



Turbulence Simulations of Transonic Flows over NACA-0012 and OAT15A Airfoils



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Introduction

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- In transonic flows over wings, above a critical angle of attack, self sustaining motions of the shock occur. The lift, drag, etc. also oscillate periodically at a fixed frequency. (Review article by Giannelis et al. (2017))
- How can we predict the buffet onset accurately and consistently?





Approach

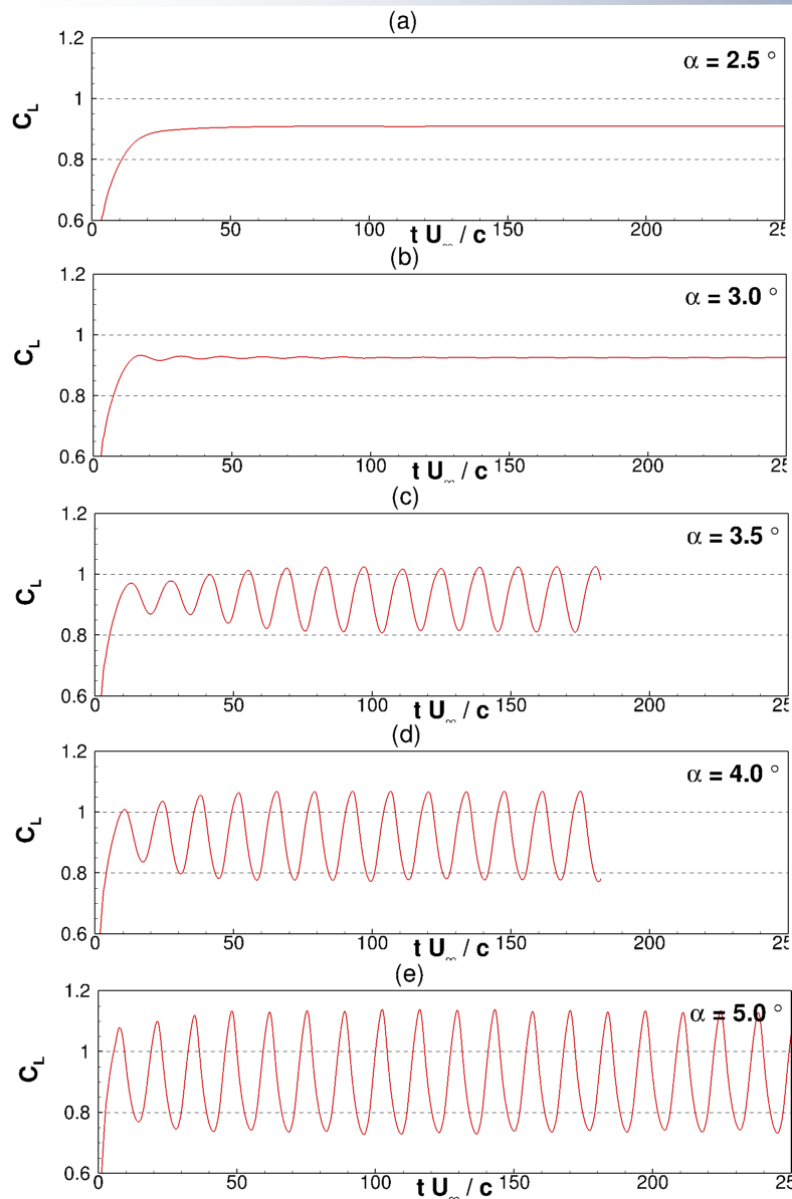
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- Four different simulation approaches are used to predict transonic buffet over 2D airfoils.
 - URANS
 - DDES
 - WMLES
 - DNS/WRLES
- Flows over three different airfoils are simulated.
 - NACA0012 (McDevitt and Okuno (1985))
 - OAT15A (Jacquin et al.(2009))
 - V2C (Dassault Aviation Laminar Flow Airfoil)

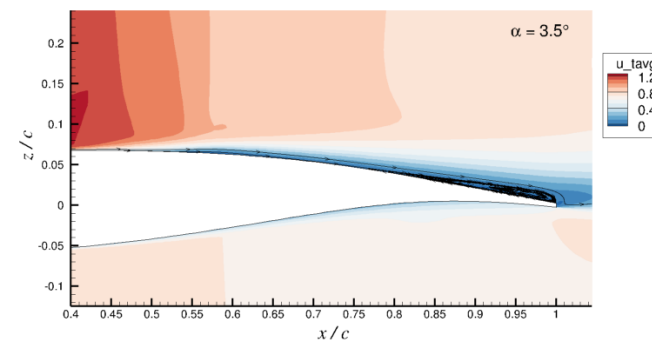
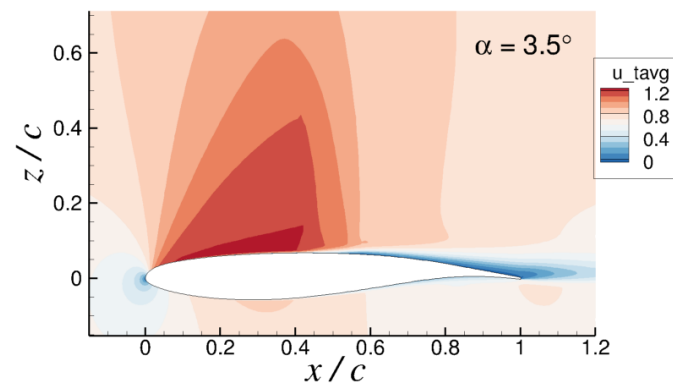


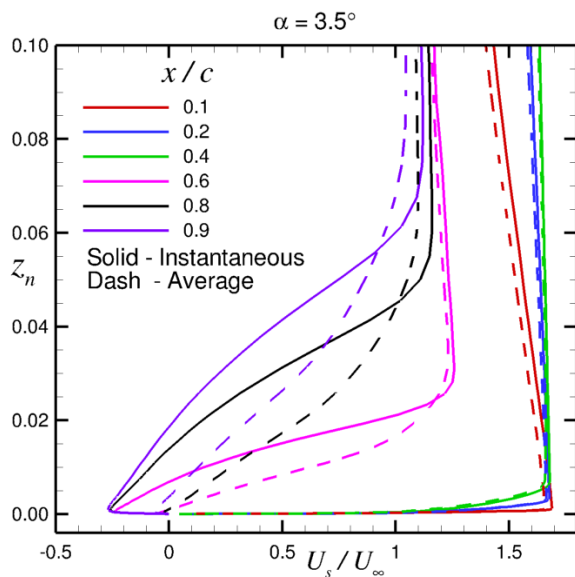
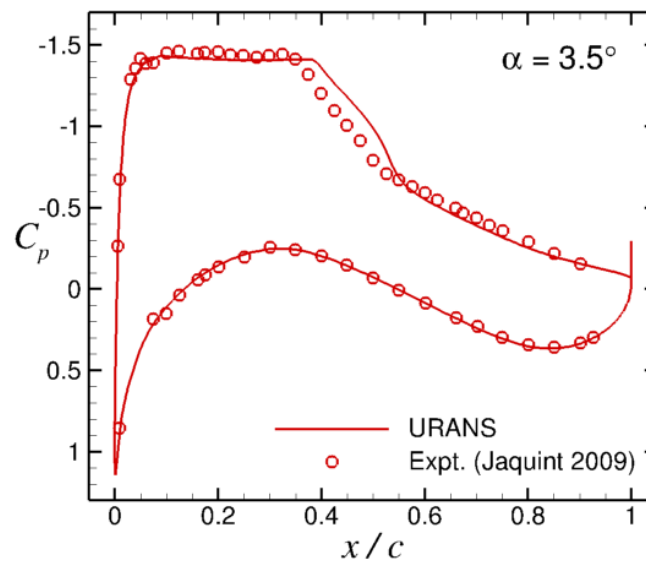
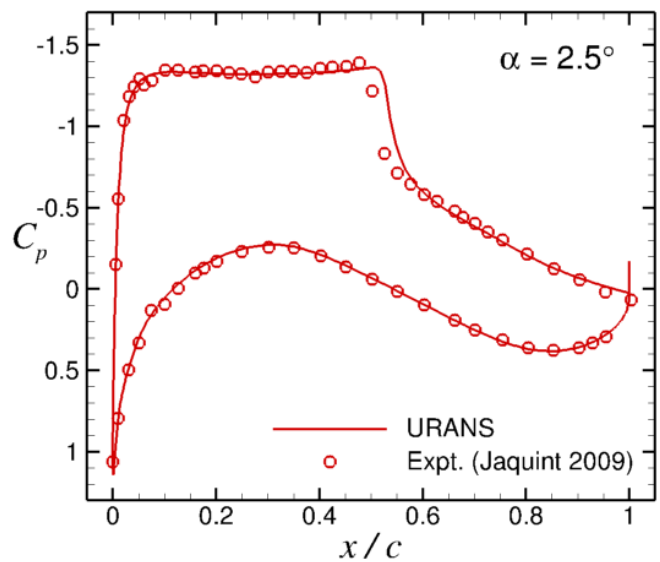
URANS-OAT15A $M = 0.73$ $Re_c = 3 * 10^6$

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α°	C_L	ΔC_L	T	St
3.0	0.93	0.00		
3.5	0.92	0.10	14.0	0.44 (0.41 Exp.)
4.5	0.93	0.14	13.3	
5.0	0.95	0.20	13.4	
6.0	0.	0.		

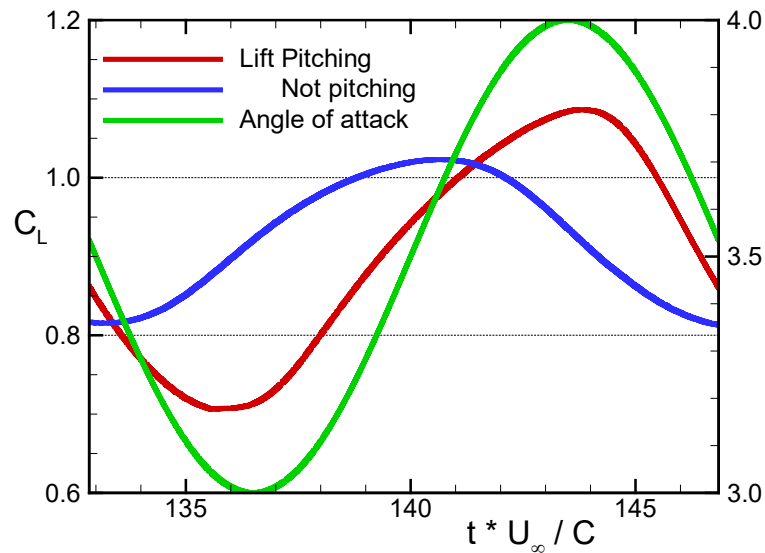
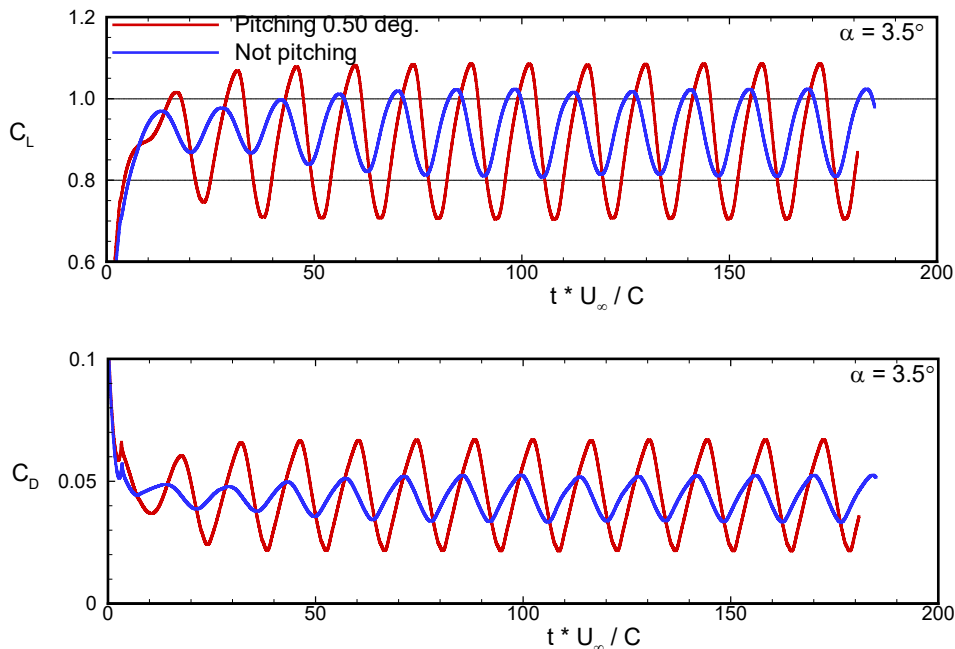




- BL thickness increases from 0.003 at $x/c \sim 0.2$ to 0.03 at $x/c \sim 0.6$.
- Eddy viscosity is about 10 upstream and is about 1500 downstream

Pitching Airfoil – OAT15A

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α°	C_L	ΔC_L	T	St
3.5 Pitching	0.92	0.10	14.0	0.44 (0.41 Exp.)
3.5 Not Pitching	0.90	0.19	14.0	



DDES - OAT15A: $\text{grad}(\rho)$ and $\text{div}(u)$



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$|\text{grad}(\rho)|$

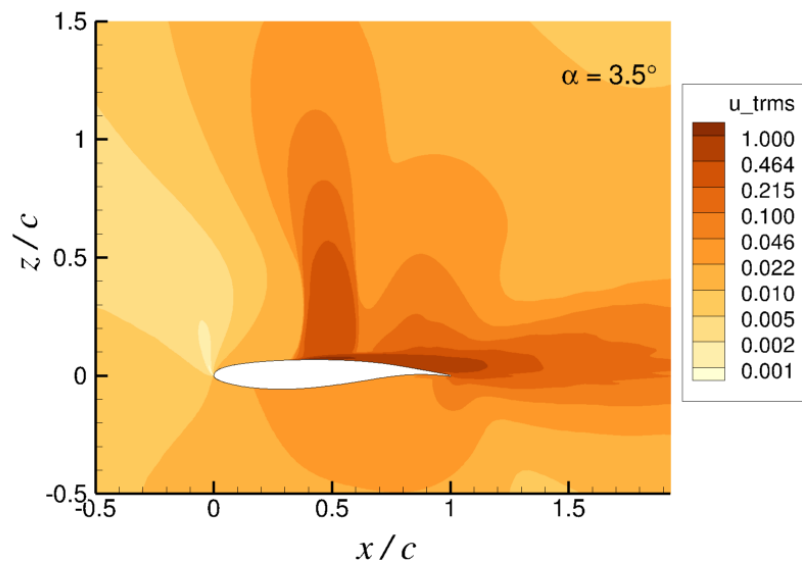
$\text{div}(u)$



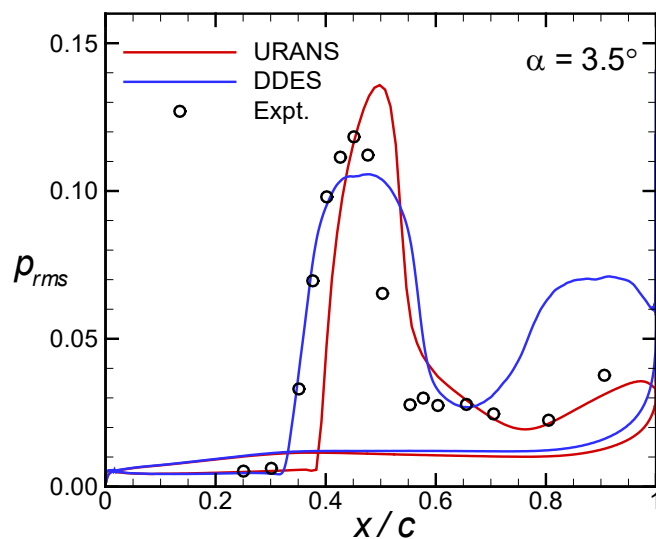
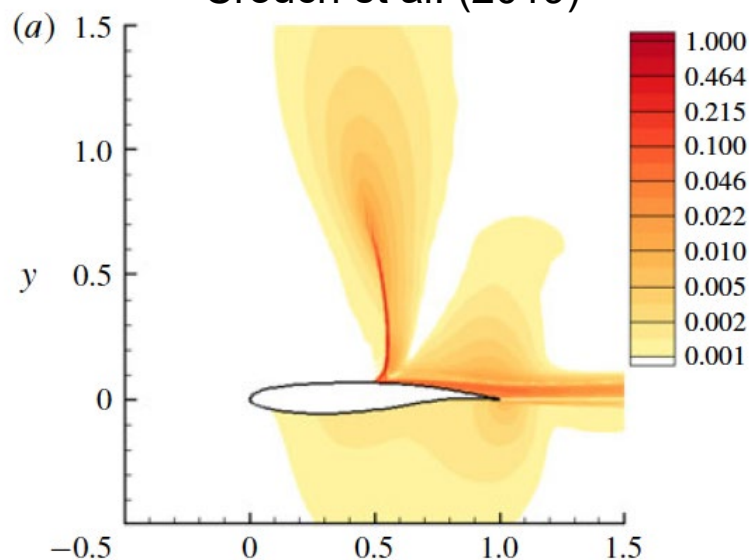
u_trms, p_trms

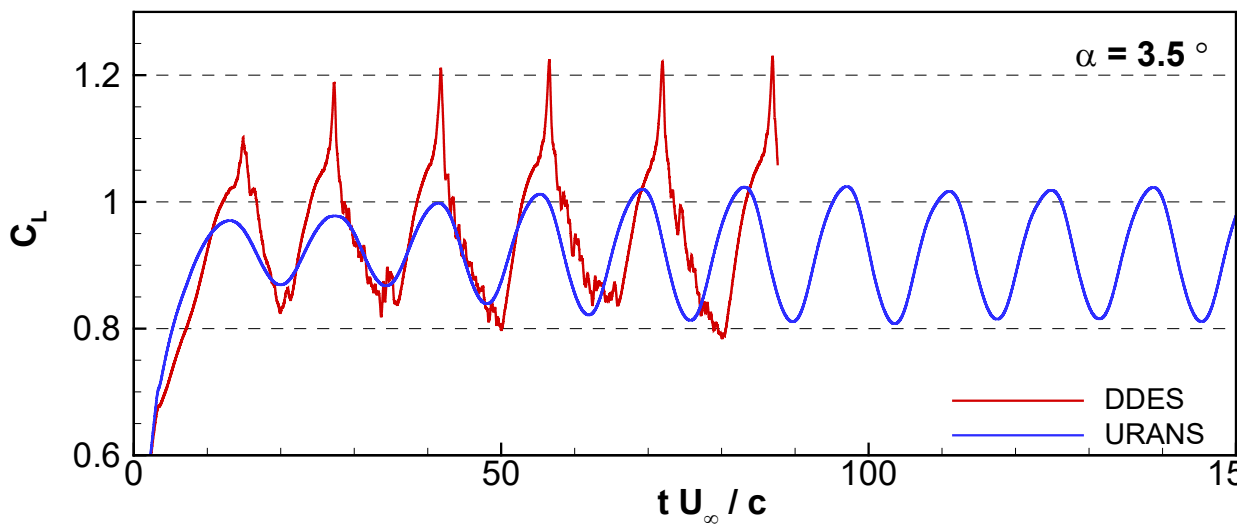
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u_{rms}

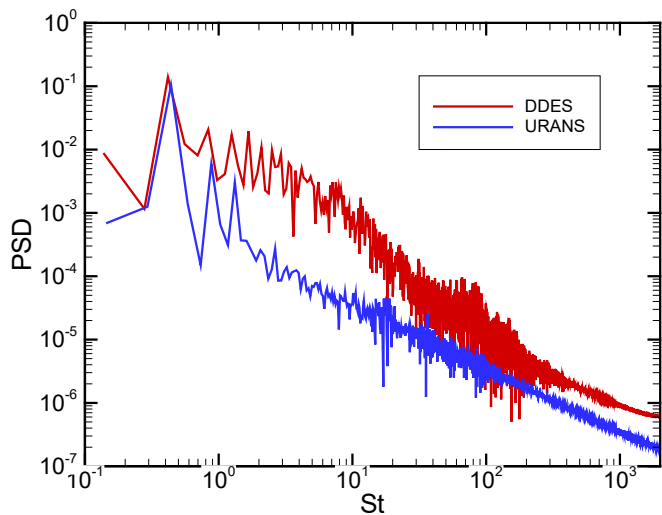


Magnitude of u component of instability
Crouch et al. (2019)





PSD



URANS

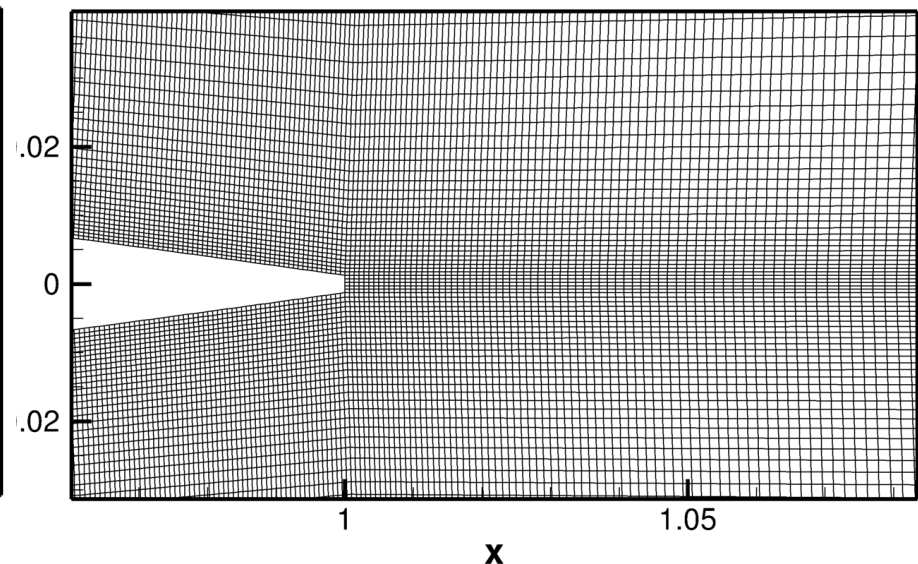
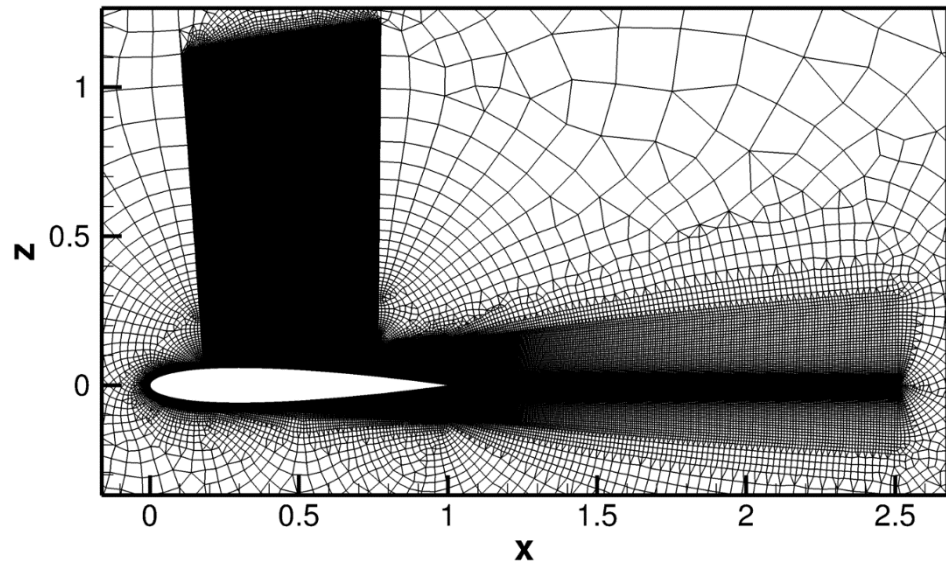
St = 0.44 (0.41 Exp.)

DDES

St = 0.42

WMLES – NACA0012: Numerical Details

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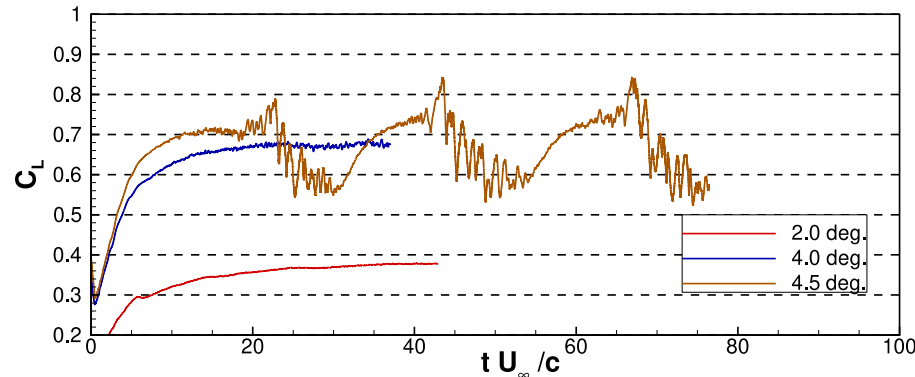


- Grid contains 0.44M points in 2D, and 12M for 2%c span. 31 and 61 points were used in the spanwise direction.
- Low dissipation ($\kappa = 0.9$), no SGS, with Ducros sensor-based limiter are used. Spalding wall function is used in the wall-model computations.
- BDF2 with $(U_{\infty} / c)\Delta t = 6.8 \times 10^{-4}$, 5 subiterations.
- $\Delta n_w / c = 1 - 7 \times 10^{-4}$, $\Delta x / c = 3 - 7 \times 10^{-4}$, $\Delta y / c = 6.7 \times 10^{-4}$, 3.3×10^{-4}

WMLES – NACA0012: Results

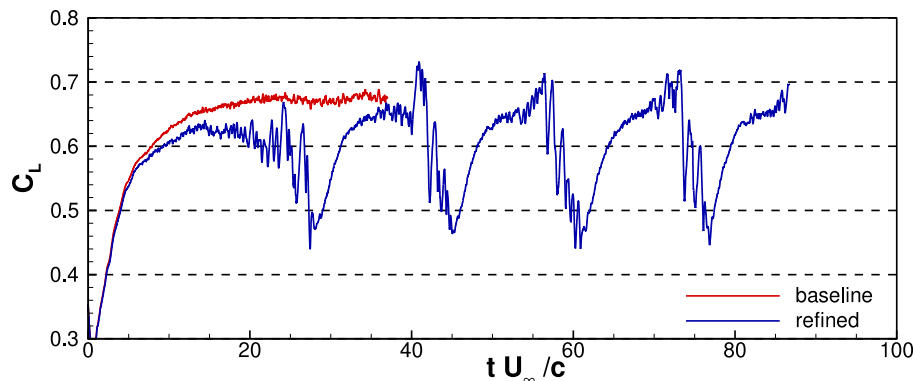
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- Variation in lift at angles of attack of 2, 4, and 4.5 degrees on the baseline grid.

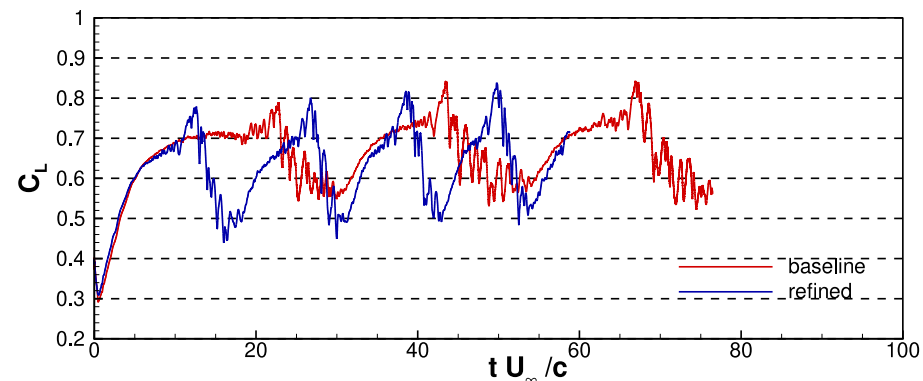


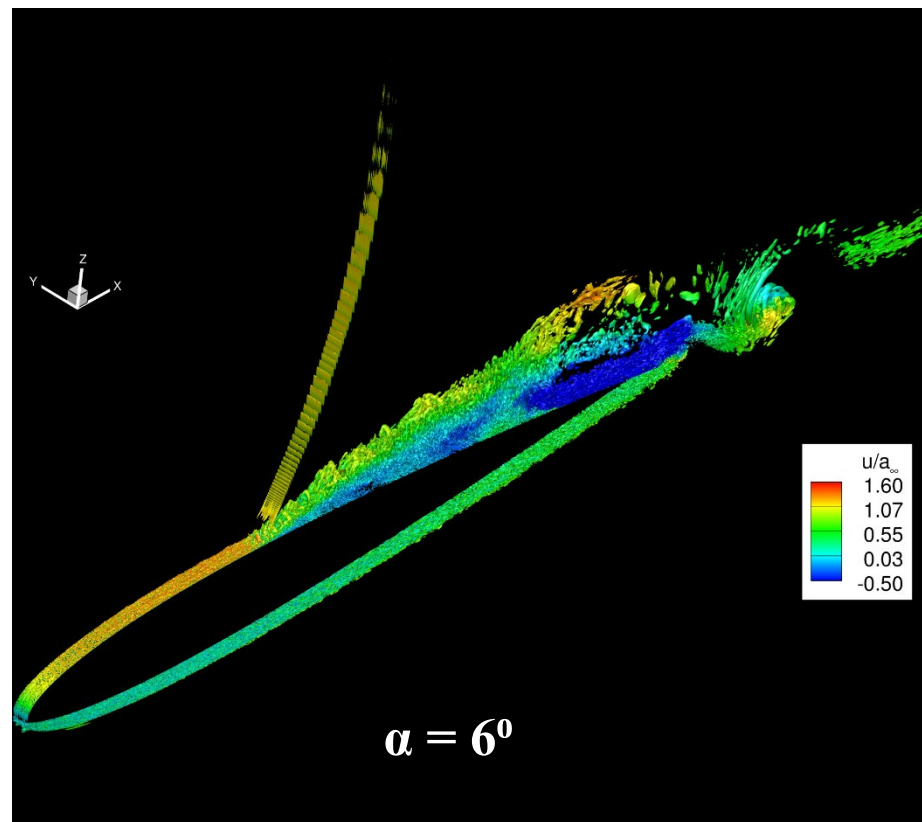
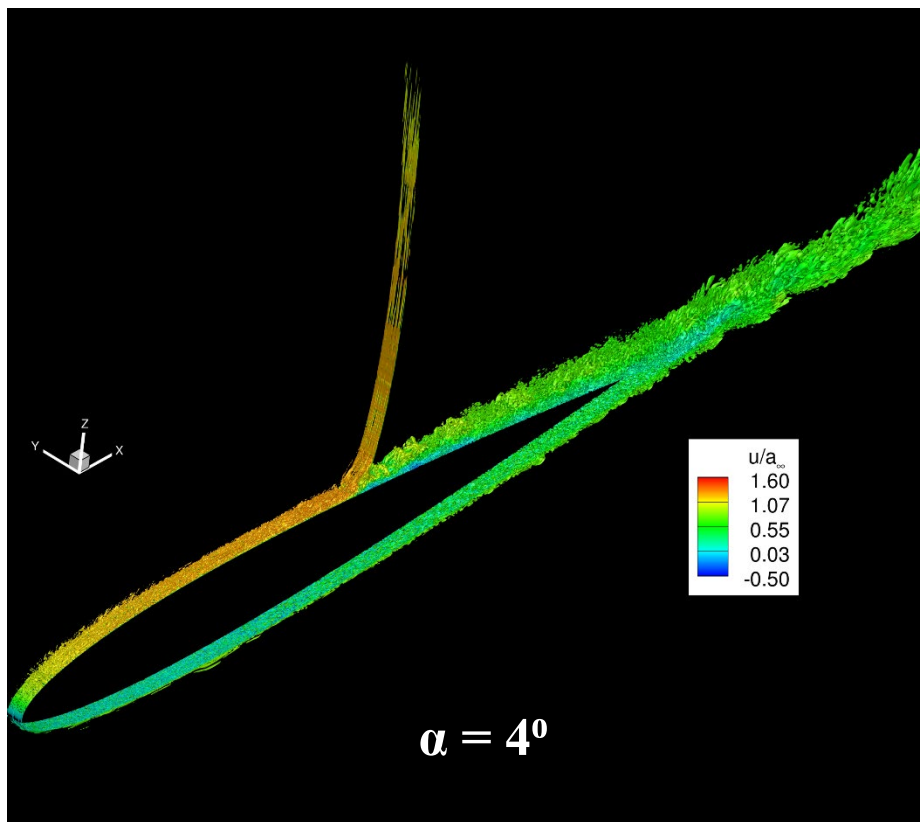
- Variation in lift at angles of attack of 4 and 4.5 degrees on the baseline and refined grids.

4 deg.



4.5 deg.



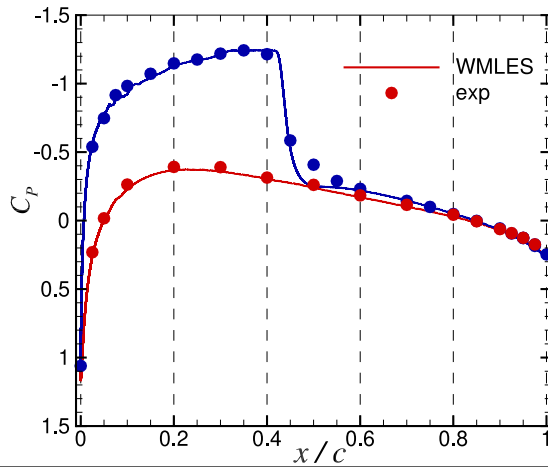


- Vortical features appear to be equivalently captured for both angles.
- Looking into why buffet is not predicted at 4° .

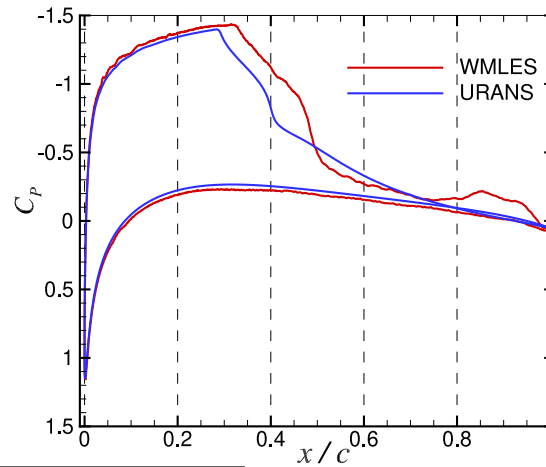
WMLES Results

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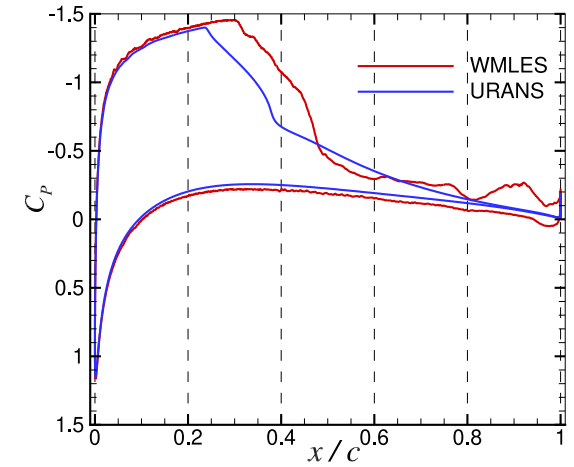
2 deg., $Re_c=11.7M$



4 deg., $Re_c=10M$

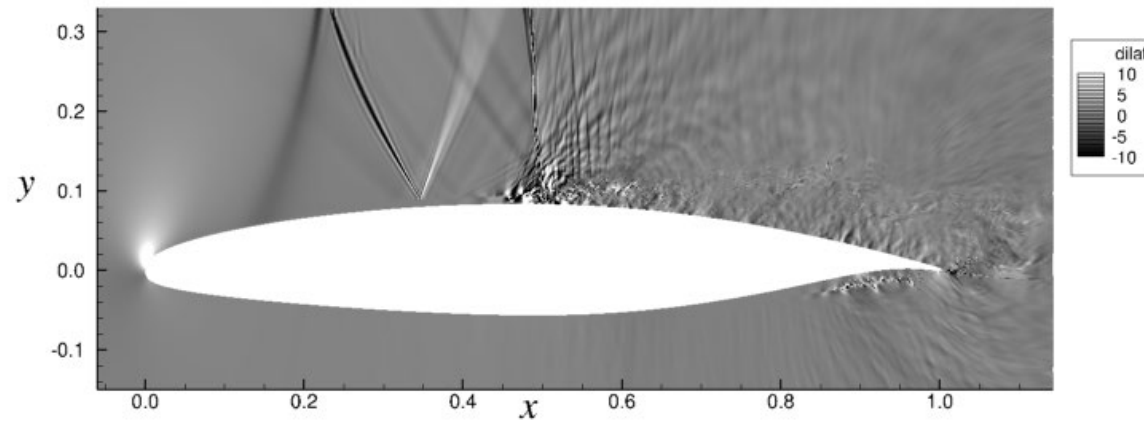
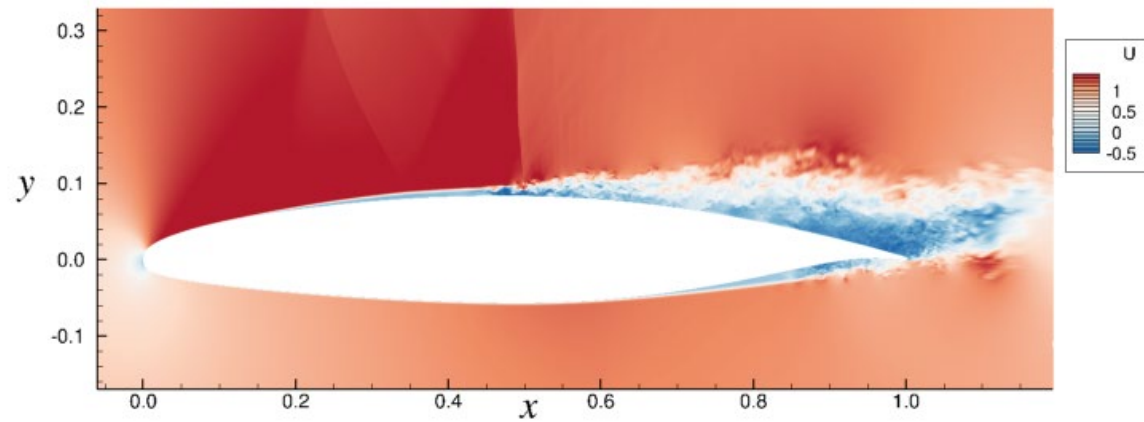


4.5 deg., $Re_c=10M$



DNS – V2C : $M = 0.70$, $Re_c = 0.5 \cdot 10^6$

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- Lusher et al. (2023) AIAA 2023 - 1222

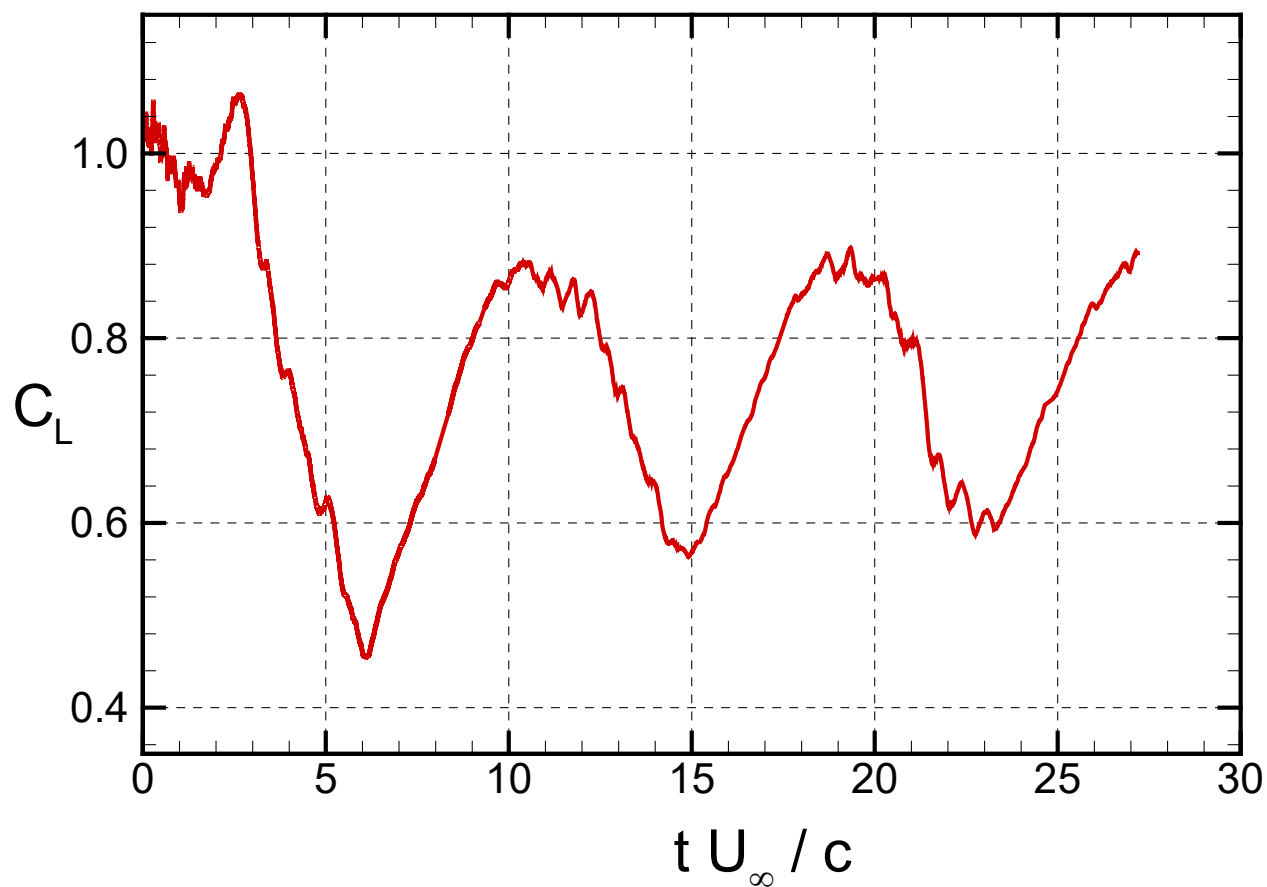


DNS – V2C: u-Velocity and $\text{div}(\mathbf{u})$

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U - Velocity

$\text{div}(\mathbf{u})$





Summary

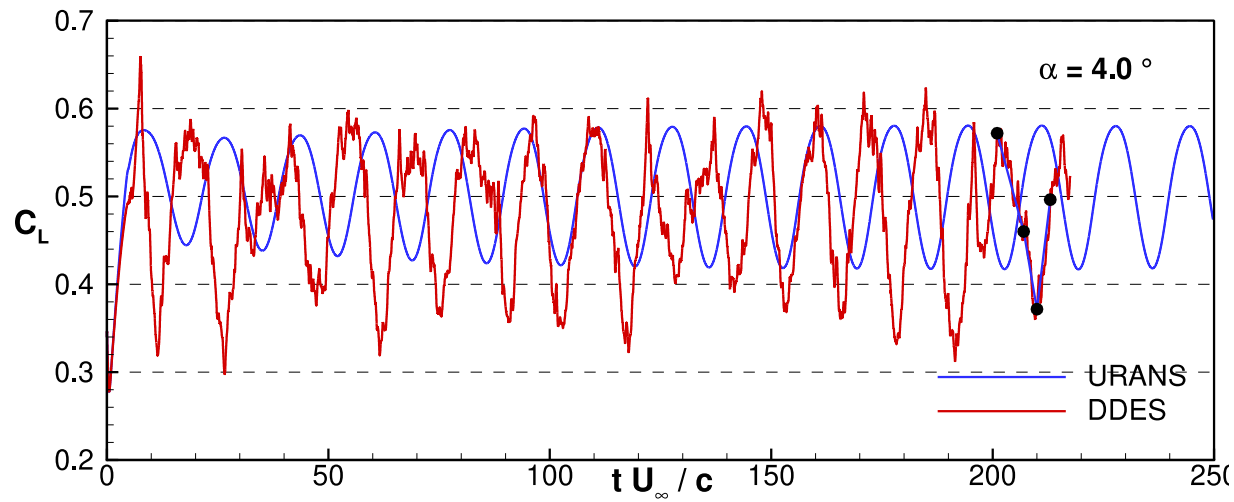
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- 2D URANS: NACA0012 and OAT15A
 - encouraging, quantitatively captures buffet onset.
 - shows buffeting only with compressibility correction.
- DDES: OAT15A, NACA0012
 - The buffeting is captured.
 - However, the buffeting is also observed at pre-buffet angle of 3 degrees with a lower lift coefficient.
- WMLES: NACA0012
 - $\alpha=2^\circ$ compared well with the experiment in terms of C_p .
 - $\alpha=4^\circ$ and 4.5° showed buffeting with refined grid.
 - Lift is higher than the predicted URANS values.
 - Frequency agrees with the experiment.
- WMLES: OAT15A
 - Buffeting is not observed in the current simulations.
- Future:
 - DNS for OAT15A
 - 3D Geometries

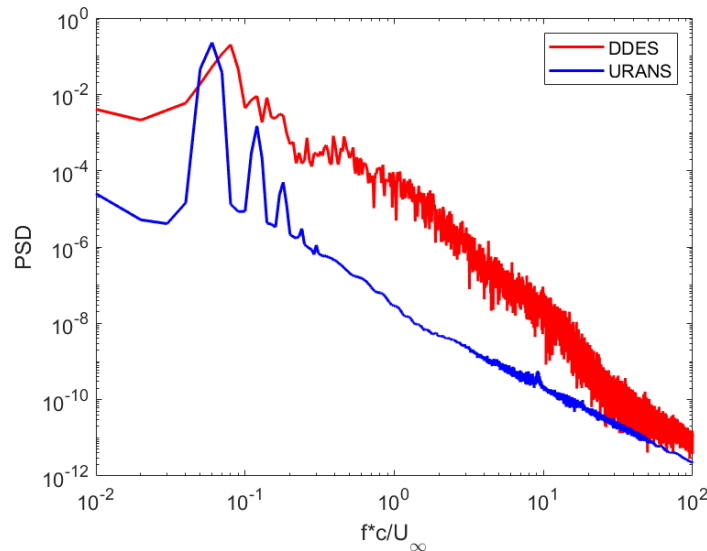


DDES-NACA0012 $M = 0.70$ $Re_c = 10^6$

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PSD



URANS

$St = 0.38$ (0.47 Exp.)

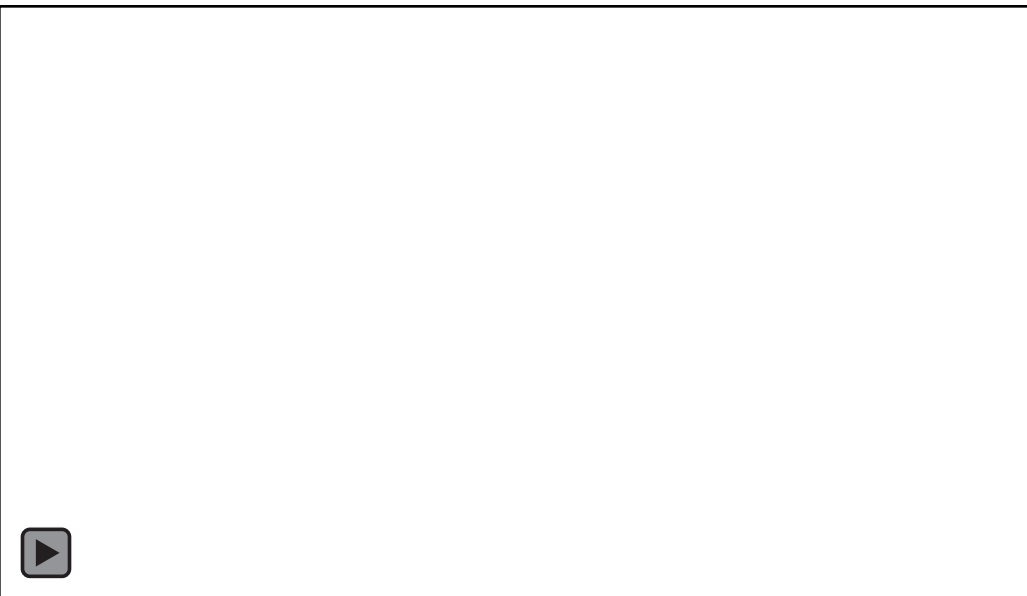
DDES

$St = 0.49$

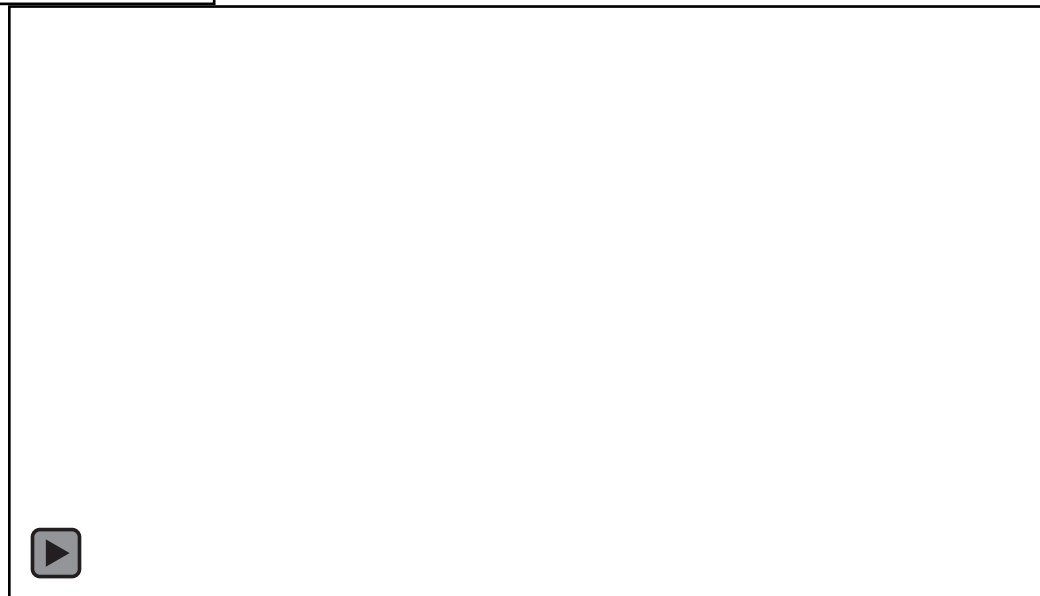


DDES- $\text{grad}(\rho)$ and $\text{div}(u)$

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$|\text{grad}(\rho)|$



$\text{div}(u)$

DDES – NACA0012 (3°)

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