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Transonic Aerodynamic Performance of a NACA 0012 Airfoil with a Leading Edge Inspired by Humpback Whale Tubercles

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INTRODUCTION & AIM

Leading-edge (LE) tubercles, sported by humpback whales on their pectoral flippers, are known to enhance lift generation in airfoils and improve their post-stall performance.

Research on these bio-inspired features, however, dwell mostly in subsonic low Reynolds flow conditions. How these structures—and changes to their amplitude — would affect the shock behavior and overall performance of the airfoil is of great interest.

Through computational fluid dynamics (CFD), this study predicts the transonic behavior of a symmetric NACA 0012 airfoil with LE protuberances at low angles of attack (AoA) and varying protuberance amplitudes.

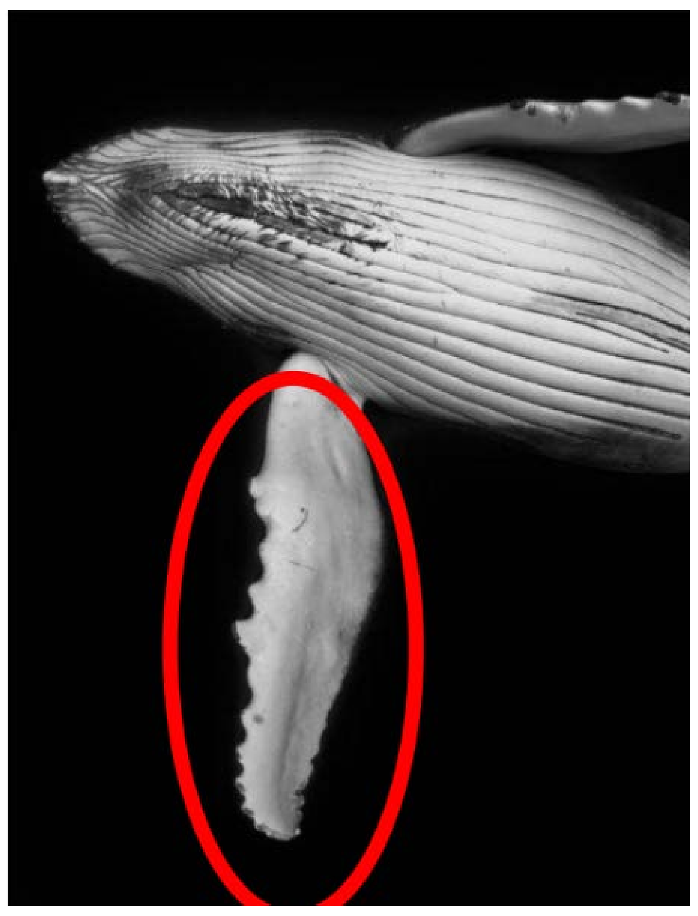


Figure 1. Humpback whale pectoral flipper. Note LE protuberances. Source: Hansen et al, 2012.

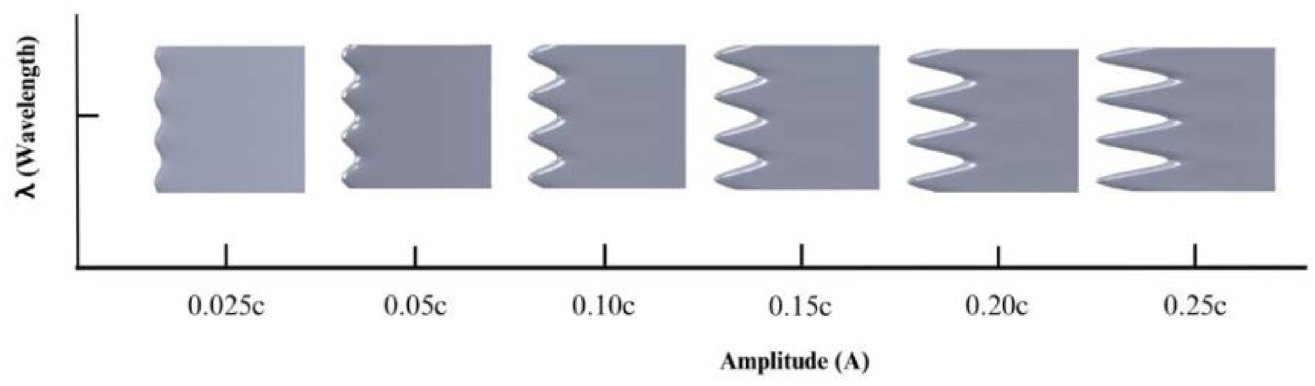


Figure 2. Tubercle Configurations from 0.025c to 0.25c..

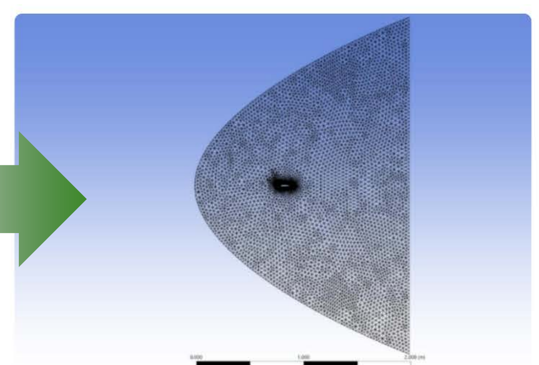
METHOD

The following steps were taken to ensure sound modeling of transonic airflow over an LE tubercled airfoil in ANSYS Fluent.

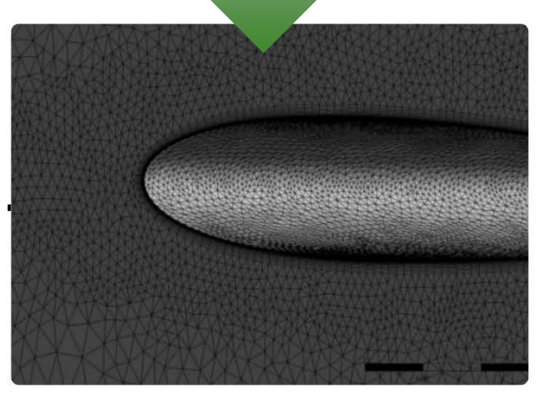
Designing the Geometry

3D CAD models with varying amplitudes (**A**) relative to chord **c** (0.025c to 0.25c)

Ideal domain shape for capturing transonic phenomena



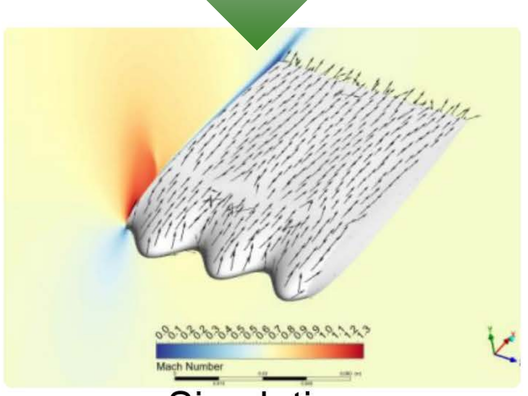
Creating Parabolic Domain



Mesh Independence Test

- Density-based steady-state approach
- SST k-ω model
- Global Ma = 0.7

Solver Configuration



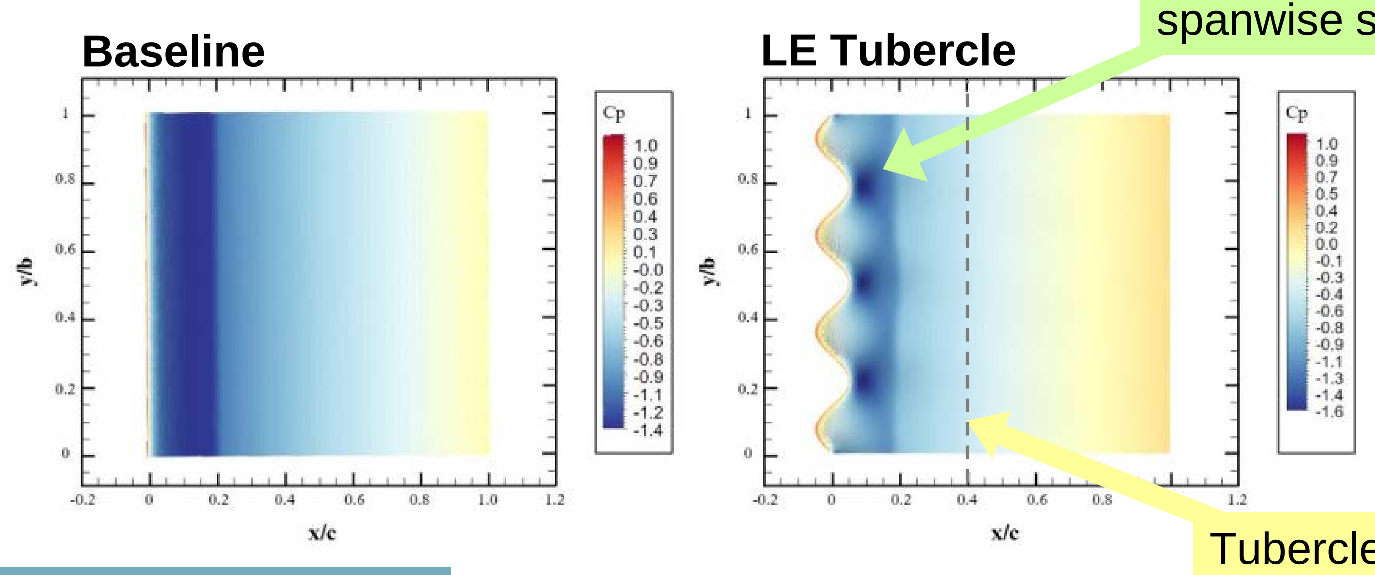
Simulation

Simulation results are then post-processed to return the following:

- Local pressure distribution and Mach number
- Lift and drag characteristics
- Vorticity

RESULTS & DISCUSSION

Pressure Coefficient (C_P) Contour Map
[A = 0.05c, Mach Number (Ma) = 0.7, AoA = 2°]

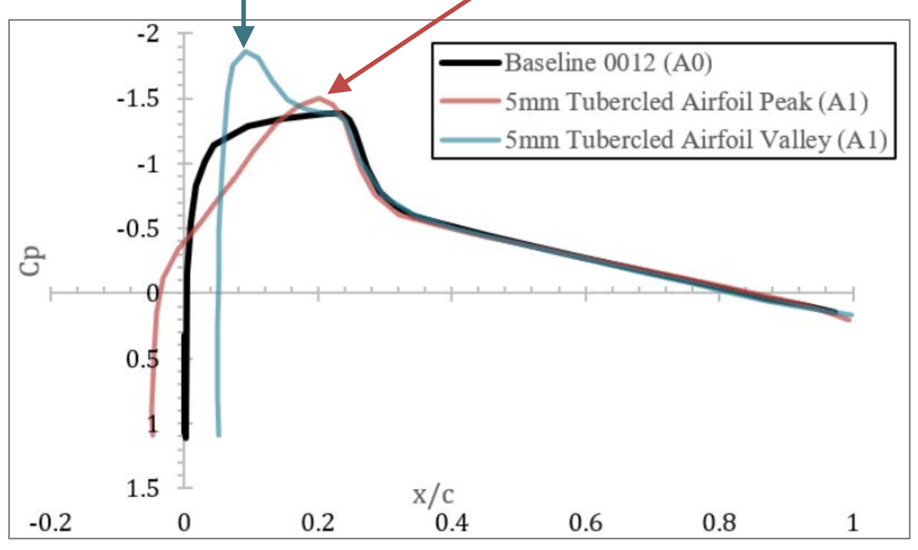


Regular pockets of localized suction in the valleys moderate spanwise shock behavior.

Tubercle flow effects peter out at 40% x/c

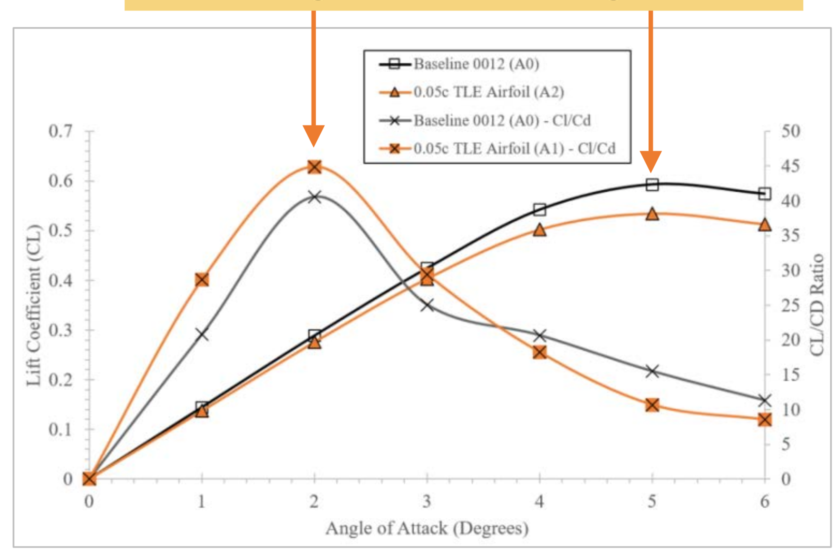
Quick shock onset in valley, but further behind the leading edge

LE Tubercle peaks **delay shock onset**

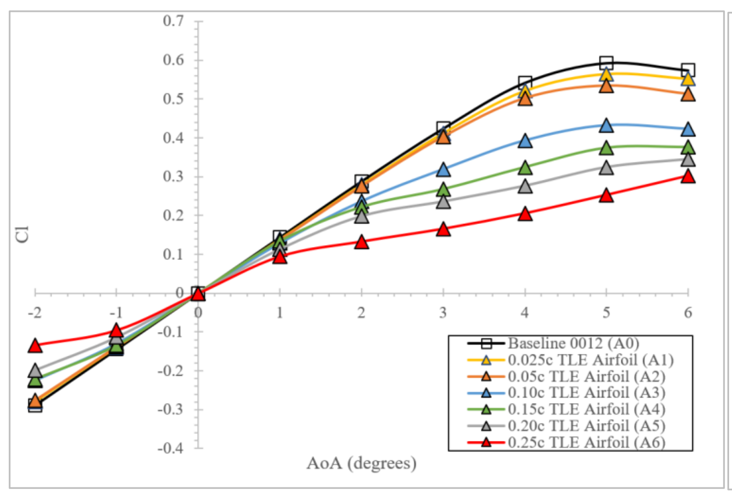


Chordwise upper surface C_P Plot
[A = 0.025c, AoA = 2°]

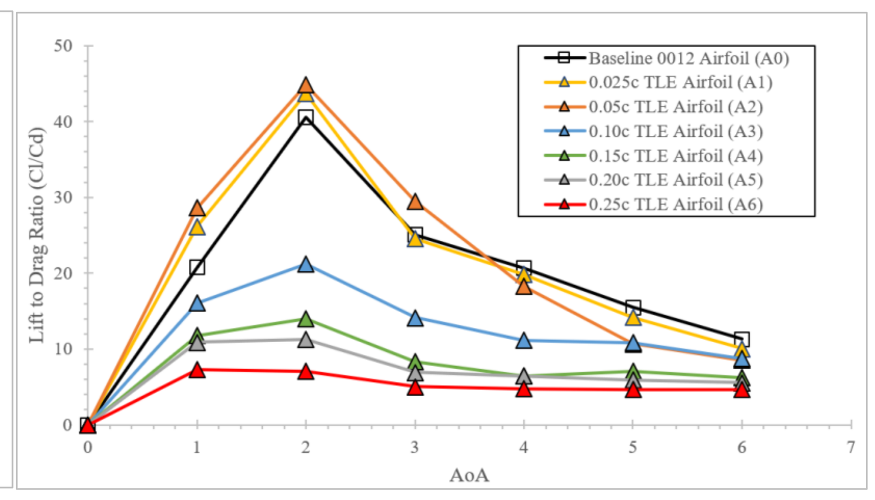
Lower peak lift, but **higher Lift-Drag ratio**



Lift Coefficient (c_L) and Lift-Drag ratio vs AoA [A=0.05c]



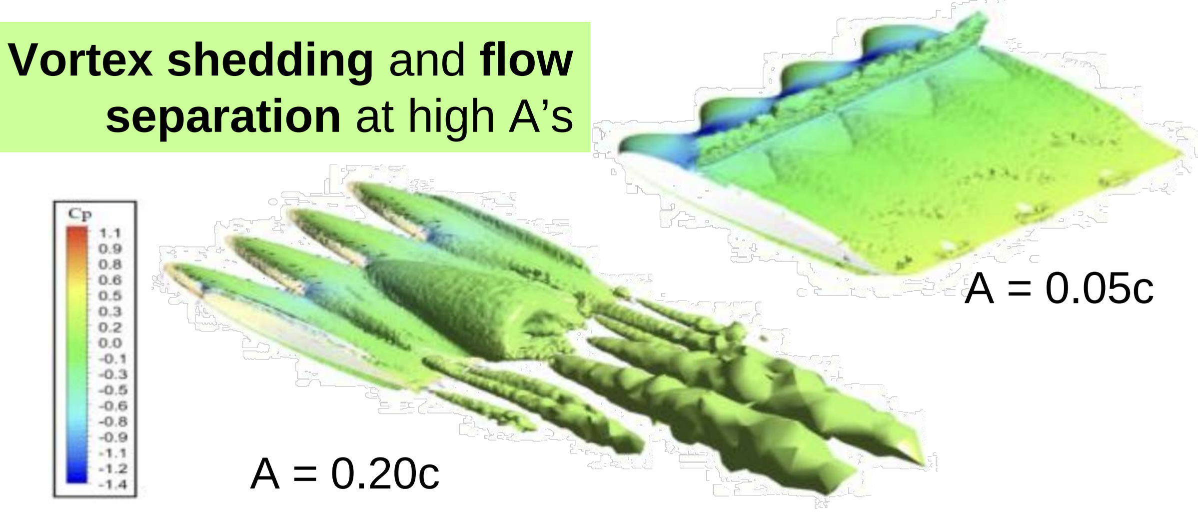
c_L vs AoA



L/D vs AoA

However,
Any LE tubercle benefits only hold for smaller amplitudes.

Vortex shedding and **flow separation** at high A's



Vortex Visualizations, [AoA = 3°]
(Q Criterion)

CONCLUSION

- Small LE tubercle amplitudes in the transonic regime improve drag performance at the cost of a small reduction in lift.
- Further exaggeration in the tubercle amplitude causes more chaotic flow patterns to develop, thereby diminishing airfoil performance to far below the baseline.

FUTURE WORK / REFERENCES

A transient analysis could provide further insight into the LE tubercle's vortex shedding and boundary layer behavior, leading to designs with improved transonic performance. It is also of great interest to see whether the conclusions of this study will be consistent when LE tubercles are applied to airfoils designed specifically for the transonic regime.

- Hansen, K.L. (2012). *PhD Thesis.*
- Sepatauskas et al. (2018). *2018 Flow Control Conference.*