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DES Prediction of a Novel High-Lift Device
Step 1: Steady Blowing

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Introduction

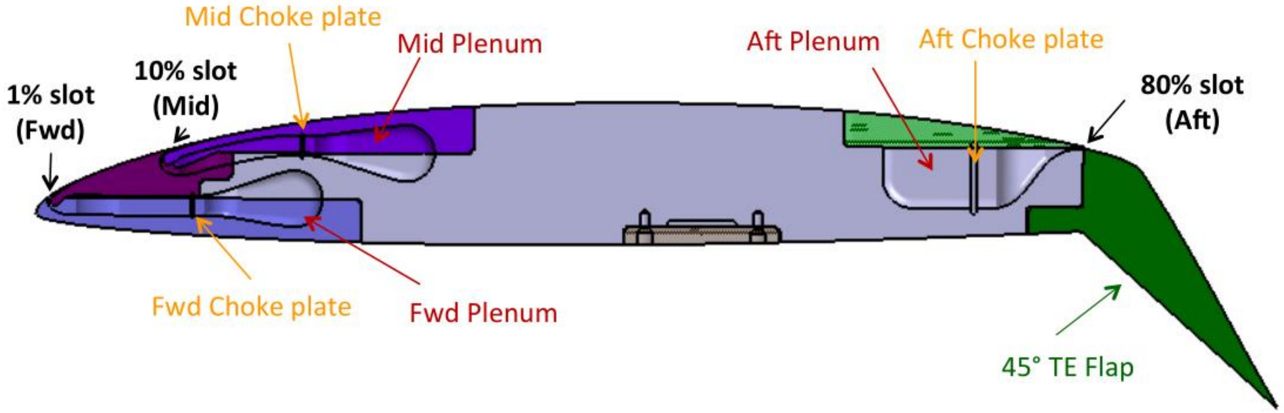

Fig. 1. A typical blowing design (Bright, 2013)

Flow control for high-lift

- To enhance the performance of passive high-lift system
- To “repair” critical areas on the wing (i.e. suppress separation)
- To enable laminar flow over larger portion of the wing

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My PhD program

Aims:

- Develop a novel high-lift device that has better performance and/or can augment the performance of existing devices.
- Develop a methodology in order to validate the design, using computational methods and possibly experimental means.

This presentation focus on my recent results from year one. I.E. Identify the best CFD method to use with high-lift devices and apply flow control to improve performance.

Motivation

- Past CFD on blown High-lift devices mostly uses RANS methods
- RANS methods (industrial standard) lose accuracy when dealing with complex separated flows; commonly seen around high-lift devices at high angles of attack (e.g. take-off/landing).
- DES are better at modelling such flows, but at a higher computational cost (less than pure LES, however).
- Benchmarking the capabilities of DES in High-lift with flow control to enable more accurate prediction

Research Objectives

- To benchmark the lift prediction performance of DES on a 30P/30N 3-element high-lift aerofoil
- To determine the range of angles of attack where DES predicts more accurately than RANS methods.
- To benchmark the prediction performance of DES when blowing flow control is implemented

Case Description

Airfoil used is the 30P/30N 3-element high-lift configuration, was extensively tested in NASA wind tunnel in 1990s-2000s.

- Free stream Re_c = 5 million, M = 0.2, slat & flap deflection = 30°.
- Model was designed to provide a test case under common take-off configurations.
- Previously, accuracy of RANS modelling for lift worsens when α ≥ 19°(Higher C_{Lmax})
- Dominant flow physics will be those due to flow reversal in the main element wake near C_{Lmax}, as well as upper surface separation over flap trailing edge at lower α (8-12)
- Tests were conducted with free transition. Total chord c = 1.2m.

Fig. 2 30P/30N airfoil geometry (Klausmeyer, 1994)

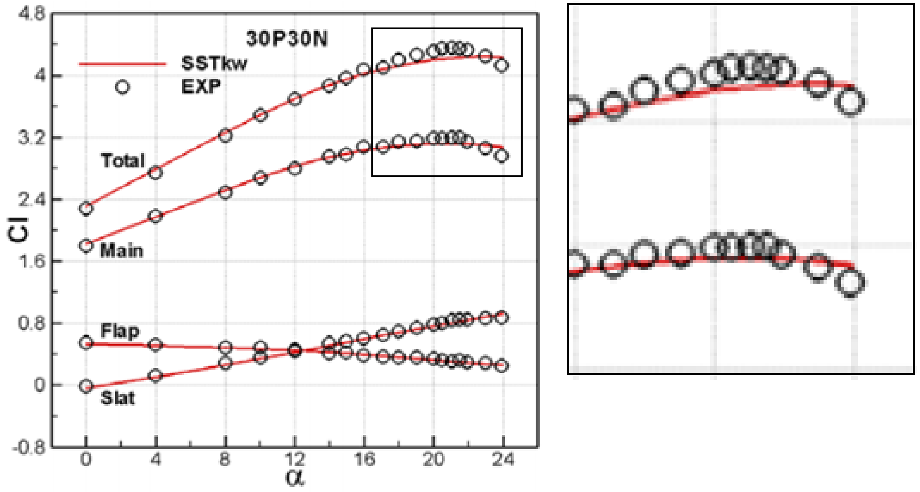


Fig. 3 A typical result with RANS model (Zhang, 2012)

- Add a detailed picture of the multi element aerofoil, show all angles (define clearly the aoa and the deflection angles), sizes of the gaps (either as a percentage of the main element chord, or of the total chord), test conditions etc

Precursor DES Study

- A previous study on 2-element airfoil
- DES data only for 14° $\leq \alpha \leq$ 16°
- DES and RANS agree well with Exp. data at low AoA
- At α =14°, DES under-predicted C_L by ~ 10%, i.e. early stall. Known problem for DES (numerical stall)
- At α =15° and 16°, RANS over predict C_L by 57% and 48% respectively.
- DES shows better accuracy at 15° and 16° (~ 9% discrepancy)

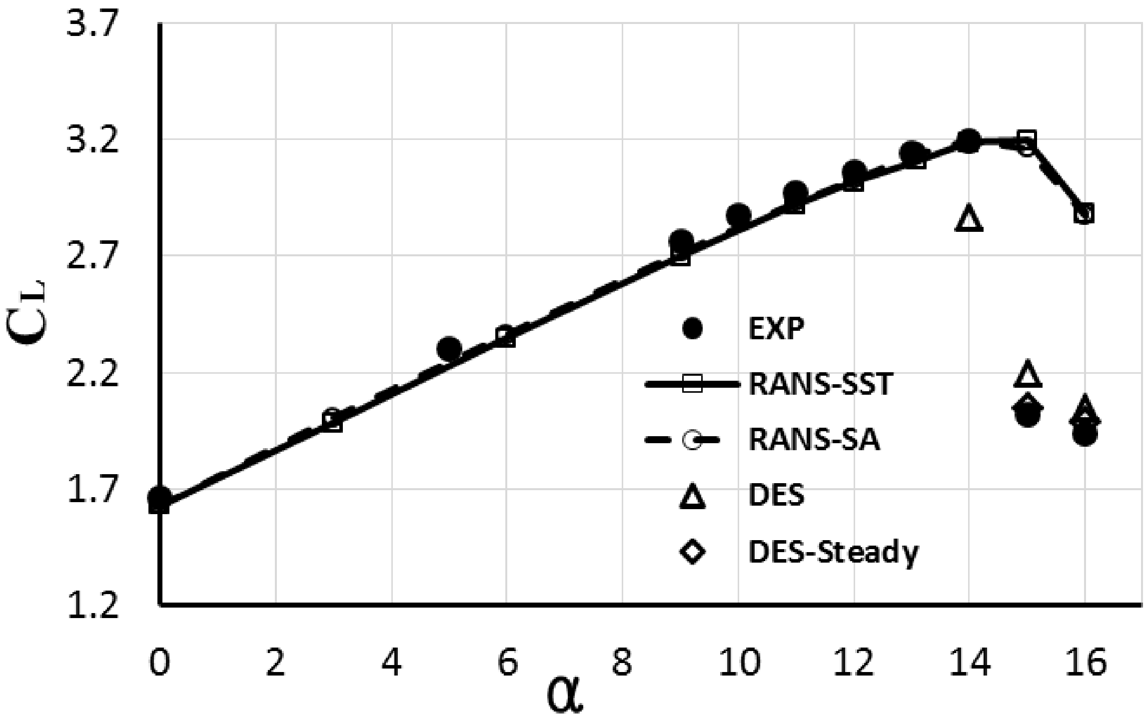
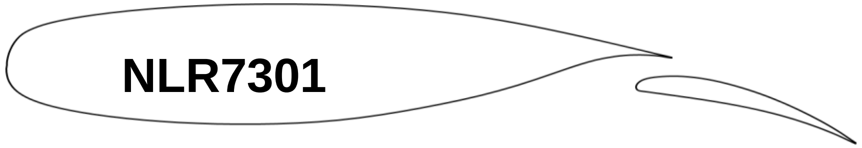


Fig. 4 C_L – α chart



Methods: Baseline

- Baseline model is studied using RANS and DES model
- Calculations are conducted with Ansys 15.0 Fluent and CFX

Table.1 CFD setup

Model	AoA (°)	Turbulence Model	Momentum discretization
RANS Steady	0-7	SST	2nd order upwind
RANS Transient	8-24	SST	2nd order upwind
DES	8-12 19-24	SST-DDES	Bounded central differencing

Table.2 Mesh statistics

	Nodes	x^+	y^+
RANS-SST	150296	355~1022	0.5~2
DDES-SST	3006525	105~1022	0.5~2

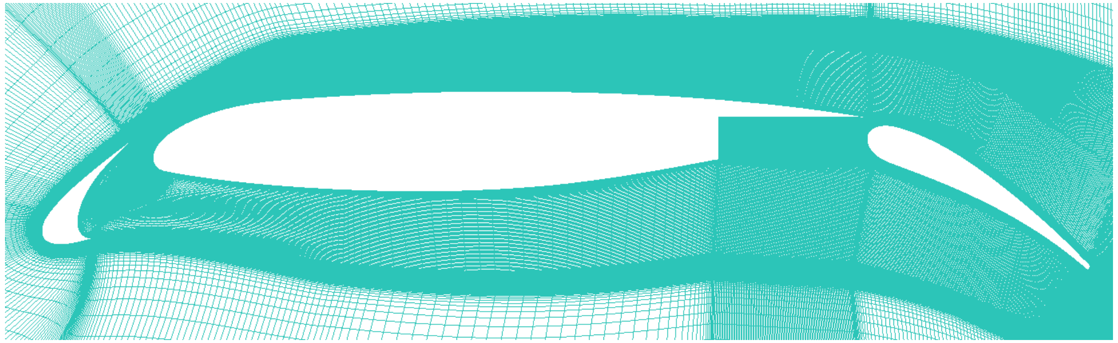


Fig. 5 RANS Mesh around the airfoil

Results: Baseline C_L Variation

- DES data only for 8-12° and 19-24°
- DES and RANS agree well with Exp at low AoA
- Both RANS and DES over-predicts lift at α ≥ 19°
- DES predicts CLmax = 23° at 4% disparity, 1% more accurate than RANS
- DES is more accurate as α increases
- DES ran with same mesh as RANS produces much worse results

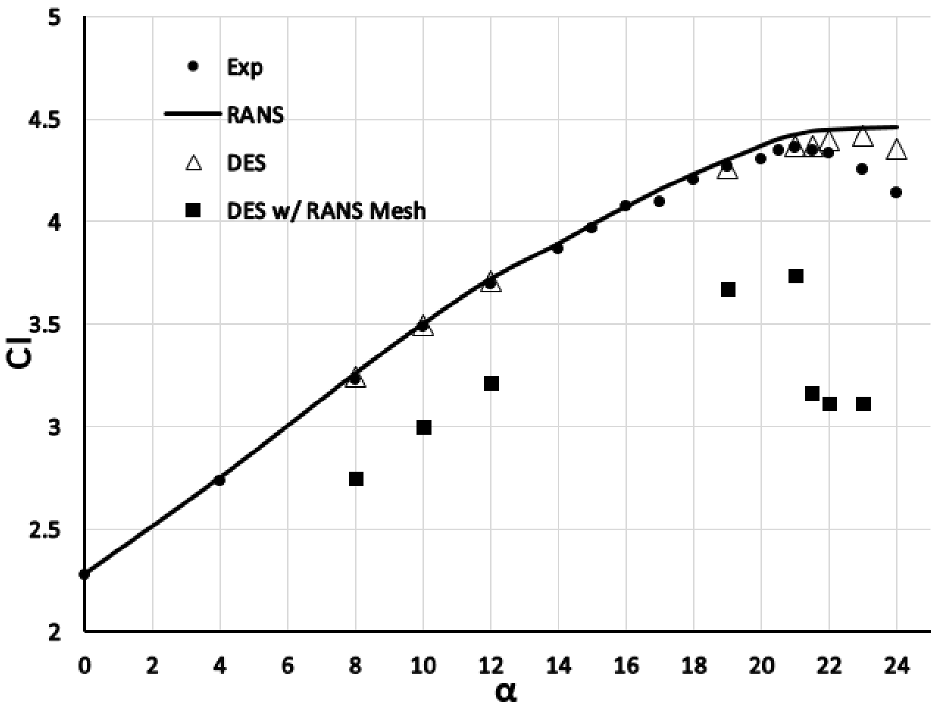


Fig. 6 C_L – angle of attack(α) chart

Results: Baseline C_P Distribution

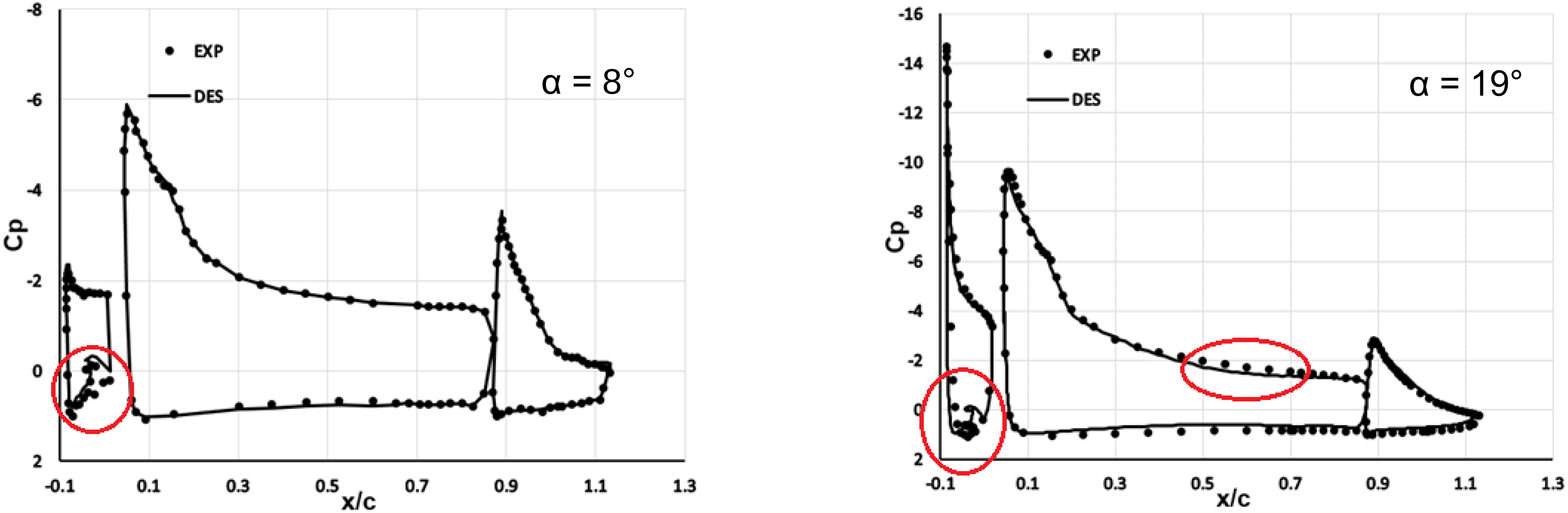


Fig. 7 DES C_P – x/c chart at α = 8° and α = 19°.

- For α = 8°, pressure distribution in the slat cove area shows some disparity against experiment, possibly due to local flow instability triggering the DES switch while local mesh quality is inadequate for LES.
- For α = 19°, same problem seems to be occurring near the slat, also along the main element upper & lower surface. Reason for this is being investigated.

Results: Baseline Flow Streamline

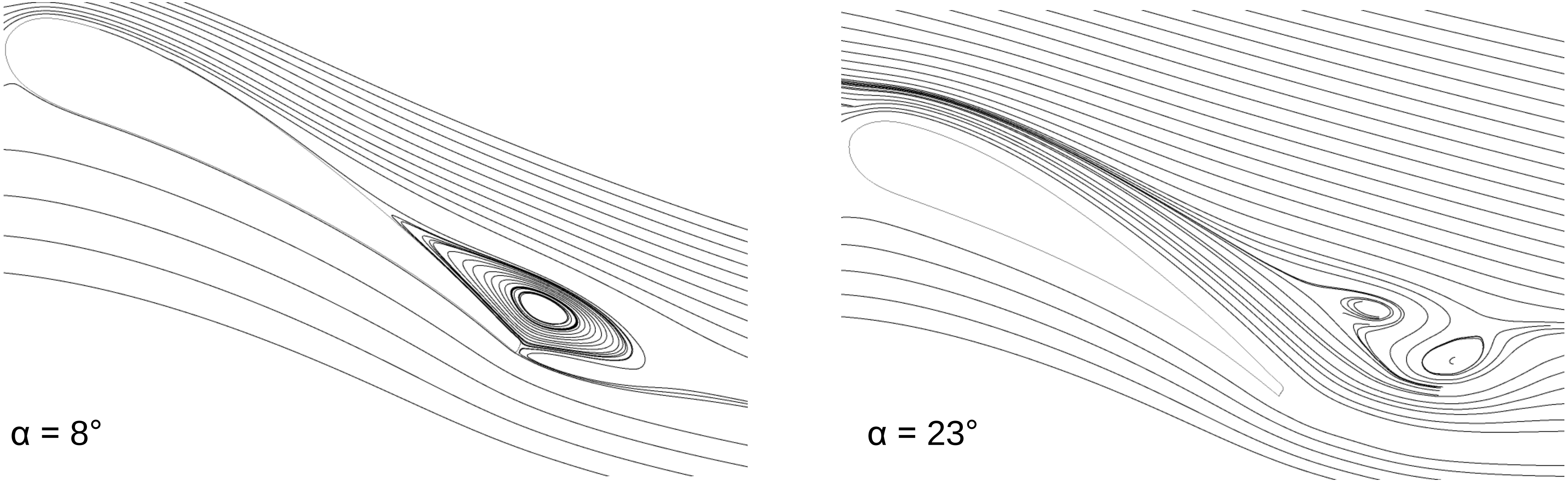


Fig. 8 DES Flow Stream line at α = 8° and α = 23°

- Both DES and RANS predicted surface flow separation at lower angle (α = 8°)
- Separation behaviour at α = 23° (i.e. flow reversal in main-element wake)is recreated by DES

Methods: Blowing

- Blown airfoil performance calculated using DES
- Calculations are conducted with Ansys 15.0 Fluent and CFX
- Blowing slot placed at 25% and 50% flap chord
- Blowing direction is 20° upwards from airfoil surface
- Steady blowing momentum coefficient C_μ set at 0.001

- C_μ is defined as: $$C_\mu = 2\frac{h}{c} \cdot \left(\frac{V_s}{V_\infty}\right)^2$$

- Blowing slot width h = 0.00015 metre

Results of blowing

<u>25% Flap Chord Slot</u>

- Flow remained attached along the flap upper surface
- Combined lift enhanced by 17%, drag reduced by 14%

<u>50% Flap Chord Slot</u>

- Flow separation is delayed from 60% to 70% flap chord location (original separation bubble in red)
- Bubble size decreased by 50%
- Combined Lift enhanced by 10%, drag reduced by 8%

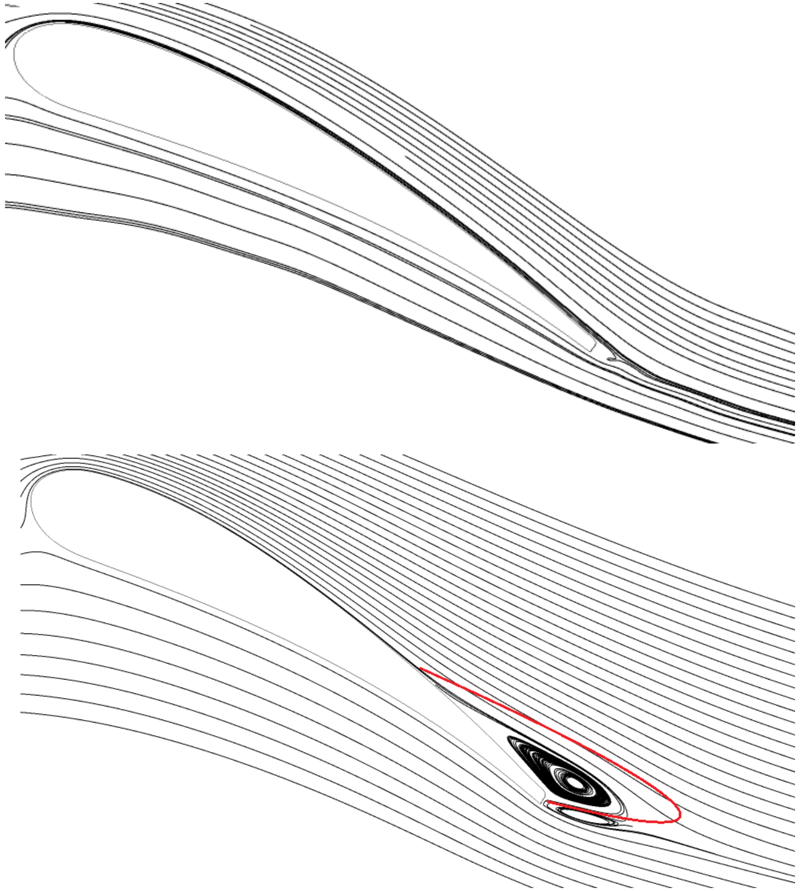


Fig. 9 DES Predicted flow streamline at α = 8° with blowing

Conclusion Remarks

- For baseline model, DES is unnecessary for lift prediction at low α, where RANS is effective while costing less computational resource.

- When RANS losses accuracy beyond stall, applying DES method can improve lift prediction accuracy.

- Applying non-tangential blowing on 30P/30N configuration’s flap upper surface can suppress the separation occurring at α = 8 thus improving lift and drag performance.

- Location of blowing slot greatly effects the flow control performance.

Future work

- Investigate RANS performance on same blowing settings
- Investigate 3D model on same configuration and blowing settings
- Investigate DES performance on different blowing configuration (i.e. tangential blowing, periodic blowing, etc.)
- Mesh quality study in DES regions
- Investigate different turbulence models and DES models

Reference

Bertelrud, Arild, and J. B. Anders. "Transition Documentation on a Three-Element High-Lift Configuration at High Reynolds Numbers: Analysis." (2002).

Bright, M.M., Korntheuer, A., Komadina, S. and Lin, J.C., 2013, January. Development of Advanced High Lift Leading Edge Technology for Laminar Flow Wings. In *51st AIAA Aerospace Sciences Meeting* (pp. 2013-0211).

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