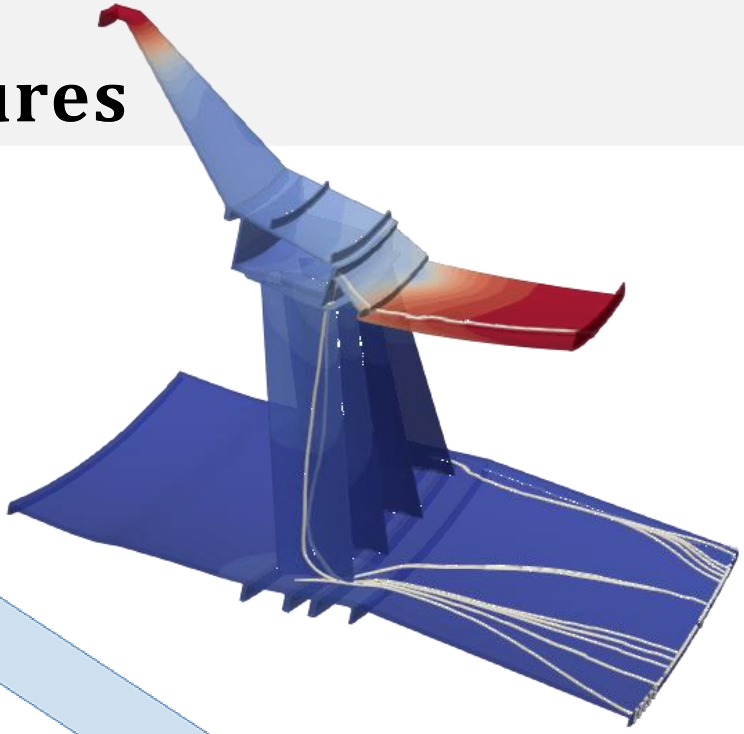
Load Path Visualization in Engine Structures



Master's Thesis in Applied Mechanics, MSc

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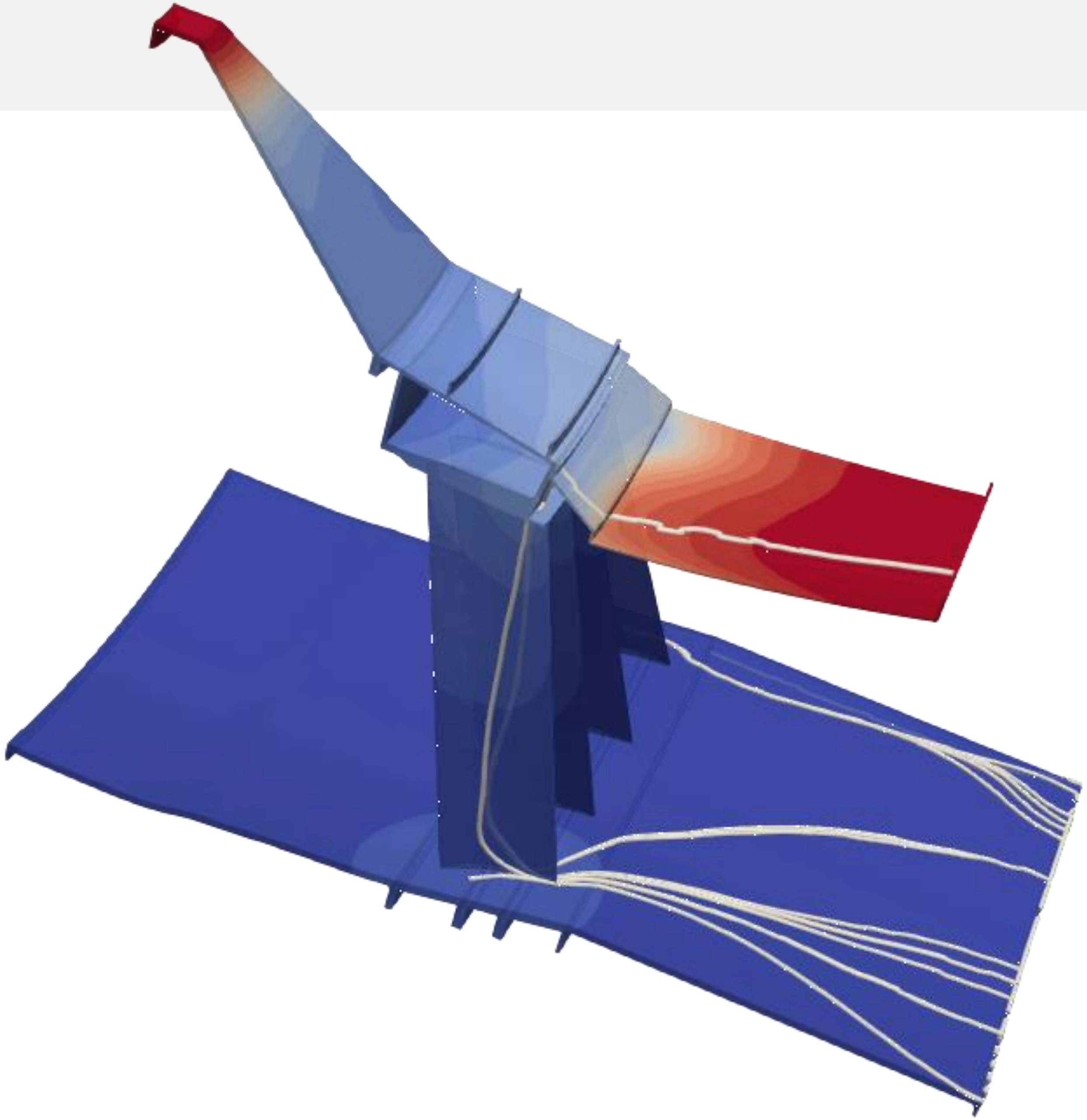


Background

- The pursuit of lightweight and cost-effective components, without compromising the strength and safety, has always been a challenge for engineers
- It is crucial to identify how the loads imposed on the structure are transferred.
- Loads are transferred from the point of application to the supports.
- Load paths are streamlines through the structure.
- The conventional methods use stress and strain.
  - Limitation: Stress Concentrations.
- Circumvent this problem using Ustar index method.

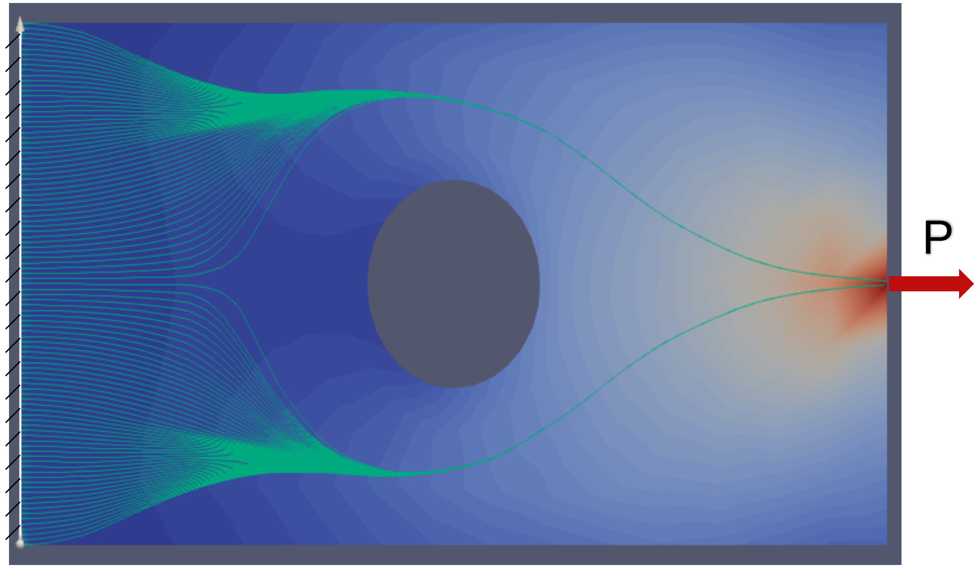


Figure : Load path as streamlines through structure..

Background: U* Index Theory

- ❑ U* is a mathematical index.
- ❑ Internal stiffness distribution in a structure.
- ❑ U* value ranges from 0 to 1.
- ❑ U* index is dependent on loading and boundary conditions.

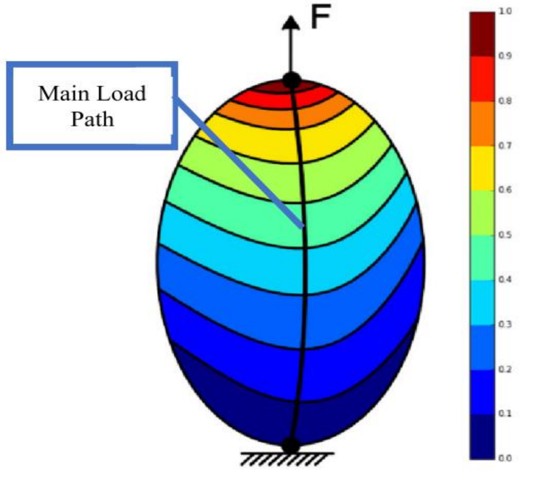


Figure : U* contours in a body

Applications:

1. Damage detection indicator(Latest)
2. Topological optimization.
3. Improve crashworthiness of automobiles.

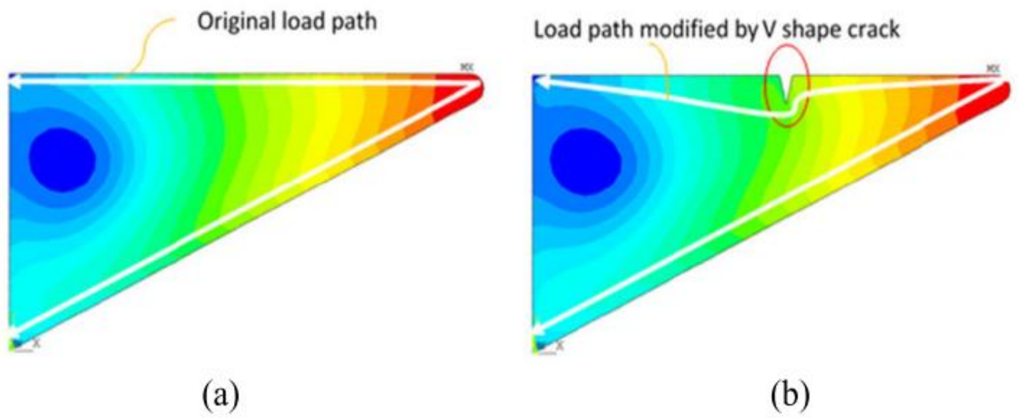


Figure : U* index used in damage detection.

Aim

- ✓ Develop an APDL script to apply distributed loads on the engine structure.
- ✓ Extend the script to incorporate multiple supports or BCs’.
- ○ Include rotational degrees of feedom in U* computation.
- ✓ Develop a method to plot the load paths and identify the principal load paths (ParaView).
- ✓ Plot the uniformity and continuity plots based on the principal load path.
- ○ Visualize the load paths on various engine structures under different loading and boundary conditions. Perform a comparison study to identify the crucial areas of load transfer in the engine structures.

Methodology: U*-Index Computation (Direct Method)

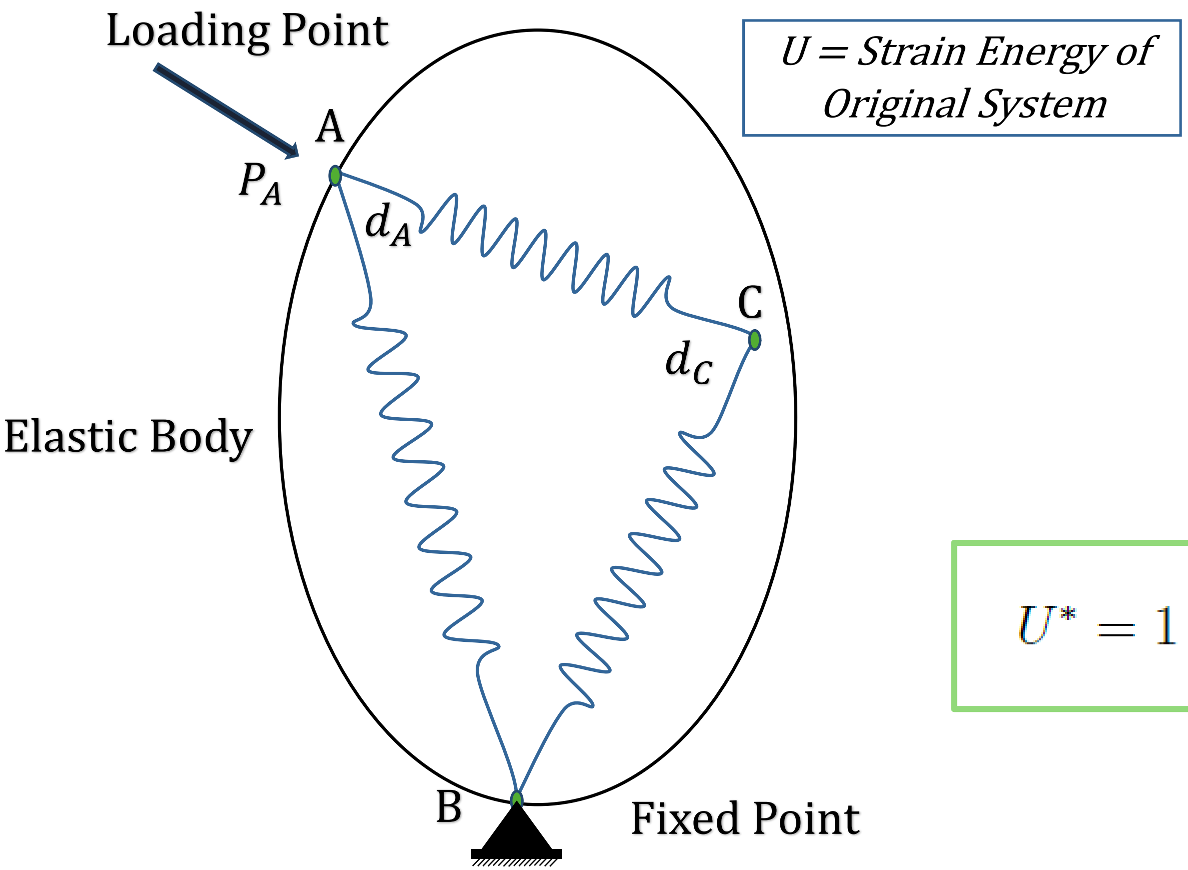


Figure : Original System.

$$U^* = 1 - \frac{U}{U'}$$

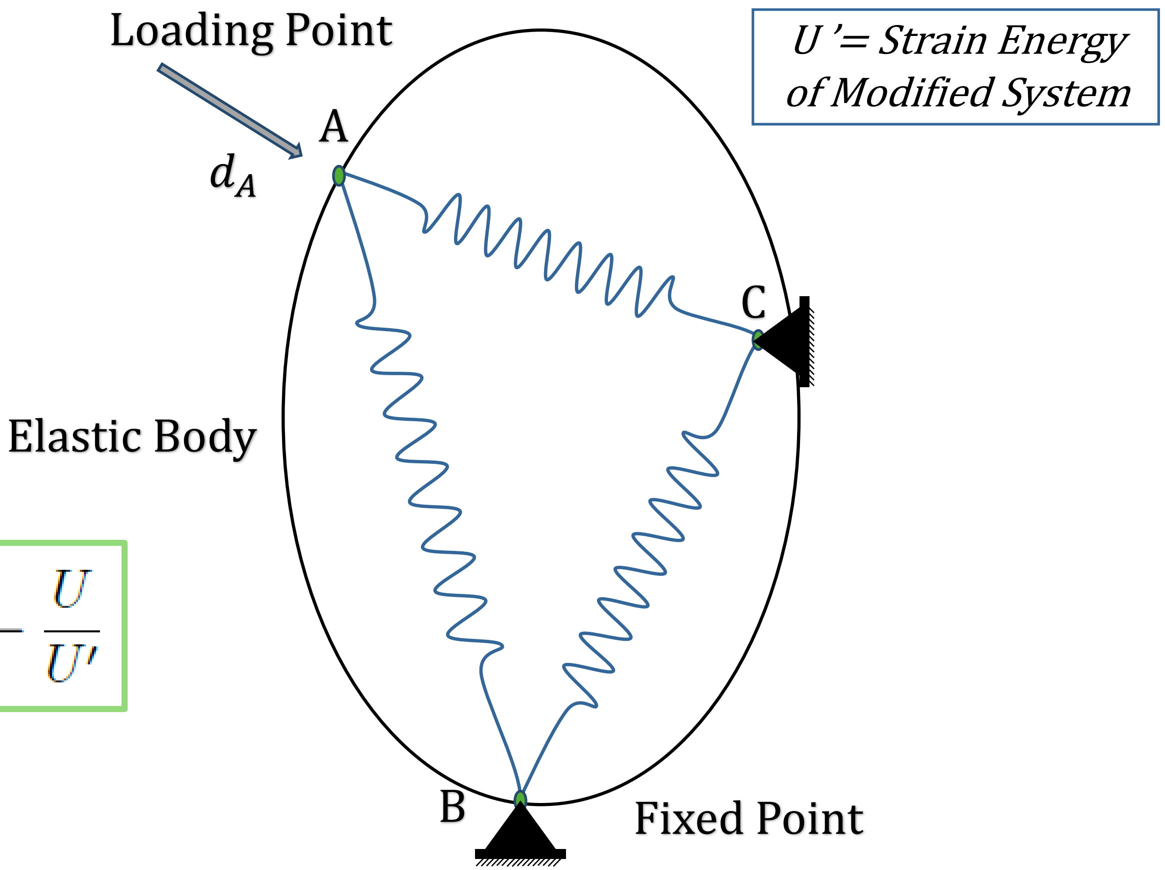


Figure : Modified System.

Methodology: Inspection Load Method

Advantages

- Reuse of global stiffness matrix
- Faster computation than Direct Method

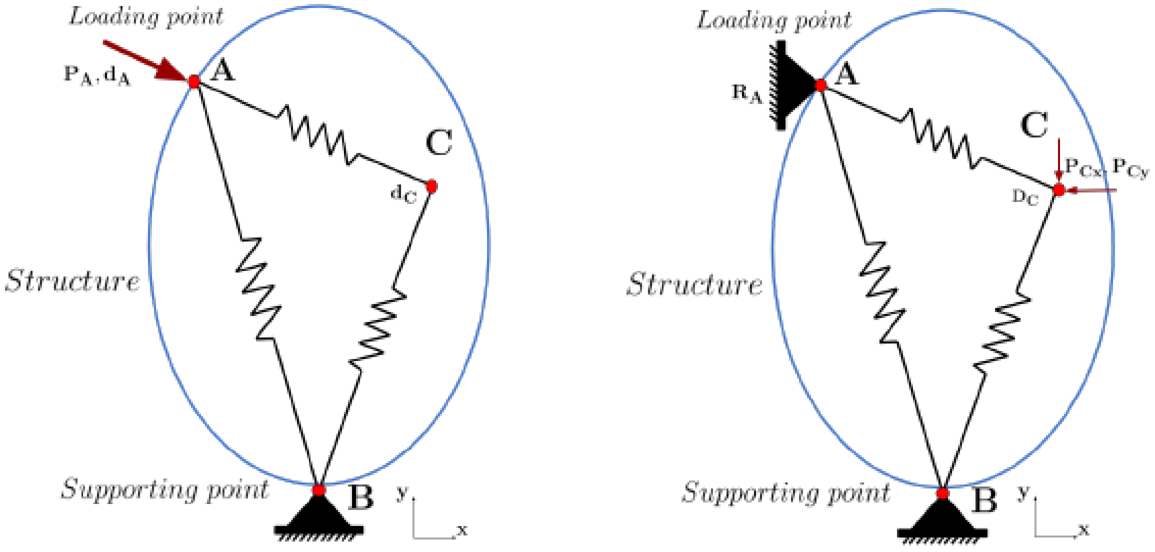
1 $$U^{*} = 1 - \frac{U}{U'} = 1 - \frac{(K_{AA}d_A + K_{AC}d_C)}{(K_{AA}d_A)} = (1 - \frac{2U}{(K_{AC}d_C)d_A})^{-1}$$

2 $$[K_{AC}] = [P_A]\,[D_C]^{-1}$$

3 $$[P_A] = [\ p_{A_1} \quad p_{A_2}\ ]$$

4 $$[D_C] = [\ d_{C_1} \quad d_{C_2}\ ]$$

Pertaining to inspection loads



(a) Unmodified load case. (b) Modified load case.

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Methodology: Continuity and Uniformity

- Conditions for a structure with desirable load path are denoted using the continuity and uniformity criteria.

1. Uniformity
   - ➢ Depicts the uniformity of the stiffness distribution.along the streamline..
   - ➢ The ideal distribution is a straight line.
   - ✓ **Objective**: Minimize the area f1
2. Continuity
   - ➢ Depicts the large curvatures in the streamline.
   - ➢ The ideal path should have zero curvature.
   - ✓ **Objective**: Minimize the area f2

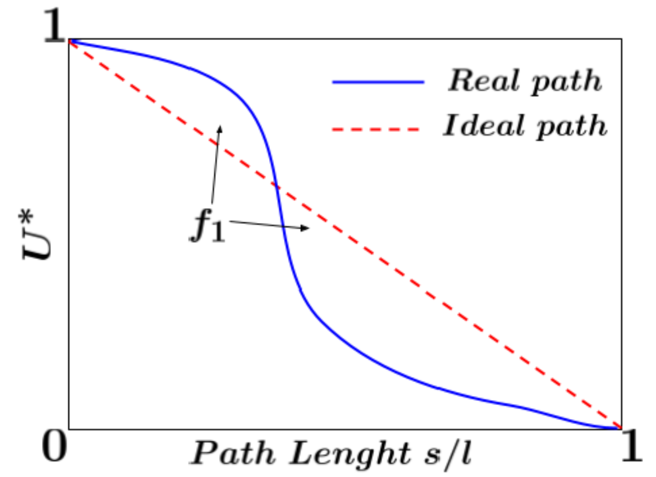

Figure : Uniformity Plot

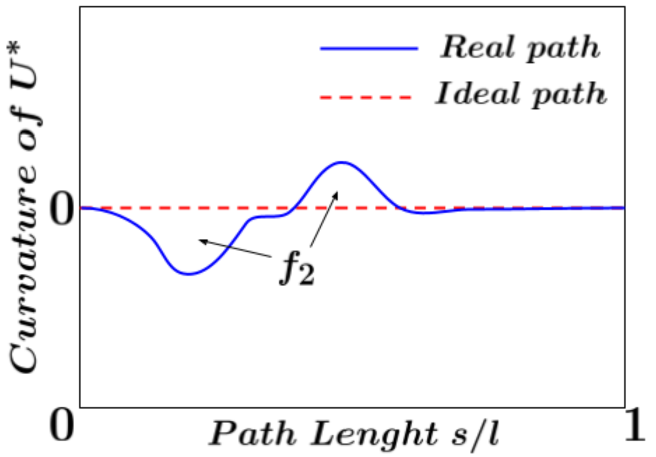

Figure : Continuity Plot

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Results

Load path visualization on:

2D geometries

- Rectangular plate with a hole – 1. Point load
  2. Single interface distributed load
  3. Multiple interface distributed load
  4. Multiple interface supports and loads

3D geometries

- 3D bar – Single interface distributed load
- GKN aero-engine structure

Rectangular Plate with Hole – Single Point Load

Boundary conditions:

- Fixed support on left edge
- Single point load on right edge : F_X = 1000N

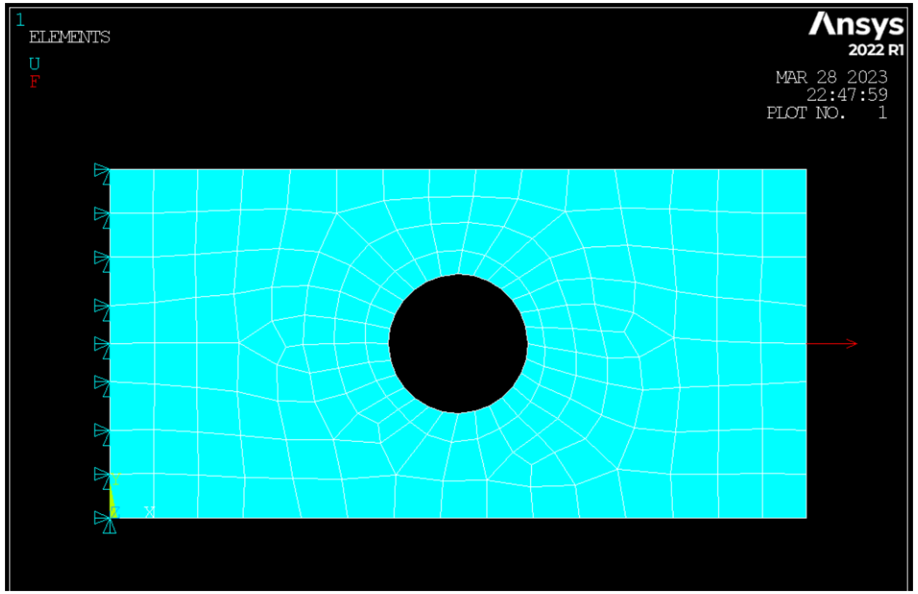

Figure : Boundary conditions

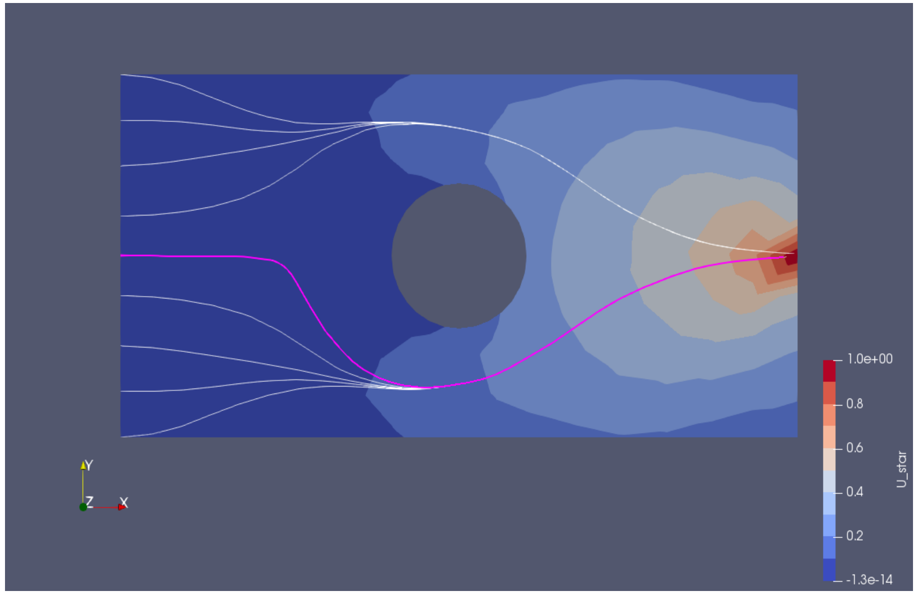

Figure : U* contour & streamlines

Rectangular Plate with Hole – Single Point Load

Load path:

- Stiffest path / principal streamline
- Highest gradient streamline

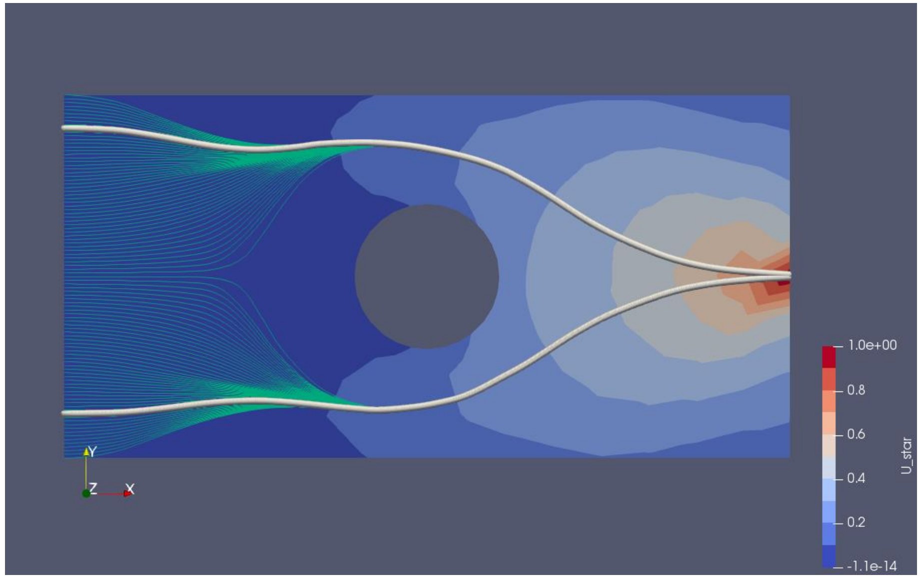

Figure : Principal streamlines / Load paths

Seed point coordinate : (0,0.12) & (0,0.91)

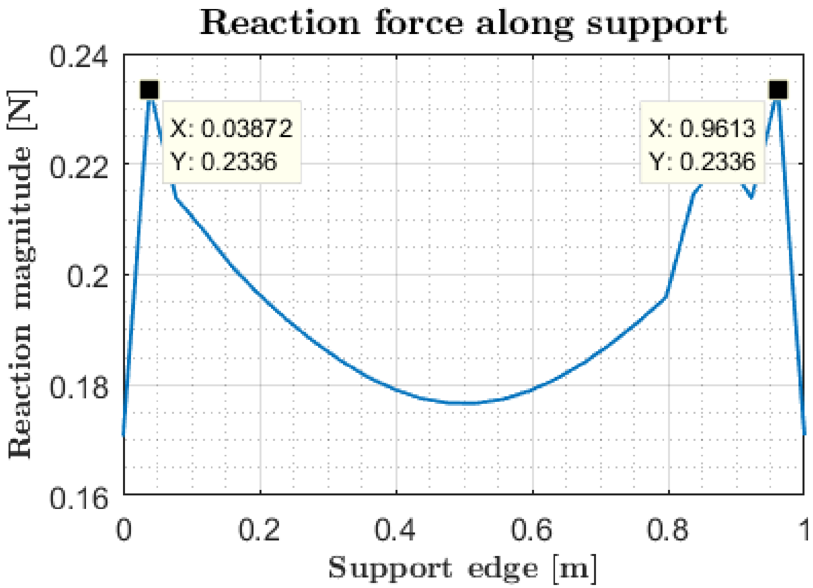

Figure : Reaction forces along support edge

Maximum reaction points : (0,0.04) & (0,0.96)

Rectangular Plate with Hole – Single Point Load

Uniformity & Continuity plots:

- For the load path / principal streamline
- Curve fitted uniformity curve for smoothness
- Polynomial of order 12

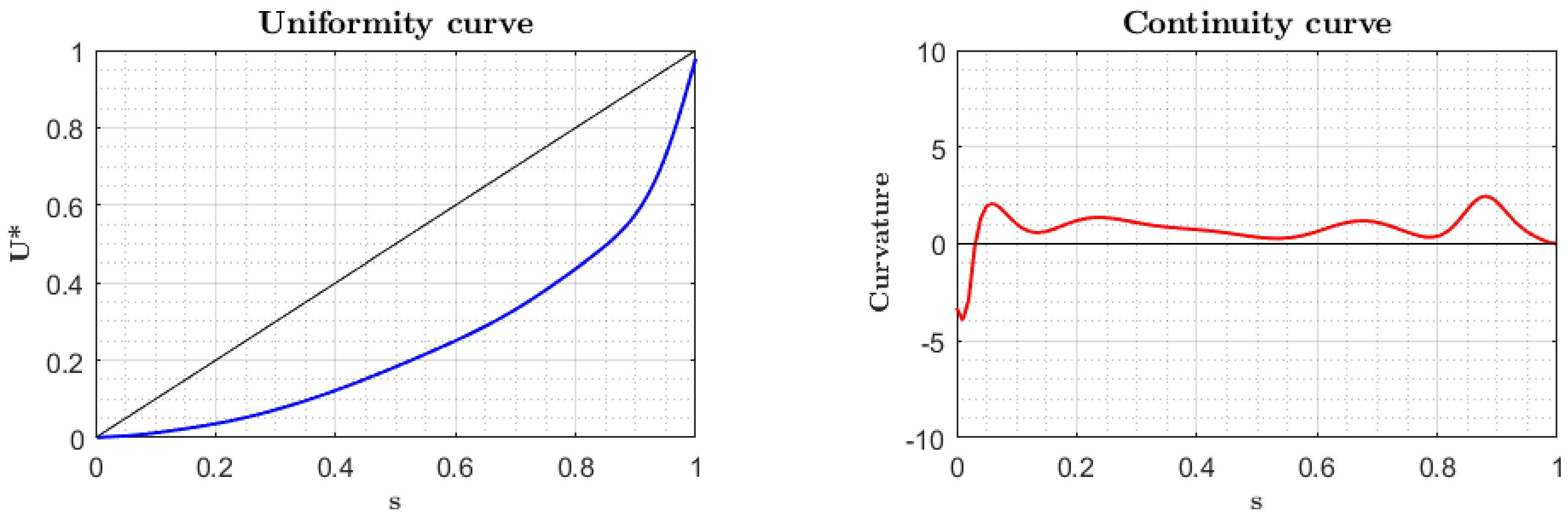

Figure : Uniformity & Continuity curves

Plate with Hole – Single Interface Distributed Load

Boundary conditions:

- Fixed support on left edge
- Distributed load on right edge : P = 1000N/m^2

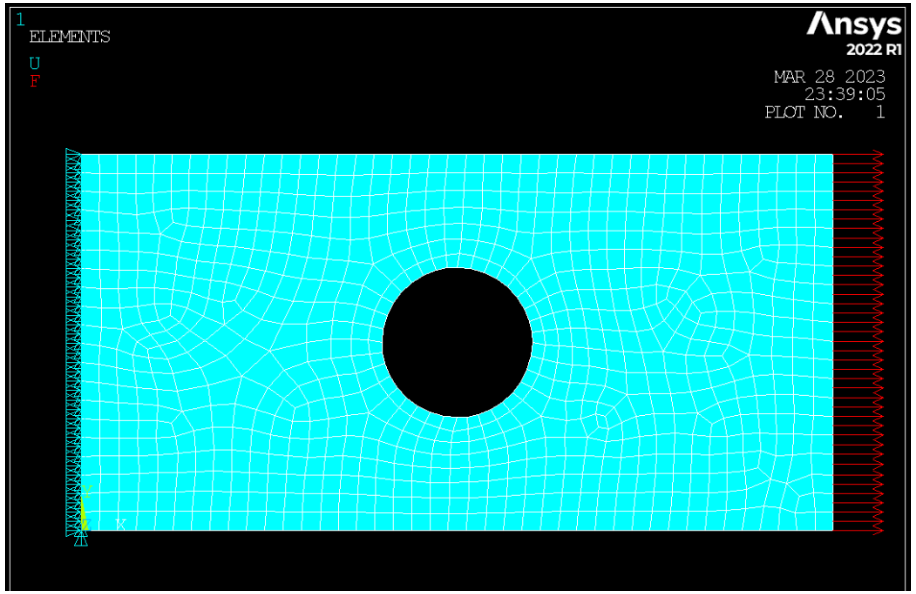

Figure : Boundary conditions

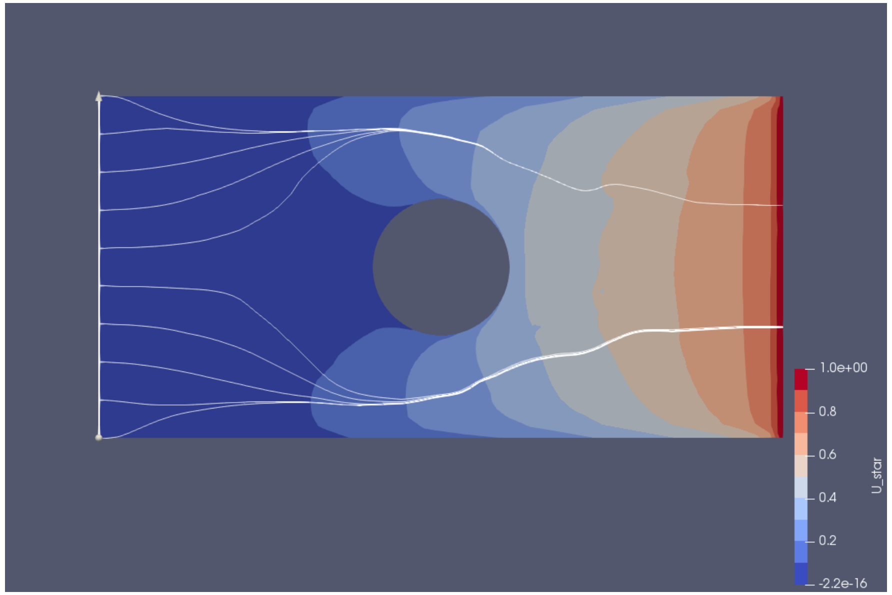

Figure : U* contour & streamlines

Plate with Hole – Single Interface Distributed Load

Load path:

- Stiffest path / principal streamline
- Highest gradient streamline

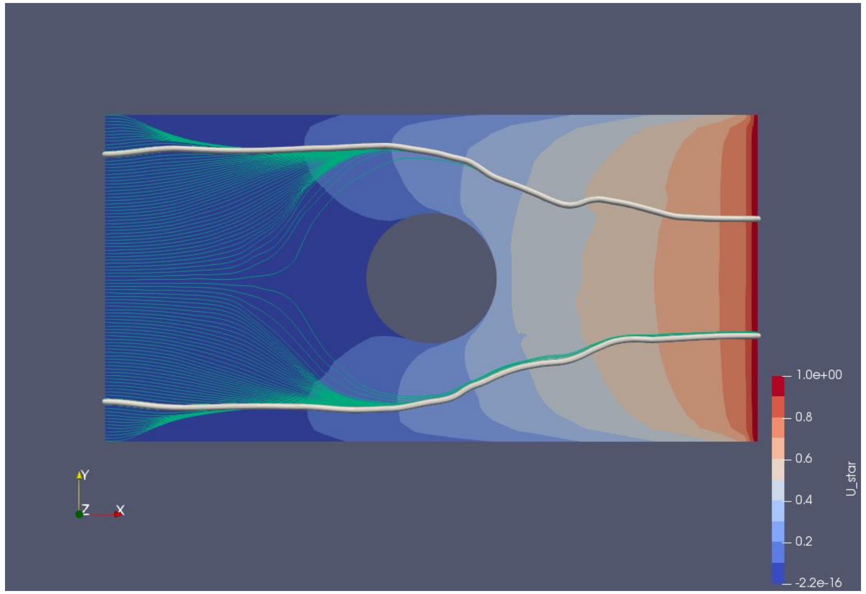

Figure : Principal streamlines / Load paths

Seed point coordinates : (0,0.12) & (0,0.89)

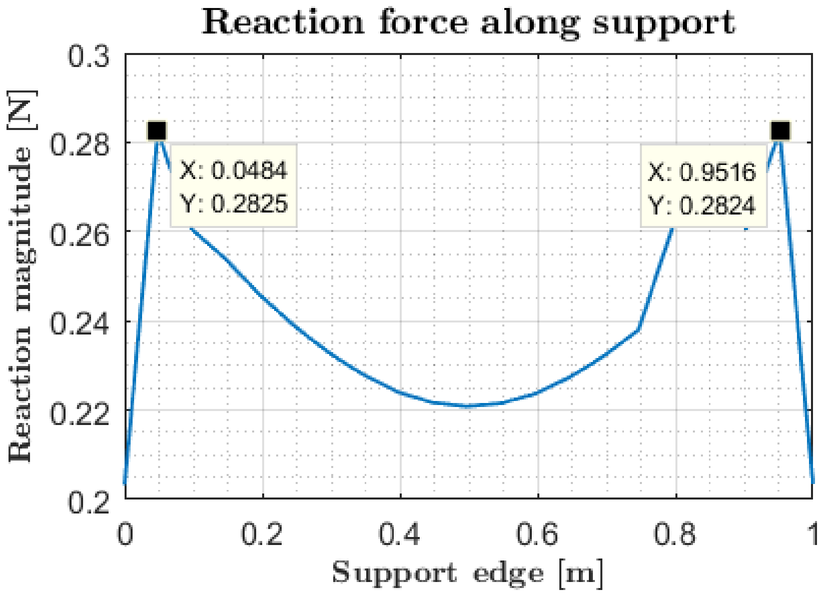

Figure : Reaction forces along support edge

Maximum reaction points : (0,0.05) & (0,0.95)

Plate with Hole – Multiple Interface Distributed Load

Boundary conditions:

- Fixed support on left edge
- Distributed load on right edge : P = 1000N/m^2

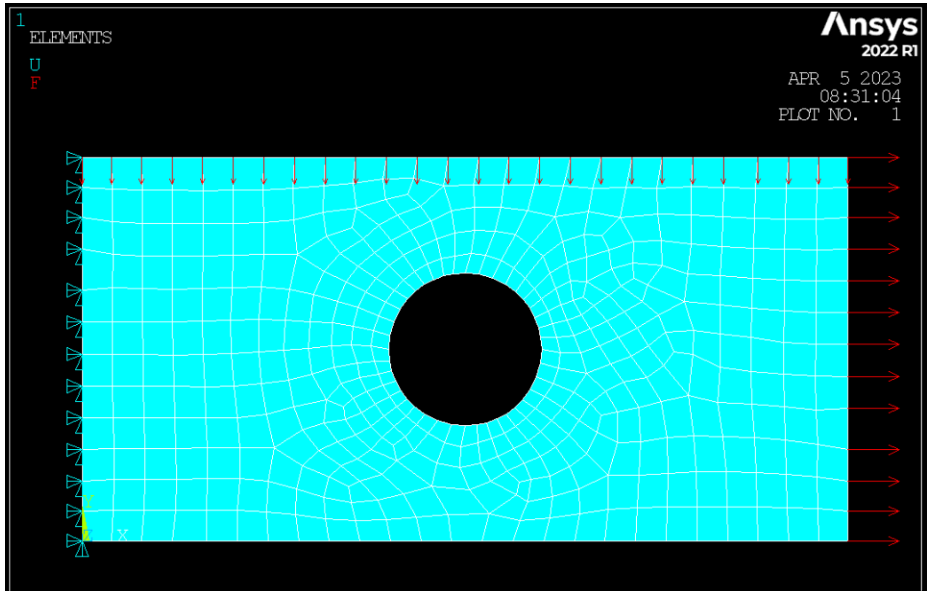

Figure : Boundary conditions

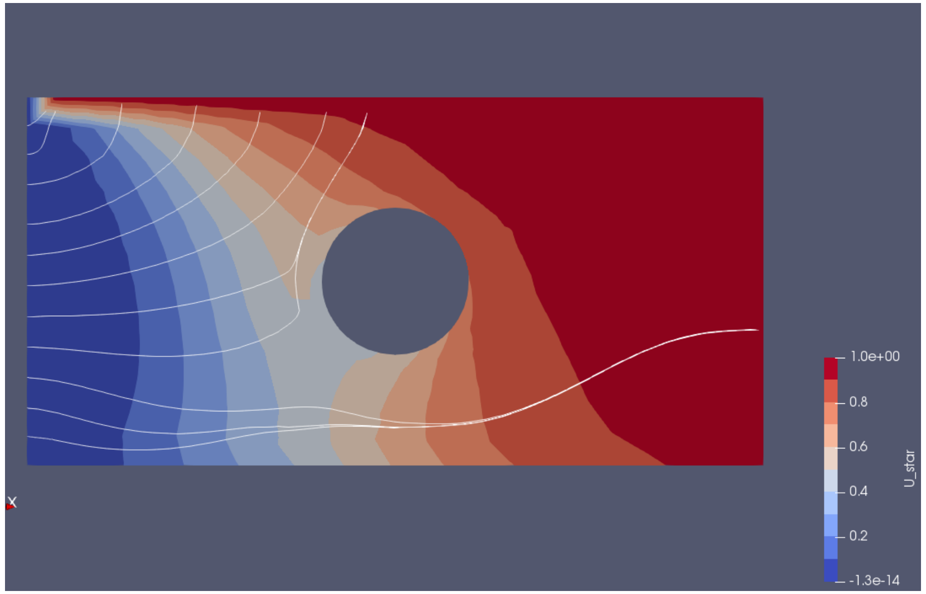

Figure : U* contour & streamlines

Plate with Hole – Multiple Interface Distributed Load

Load path:

- Stiffest path / principal streamline
- Highest gradient streamline

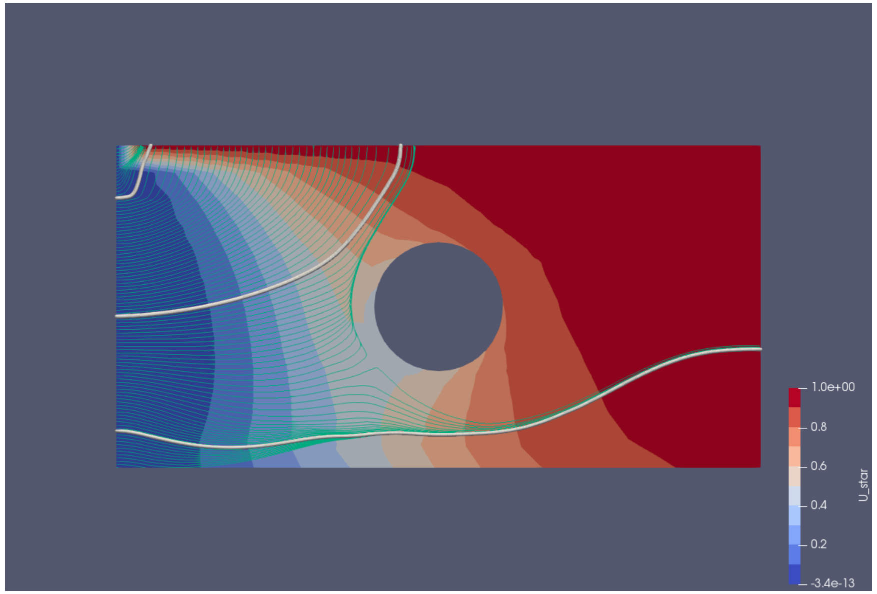

Figure : Principal streamlines / Load paths

Seed point coordinates : (0,0.84), (0,0.47) & (0,0.11)

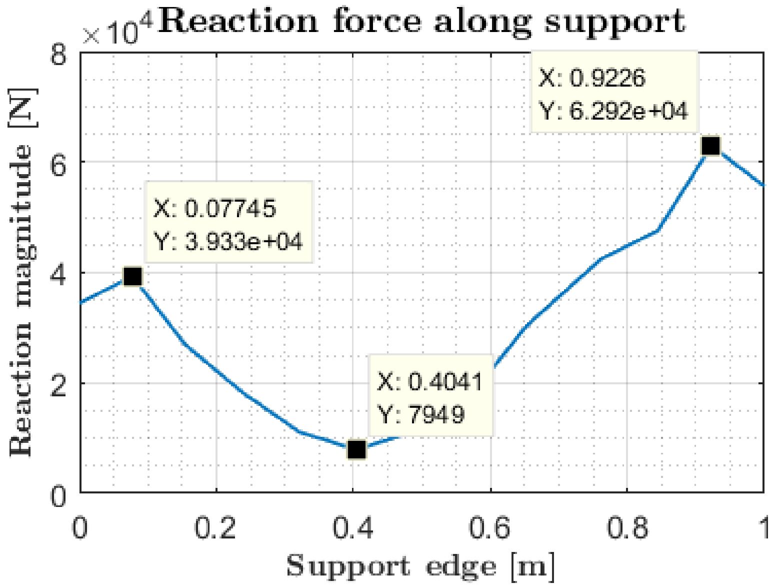

Figure : Reaction forces along support edge

Extremum reaction points : (0,0.92), (0,0.40) & (0,0.08)

Plate with Hole – Multiple Loads & Multiple Supports

Boundary conditions:

- Fixed support on left and bottom edge
- Distributed loads on top edge F_y = 30000 N
- Distributed load on right edge F_x = 12000 N

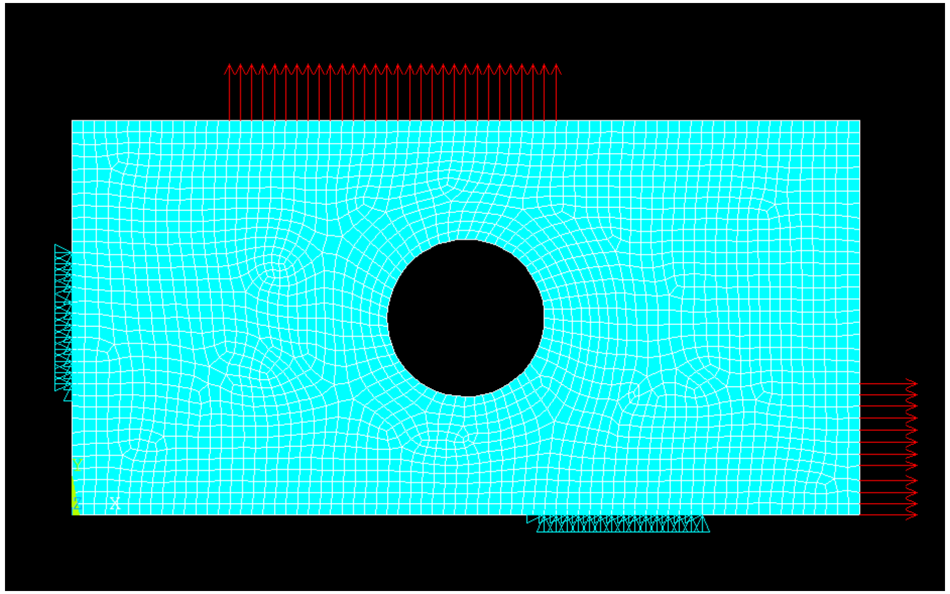

Figure : Boundary conditions

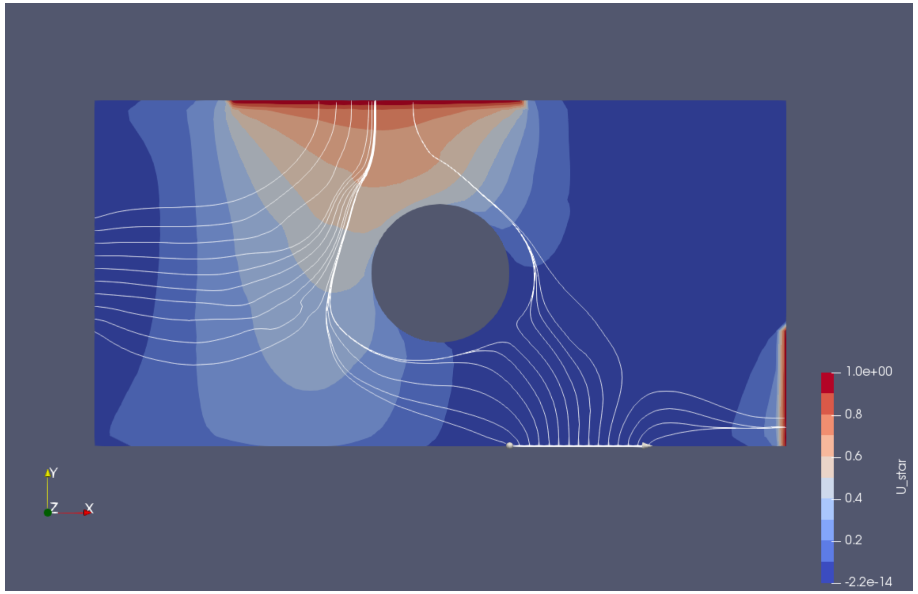

Figure : U* contour & streamlines

Plate with Hole – Multiple Loads & Multiple Supports

Load path:

- Stiffest path / principal streamline
- Highest gradient streamline

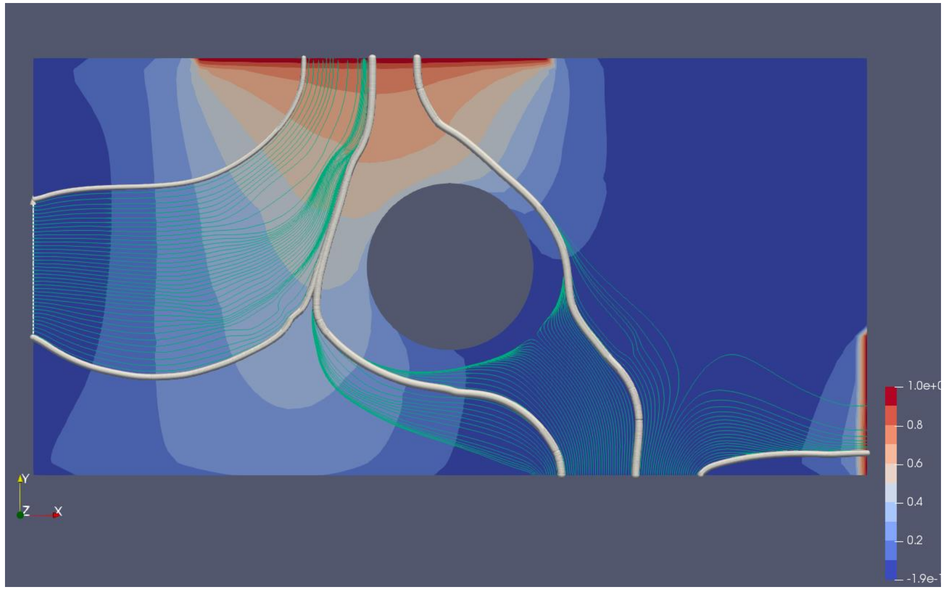

Figure : Principal streamlines / Load paths

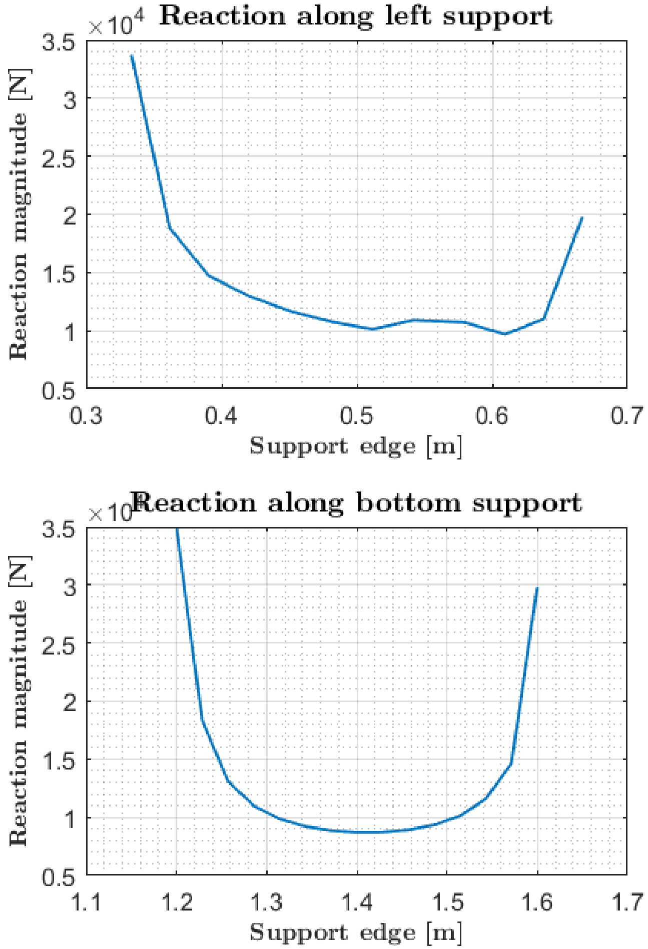

Figure : Reaction forces along support edge

3D bar – Single Interface Distributed Load

Boundary conditions:

- Fixed support on left surface
- Distributed tensile load on right surface

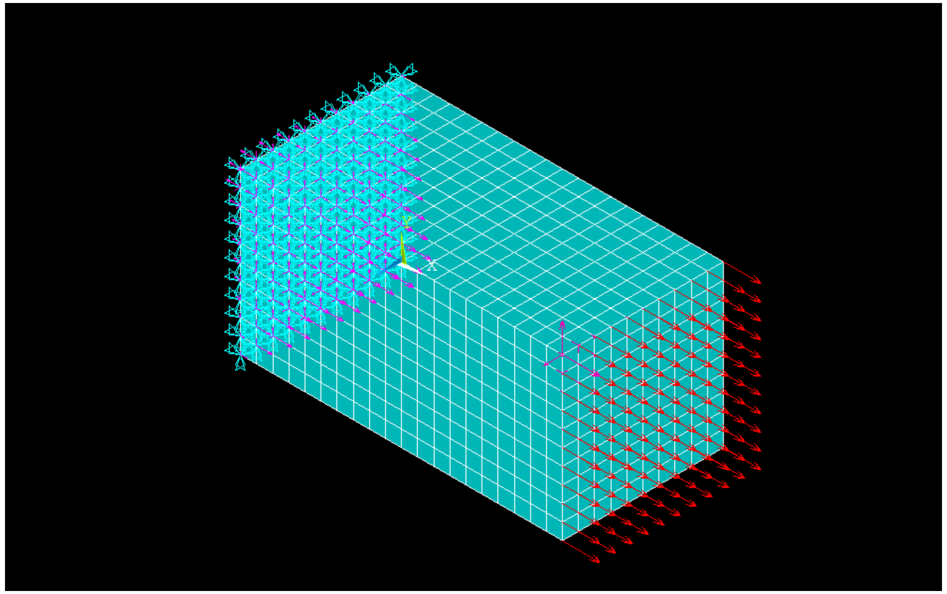

Figure : Boundary conditions

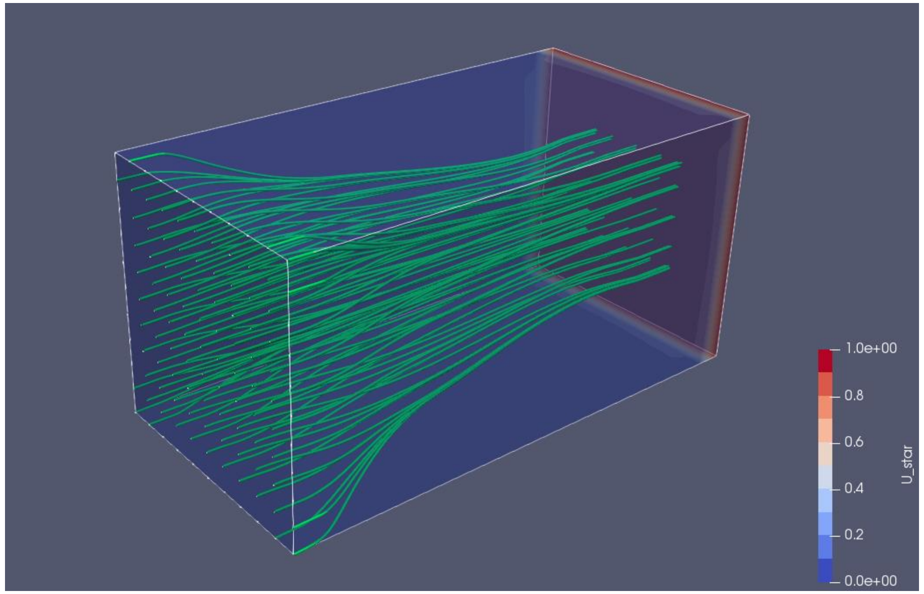

Figure : U* contour & streamlines

GKN Aero-engine structure

Engine Structure & Cut Section

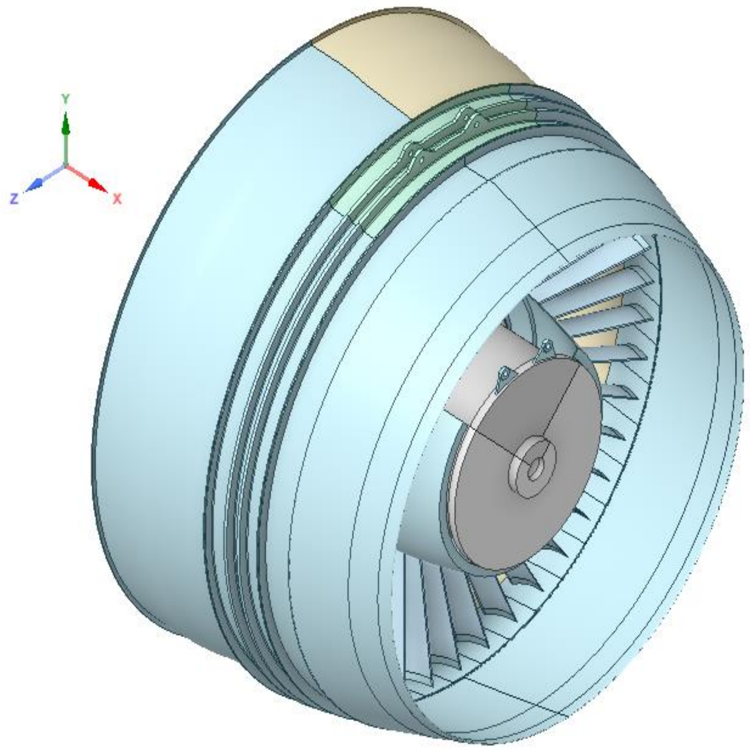

Figure : GKN Aero-engine structure

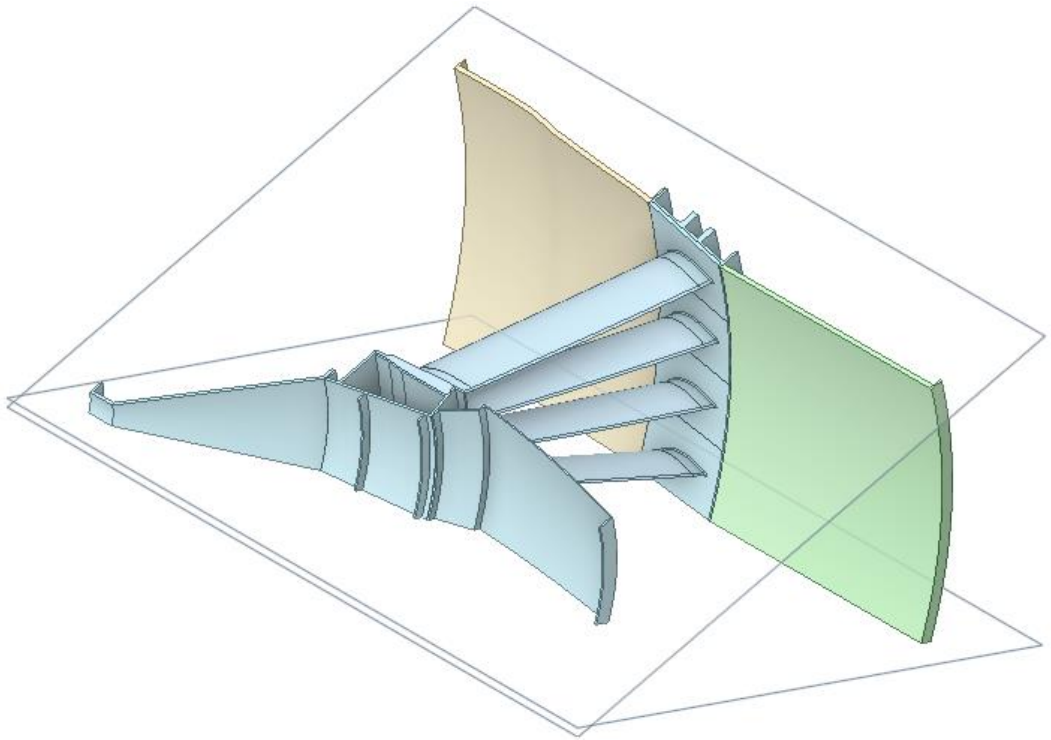

Figure : Cut Section

GKN Aero-engine structure

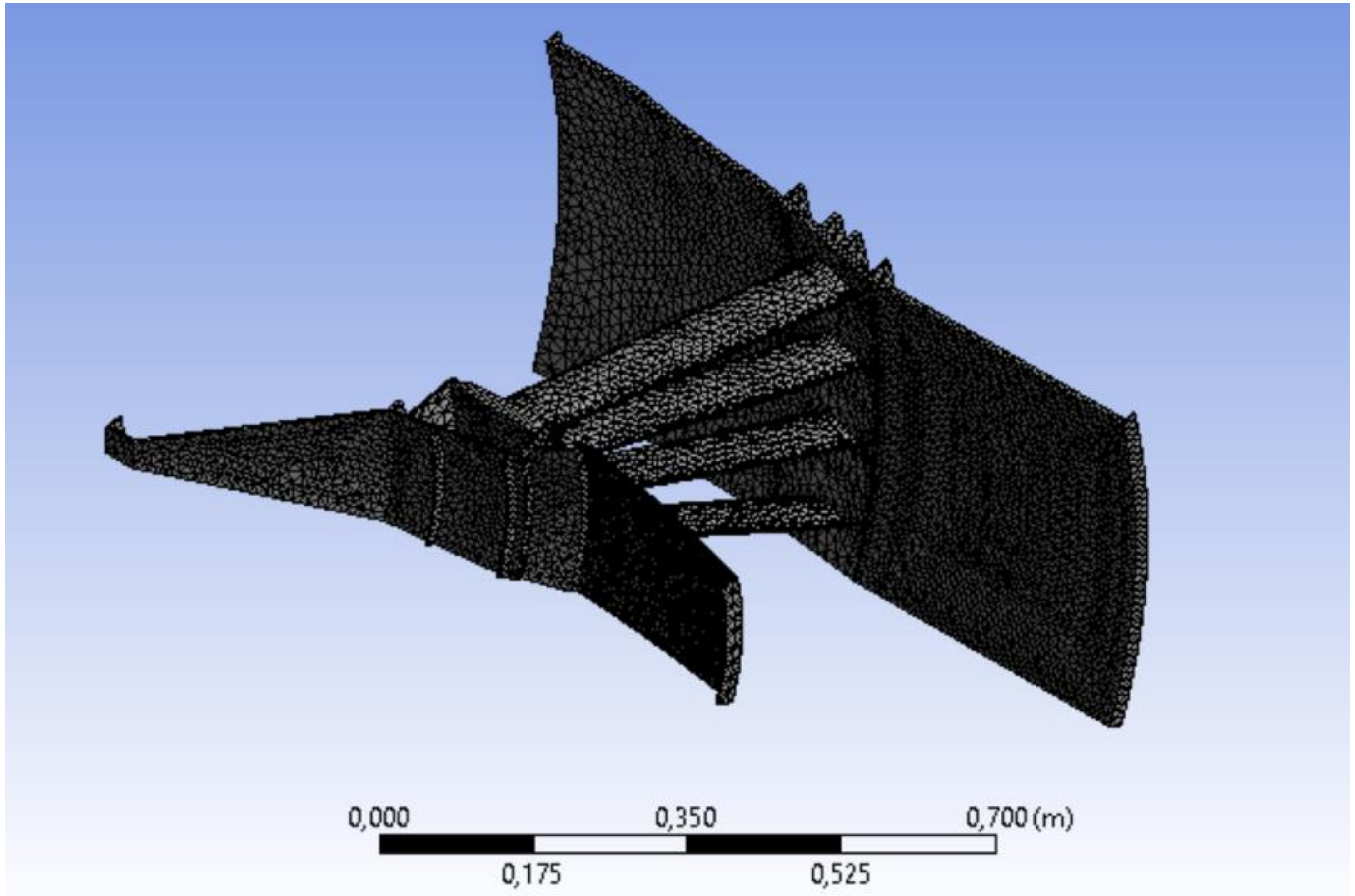

Figure : Meshed component

GKN Aero-engine structure

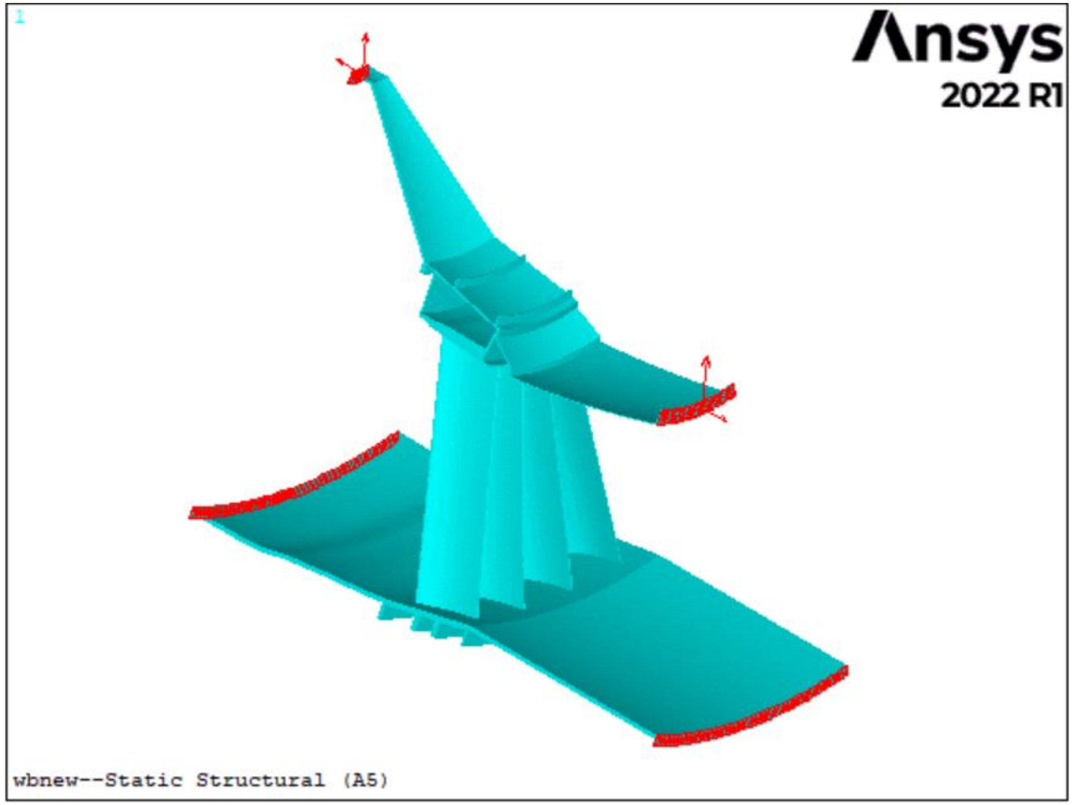

Figure : Boundary conditions

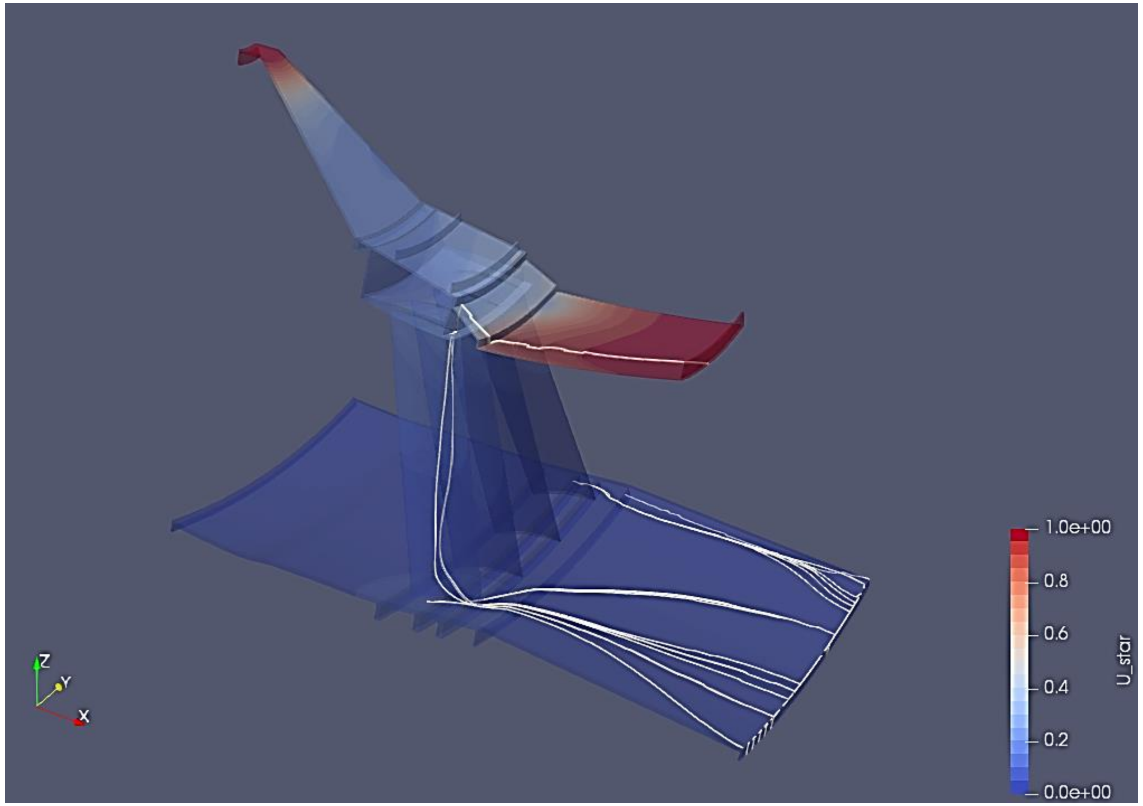

Figure : U* contour & load path