Research Project

NUMERICAL ANALYSIS OF A MORPHING WING

Major in Aerospace Structures + Aircraft Design Pathway

Presented by:
Sneha Dwivedi
Under the guidance of:
Prof. E. Benard, Prof. J. Morlier & S. Coniglio

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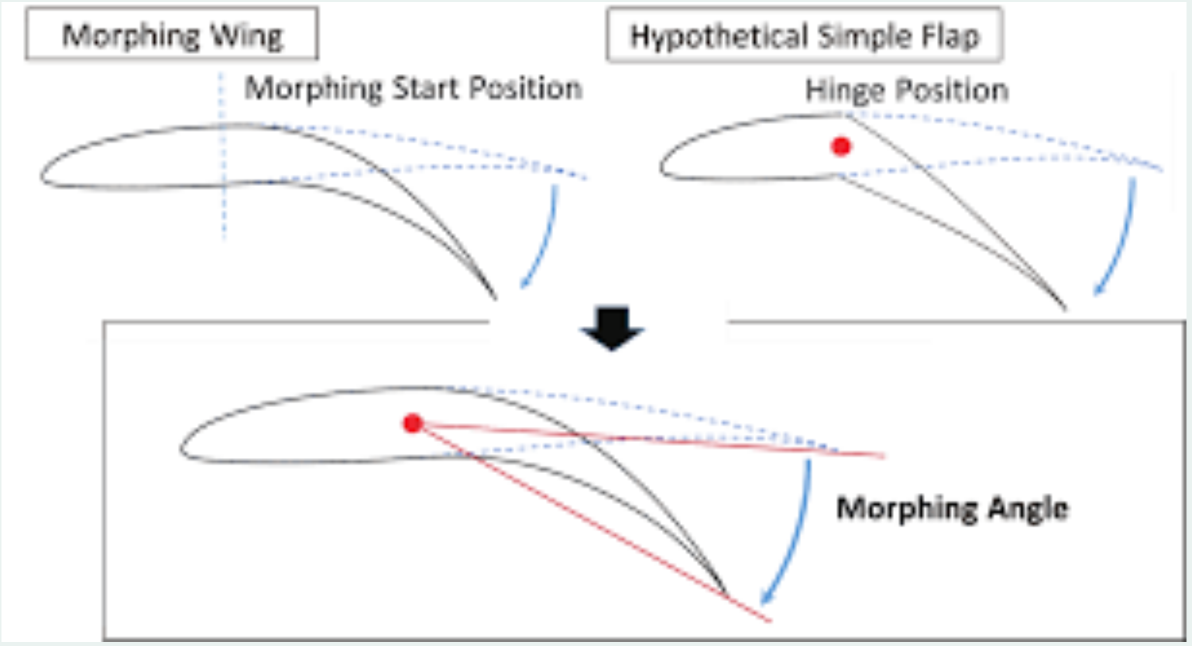
TABLE OF CONTENT

INTRODUCTION

Numerical analysis deals with the approximation based machine learning algorithms. Numerical analysis has been considered for computing the solutions for differential equations.

The mesh based method are used dominantly in the field of engineering. The most known method is the Finite Element Method (FEM).

Numerical analysis has been used in various domains and applications and one of the most interesting one at present is morphing wings.



Definition of Morphing wing. *Cited in [4]

NUMERICAL ANALYSIS

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SUPAERO

MESH BASED

MAPPING

Transformation of all data

Physical Domain → **Computational Domain**

All the calculations performed

MAPPING

Transformation of all data

MESH LESS

Physical Domain

All the calculations performed

Very practical to have a geometric definition of your domain.

STATE OF THE ART

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1977 SMOOTH PARTICLE HYDRODYNAMICS(SPH) (Lucy)

DIFFUSE ELEMENT METHOD(DEM) (Nayroles et al.) 1992

1994 ELEMENT FREE GALERKIN METHOD(EFG) (Balyschko et al.)

REPRODUCING KERNEL PARTICLE METHOD(RKPM) (Liu et al.) 1995

1996 HP-CLOUDS METHOD (Duarte and Oden)

PARTITION OF UNITY METHOD(PUM) (Babuska and Melenk) 1977

1998 LOCAL BOUNDARY INTEGRAL EQUATION METHOD(Zhu and Zhang)

MESHLESS LOCAL PETROV GALERKIN METHOD(Zhu and Atluri) 1998

2004 MESHLESS NATURAL ELEMENT METHOD(NEM) (Yvonnet)

MORPHING WINGS

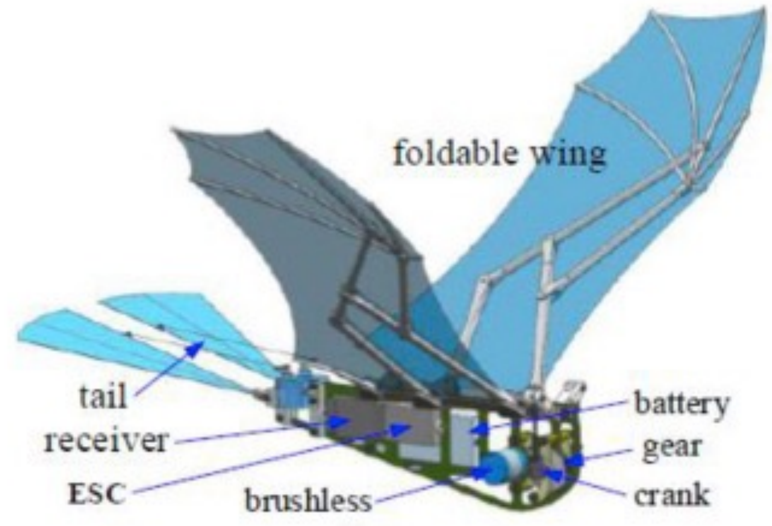
- Morphing Wing is a simplified structure that reduces the fuel efficiency by amplifying the aerodynamics of the wing and simplify the manufacturing process.

- A morphing wing is a light weight but high strength structure which alloys the production to be composite based.

A test version of the deformable wing designed by the MIT and NASA researchers is shown undergoing its twisting motions, which could replace the need for separate, hinged panels for controlling a plane's motion. (Kenneth Cheung/NASA). *Cited in reference [1]

MORPHING WINGS

- A new wing is designed in order to sustain fuel less consumption and simplification of the manufacturing process.
- The basic aim towards the development of the morphing is to improve the aerodynamics of the wing and also its agility.



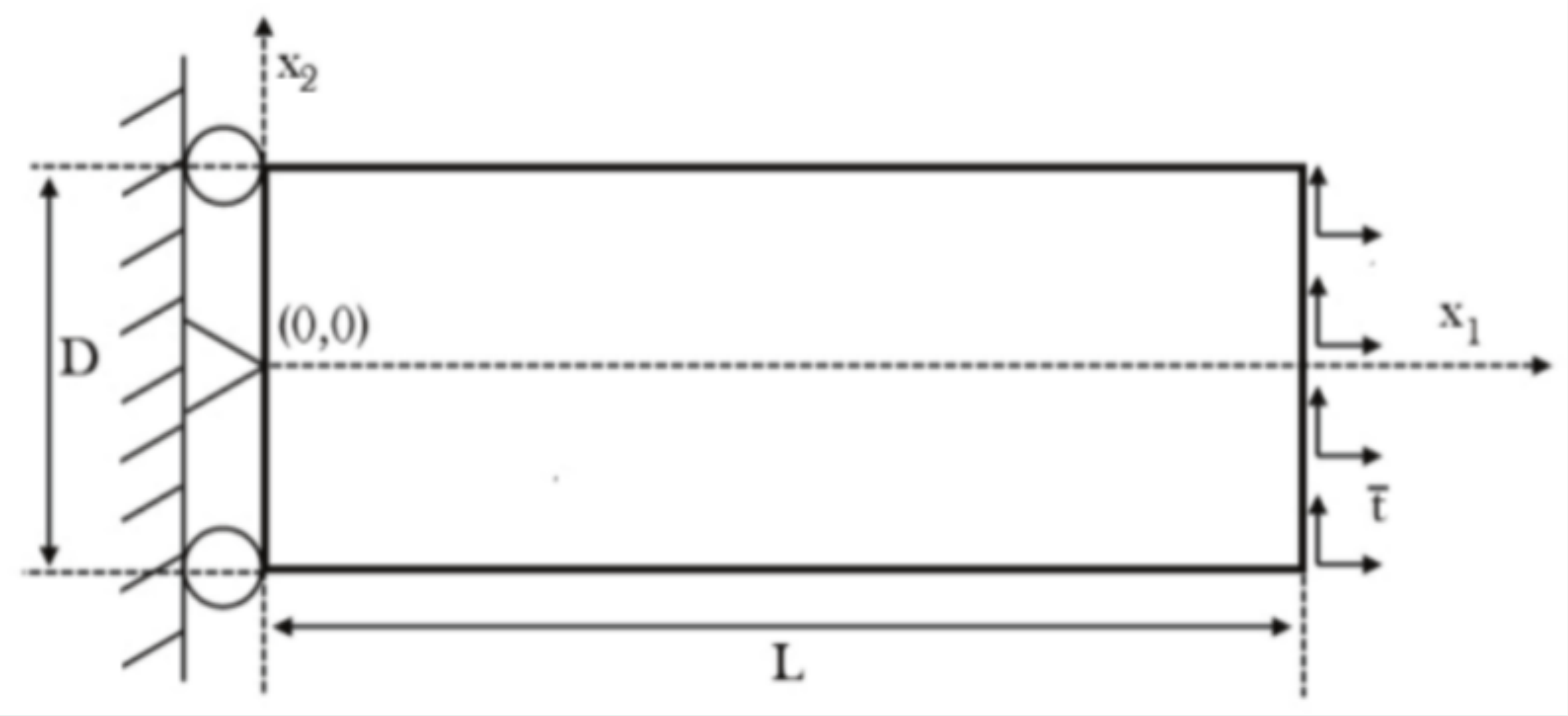
(a) Bioinspired bat-like robot [61]

(b) Bioinspired feathered wing [63]

A review of modelling and analysis of morphing wings. Science Direct Journal, Li, Zhao, Xiang. *Cited in reference [2]

PREVIOUS RESULTS

Previously working on Overvelde's code, the aim was to observe the outcomes while changing the kernels. The initial problem consists of a cantilever beam that has been made initially with the boundary conditions wherein the left edge has been fixed and a transverse load is applied on the right edge.

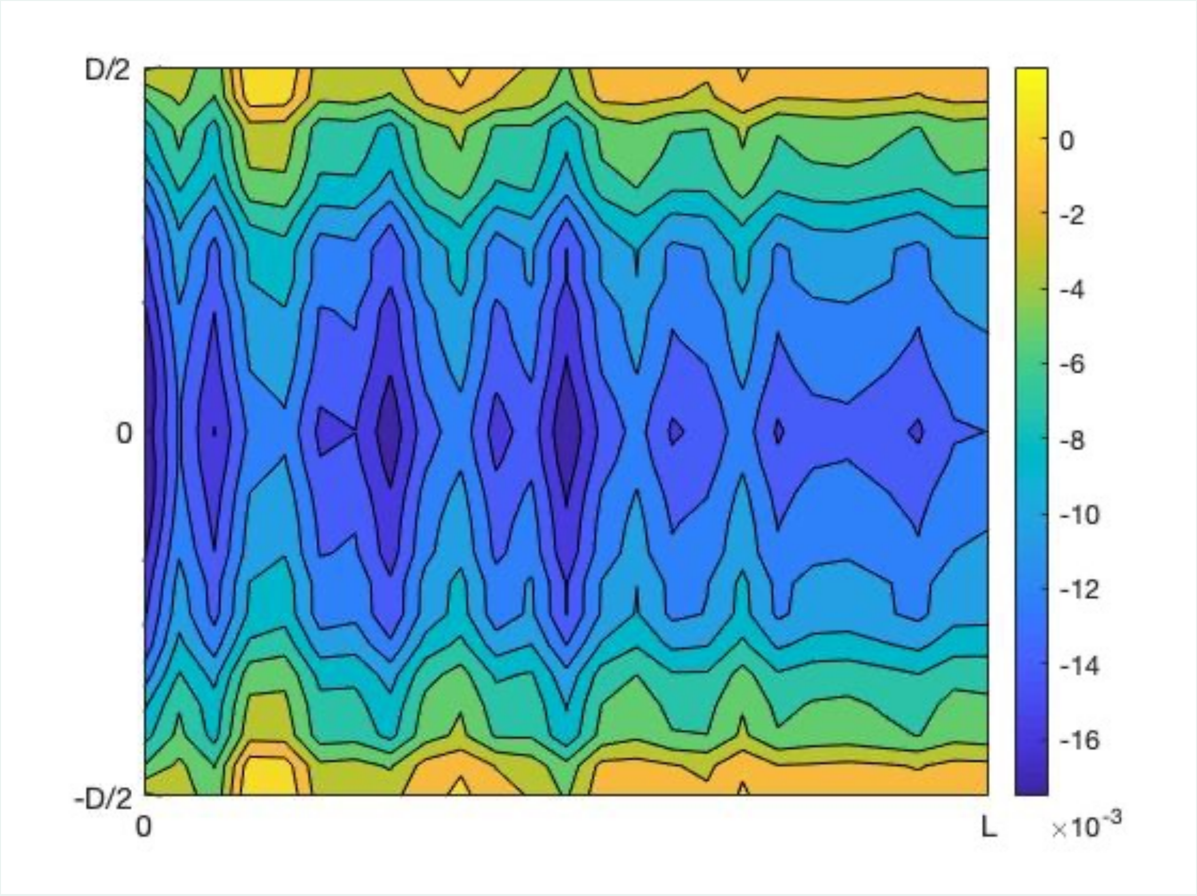


A cantilever beam of length L and height D is subjected to traction force on right and fixed condition on left. *Cited in reference [3]

CHANGE IN KERNELS

Under this section, the kernel functions has been changed in the code in order to understand the analysis of the structure problem.

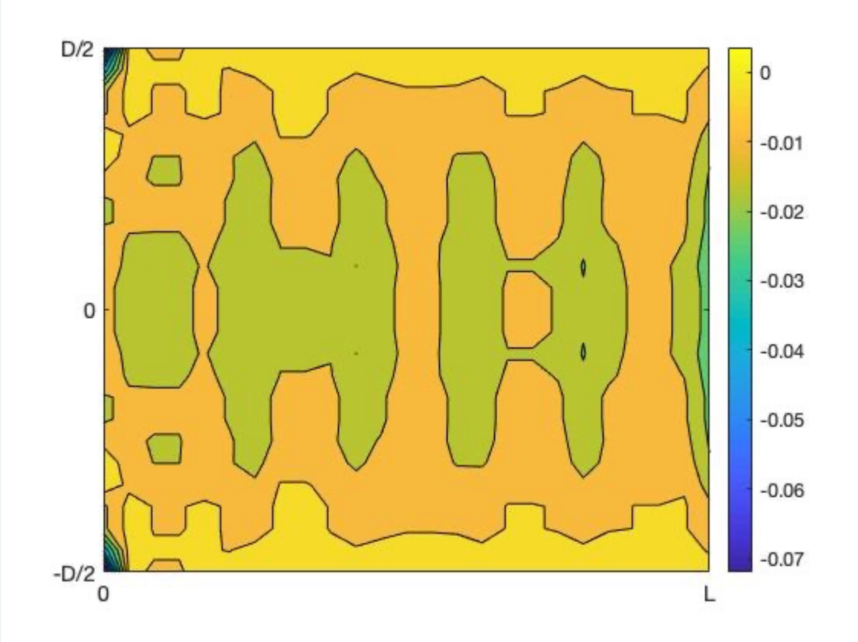
- **Radial Basis Function (RBF) -** which has a value depending upon the distance from the origin or some particular point.



Representation of shear stress on the beam using RBF kernel with error norm achieved for this particular case as 7.18%.

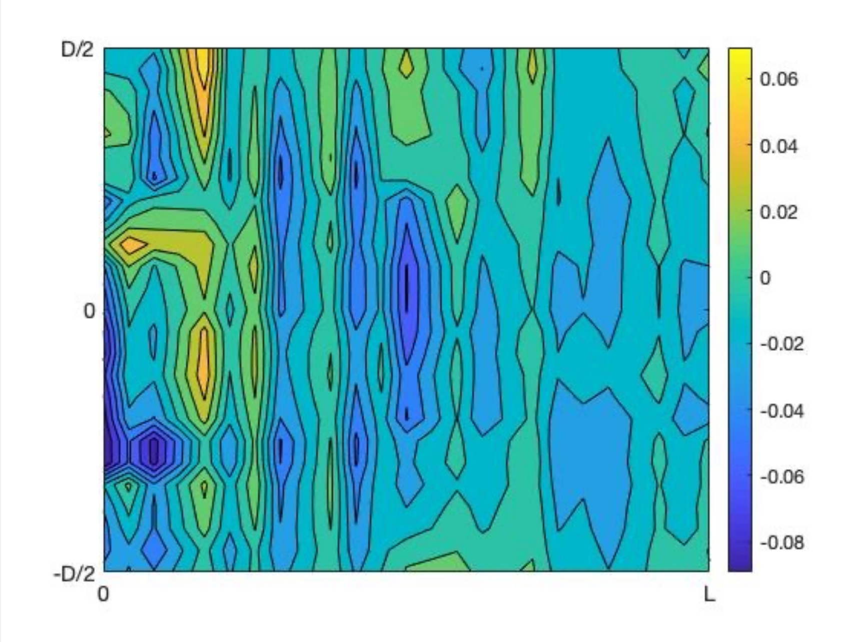
CHANGE IN KERNELS

- **Gaussian kernel -** which is a type of a RBF kernel.



The oscillations observed in the shear stress representation using Gaussian kernels with the error norm has been achieved as 27.13%, which is very high than compared to the RBF kernel.

- **Laplace Radial Basis Function kernel -** is a general purpose kernel which is used when there is no prior knowledge of the data.



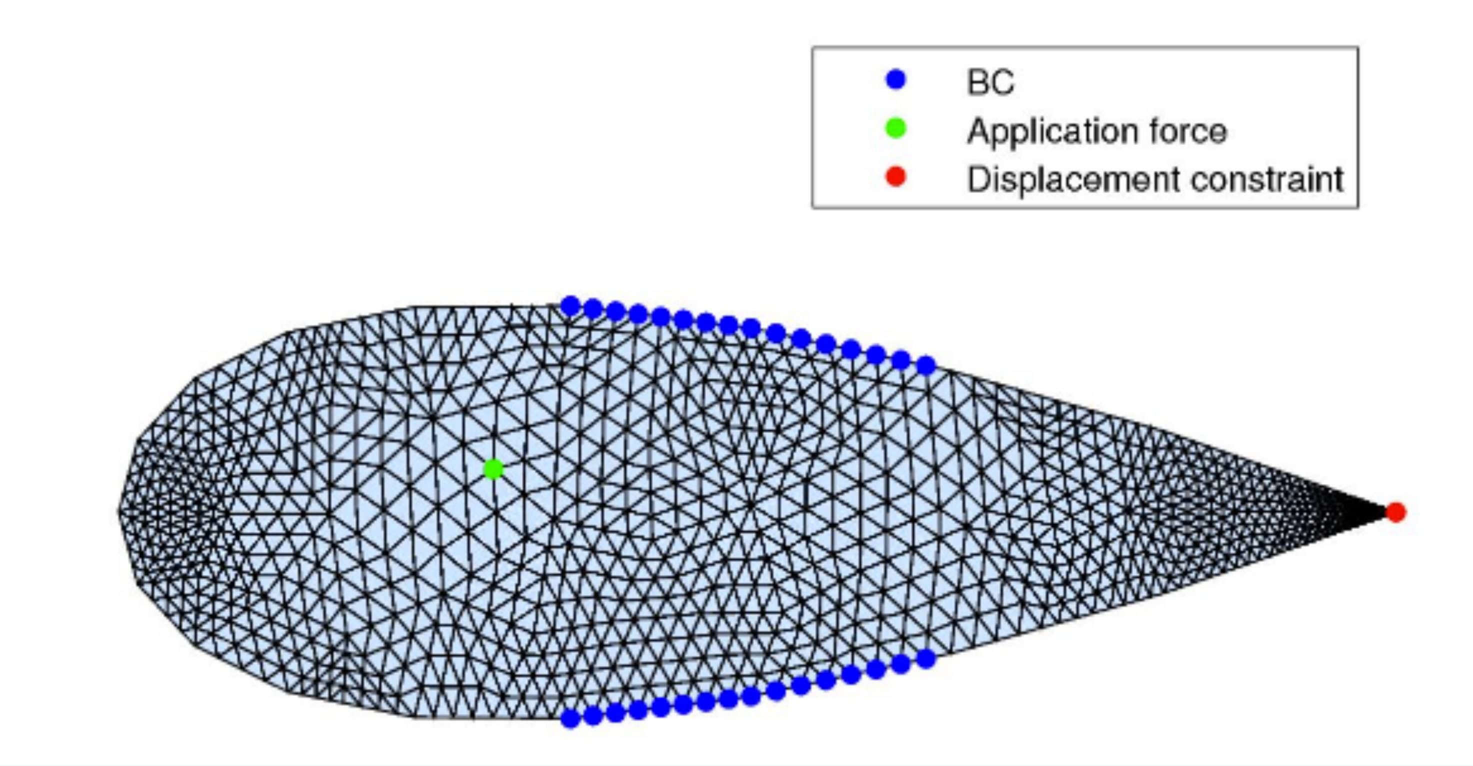
The oscillations observed in the shear stress representation using Laplace kernels with the error norm as 41.9% suggesting the best kernel is RBF.

S3 PROJECT PROGRESS

Initially, a researchers code on Topology optimisation of a morphing wing is being studied.

The idea of using non-linear elastic material has been originated while studying this paper. *Cited in reference [5]

The finite element analysis is treated as a minimisation problem and the function here to minimise is the total energy of the system.

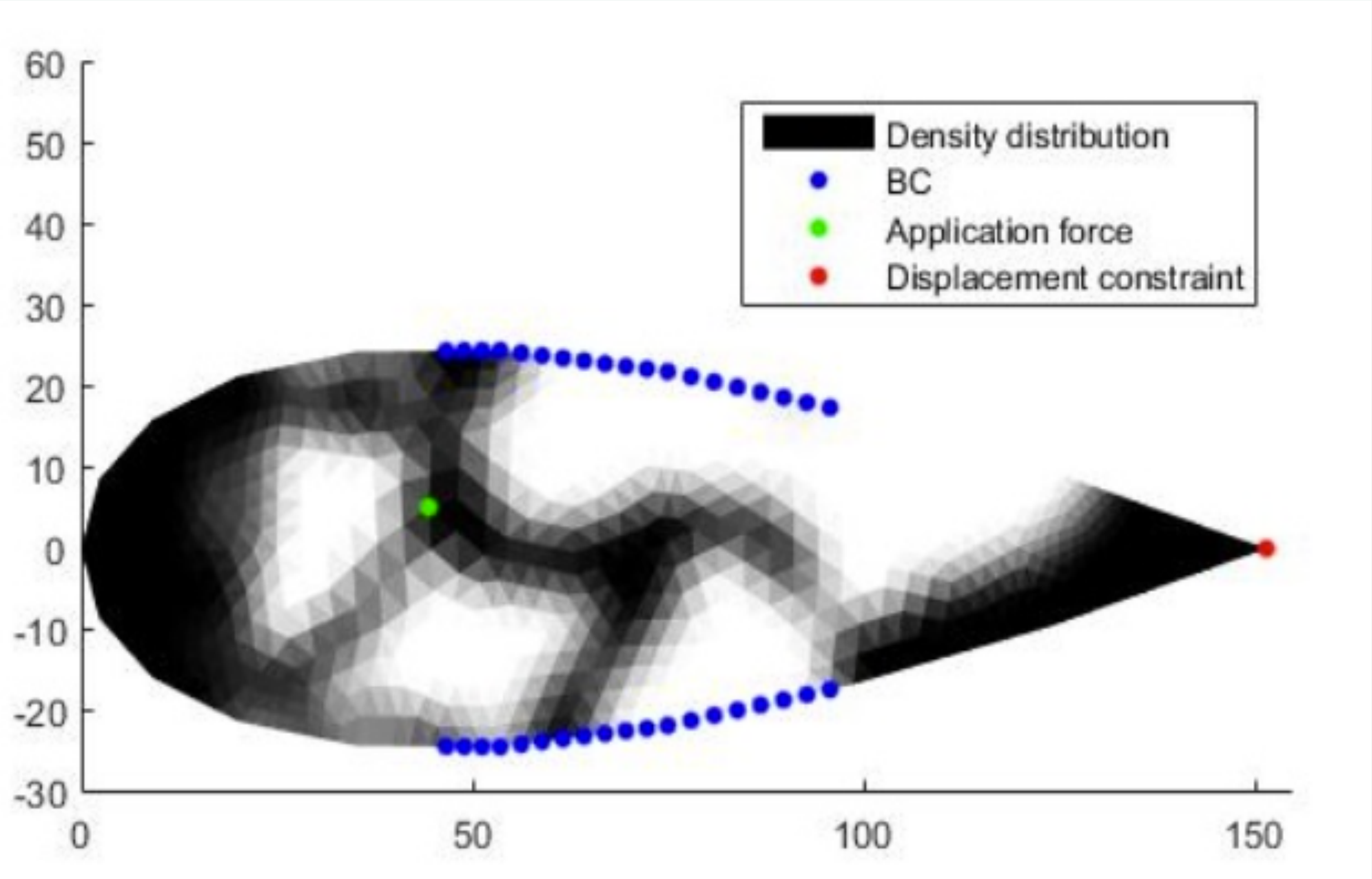


The initial design and domain description of a morphing. *Cited in reference [5].

TOPOLOGY OPTIMISATION CODE

The structure has been divided into 4 different sections. One of the most influential application that was felt while studying the sections was the positioning of the boundary condition ranges.

The case below validates the range from 30 to 65% of the chord which is been selected by the author as the reliable optimised structure.

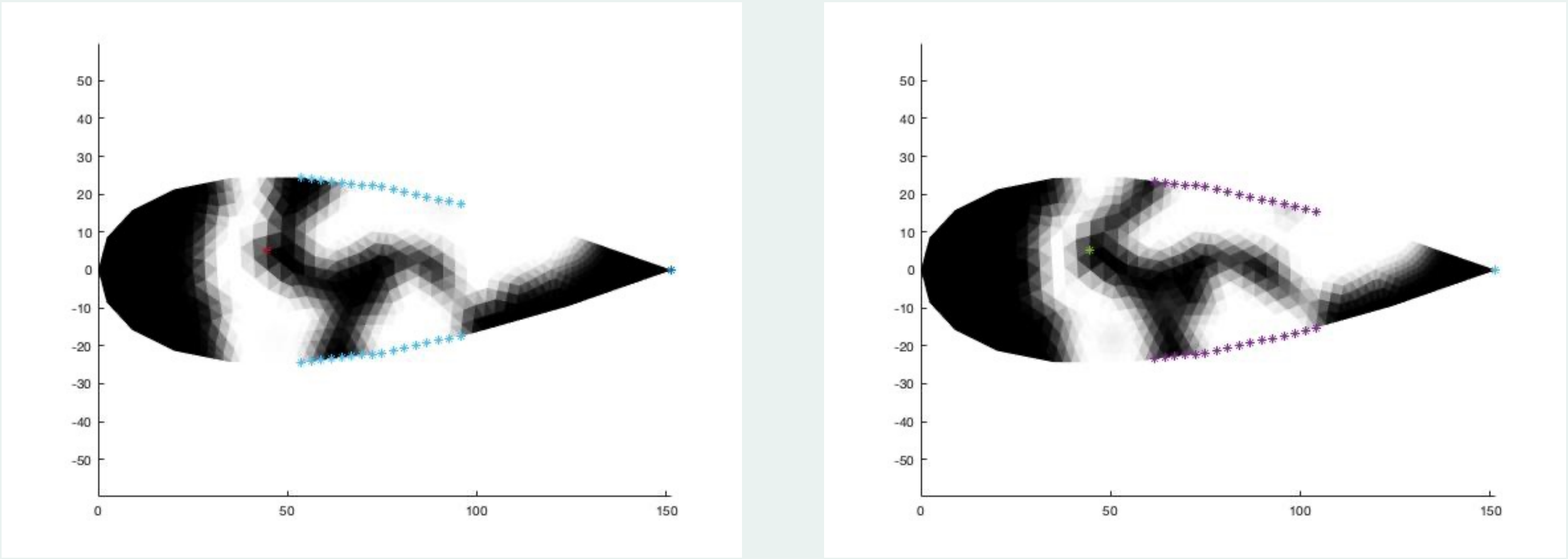


Topology optimisation for boundary condition ranging from 30 to 65% of the chord *Cited in reference [5].

CHANGES IN BOUNDARY CONDITIONS

The present work would focus on reducing the volume fraction furthermore in order to have more accurate results of the topology.

Upon changing the range to 35 to 65% and 40 to 70% of the chord, it is observed that the time of convergence has increased a lot and the favourable results are obtained after many iterations.



Topology optimisation for boundary condition ranging from 35 to 65% and 40 to 70% of the chord

TOOL DEVELOPMENT

The development of this tool takes place taking into account various functions that are often used during the analysis of elastic non-linear structure. The basic principle of the analysis will be the minimisation of the potential energy of the system.

Certain material properties has been entered to initialise the problem. MATLAB has been used for the analysis.

```
%% TO LOAD RECTANGULAR MESH
% load mesh_coarse
%% TO LOAD AIRFOIL MESH
[p,t] = tessellation('N0012_Airfoil.mat');
%% Material properties
E = 7e4; %young's modulus
nu = 0.33; %poissons ration
lambdael = E*nu/(1+nu)/(1-2*nu);
mu = E/2/(1+nu);
Fext = -1000;
```

Material properties being mentioned in the tool.

STRAIN ENERGY

A linearisation procedure is required, like Newton- Raphson method. The structural material is elastic and strain energy density W exist, which upon differentiating can lead to obtaining stress.

$$W(E) = 1/2(E:D:E)$$

where, D is the fourth-order constitutive tensor for isotropic materials.

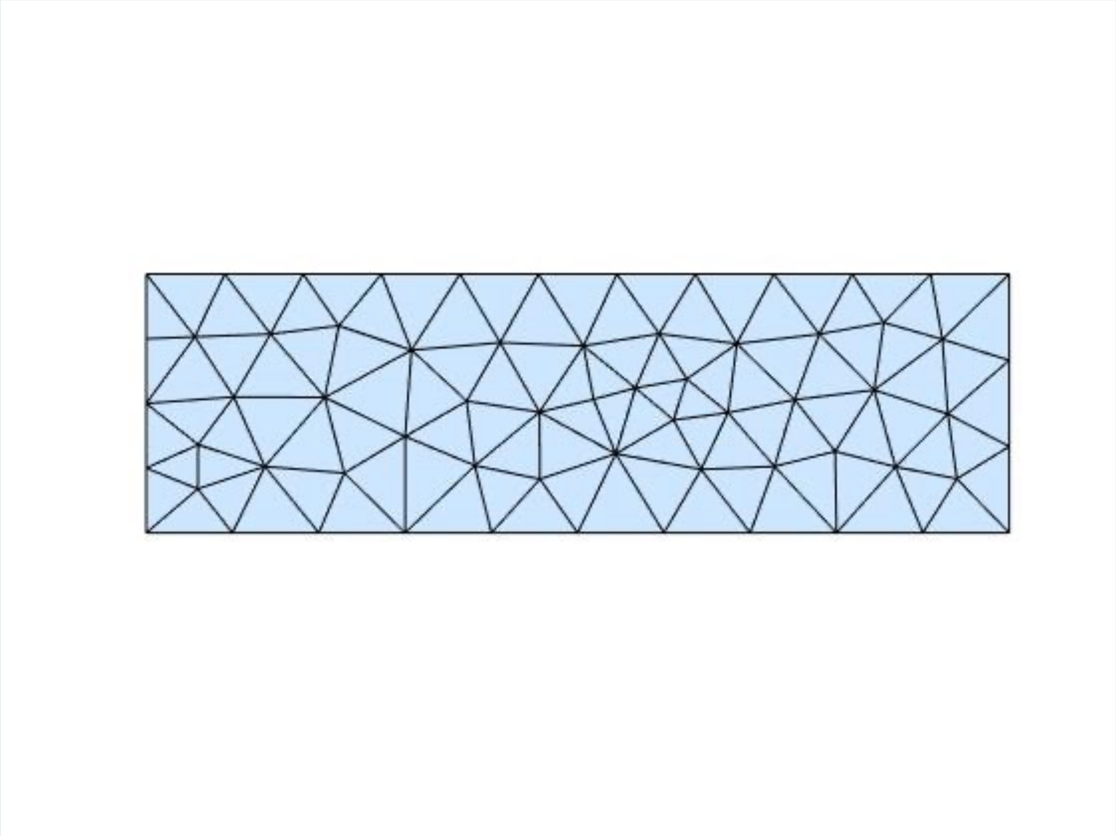
The principle of minimising the potential energy of the system depends upon minimisation of the displacement field.

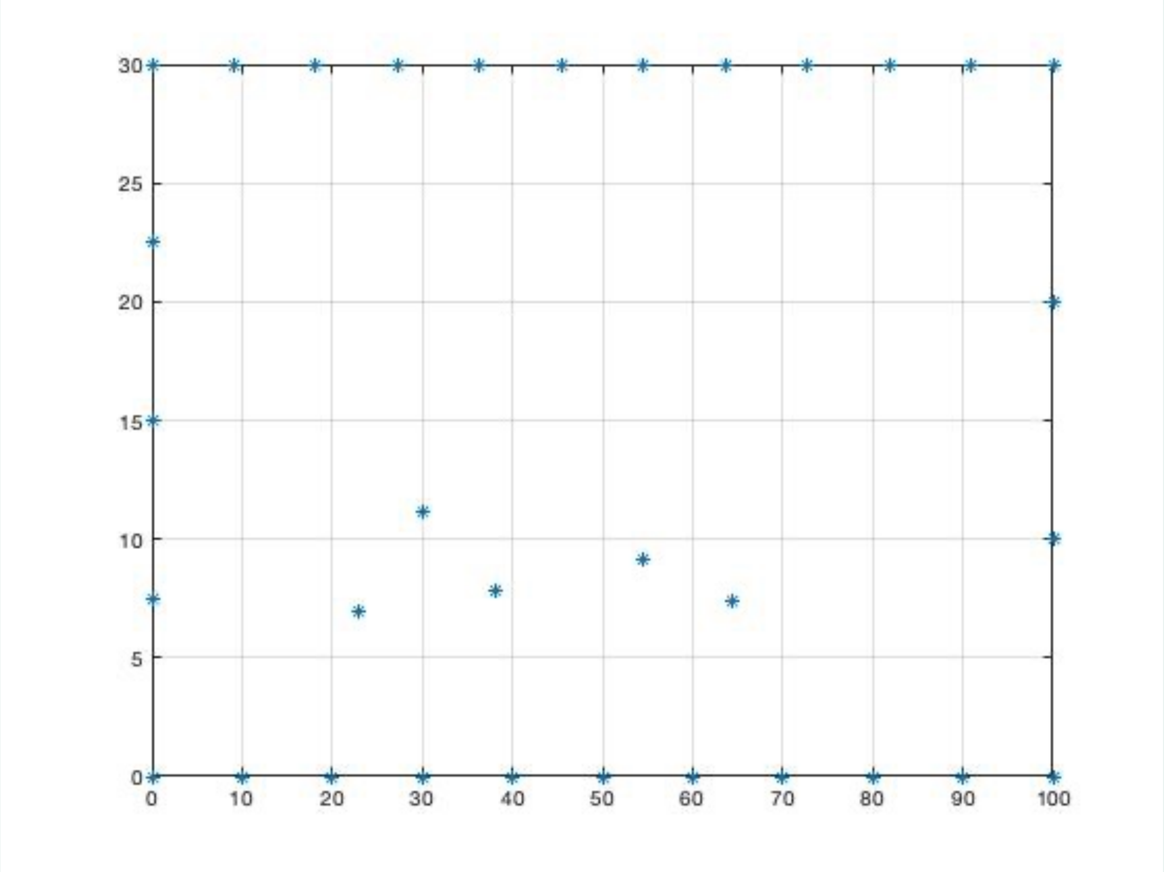
Another relation is used for the calculation of second Piola-Kirchhoff stress S. The relation between the stress S and strain E is linear here.

INITIAL PLOTTING

In the development of the tool, a beam structure is taken into consideration. The tool provides various nodes and the connectivity matrix "t" to connect the various nodes to form the triangular mesh.

The boundary conditions are provided to the structure with forced nodes and imposed nodes on the structure.





The initial plot of the rectangular structure obtained by the tool and the boundary condition imposed on it.

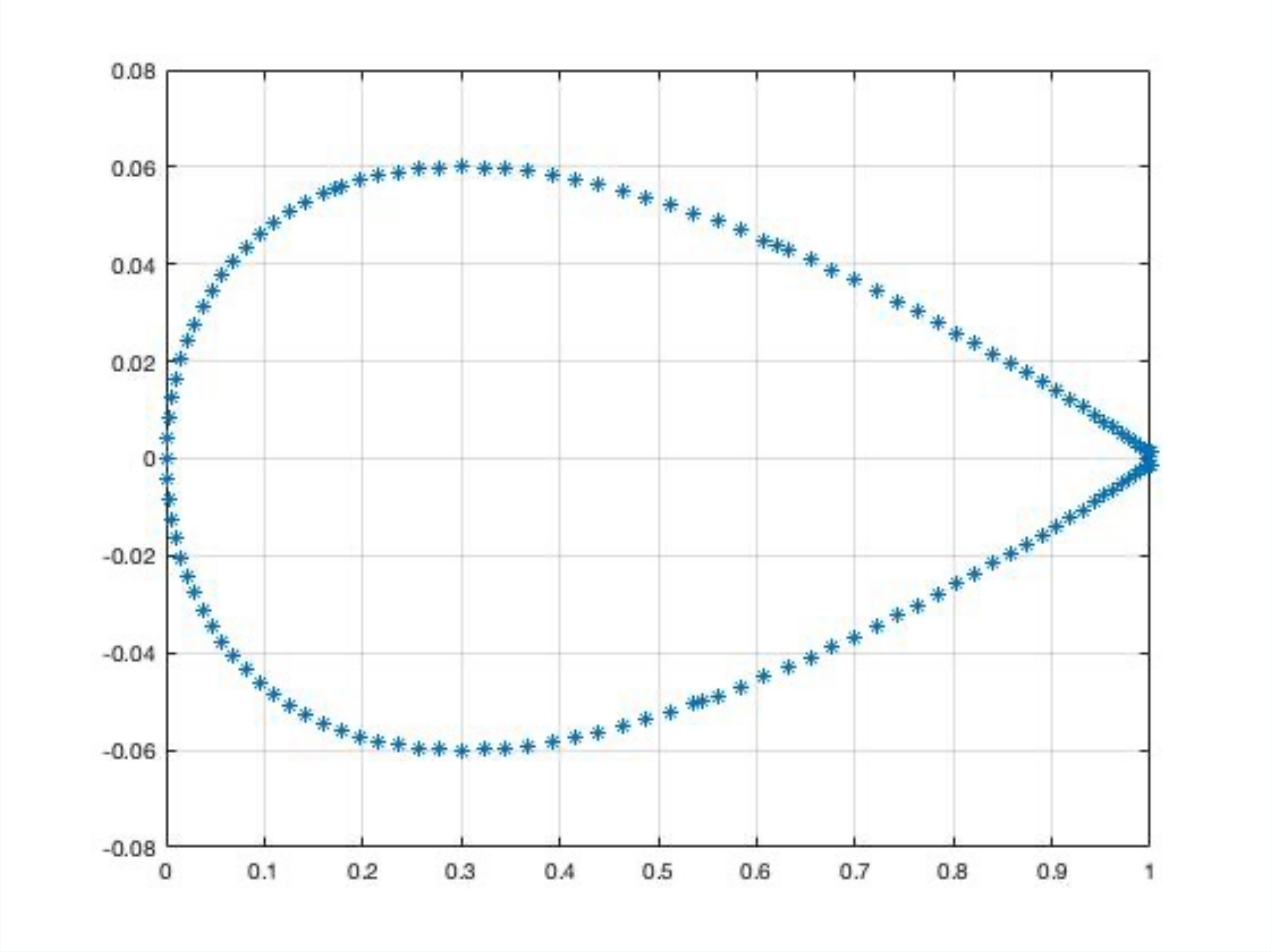
MORPHING WING ANALYSIS

In order to design a morphing airfoil, NACA 0012 has been selected. This is a very basic airfoil and because it has no camber, the lift to drag ratio will certainly be better for certain flight profiles.

The initial structure input for the morphing analysis.

MORPHING WING ANALYSIS

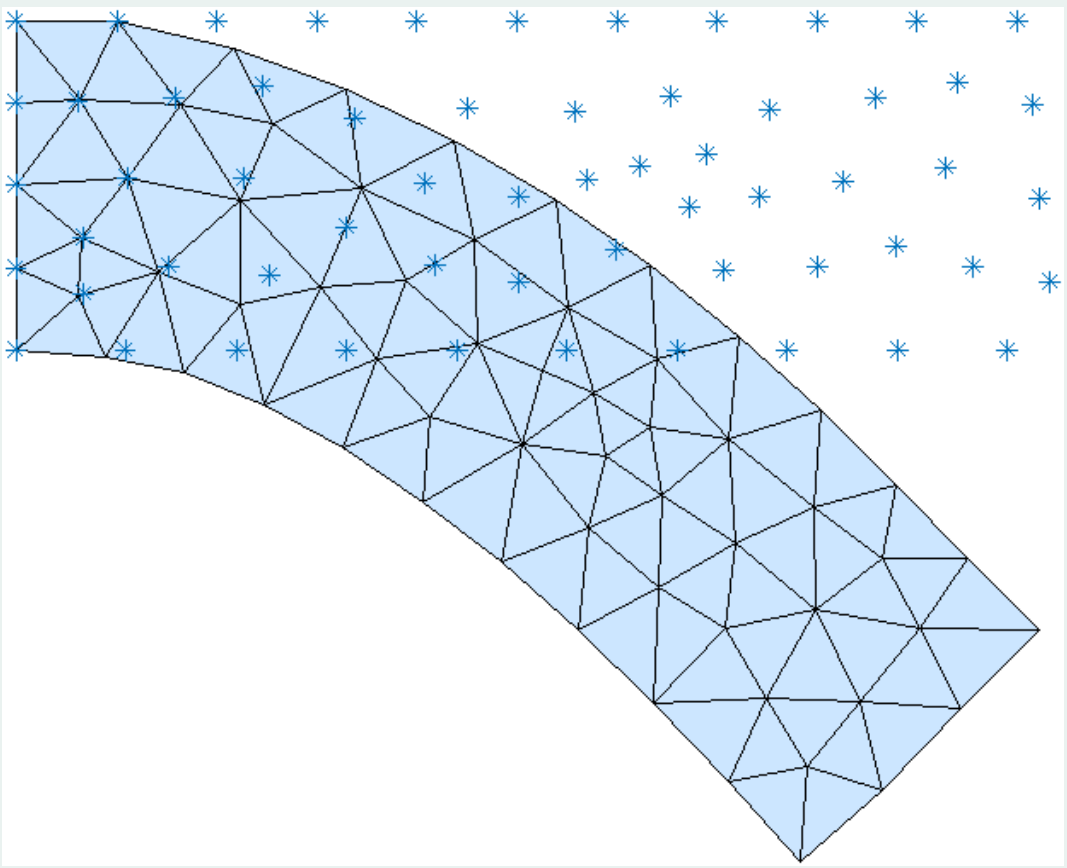
The structure has been highly meshed. The boundary conditions are provided as suggested from the previous works on the morphing wings that is 30 to 65% of the chord length.

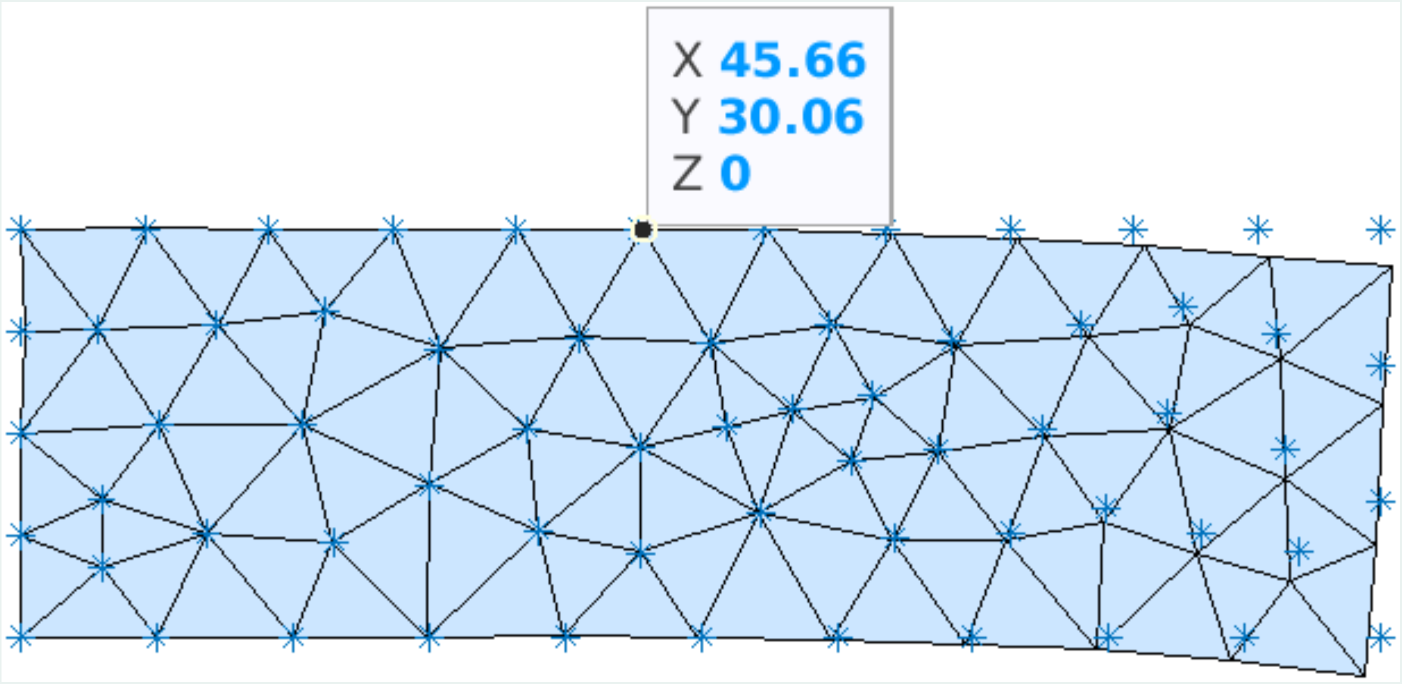


The boundary conditions applied to the morphing structure.

RESULTS

For the cantilever beam, the analysis takes place under both fmincon and fminunc functions and the results are -



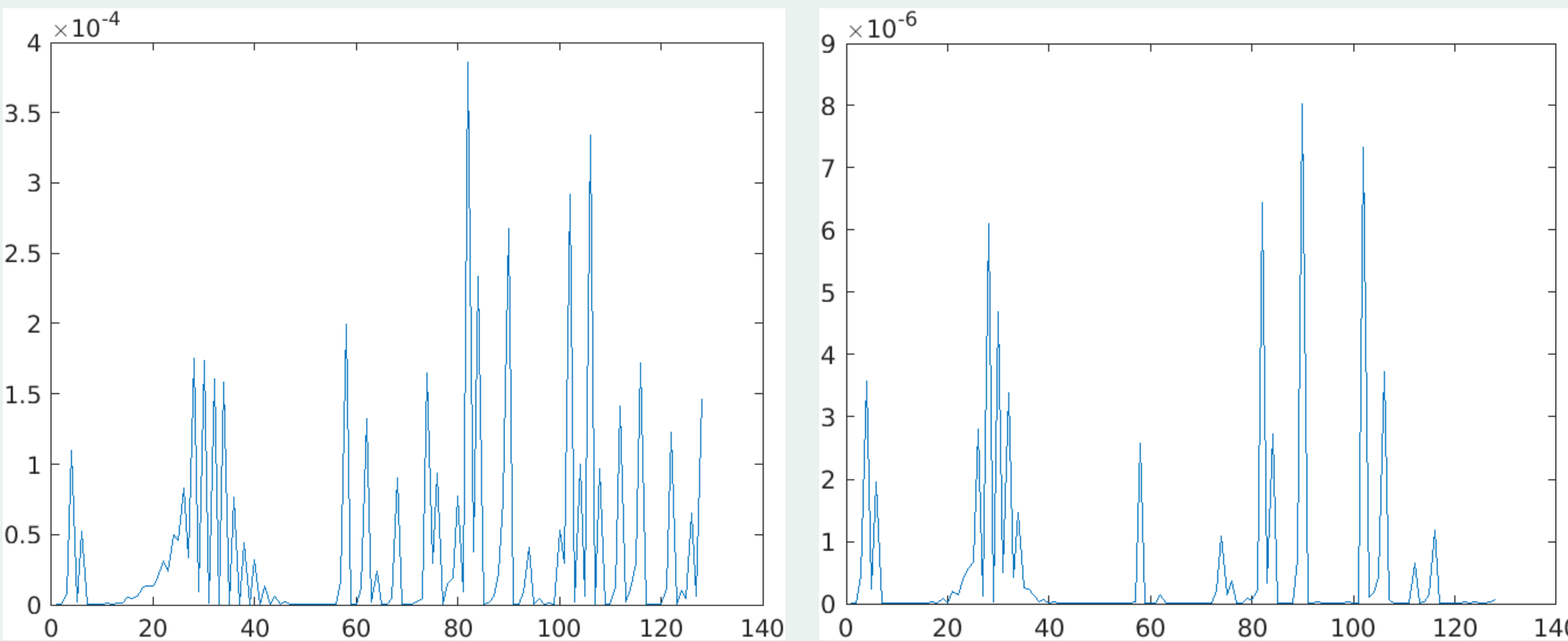


Following are the resulting displacement in the beam using fmincon and fminunc function respectively.

RESULTS

The error in the gradient calculation has been generated and the minimal in the potential has been observed in both the cases.

The external force though has been mentioned to be -1000N, but in the case of fmincon, the value has been risen to -10000N to check the deflection in large scale.

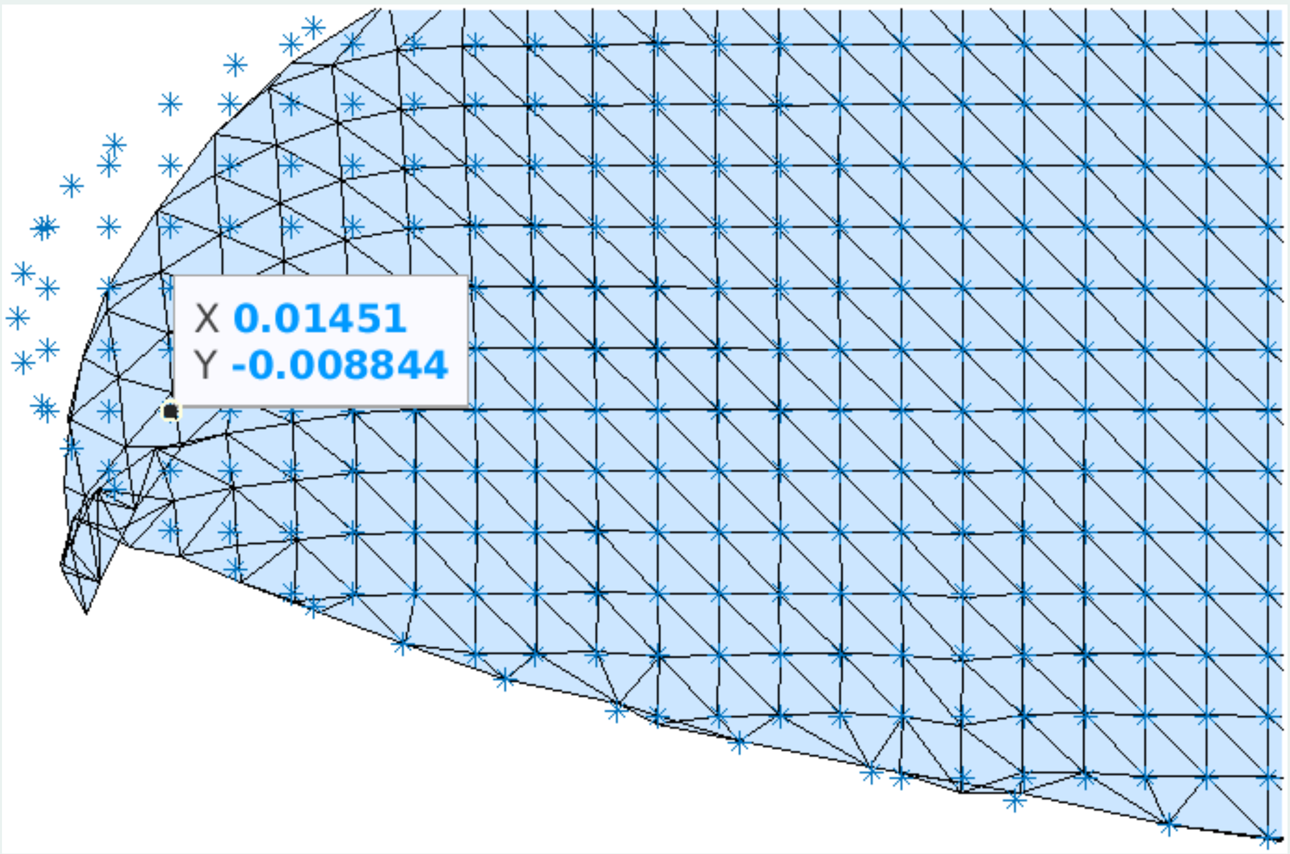


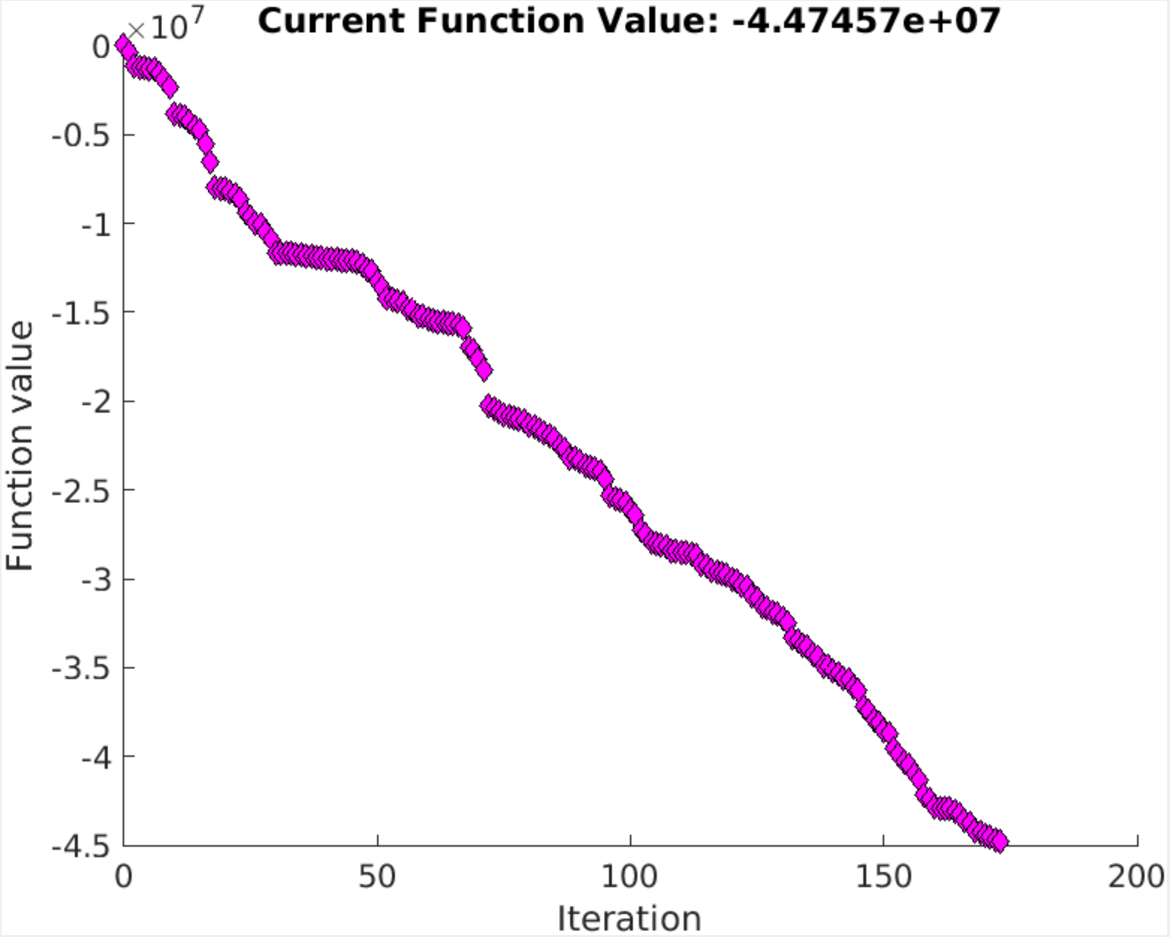
	Fmincon	Fminunc
Min Potential	-27029	-2608.05

Following are the error in gradient using fmincon and fminunc function respectively.

RESULTS

For the morphing airfoil, the analysis takes place for fmincon functions and the results are -





Following are the resulting displacement and the value of the minimum potential derived from the morphing wing.

CONCLUSION

- The tool had worked as expected to solve non linear problems.
- Fmincon had provide better and accurate results.
- The finite difference allowed the validation of the gradient.
- The errors are very small which suggests that the potential function has been generating near to accurate results.
- The major issue had been with the potential function as there are many variables in it and the magnitude of the variables seems to be very high.
- A lot of computational time is required for this.
- The future work can be included as by changing the point force and the position of the force.
- Change the NACA airfoil in order to attain better results.
- Topology optimisation of the structure.

REFERENCES

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3. Johannes T.B. Overvelde, “The Moving Node Approach in Topology Optimisation”, Master Thesis TU Delft University. April 18, 2012.
4. Sato Keigo, Yokozeki Tomohiro. “Structural design of morphing control surface using corrugated panels.” University of Tokyo.
5. Gabriele Capasso, "Topology Optimisation of Feasible Morphing wing using Non Linear Mechanics", July 2018.