

## **Computational Fluid Dynamic Analysis of Nasal Airway Model**

**Shubham Singhmar, Deepak Duhan, Rishabh Thakur**

Student, Department of mechanical engineering, Chandigarh University, India

Student, Department of biotechnology, Chandigarh University, India

Student, Department of biotechnology, Chandigarh University, India

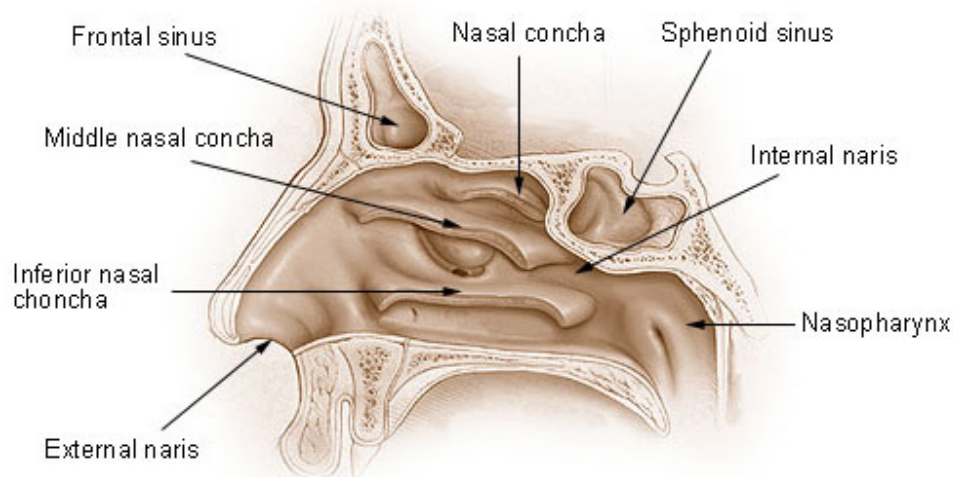
### **Abstract**

*This Paper is designed to show the process of extracting a nasal airway cavity geometry from a set of CT scans using Materialize MIMICs software. The tutorial also explains meshing the geometry in ICEM CFD and solving the model in FLUENT. This process was created for research which the goal is to model and quantify nasal reconstruction surgical procedures. Comparing the various surgical techniques using CFD results will help surgeons determine the proper procedure for the type of nasal airway obstruction in the patient.*

### **Introduction**

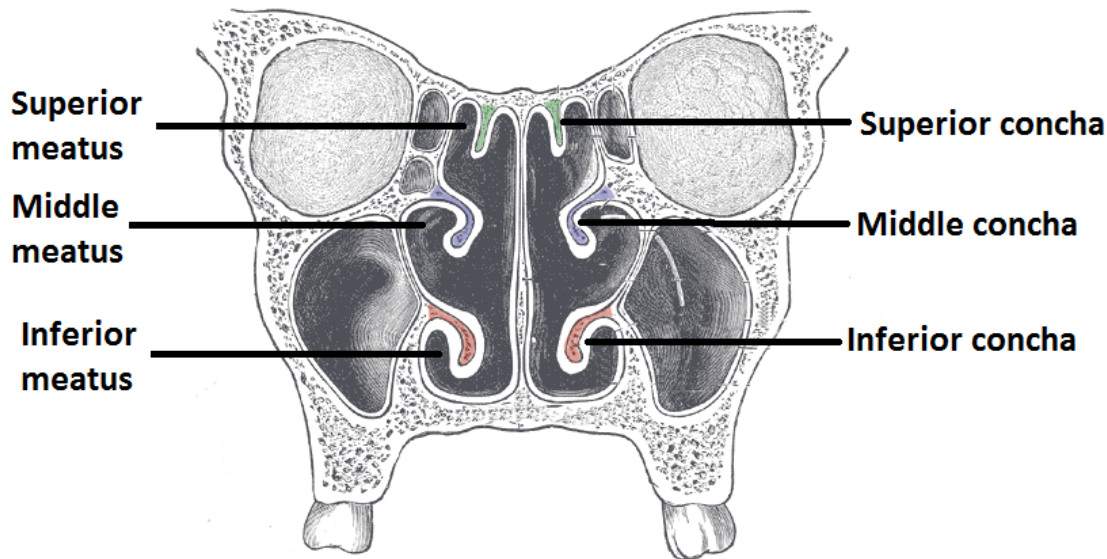
Understanding the nasal anatomy is essential in determining the proper geometry for the model. The nasal airway cavity is a very complex structure extending from the nostrils at the anterior of the head, to the naso pharynx at the posterior of the throat. For a reference the cavity extends all the way to the uvula in the back of your throat, so your nasal cavity extends deep inside the skull. The right and left nostril are separated by the septum, a membrane that is mostly cartilage in the anterior of the nose but becomes a thin bone in the posterior of the cavity. Air flow enters the nose through the nostrils, entering vertically and the flow is redirected horizontally with the curvature of the nose. The nose itself contains flaps of cartilage that act as valves, during a deep inhale the sides of the nose collapse controlling flow.

### Nose and Nasal Cavities



The most complex section of the geometry is nasal concha or turbinates that occupy most of the cavity. These bones are long finger-like shelves in the nasal passage, extending from the top of the exterior nose to the nasopharynx. There are three sets of concha, inferior, middle and superior. Viewing the skull from the coronal plane, like you are facing the patient, shows that these conchae are actually curved. These

concha serve to distribute the incoming air and also warm and moisten the air before entering the lungs. Additionally there are four sets of sinuses around nasal cavity, which for this study will be removed from the geometry. The entrance of the sinuses into the nasal cavity is relatively small and does not impact the flow in cavity to any great extent.



Nasal Airway Obstructions (NAO)- The focus of this study is relieving the stress to the patient cause by nasal airway obstructions. There are many types of obstructions but the most common is a deviated septum caused by some trauma to the nose. This causes a change in the geometry between the right and left nasal passage, and the patient then experiences constant discomfort when inhaling due to the differences in pressure or shear stress on the nasal wall. Correction of these NAO is done with a 'shot-gun' surgical approach, doing as many surgeries in one procedure in hope of alleviating the problem. Being able to quantify the various surgical procedures would then help determine a single proper surgery for the patient.

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#### Biological

#### Specifications

- 1- A negative pressure should be placed at the nasopharynx, to simulate a normal inhale
- 2- From rhinometry data, the targeted flow out the nasopharynx should be 15 L/min during normal inhale
- 3- The provided patient has a deviated septum, so there should clear distinction between the pressure on the nasal wall in the right and left nasal passages
- 4- From previous studies, the flow may be modeled as laminar

#### Pre-Analysis & Start-Up

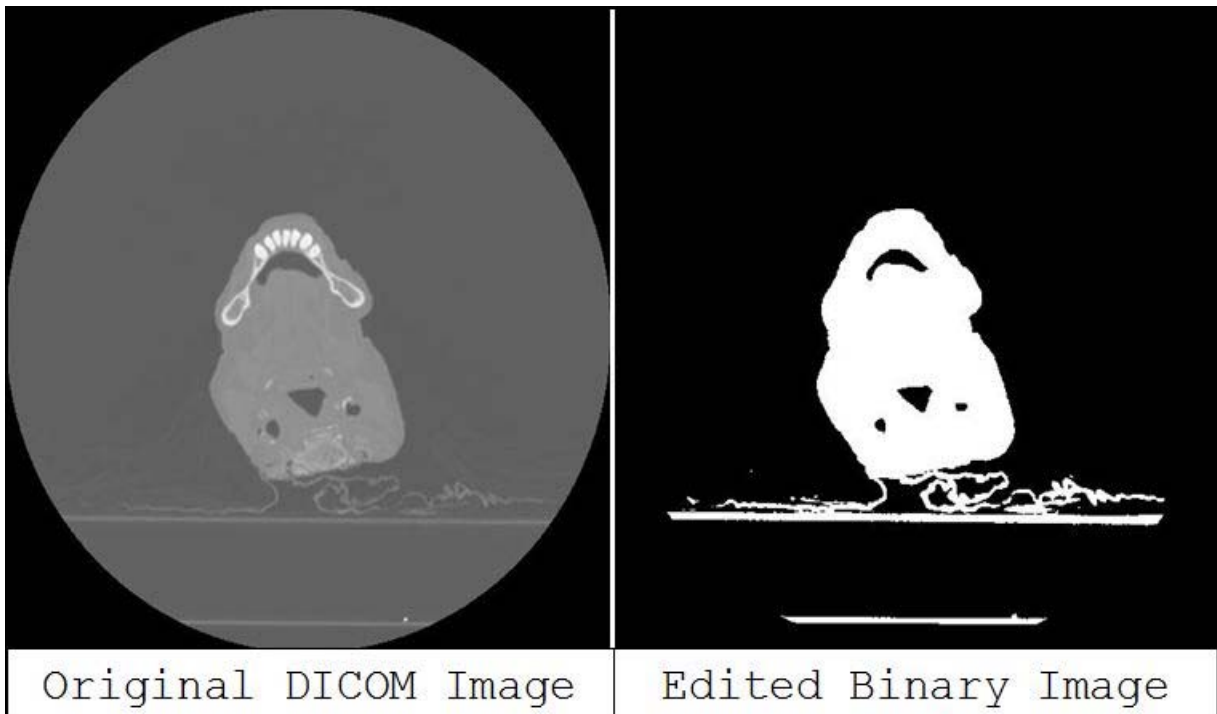
**Image**

Attached is a set of original CT scan images, a set of edited binary images and the MATLAB code used to create the edited images. For simplicity using the edited set of images to proceed with the tutorial will be sufficient. Below is an explanation of how and why the images were edited.

CT scan images are called DICOM images, a file format that contains patient information, and require specific programs to read. MATLAB contains a image processing toolbox that can read the images.

**Processing**

For a CT scan, a set of images are taken of the patient in slices across the transverse plane. Pixel size and slice thickness determine the resolution of the images and the quality of the model created. Smaller pixels and smaller slices result in more details, but this means more radiation to the patient and in conventional CT machines the smallest resolution is a pixel size of  $(0.6 \text{ mm})^2$  and a slice thickness of 0.6 mm. The value of the pixel intensity is related to the density of the tissue, with air being black and cortical bone being white.



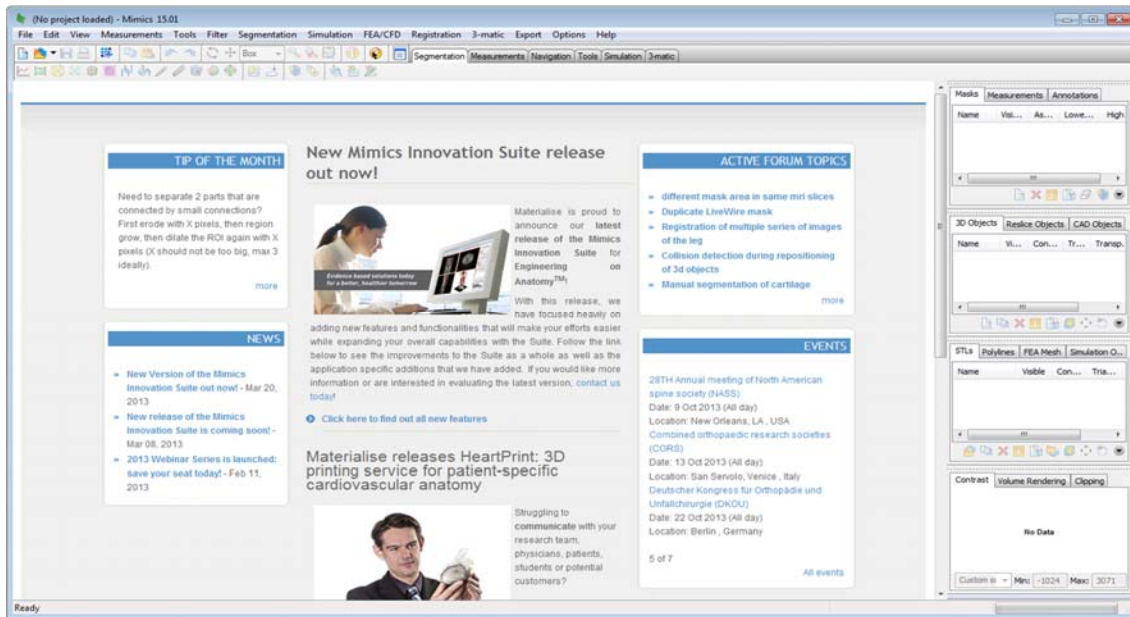
Noise removal- The included program removes the signal noise from each image in the set. Since every machine contains some electronic noise, there is a variation in the pixel intensities of the pure air in the images. By removing the average and one standard deviation of a large sample of air pixel from each image, it will remove the noise and equalize most the backgrounds and air of the images to zero intensity.

Binary images- Since we want to extract the cavity and are not concerned with the different tissues scanned, it is beneficial to create binary images. These contain only two pixel values, black for air and white for any tissue. Since the features in the nose have small sizes compared to the pixel size, like the septum has a thickness of about 0.8 mm, this creation of binary images will ensure that the cavity geometry stays

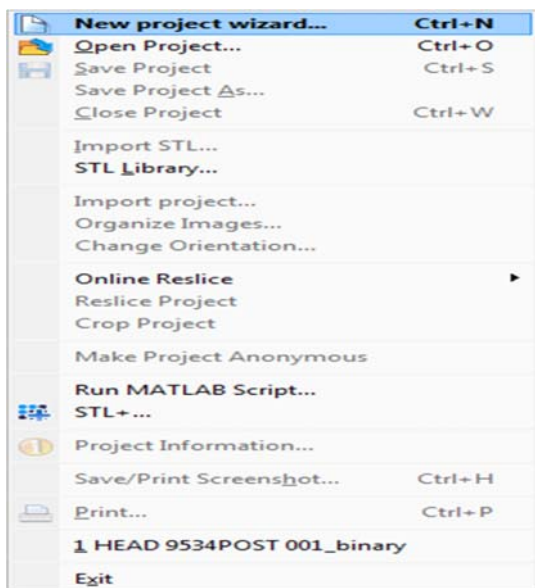
separated. The binary images also help ease geometry extraction process in the next step.

## Geometry

First open MIMICs and the home screen will appear below.

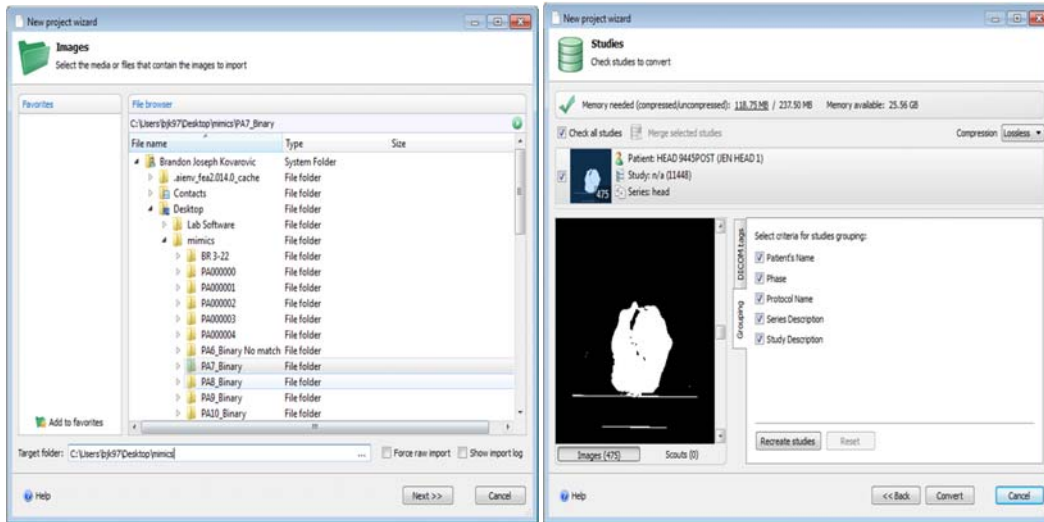


Next select File -> New Project Wizard



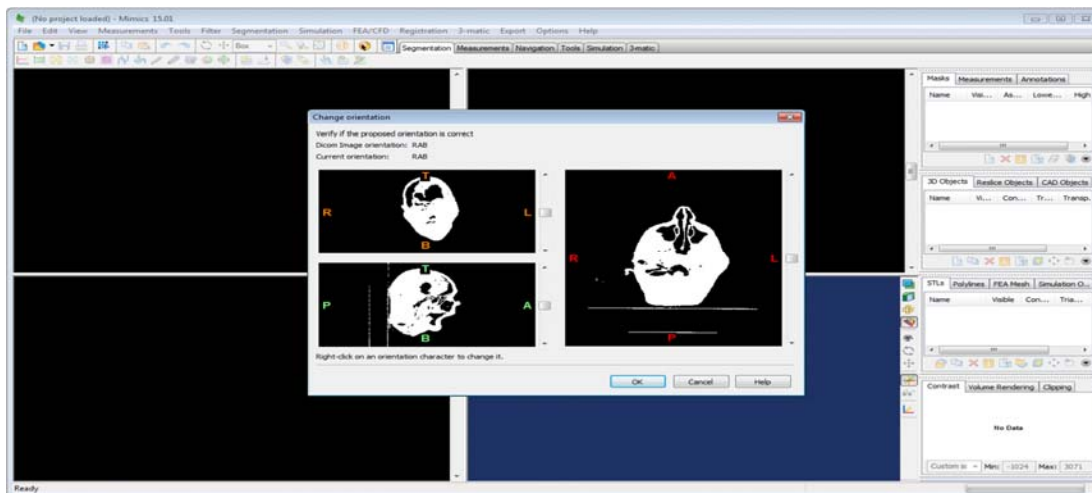


Select the folder containing the DICOM images of the CT scan, MIMICS will detect the order based on the file names of images. Also select the output folder for the project.



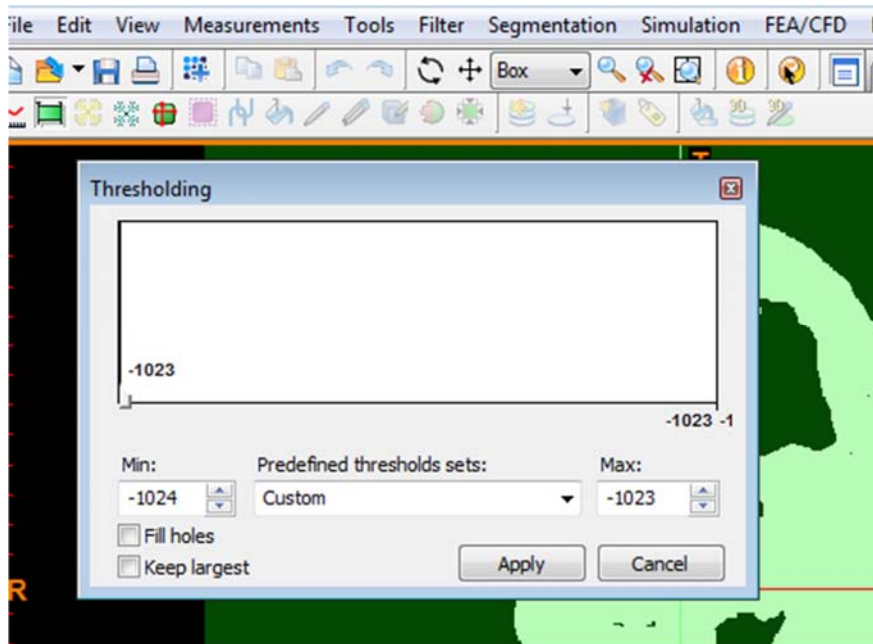
Press next and confirm all the settings and order of the images

Set all the planes of the images, aligning the posterior, top and right side to the images

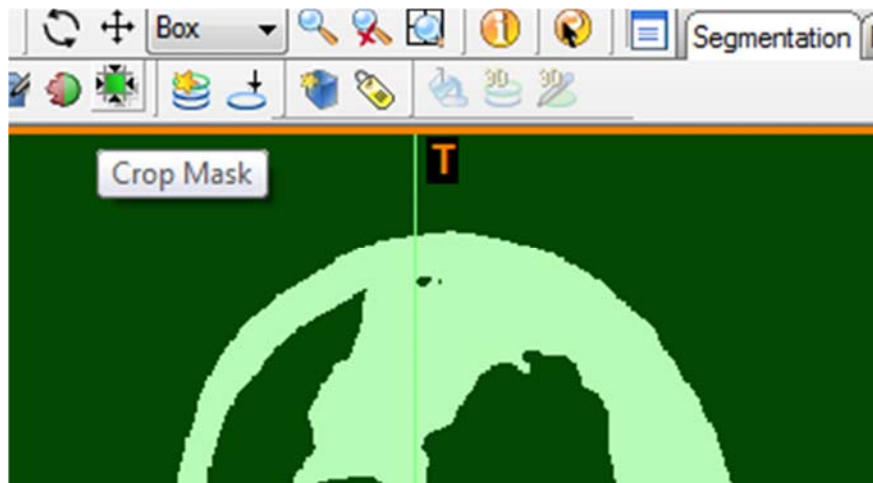


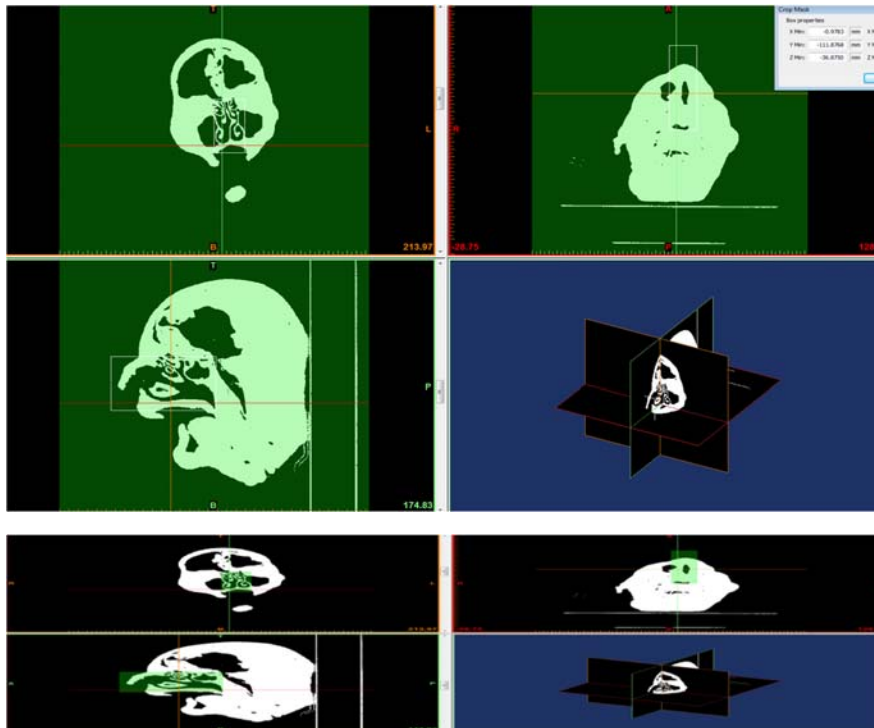
The next step is to start creating the masks of the images that contain the outline of the volumes used in the CFD calculation. Creating the mask is based on first selecting a threshold of pixel values or tissue densities that the primary mask will have. Since the images are now binary, the images have

only two pixel values. Press the threshold button to create the first mask. The primary mask should contain both pixel values to include both the air and the tissue, so make sure the min and max values are at the lowest and highest values or that the slider has the entire range.



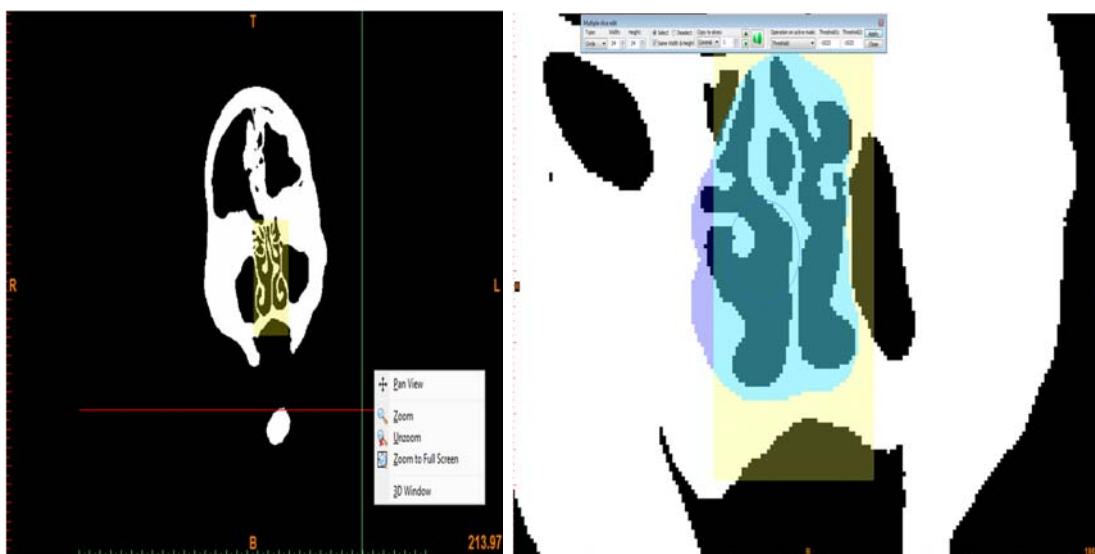
Next the mask needs to be cropped with the crop mask button to select only the area around the nasal cavity. Adjust the height, width and length of the rectangular mask in the three viewing planes.



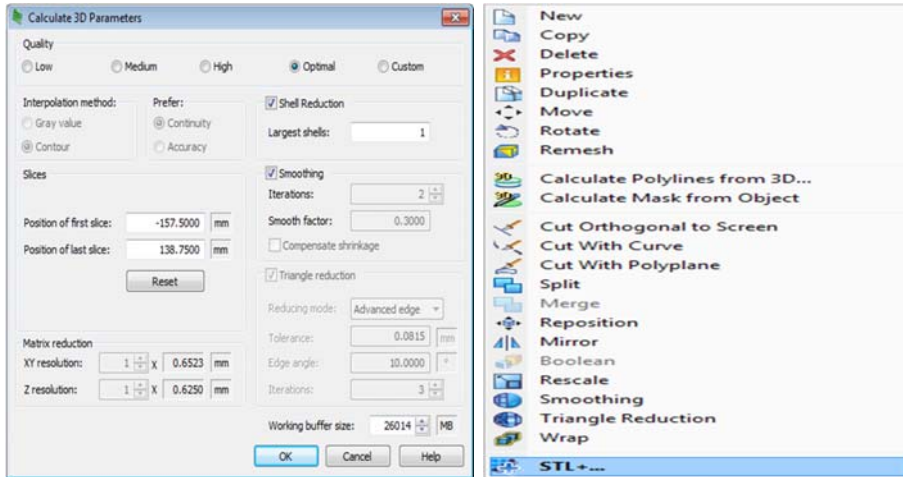


Now on the right side there is the created and cropped mask, by default labeled "Green", right click on this mask and select Duplicate Mask. This will create a copy of the mask in a new color. The purpose of having multiple masks is that you can do

boolean operations to the masks, subtracting one or adding one to the other. In this tutorial we will later subtract the secondary mask from the primary to leave a third mask containing only the nasal volume.



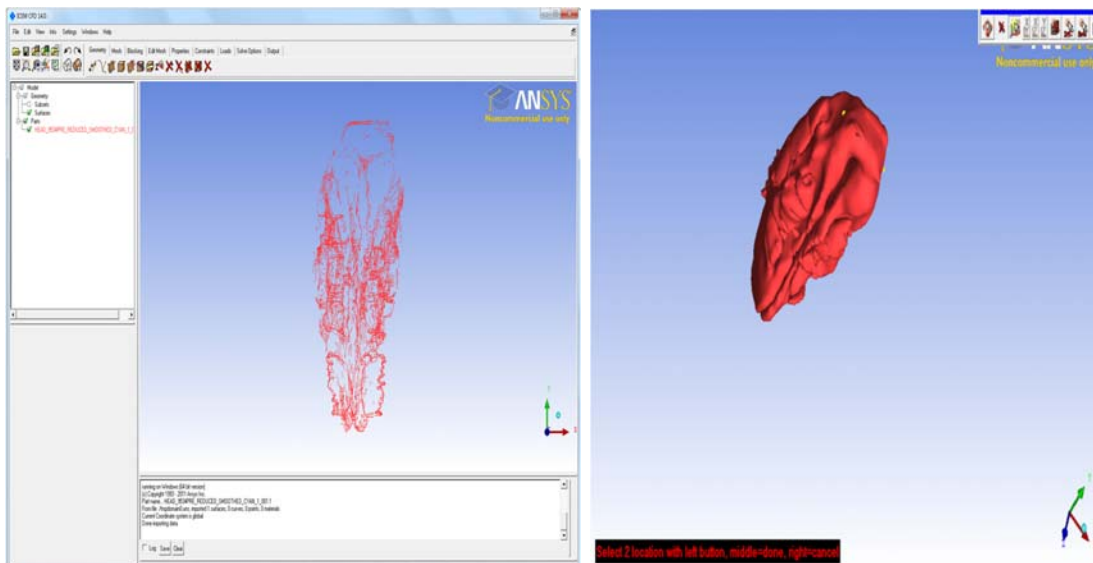


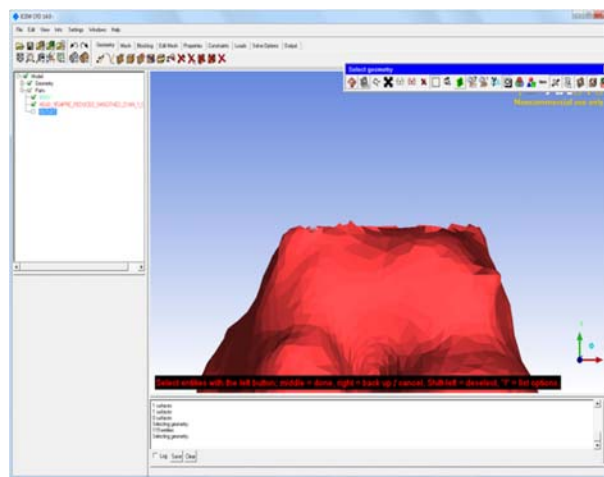
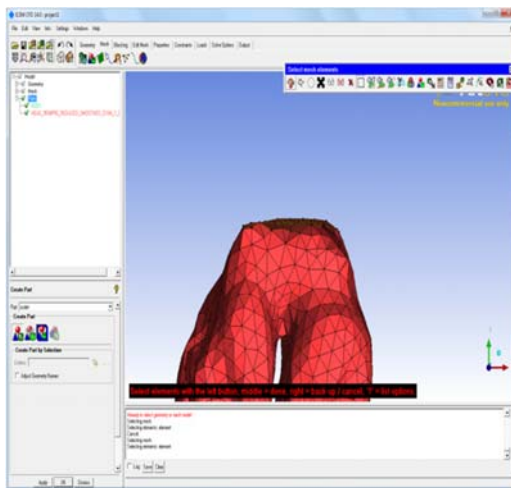
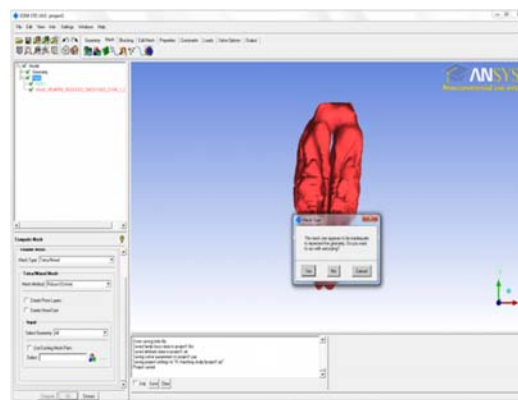
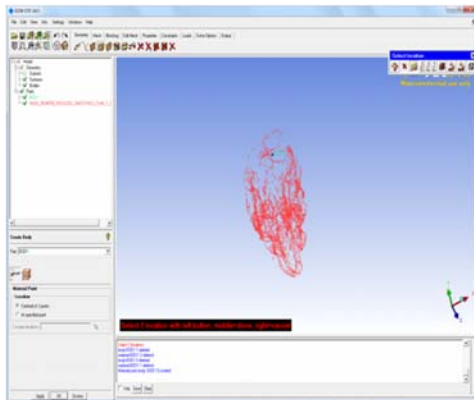


Import Geometry -> STL. Locate the STL created in MIMICS. Select the Generate option in STL import options that appears.

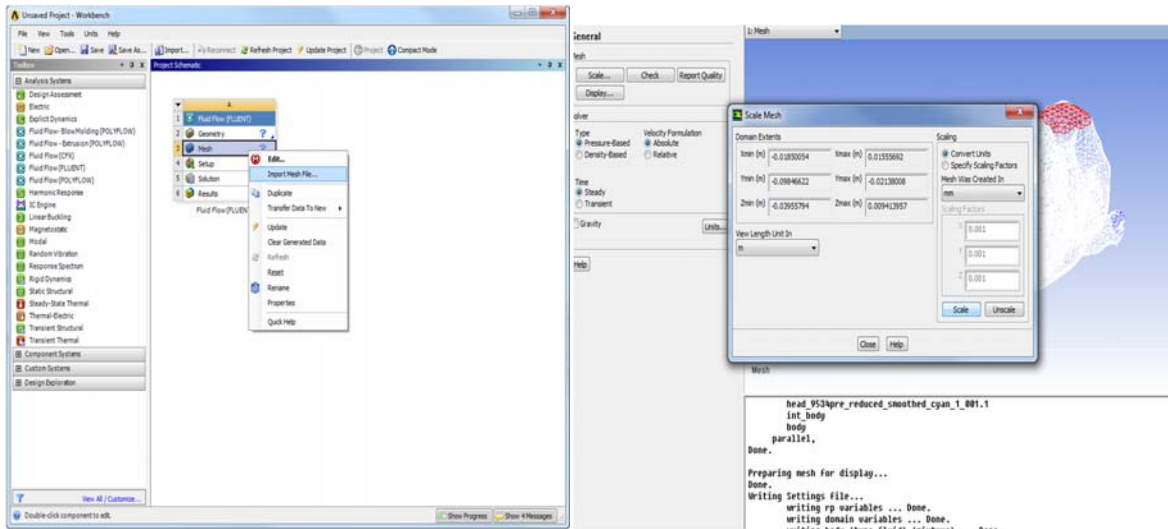
## Mesh

Open up ICEM CFD in the ANSYS 14 meshing folder. After it loads, select File ->





## Physics Setup



### Stages in a CFD Simulation

The main stages in a CFD simulation are:

#### Pre-processing:

- Formulation of the problem (governing equations and boundary conditions);
- Construction of a computational mesh (set of control volumes).

#### Solving:

- Discretisation of the governing equations;
- Solution of the resulting algebraic equations.

#### Post-processing:

- Analysis of results (calculation of derived quantities: forces, flow rates,)
- Visualization (graphs and plots of the solution).

### Fluid-Flow Equations

The equations of fluid flow are based on fundamental physical conservation principles:

- *mass*: change of mass = 0
  - *momentum*: change of momentum = force
  - *energy*: change of energy = work + h
- In fluid flow these are usually expressed as rate equ

Additional equations may apply for *non-homogeneous* fluids (e.g. multiphase, or containing dissolved chemicals or suspended particles). When applied to a fluid continuum these *conservation* principles may be expressed mathematically as either:

- Integral* (i.e. *control-volume*) equations;
- Differential* equations.

### Result

*Nasal airflow* is defined as the volume of air inspired over a defined time. All maneuvers had a positive effect on nasal airflow when compared with the flow within the STE model. The largest increases in bilateral nasal airflow were seen with the medial and modified flare sutures, with 16.9% and 15.1% increases, respectively. The spreader graft and flare suture combination allowed a 13.2% gain in bilateral airflow. The lateral flare suture provided a 10.0% increase in airflow, while the spreader graft alone afforded a modest 5.9% increase

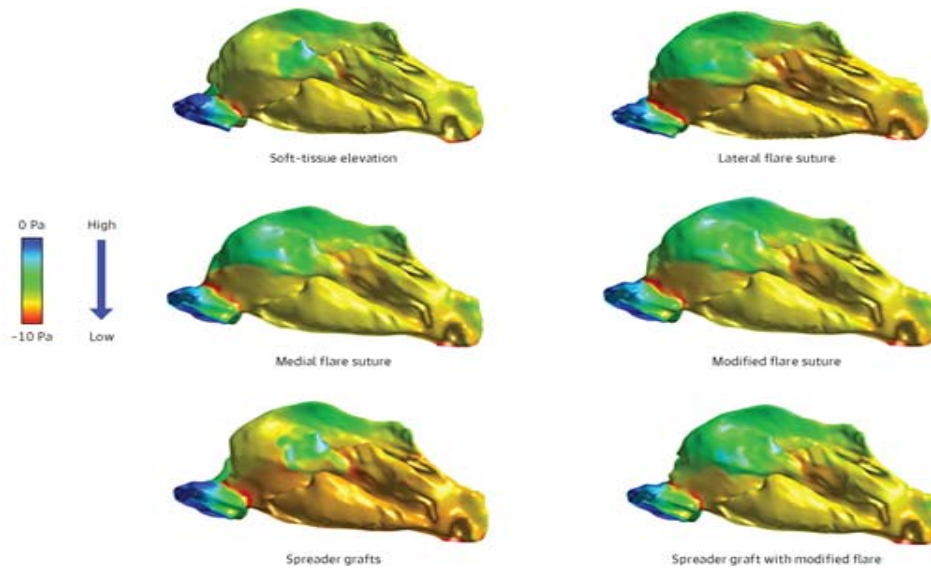


Figure: CFD Analysis of Nasal in Fluent

## Conclusion

Computational fluid dynamics analysis examining the exact position of flare sutures has not been published before our study. Our preliminary cadaveric data suggest that medially positioned flare sutures may clinically outperform spreader grafts alone or in combination with flare sutures, with minimal to no disruption or weakening of the underlying nasal architecture. Future studies using additional specimens and living subjects are needed for comparison, with attention directed to subjective and objective data correlation using Nasal Obstruction Symptom Evaluation scores<sup>9</sup> and CFD measures, such as nasal resistance and heat flux, in combination with the flare suture.

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