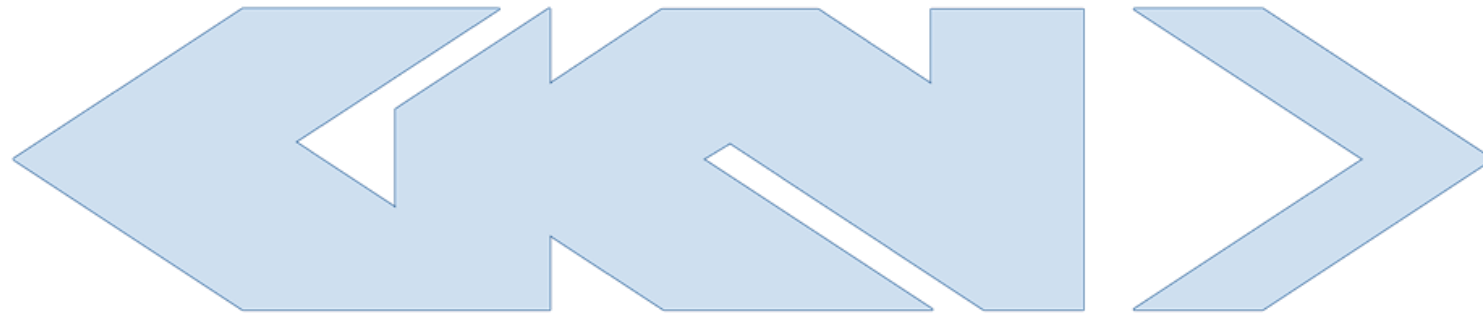


# Load Path Visualization in Engine Structures

Master's Thesis in Applied Mechanics, MSc

Ram Jayanath Ainikkattil

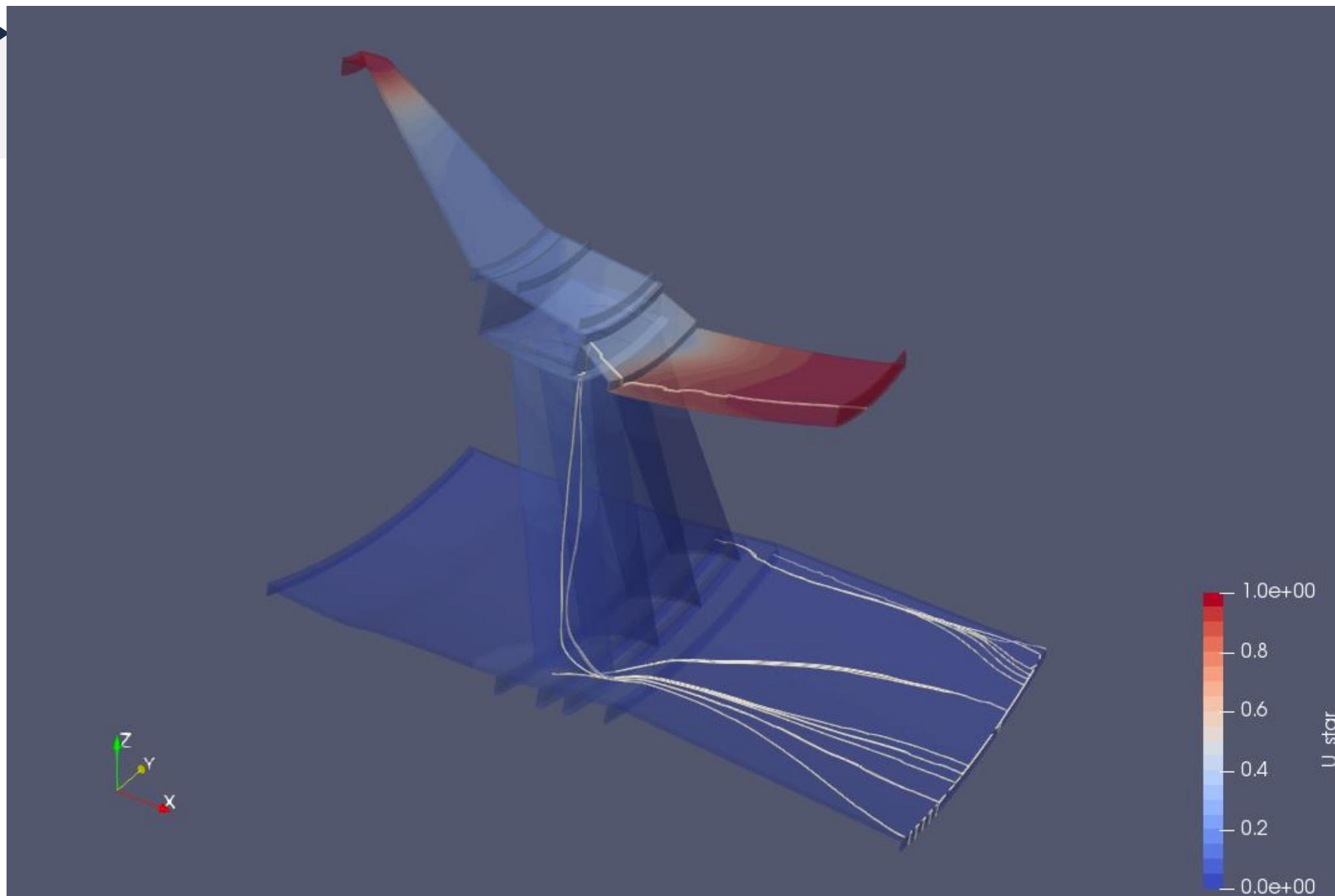
Ponkumar Santhosh Elango



GKN AEROSPACE

Supervision:

- Visakha Raja
- Rajesh Ramesh
- Jonathan Muistama



# 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.

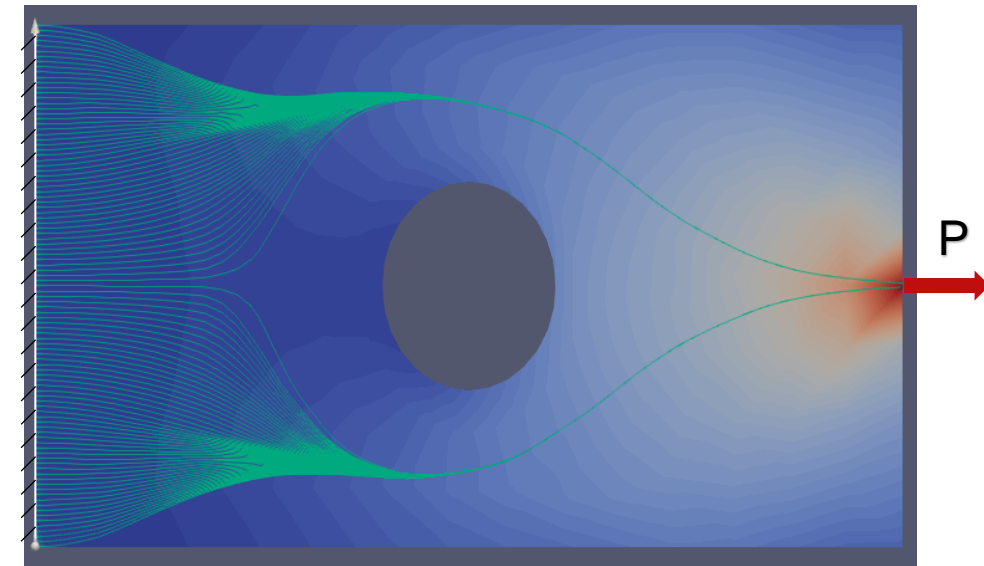


Figure : Load path as streamlines through structure..

# 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.

Applications:

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

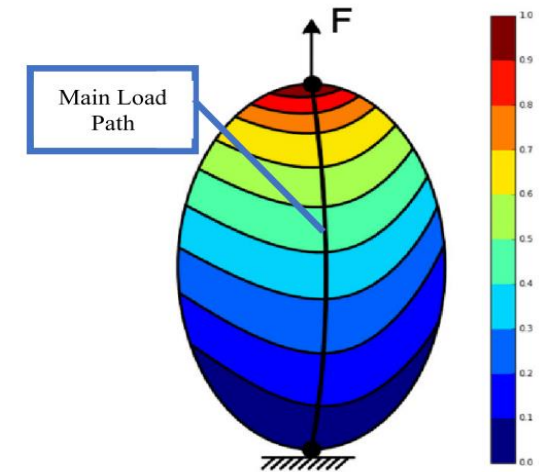


Figure :  $U^*$  contours in a body

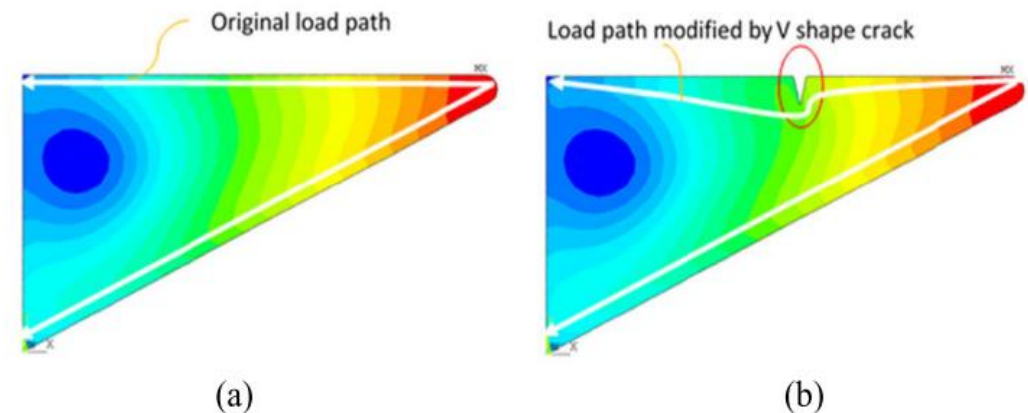


Figure :  $U^*$  index used in damage detection.

# 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 freedom 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)

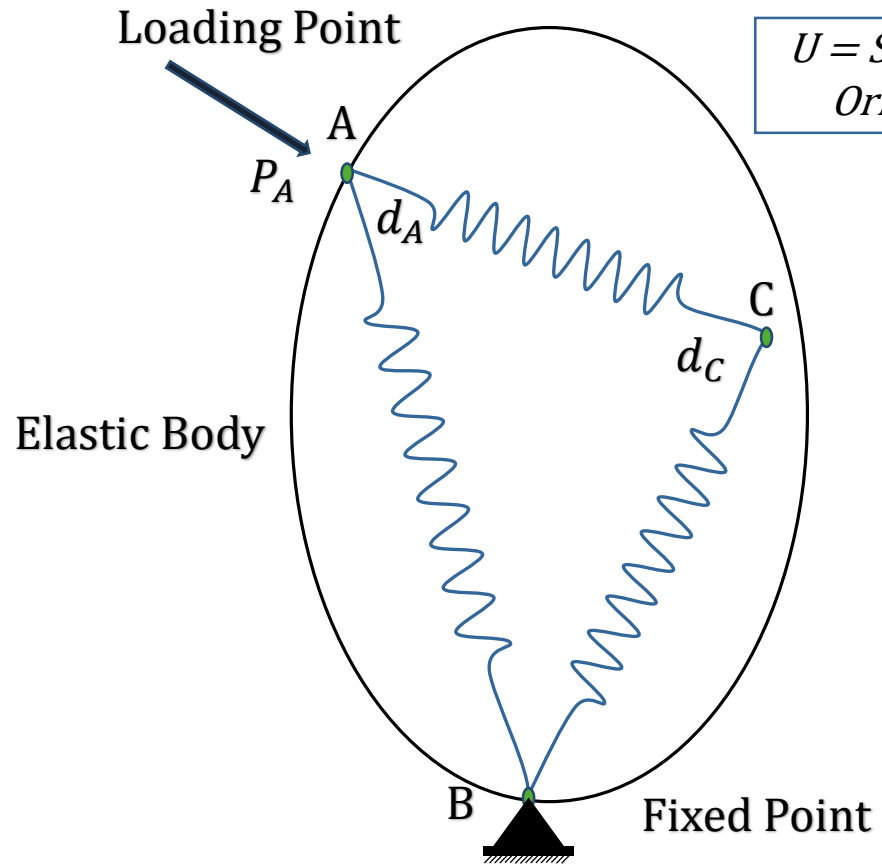


Figure : Original System.

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

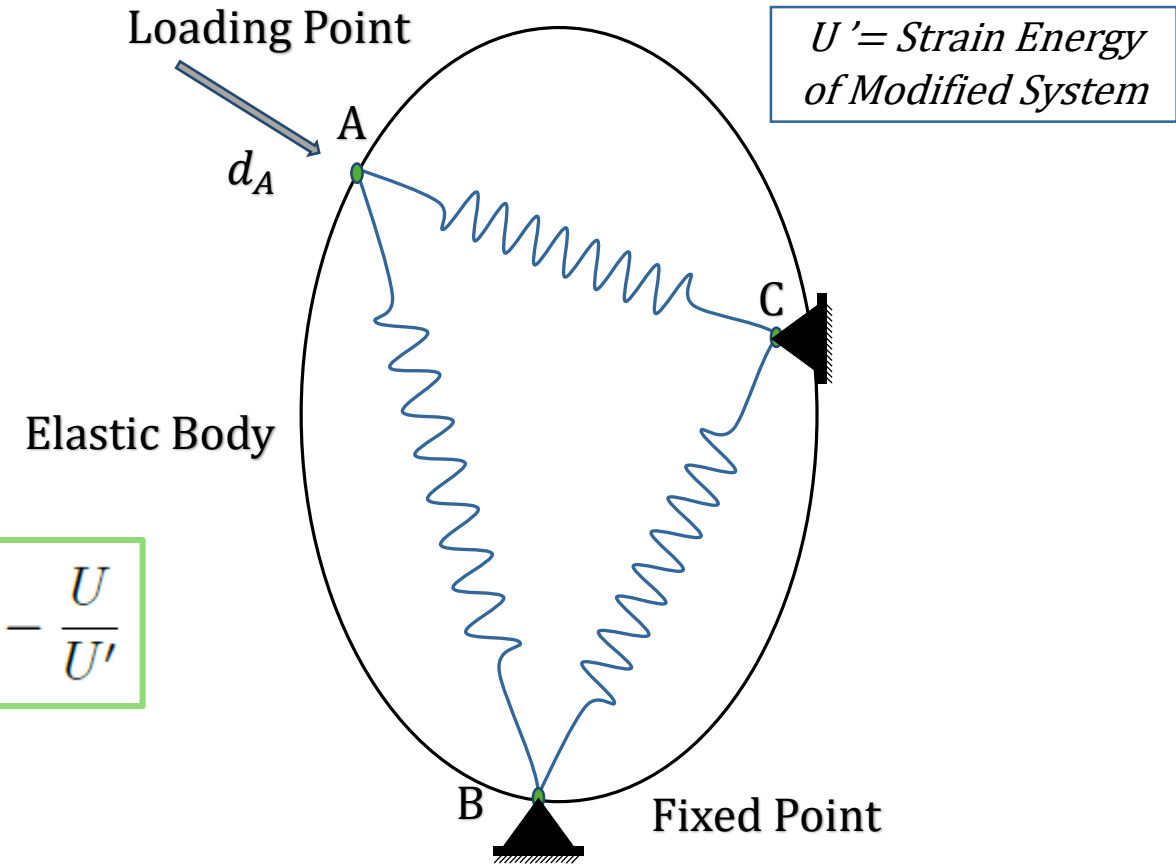


Figure : Modified System.

# Methodology: Inspection Load Method

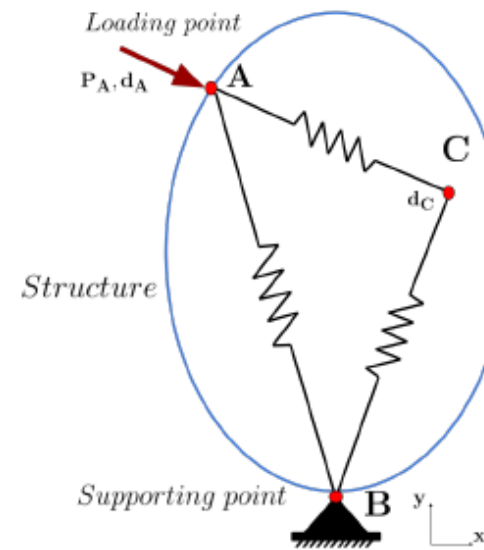
$$1 \quad U^* = 1 - \frac{U}{U'} = 1 - \frac{(K_{AA}d_A + K_{AC}d_C)}{(K_{AA}d_A)} = \left(1 - \frac{2U}{(K_{AC}d_C)d_A}\right)^{-1}$$

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

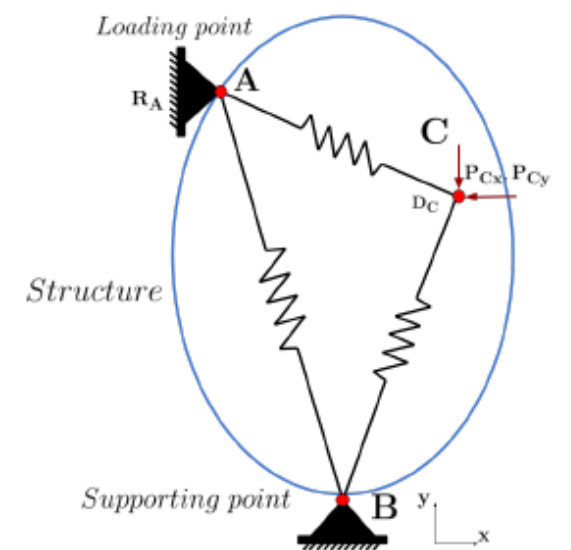
$$3 \quad [P_A] = \begin{bmatrix} p_{A_1} & p_{A_2} \end{bmatrix}$$

$$4 \quad [D_C] = \begin{bmatrix} d_{C_1} & d_{C_2} \end{bmatrix}$$

Pertaining to inspection loads



(a) Unmodified load case.



(b) Modified load case.

# 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  $f_1$

## 2. Continuity

- Depicts the large curvatures in the streamline.
- The ideal path should have zero curvature.
- ✓ **Objective:** Minimize the area  $f_2$

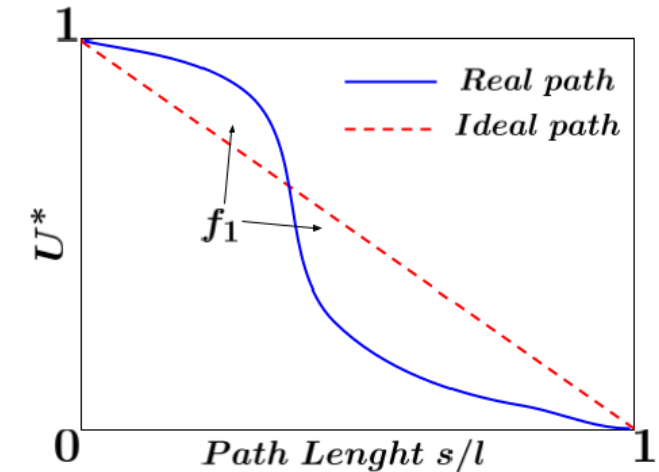


Figure : Uniformity Plot

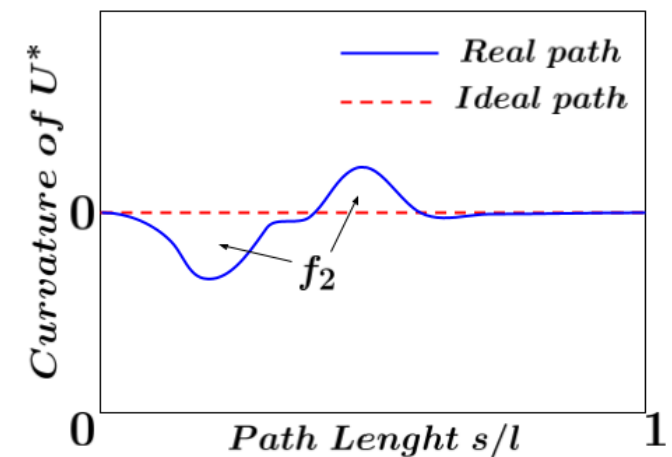


Figure : Continuity Plot



# Results

## 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 :  $F_x = 1000\text{N}$

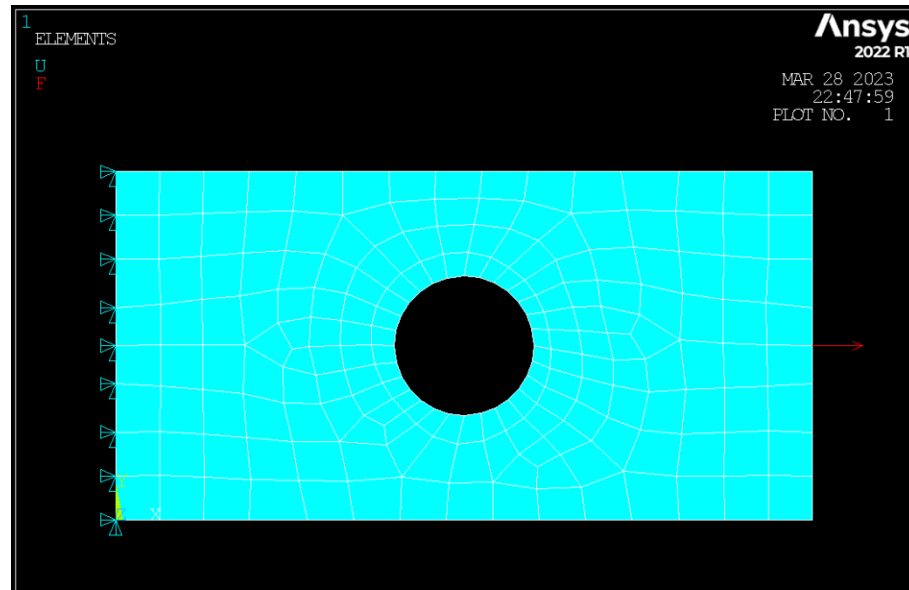


Figure : Boundary conditions

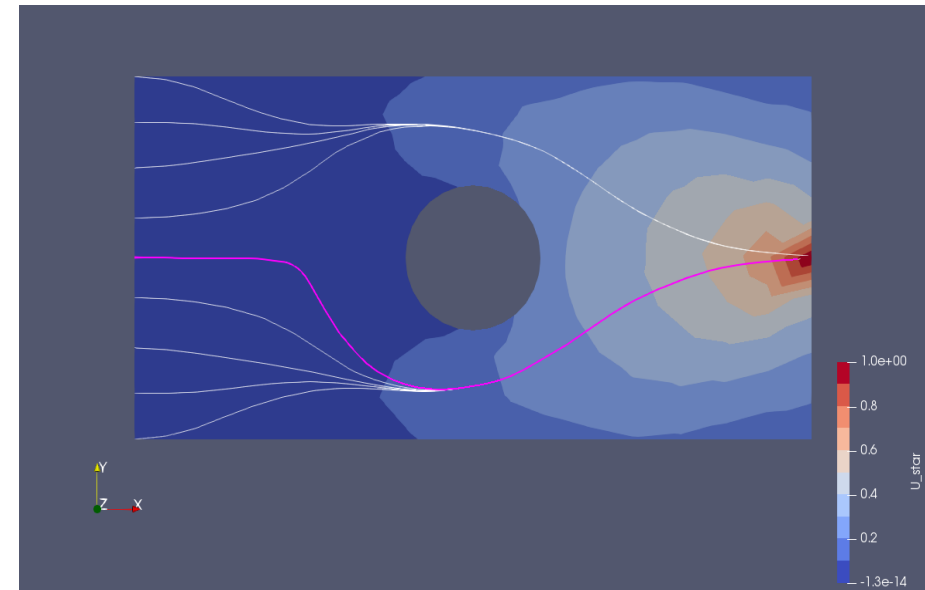


Figure :  $U^*$  contour & streamlines

# Rectangular Plate with Hole – Single Point Load

## Load path:

- Stiffest path / principal streamline
- Highest gradient streamline

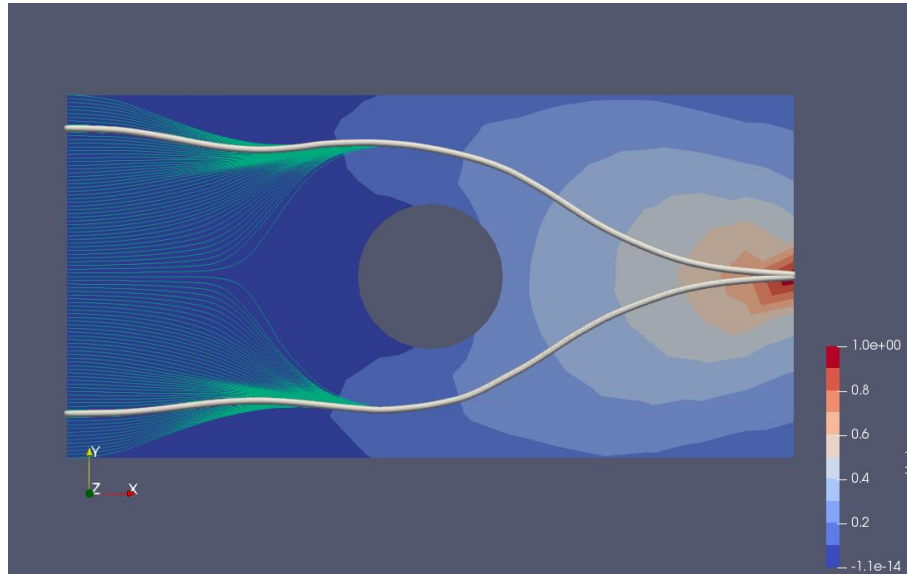


Figure : Principal streamlines / Load paths

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

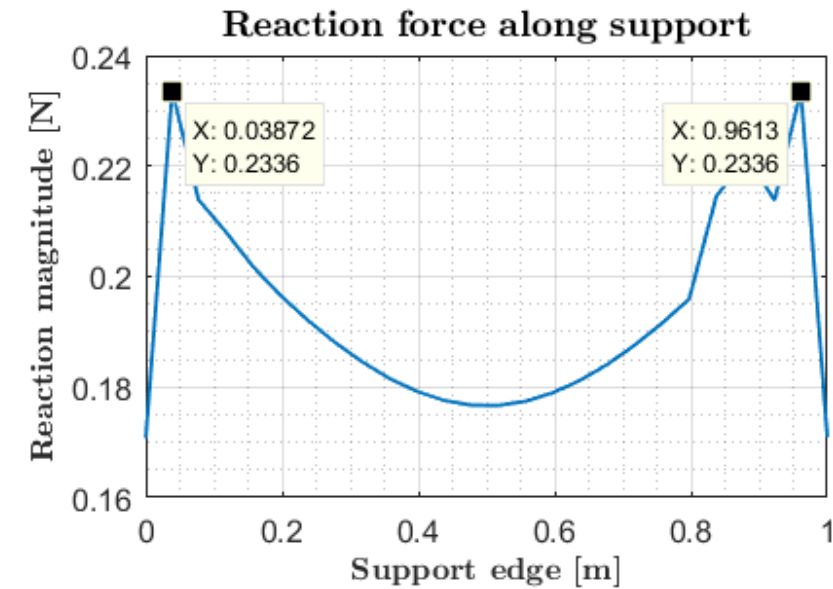


Figure : Reaction forces along support edge

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

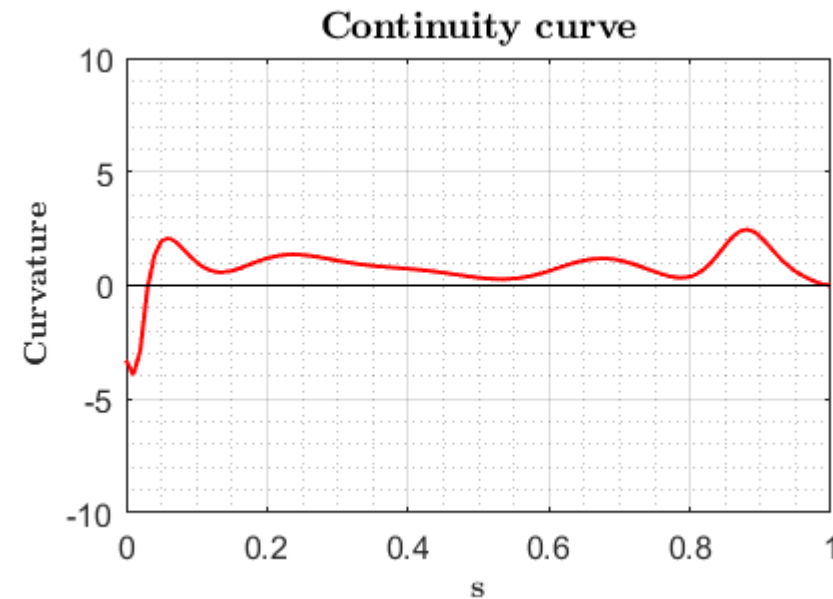
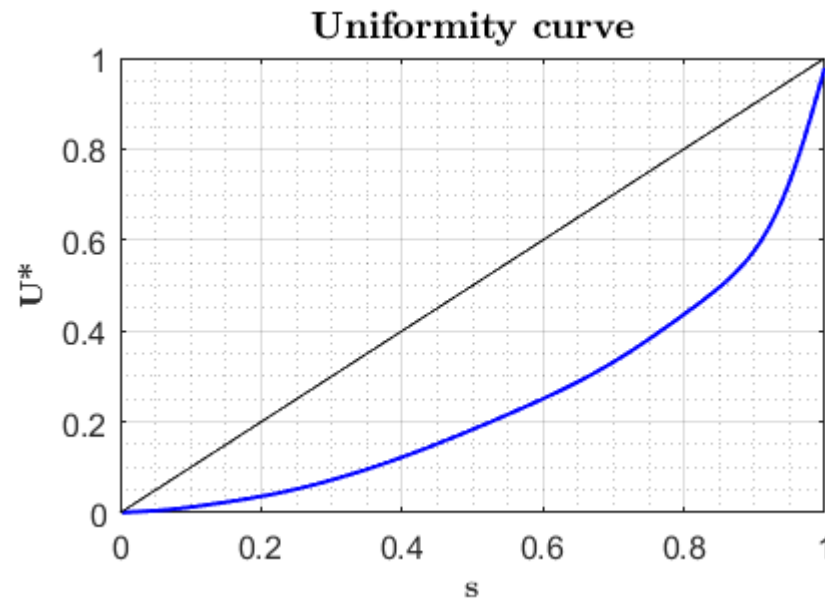


Figure : Uniformity & Continuity curves

# Plate with Hole – Single Interface Distributed Load

## Boundary conditions:

- Fixed support on left edge
- Distributed load on right edge :  $P = 1000\text{N/m}^2$

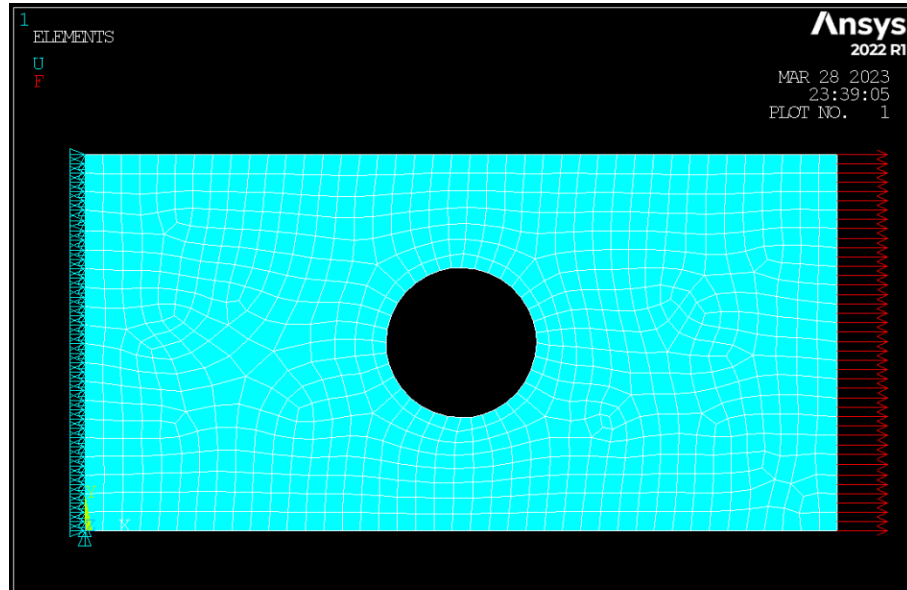


Figure : Boundary conditions

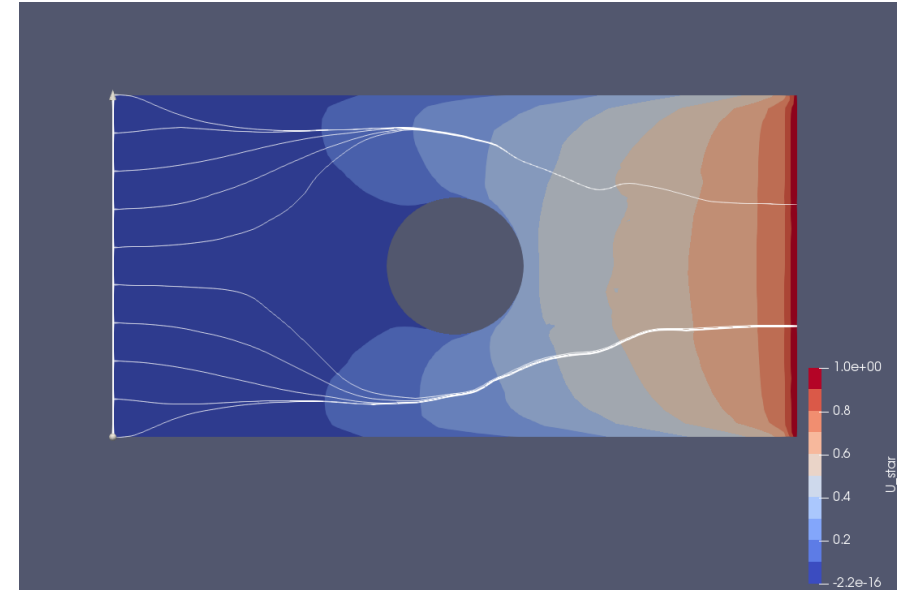


Figure :  $U^*$  contour & streamlines

# Plate with Hole – Single Interface Distributed Load

## Load path:

- Stiffest path / principal streamline
- Highest gradient streamline

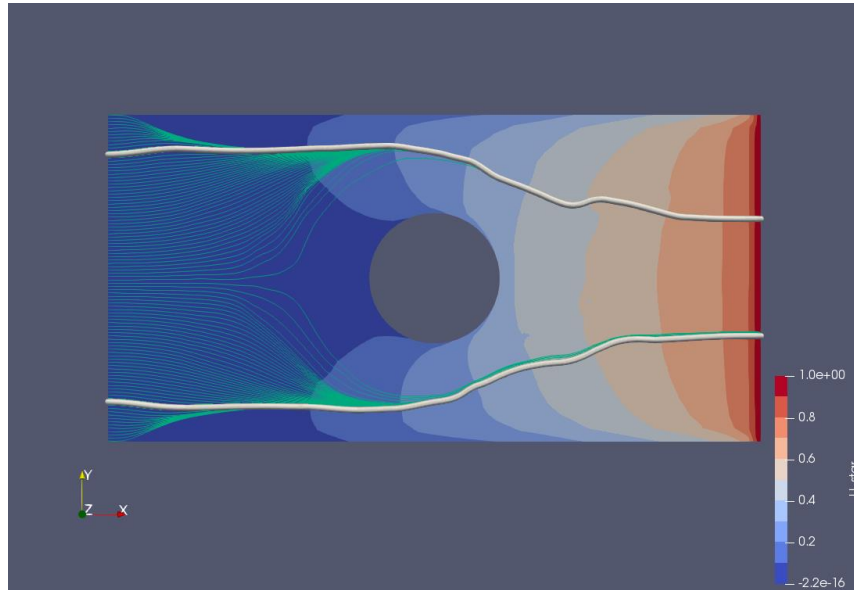


Figure : Principal streamlines / Load paths

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

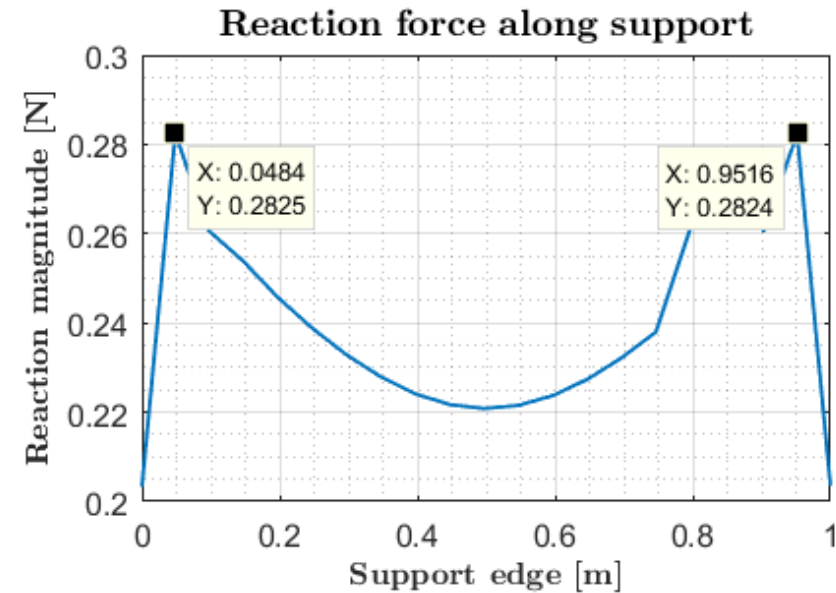


Figure : Reaction forces along support edge

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 :  $P = 1000\text{N/m}^2$

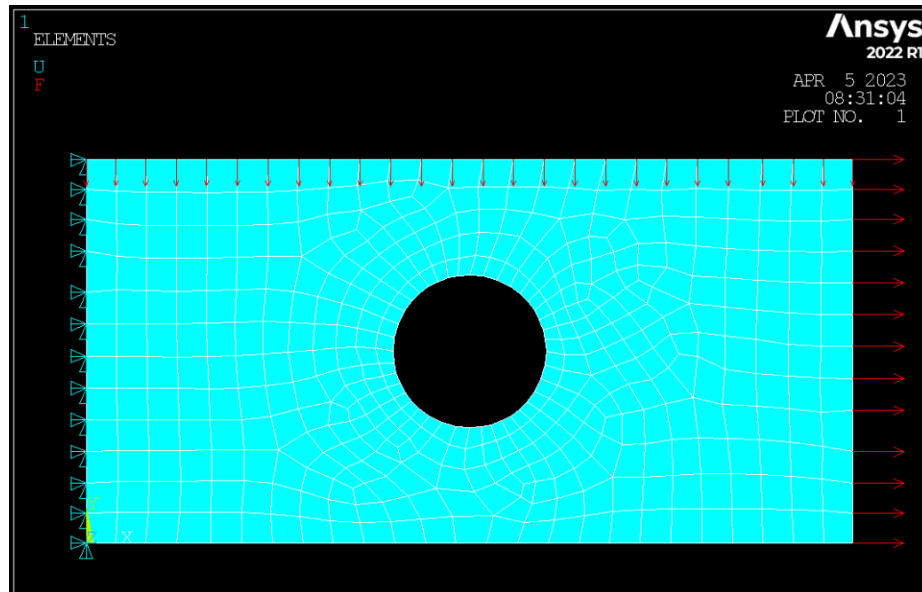


Figure : Boundary conditions

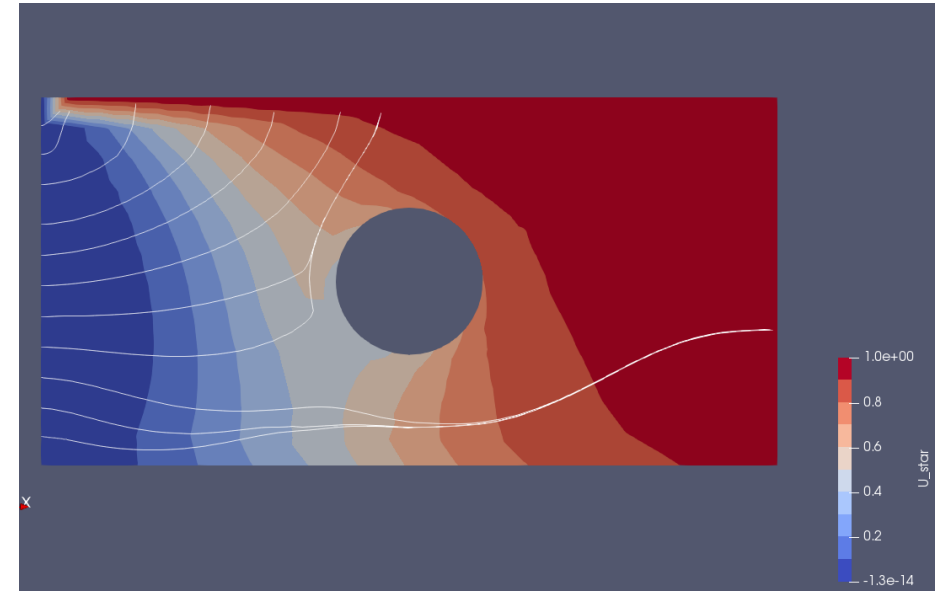


Figure :  $U^*$  contour & streamlines

# Plate with Hole – Multiple Interface Distributed Load

## Load path:

- Stiffest path / principal streamline
- Highest gradient streamline

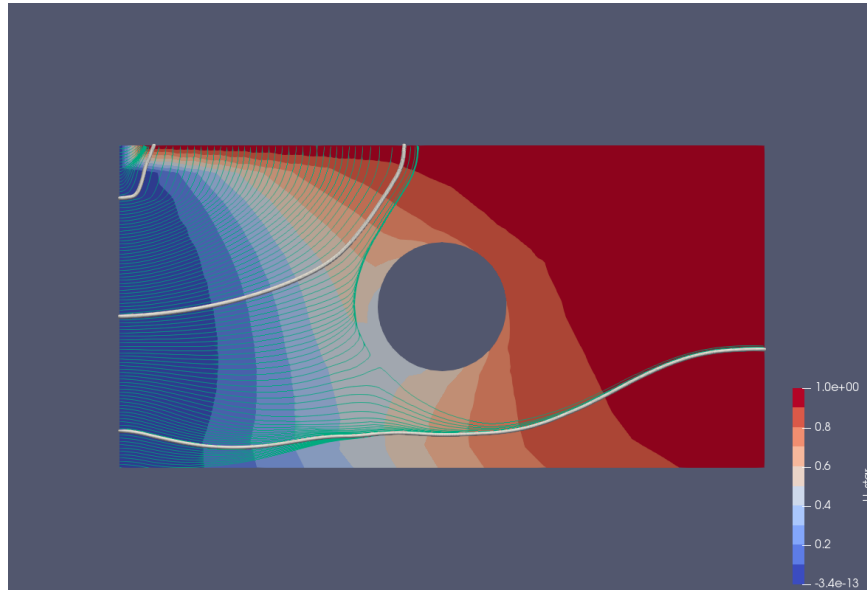


Figure : Principal streamlines / Load paths

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

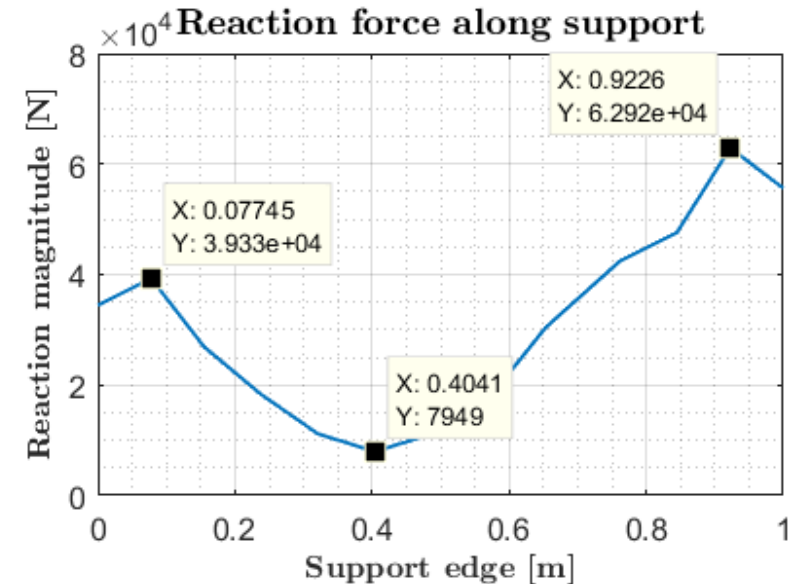


Figure : Reaction forces along support edge

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

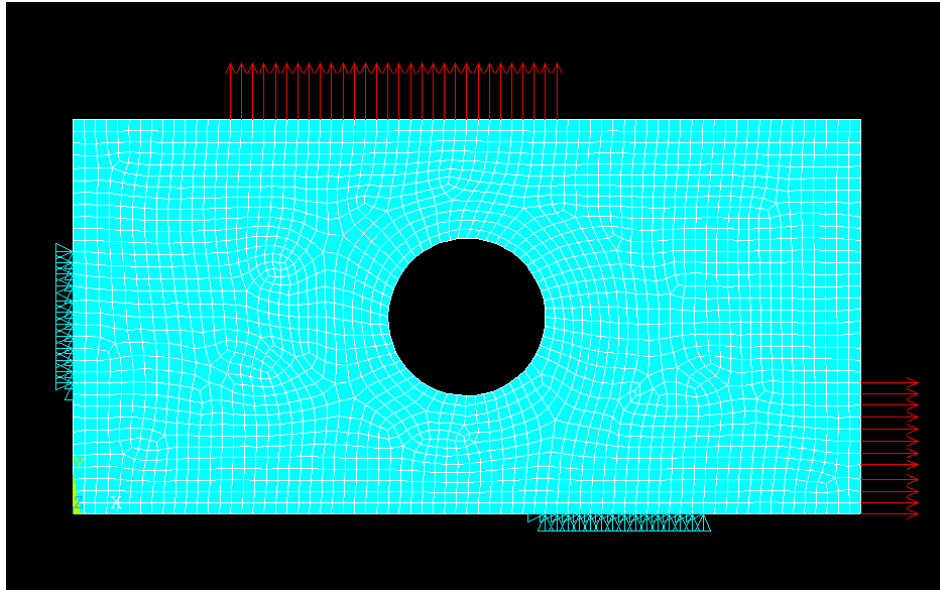


Figure : Boundary conditions

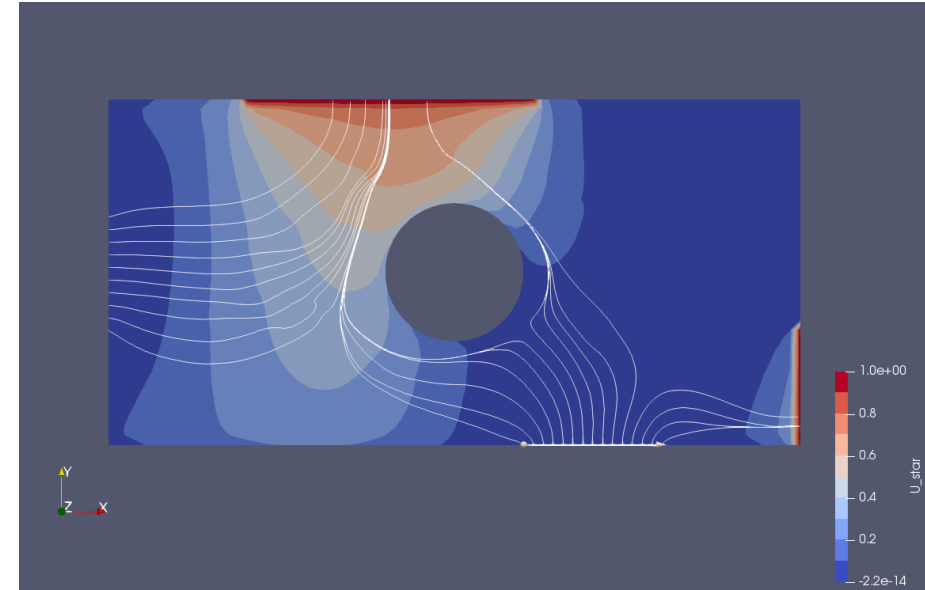


Figure :  $U^*$  contour & streamlines

# Plate with Hole – Multiple Loads & Multiple Supports

## Load path:

- Stiffest path / principal streamline
- Highest gradient streamline

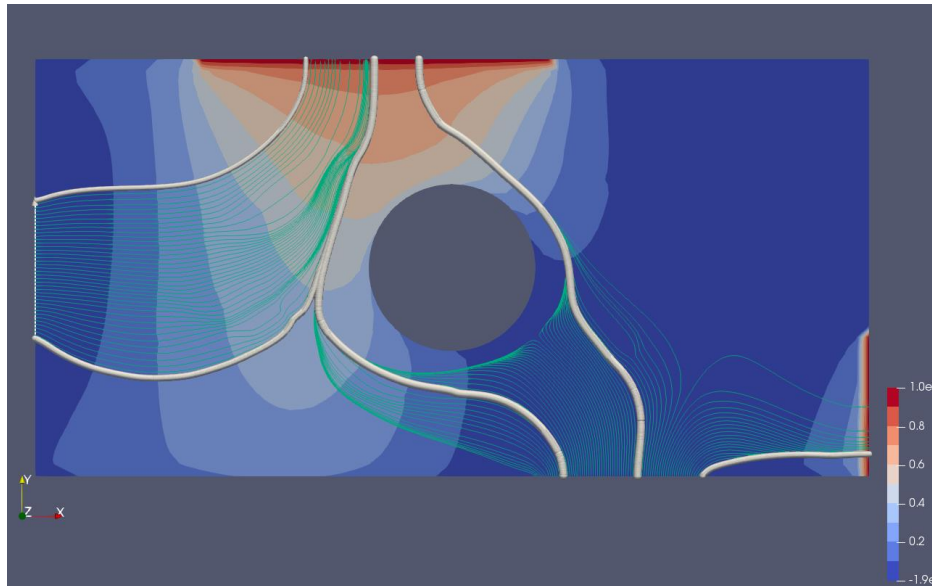


Figure : Principal streamlines / Load paths

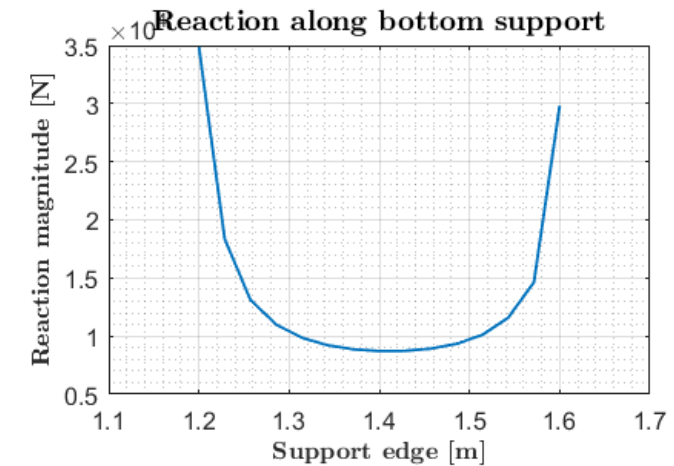
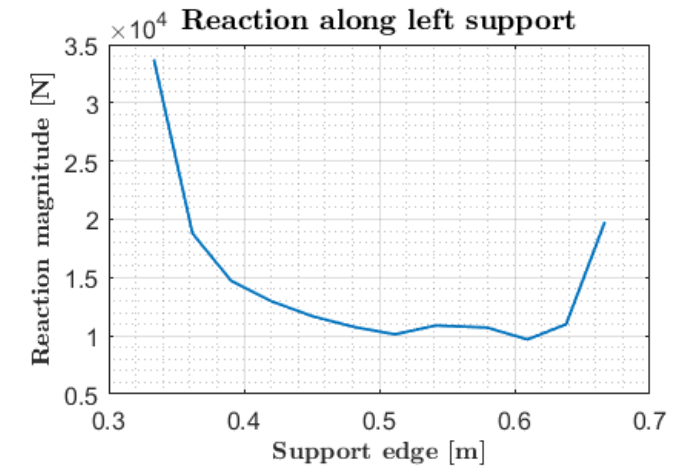


Figure : Reaction forces along support edge

# 3D bar – Single Interface Distributed Load

## Boundary conditions:

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

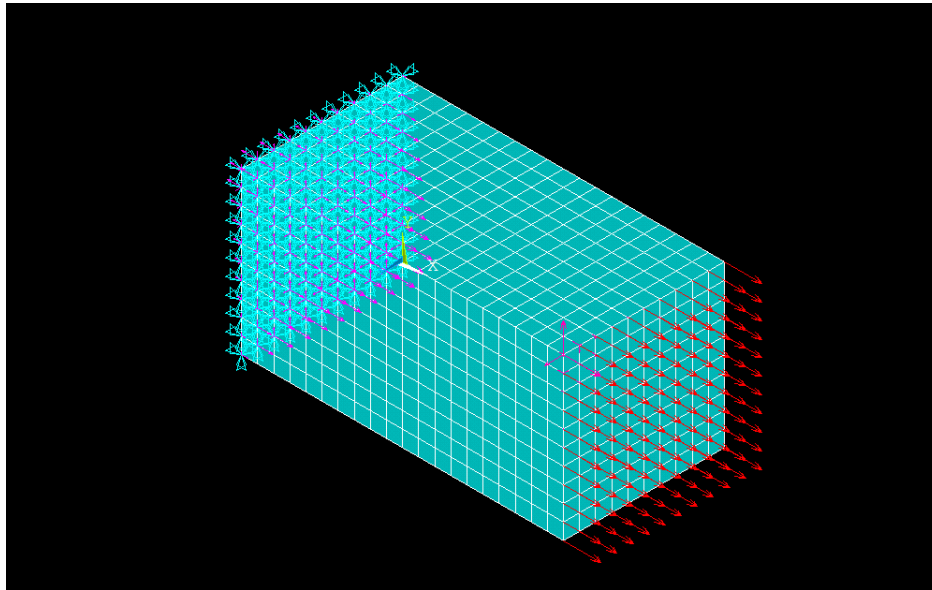


Figure : Boundary conditions

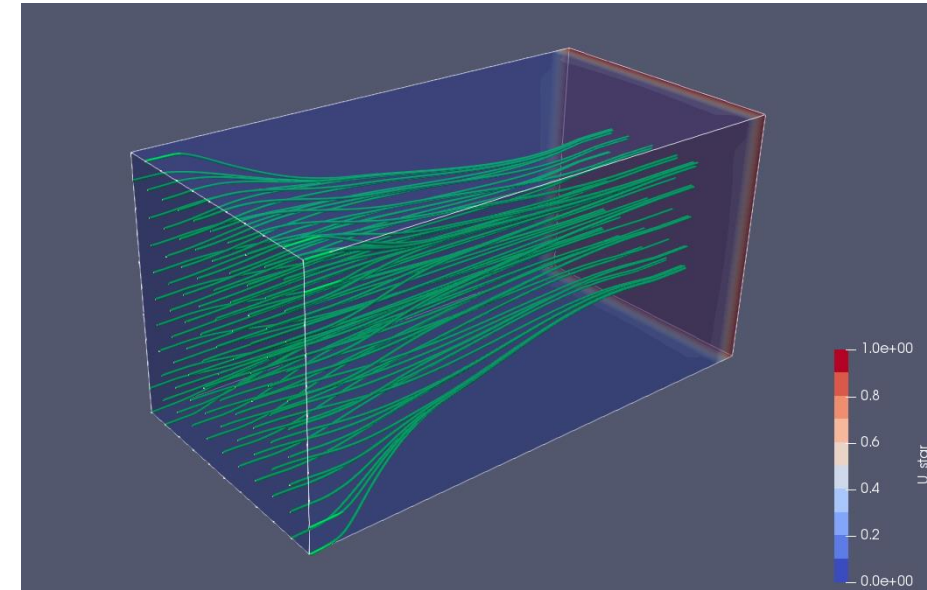


Figure :  $U^*$  contour & streamlines

# GKN Aero-engine structure

## Engine Structure & Cut Section

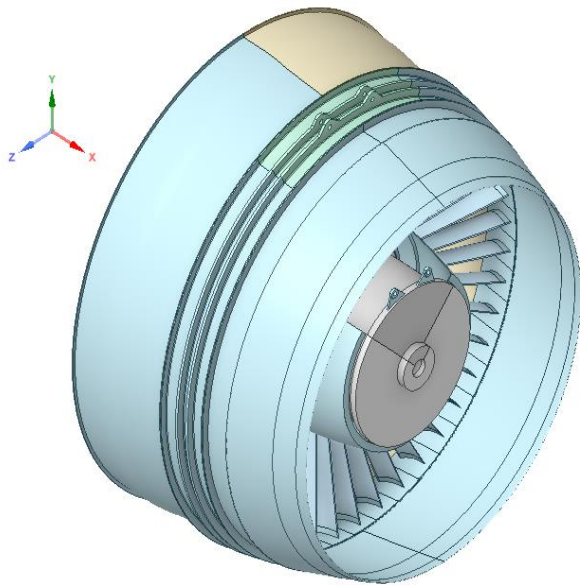


Figure : GKN Aero-engine structure

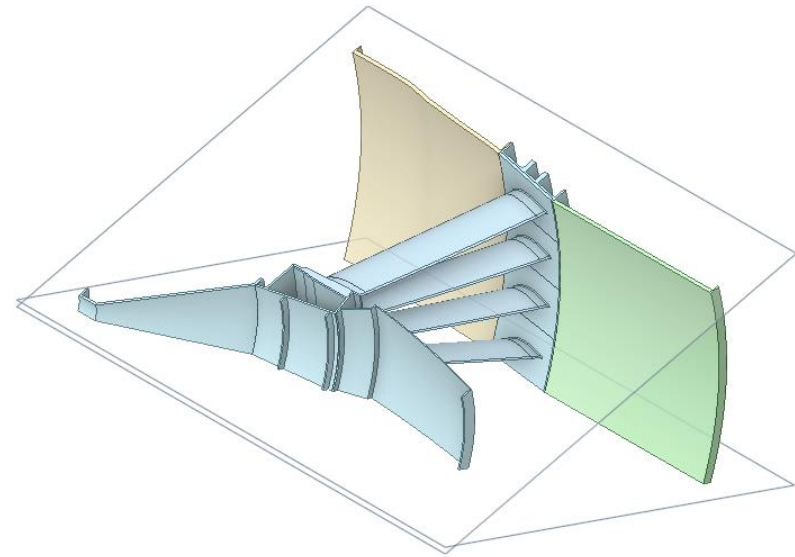


Figure : Cut Section

# GKN Aero-engine structure

## Engine Structure & Cut Section

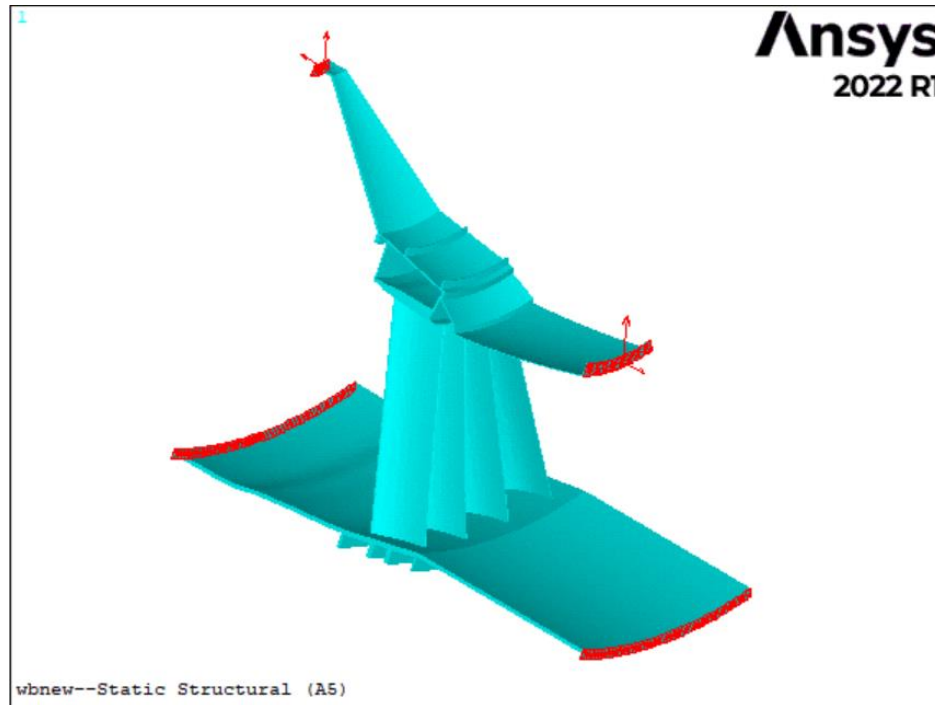


Figure : Boundary conditions

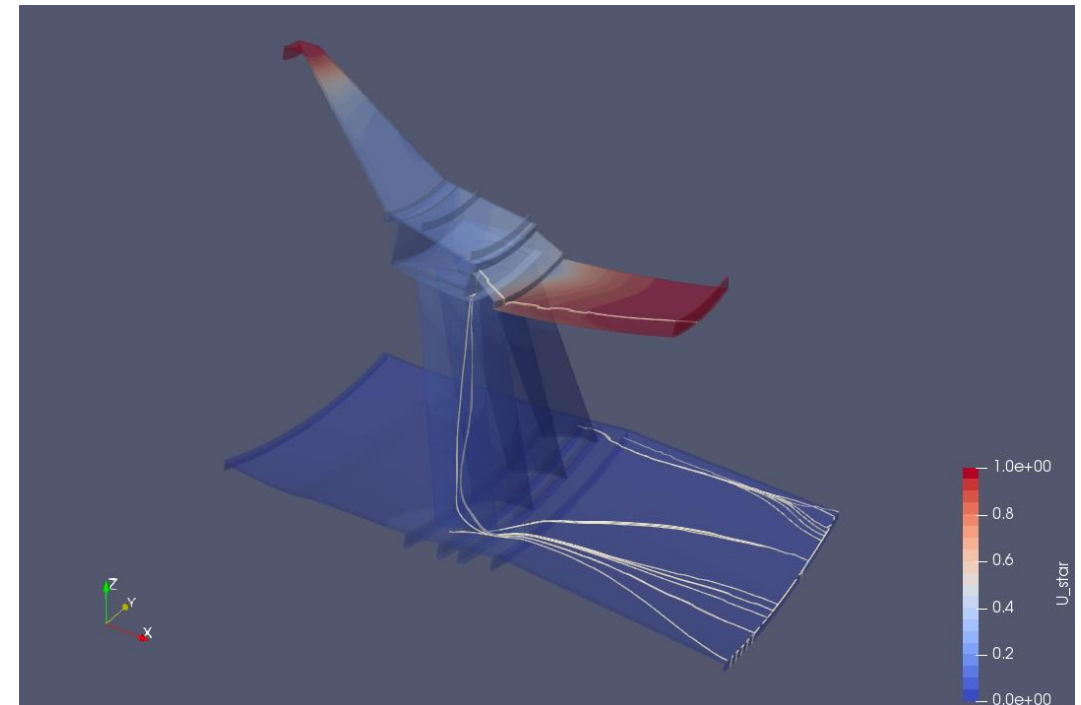


Figure : U\* contour & streamlines