# AIRFOIL Design Project

ME 492 Senior project – Spring 2020-2021

TED UNIVERSITY

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## Abstract

The following paper includes a study made on NACA0012 airfoil, several bumpy surface configurations were simulated and the effects of the geometrical parameters (bump size, location) of the bumpy surfaces on the external airflow in the flow domain were observed. Domain used for these simulations includes 276.800 quadrilateral cells which leads to a structured mesh. Design alternatives are 10 and 20 radius bumps that are located at 100, 200, 300, 400, 500, 600, 700, 800, 900 mm's of the whole 1000m of the chord length. The changes with the location of the bumps at different proportions of the chord length are interpreted. Lift and drag coefficients were evaluated for the different CAD models and their values are collected. the objective of the paper is to achieve an improved airfoil design by increasing the lift to drag coefficients ratio. The end study resulted in an airfoil design with a 10 mm bump at 800 mm from the leading edge, that had an increase in Cl/Cd value of around 85% at zero angle of attack and 54% at ten angle of attack.

## AIRFOILS

Cross sectional shape obtained by intersection of wing with the perpendicular plane

### APPLICATIONS

Cross-section of propellers, wings, blades etc.

### PARAMETERS

leading-edge radius, the maximum thickness and its location, the maximum camber and its location, mean camber line, and the length of the chord line connecting the leading - edge with the trailing - edge

### CATEGORIES

main categories: symmetrical and asymmetrical airfoils. Depending on usage

## PERFORMANCE CRITERIA

01. Lift - Drag ratio

The amount of lift generated by the airfoil vs. the drag

02. Stall vs. angle of attack

a stall is a reduction in the lift coefficient generated by an airfoil as angle of attack increases. This occurs when the critical angle of attack of the airfoil is exceeded.

03. Separation location

Flow separation is the point where the boundary layer detach, flow separation results in reduced lift and increased pressure drag

## Passive and Active Methods For Flow Control

**Passive Flow Separation Control**
- Vortex generator
- Distributed roughness (Bumpy Surfaces )
- Streamlining
- Uniform blowing and suction
- Leading-edge cuffs
- Slots - Flaps - Dimples

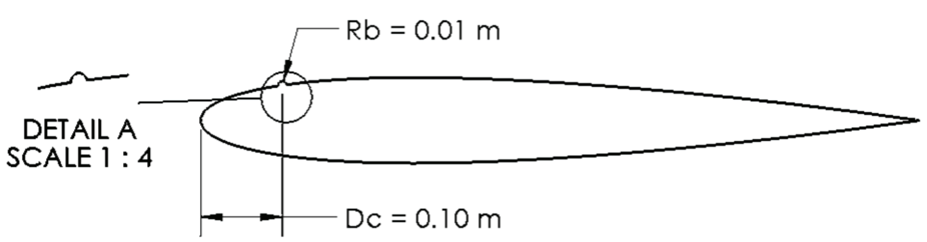
**Active Flow Separation Control**
- Heating wall
- Movement of surface elements
- Oscillatory blowing and suction
- Synthetic jets
- Wind blowers
- Spoilers

## Bumpy Surfaces

Passive control by geometry modification

- Aerodynamic characteristics
- Effects of large-scale surface roughness through static curvature modifications
- Also, lift is increased by the bumpy surfaces

Modified Airfoil Design




Partial Bumpy Surface at the Trailing Edge

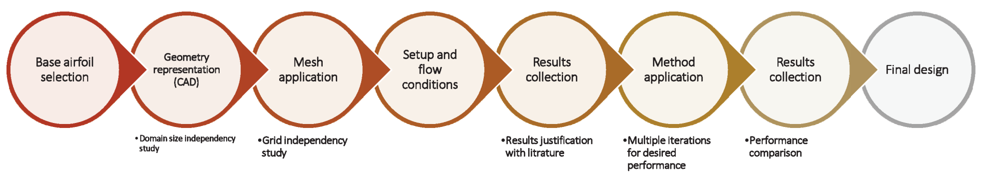
## DESIGN TASK

- Designing a mechanism to control the flow over symmetrical airfoil. Our design objective is improving the performance of the airfoil (Cl/Cd).
- We propose to use Geometry modifications: bumpy surfaces

Flow field will be subsonic and the flow type that will be considered is incompressible.

- Design will be provided along with the related lift and drag coefficients, contour plots, angle of attack ranges, flow conditions, and suggested uses.

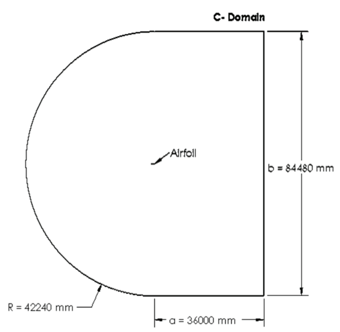
## Preliminary Design Flow Chart

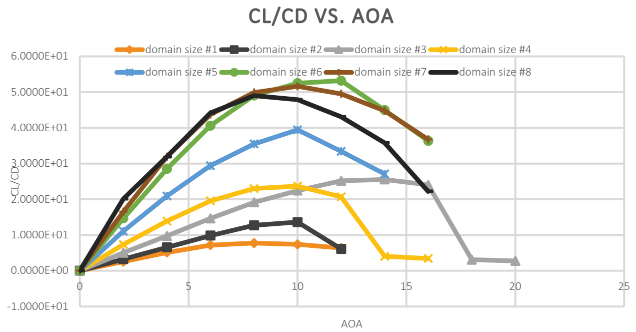



## Design details Base Case Justification Studies

### Domain Size Independency Study

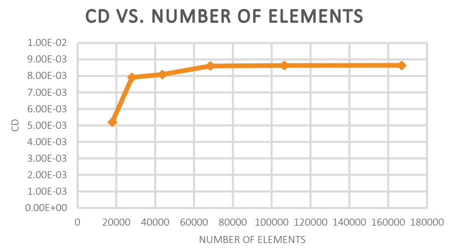
| Domain size # | Domain dimensions a (m) | Domain dimensions b (m) | Cd at 8° AoA | Error (%) |
|---|---|---|---|---|
| 1 | 6 | 1.32 | 1.8527E+00 | - |
| 2 | 11 | 2.64 | 6.8213E-01 | 171.61 |
| 3 | 16 | 5.28 | 3.4101E-01 | 100.03 |
| 4 | 21 | 10.56 | 2.3294E-01 | 46.39 |
| 5 | 26 | 21.12 | 1.38530E-01 | 68.15 |
| 6 | 31 | 42.24 | 9.9195E-02 | 39.65 |
| **7** | **36** | **84.48** | **9.4252E-02** | **5.24** |
| 8 | 100 | 168.96 | 9.3660E-02 | 0.63 |




## Grid Independency Study

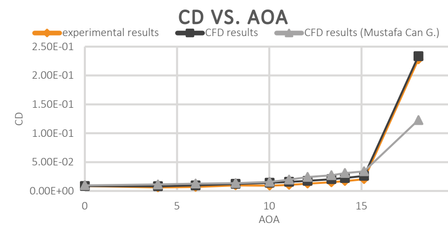
| Mesh | Number of Elements | Cd | Error (%) | Y+ |
|---|---|---|---|---|
| 1 | 17864 | 5.20E-03 | _ | <0.3 |
| 2 | 28032 | 7.92E-03 | 34.29 | <0.24 |
| 3 | 43680 | 8.09E-03 | 2.13 | <0.2 |
| 4 | 68400 | 8.61E-03 | 6.01 | <0.16 |
| 5 | **106500** | **8.64E-03** | **0.30** | **<0.13** |
| 6 | 166964 | 8.64E-03 | 0.07 | <0.11 |

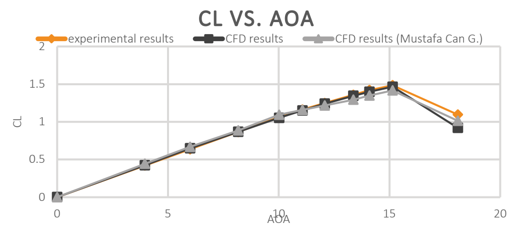



## Experimental vs. CFD Comparison Study

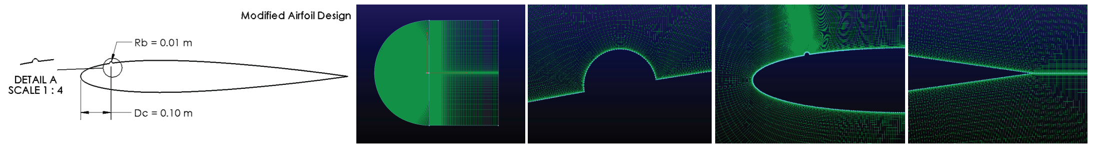
| Parameter | Value |
|---|---|
| **Flow velocity** | 52.083 m/s |
| **Pressure** | 101359.121 Pa |
| **Density** | 1.177 kg/$m^3$ |
| **Viscosity** | 1.568x$10^{-5}$ $m^2/s$ |
| **Temperature** | 300 K |
| **Mach number** | 0.15 |
| **Airfoil chord** | 1 m |
| **Reynold's number** | 3.32x$10^6$ |

| | Experimental results | | CFD results | | CFD results vs. Exp. | |
|---|---|---|---|---|---|---|
| AoA | Cd | Cl | Cd | Cl | Cd error (%) | Cl error (%) |
| 0 | 8.64E-03 | 0 | 8.64E-03 | 7.23E-04 | 0.05 | - |
| 3.96 | 6.31E-03 | 4.20E-01 | 8.22E-03 | 4.23E-01 | 23.23 | 0.71 |
| 6 | 7.12E-03 | 6.36E-01 | 9.76E-03 | 6.49E-01 | 27.04 | 1.94 |
| 8.17 | 9.85E-03 | 8.66E-01 | 1.23E-02 | 8.67E-01 | 19.83 | 0.20 |
| 10.02 | 9.34E-03 | 1.06E+00 | 1.43E-02 | 1.05E+00 | 34.52 | 0.95 |
| 11.07 | 1.07E-02 | 1.16E+00 | 1.58E-02 | 1.15E+00 | 32.37 | 0.96 |
| 12.08 | 1.29E-02 | 1.25E+00 | 1.76E-02 | 1.24E+00 | 26.81 | 0.63 |
| 13.37 | 1.52E-02 | 1.36E+00 | 2.05E-02 | 1.35E+00 | 25.71 | 0.92 |
| 14.1 | 1.73E-02 | 1.42E+00 | 2.25E-02 | 1.40E+00 | 23.45 | 1.54 |
| 15.14 | 2.05E-02 | 1.48E+00 | 2.61E-02 | 1.47E+00 | 21.79 | 1.25 |
| 18.09 | 2.28E-01 | 1.09E+00 | 2.33E-01 | 9.19E-01 | 2.43 | 19.05 |

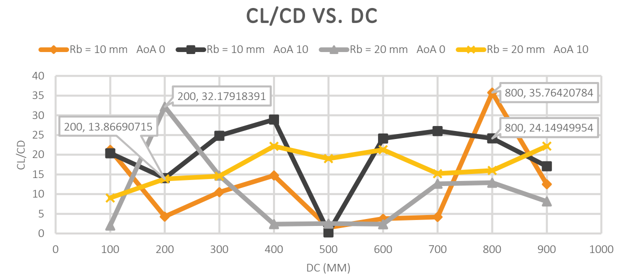


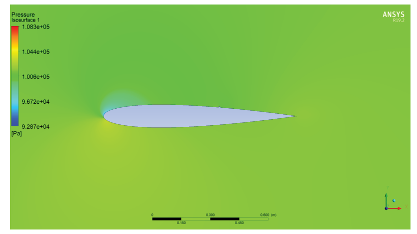

## Design details Design Modifications



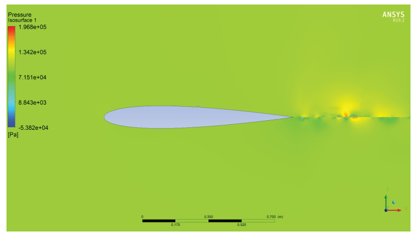

### Design modifications collected results



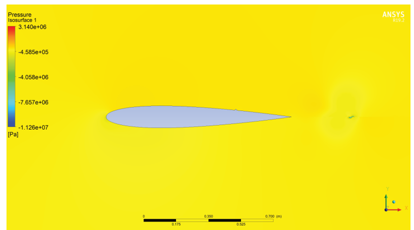

- Comparing the results of the best design with the base/ smooth NACA 0012 airfoil, the Cl/Cd ration increased by around 85% at 0° AoA, and around 54% at 10° AoA.
- From the results it can be said that the behavior of the airfoil when adding a bump is best at a location near the leading or trailing edges and have a lower performance when added to the middle section of the airfoil chord length.
- The radius of the bump also has an effect on the change in the performance of the airfoil, the airfoil with 10 mm radius bump behaved better than the airfoil with 20 mm radius bump.
- The airfoil design with the lowest Cd value is airfoil with 10 mm radius bump at 100 mm location on the chord length.



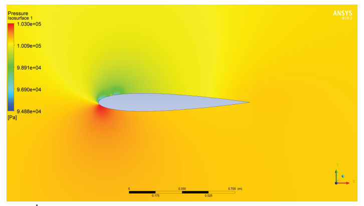
Rb = 10 mm, Dc = 600 mm, 10 AoA



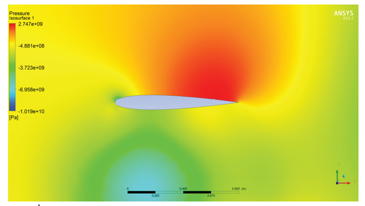
Rb = 10 mm, Dc = 500 mm, 0 AoA



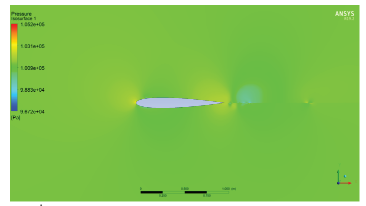
Rb = 10 mm, Dc = 700 mm, 0 AoA



Rb = 10 mm, Dc = 100 mm, 10 AoA



Rb = 10 mm, Dc = 800 mm, 10 AoA



Rb = 10 mm, Dc = 100 mm, 0 AoA