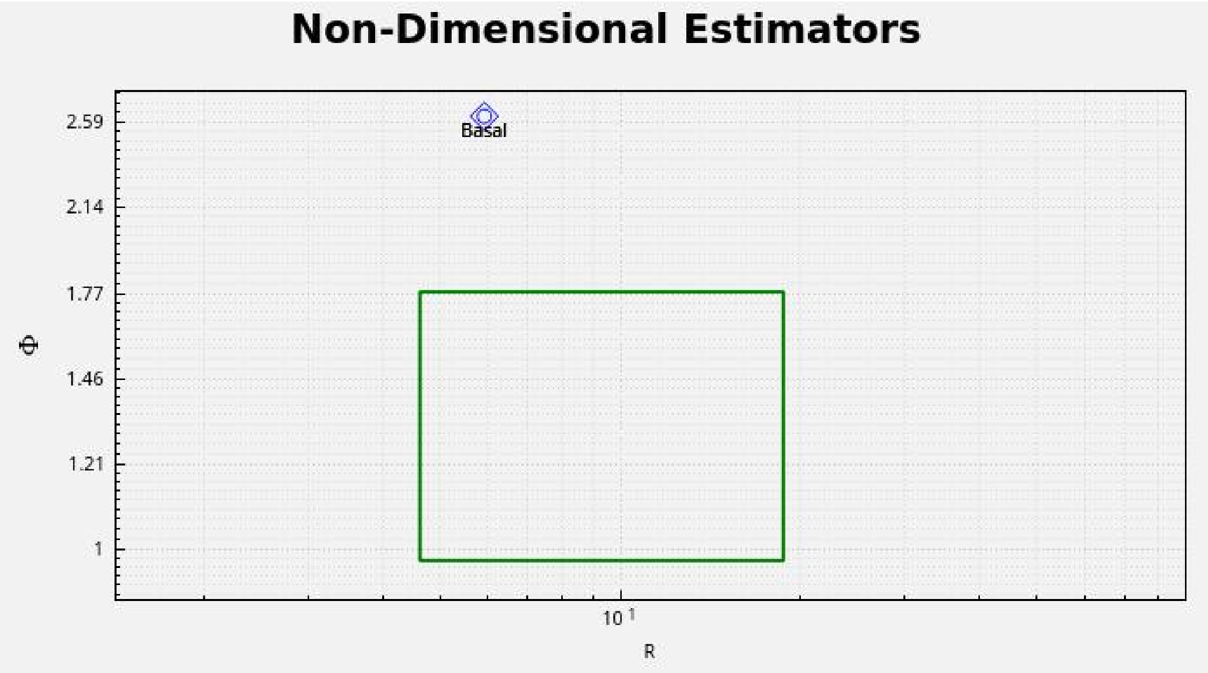

Figure 4: Graphical representation of the non-dimensional estimators Φ (Flow Symmetry) and R (Resistance).

CFD Results

The following table shows the numerical results derived from the CFD simulation.

$Name$	A A_R and A_L [74.90 - 139.10]		Q		P_{atm}	P_c	ΔP	Φ [0.97 - 1.7]	R [4.5 - 18.3]		NR
	A_R	A_L	Q_R	Q_L					R_R	R_L	
Basal	222.189		14.350		101334	101321	13.00	2.63273	5.91043		0.05436
	114.515	107.674	2.291	12.059					191.133	6.09903	

A: Total Area Nostrils (mm^2)
A_R: Area Right Nostril (mm^2) *Values between 74.9 and 139.1* mm^2 *are assumed to be within the normal range.*
A_L: Area Left Nostril (mm^2) *Values between 74.9 and 139.1* mm^2 *are assumed to be within the normal range.*
Q: Total Flow Rate (L/min)
Q_R: Flow Rate Right Nostril (L/min)
Q_L: Flow Rate Left Nostril (L/min)
Q_T: Flow Rate Total (L/min) Q_T is the sum of Q_R and Q_L.
P_{atm}: Atmosferic Pressure (P_a)
P_c: Pressure at the Choana (P_a)
ΔP: Drop Pressure between Atmosphere and Choana (P_a)
Φ: Flow Symmetry. *Values between 0.97 and 1.7 indicate in the first instance that there is no nasal obstruction. This parameter can be observed in the table of non-dimensional estimators.*
R: Resistance. *Values between 4.5 and 18.3 indicate in the first instance that there is no nasal obstruction. This parameter can be observed in the table of non-dimensional estimators.*
R_R: Right Resistance.
R_L: Left Resistance.
NR: Nasal Resistance in $P_a\,s\,/cm^3$

Streamlines

Streamlines show the flow of air entering the nasal cavity and its behavior within the nasal and paranasal cavities.

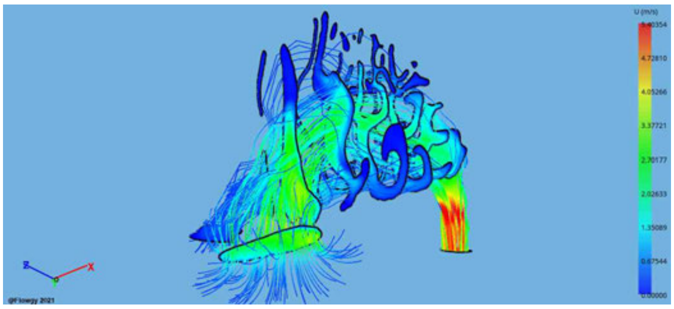

Figure 5: Generic frontal 3D view of the streamlines through five anatomical cuts with the velocity field.

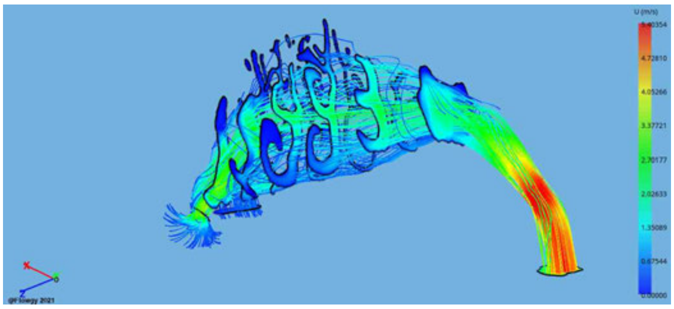

Figure 6: Generic back 3D view of the streamlines through five anatomical cuts with the velocity field.

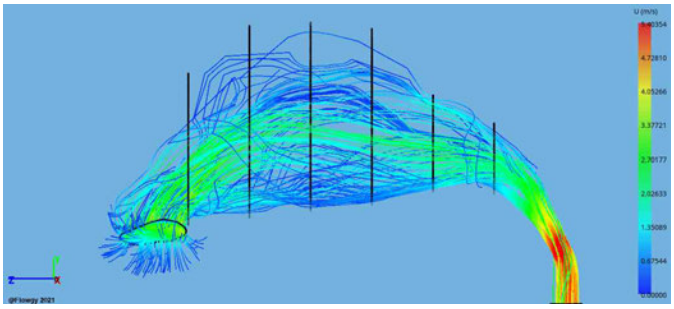

Figure 7: Sagittal right side view of the streamlines with velocity field.

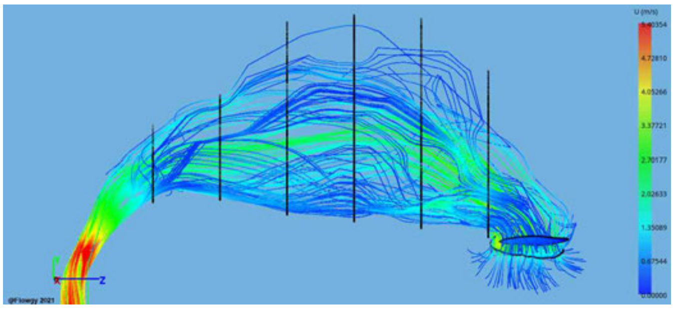

Figure 8: Sagittal left side view of the streamlines with velocity field.

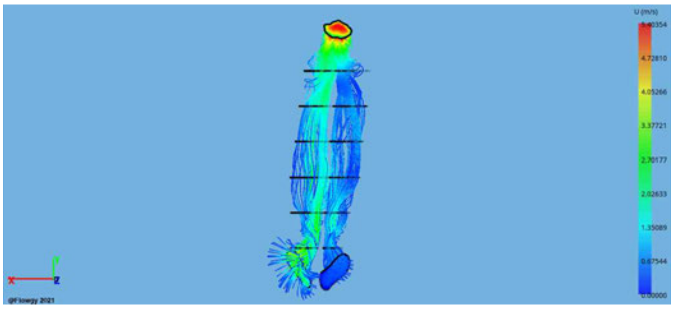

Figure 9: Axial view of the streamlines with velocity field.

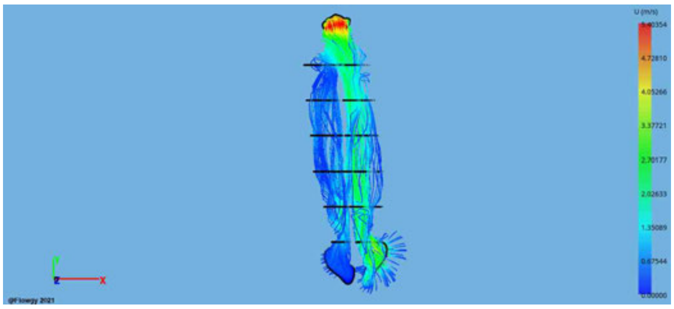

Figure 10: Axial back view of the streamlines with velocity field.

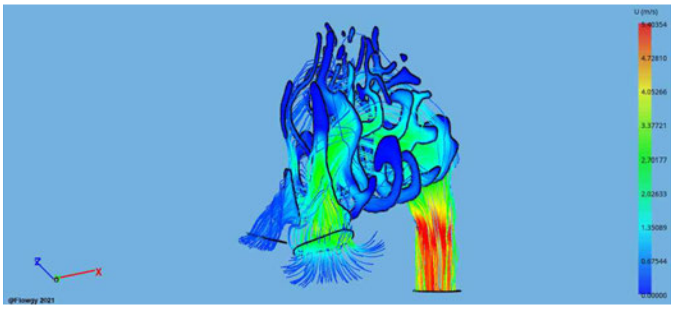

Figure 11: Coronal back view of the streamlines with the velocity field.

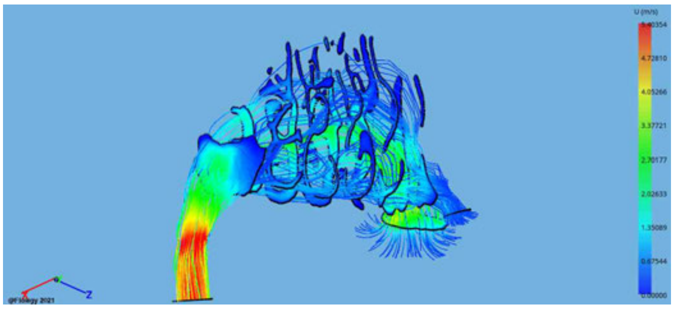

Figure 12: Coronal front view of the streamlines with the velocity field.

Pressure Field

Pressure is defined as the force per unit area acting in the normal direction to that area. The figure shows the solid surface bounding the nasal cavity through which air flows, and this surface has been colored with the values of the pressure at each point on the surface. The color scheme shows a range of colors from blue (low pressure) to red (high pressure).

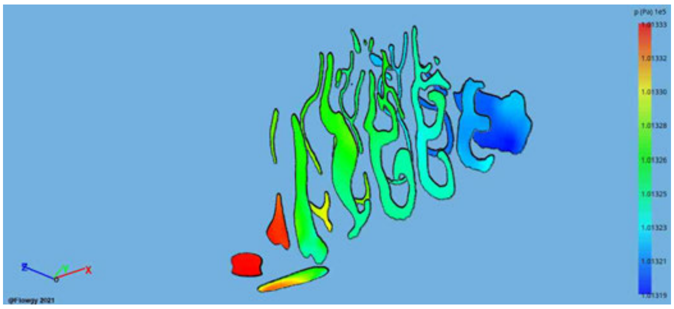

Figure 13: Pressure field back view shown in anatomical cuts of the interior of the nasal cavity.

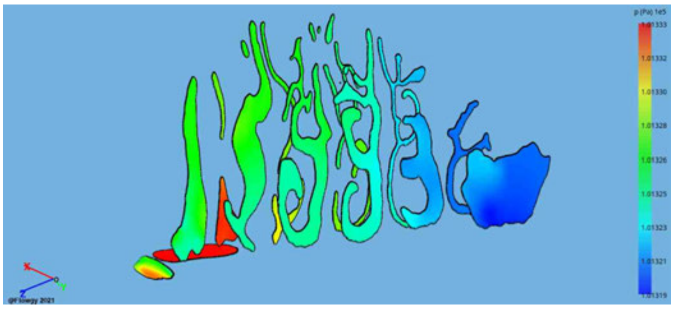

Figure 14: Pressure field front view shown in anatomical cuts of the interior of the nasal cavity.

Velocity Field

Velocity is defined as a vector measurement of the rate and direction of motion. Put simply, velocity is the speed at which something moves in one direction. Flowgy displays the results of velocity in units of m/s (meters per second). The color scheme shows a range of colors from blue (low velocity) to red (high velocity).

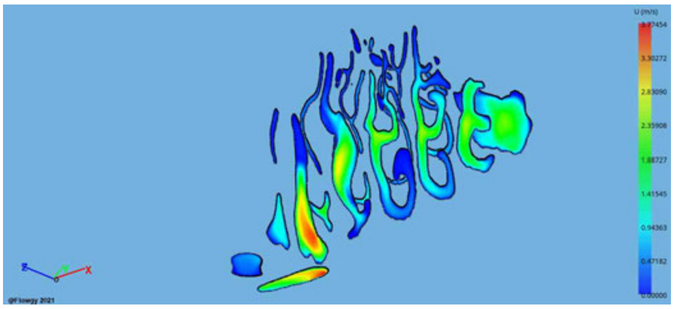

Figure 15: Velocity field front view shown in anatomical cuts of the interior of the nasal cavity.

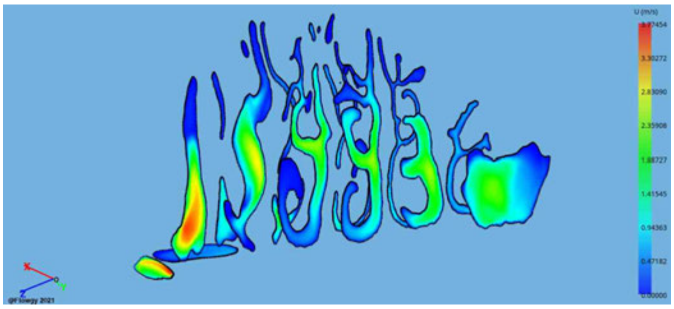

Figure 16: Velocity field back view shown in anatomical cuts of the interior of the nasal cavity.

Temperature Field

Temperature is a physical quantity that expresses hot and cold. It is the manifestation of thermal energy, present in all matter. Flowgy displays temperature results in degrees Celsius. The color scheme shows a range of colors from blue (low temperature) to red (high temperature).

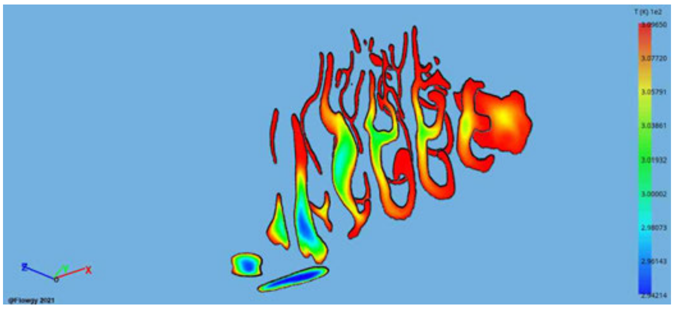

Figure 17: Temperature field front view shown in anatomical cuts of the interior of the nasal cavity.

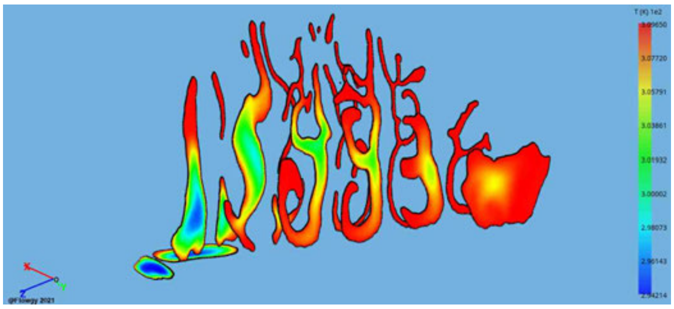

Figure 18: Temperature field back view shown in anatomical cuts of the interior of the nasal cavity.

Humidity

Humidity is the concentration of water vapour present in the air. It depends on the temperature and pressure of the system of the nasal cavity. The color scheme shows a range of colors from blue (low humidity) to red (high humidity).

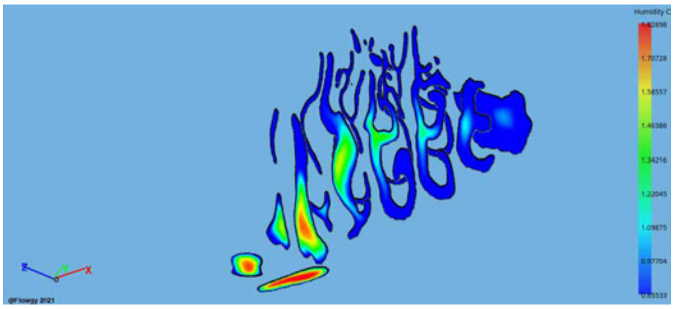

Figure 19: Humidity field front view shown in anatomical cuts of the interior of the nasal cavity.

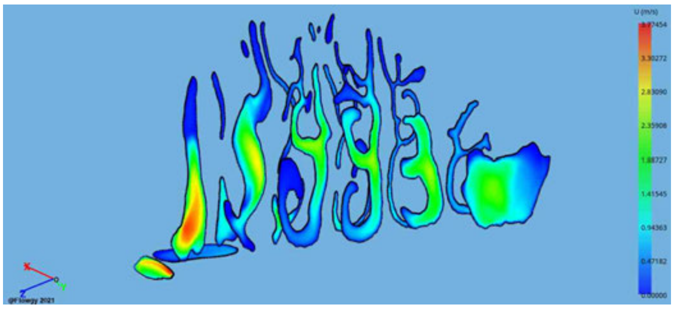

Figure 20: Humidity field back view shown in anatomical cuts of the interior of the nasal cavity.

Wall Shear Stress (WSS)

Wall shear stress is the shear stress in the layer of fluid next to the wall. The wall shear stress expresses the force per unit area exerted by the wall on the fluid in a direction on the local tangent plane. The color scheme shows a range of colors from blue (low WSS) to red (high WSS).

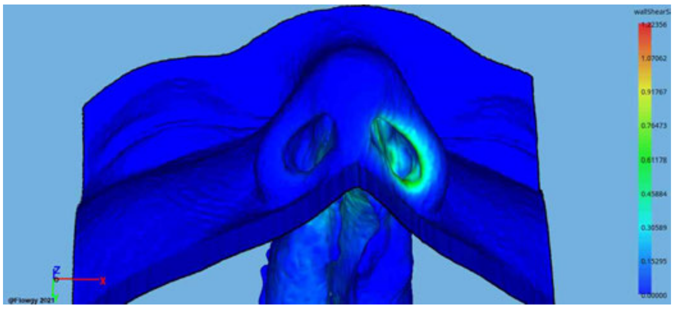

Figure 21: 3D View of WSS.

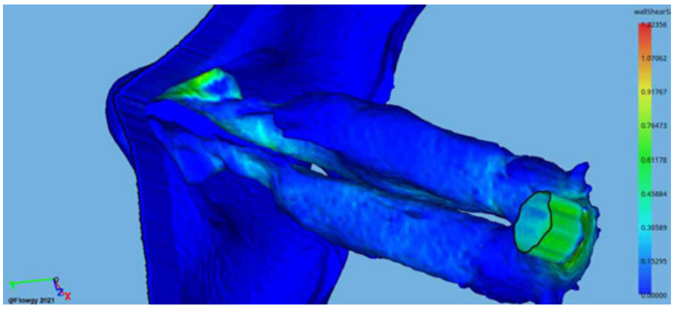

Figure 22: 3D View of WSS.

Convergence Residuals and Non-Dimensional Estimators

The residual is one of the most fundamental measures of an iterative solution's convergence, as it directly quantifies the error in the solution of the system of equations. In a CFD analysis, the residual measures the local imbalance of a conserved variable in each control volume. The lower the residual value is, the more numerically accurate the solution.

Graphical representation of dimensional estimators. Φ: parameter measuring flow symmetry. R: parameter measuring the resistance.

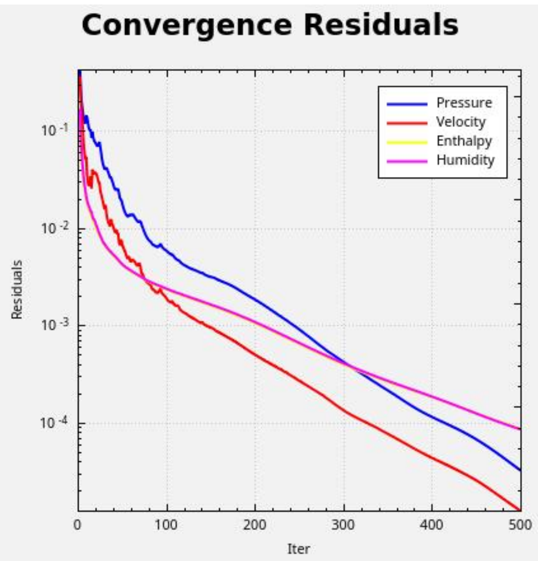

Figure 23: Convergence Residuals.

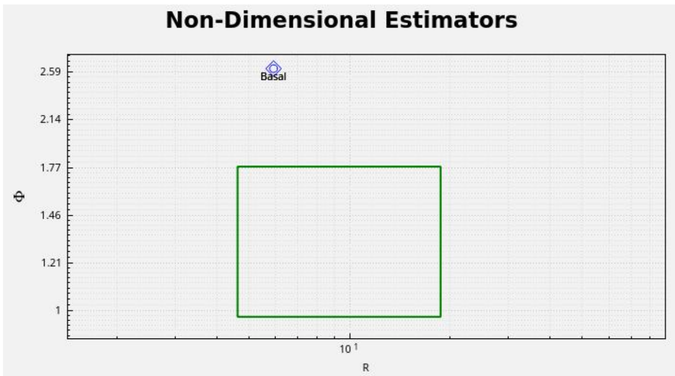

Figure 24: Non-Dimensional Estimators.

Glosary

CFD

It is an acronym for Computational Fluid Dynamics. Fluid Dynamics is the science that describes the motion of a fluid (gas or liquid) by means of mathematical equations. These equations, when solved, give the values of all quantities which describe the fluid motion, like velocity, pressure, temperature. The attribute Computational indicates that these equations are solved by means of numerical methods. So, basically, CFD is a numerical method that can be implemented on a computer that, solving mathematical equations, describes the behavior of a given fluid in a given condition. CFD is used in a wide set of fields, here some examples: to describe the air motion around a vehicle, the fluid motion inside a valve, the smoke dispersion inside a parking lot or the airflow of the nasal cavities.

https://conself.com/blog/common-cfd-terms-explained/

Virtual Surgery

It refers to the virtual simulation of surgical procedures with the objective of training medical professionals, without the need of a patient, cadaver or animal. Flowgy integrates and combines different virtual surgery technologies that allow to modify, either on the CT Scan or on a three-dimensional model of the patient's own nasal cavity, the anatomical structure allowing the simulation of a surgical procedure.

https://www.sciencedirect.com/science/article/abs/pii/S001048251830129X?via%3Dihub

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Fluid mechanics

It is the branch of physics concerned with the mechanics of fluids (liquids, gases, and plasmas) and the forces on them. It has applications in a wide range of disciplines, including mechanical, civil, chemical and biomedical engineering, geophysics, oceanography, meteorology, astrophysics, and biology.

https://en.wikipedia.org/wiki/Fluid_mechanics

Rhinomanometry

It measures nasal pressure and airflow during breathing. It gives a functional measure of the pressure- flow relationships during the respiratory cycle, is accepted as the standard technique for measuring nasal airway resistance and assessing the patency of the nose.

https://www.sciencedirect.com/topics/medicine-and-dentistry/rhinomanometry

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Acoustic rhinometry

It uses a reflected sound signal to measure the cross-sectional area and volume of the nasal passage. Acoustic rhinometry gives an anatomic description of a nasal passage.

https://www.sciencedirect.com/topics/medicine-and-dentistry/rhinomanometry

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CT Scan

A CT scan or computed tomography scan (formerly known as computed axial tomography or CAT scan) is a medical imaging technique used in radiology to get detailed images of the body non-invasively for diagnostic purposes. The personnel that perform CT scans are called radiographers or radiology technologists.

https://en.wikipedia.org/wiki/CT_scan

Image Segmentation

It is the process by which a digital image is partitioned into multiple segments (pixels), and whose objective is to simplify the representation of the image for a more efficient analysis.

https://en.wikipedia.org/wiki/Image_segmentation

Convergence	The Fluid Dynamics equations are solved by means of numerical methods, that are generally iterative. The number of iterations needed to obtain the correct solution varies. It is possible to measure how far one is from the correct solution, and to use that measure to stop the iterative method when the correct solution is reached. When it happens, the analysis is said to be Converged or to have reached Convergence, which simply means that the obtained solution is correct. `https://conself.com/blog/common-cfd-terms-explained/`
Non- Dimensional Estimators	The Non-Dimensional parameters are used by Flowgy to quantitatively measure the grade of nasal cavity obstruction. The first mathematical estimator Φ is a function of geometric features and possible asymmetries between the nostrils, whereas the second estimator R represents in fluid mechanics terms the total nasal resistance corresponding to the atmosphere-channel pressure drop. `https://onlinelibrary.wiley.com/doi/10.1002/cnm.2906`

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Flowgy S.L.

CEDIT UPCT Parque tecnológico de Fuente Álamo.

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Flowgy – Software de diagnóstico y cirugía nasal Versión: 1.2.1.

Conformidad con la Directiva Europea 93/42/CEE

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