High-lift device aerodynamic prediction using Embedded Large Eddy Simulation by FaSTAR

FaSTARによるEmbedded-LESを用いた高揚力装置モデルの空力特性予測

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Test cases

- Case 1-3
  30P30N unsteady aerodynamic prediction
  (5.5 deg., 9.5deg.)

- Case 3-1
  Aeroacoustics prediction (near field)
  (5.5 deg., 9.5deg.)

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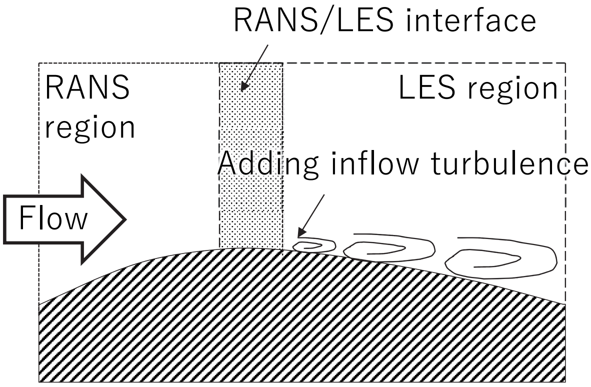
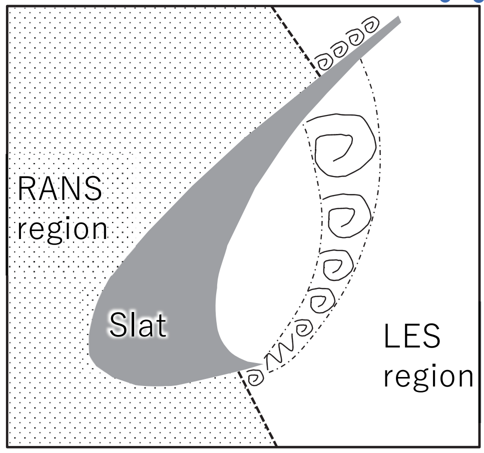
Embedded-LES



Schematic view of Embedded-LES

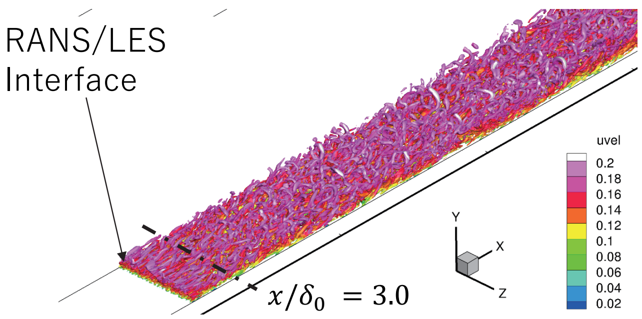


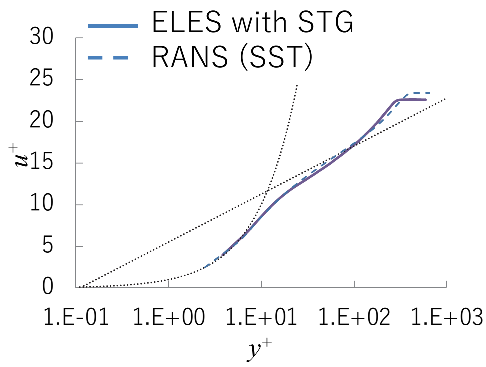
Location of interfaces on the slat

- Upstream part of the flow field is solved with URANS and downstream part is solved with LES
- Why ELES?
  →To reconstruct turbulence contents in the LES region

STG[2](Synthetic Turbulence Generator)

- Fluctuation $v_j\ (\boldsymbol{r},t)$ have von-Karman type spectrum:
  $E(k)=\frac{(k/k_e)^4}{[1+2.4(k/k_e)^2]^{\frac{17}{6}}}$ (k : wave num., k_e : dominant wn.)
- $U_i^{LES}=U_i^{RANS}+a_{ij}v_j(\boldsymbol{r},t)$
  - $R_{ij}=a_{ik}a_{kj}$: Cholesky decomposition of Reynolds stress tensor





[2] M. L. Shur, P. R. Spalart, M. K. Strelets, and A. K. Travin, “Synthetic turbulence generators for RANS-LES interfaces in zonal simulations of aerodynamic and aeroacoustic problems,” Flow, Turbul. Combust., vol. 93, no. 1, pp. 63–92, 2014.

Simulation setup

Numerical method	
Flow solver	FaSTAR with STG
Governing eq.	3 dim. compressible NS-eq.
Inviscid flux	KEP(Kinetic Energy Preserving) [3] with wiggle sensor
Limiter	NS eq. : None, Turb. eq. : Hishida(vL type)
Time stepping	LU-SGS with dual time stepping
Turbulence model	SST-2003sust based IDDES (Improved Delayed Detached Eddy Simulation)

Flow condition	
Mach number	0.17
Reynolds number	1.71×10^6
AoA	5.5, 9.5 deg.

[3] A. Jameson, "The Construction of Discretely Conservative Finite Volume Schemes that Also Globally Conserve Energy or Entropy," J. Sci. Comput., 34, pp. 152–187, 2008.

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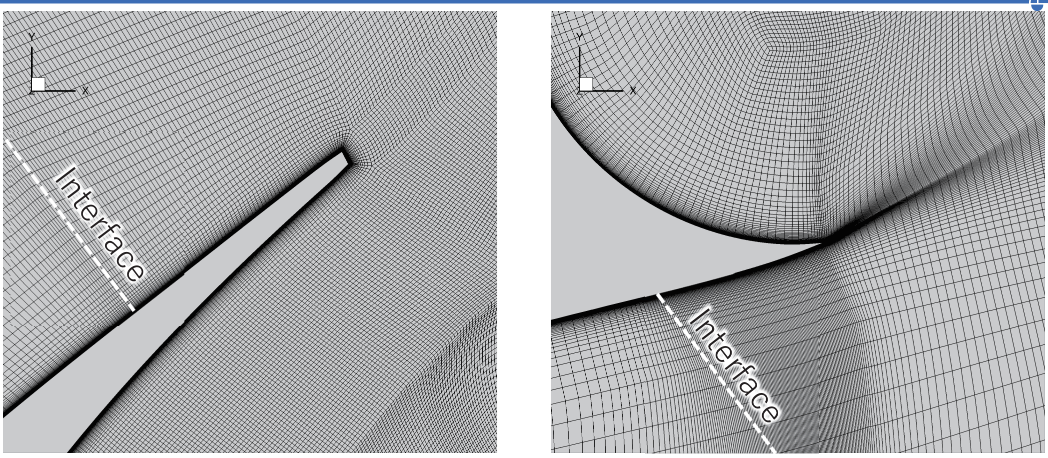
Grid configuration



Grid distribution around slat TE and cusp

- Modified L3 grid (88million cells)
- Interfaces are far from TE or cusp about $10\delta_0$
  (δ_0: local thickness of turbulent boundary layer)
- Improving grid quality on behind RANS/LES interfaces
  → To maintain unsteady motion inside boundary layer

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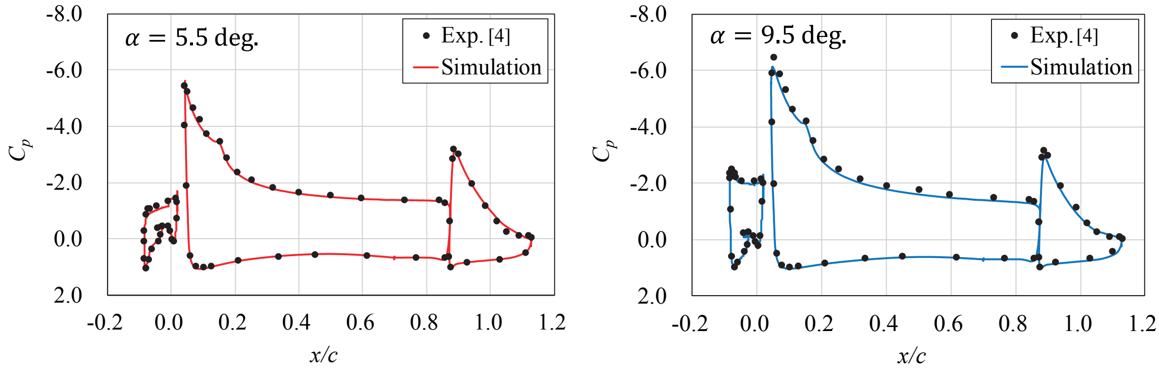
Results: Cp and C_L

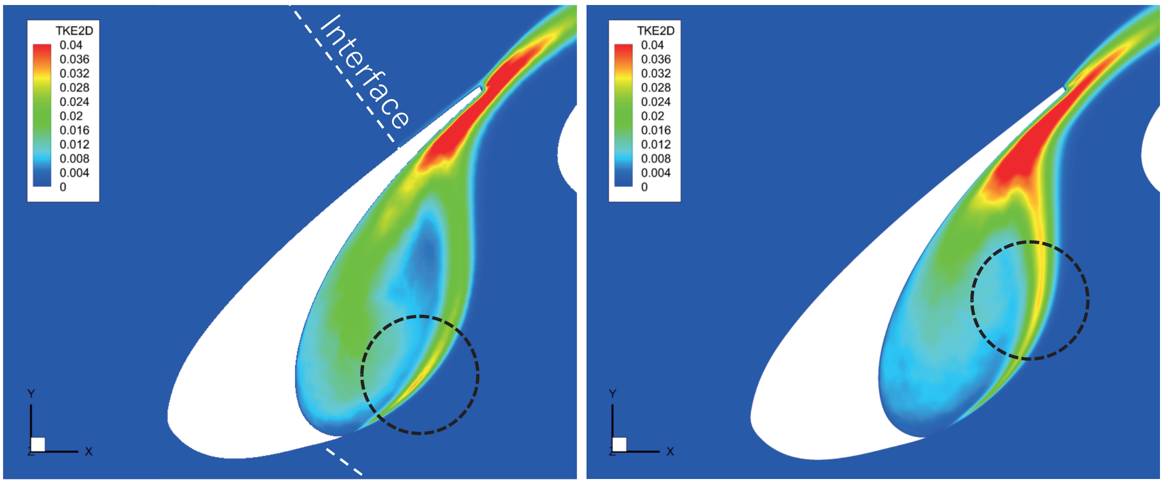


α [deg.]	5.5	9.5
C_L (Exp.[4])	2.84	3.29
C_L (Simulation)	2.78	3.13

- Time-Averaged Cp is good agreement with experiment
- C_L value is slightly lower than experimental results
- Time-Averaged flow field is well simulated

[4] M. Murayama et al., "Experimental Study on Slat Noise from 30P30N Three-Element High-Lift Airfoil at JAXA Hard-Wall Lowspeed Wind Tunnel," *20th AIAA/CEAS Aeroacoustics Conference*, AIAA 2014-2080, 2014, pp. 6–13.

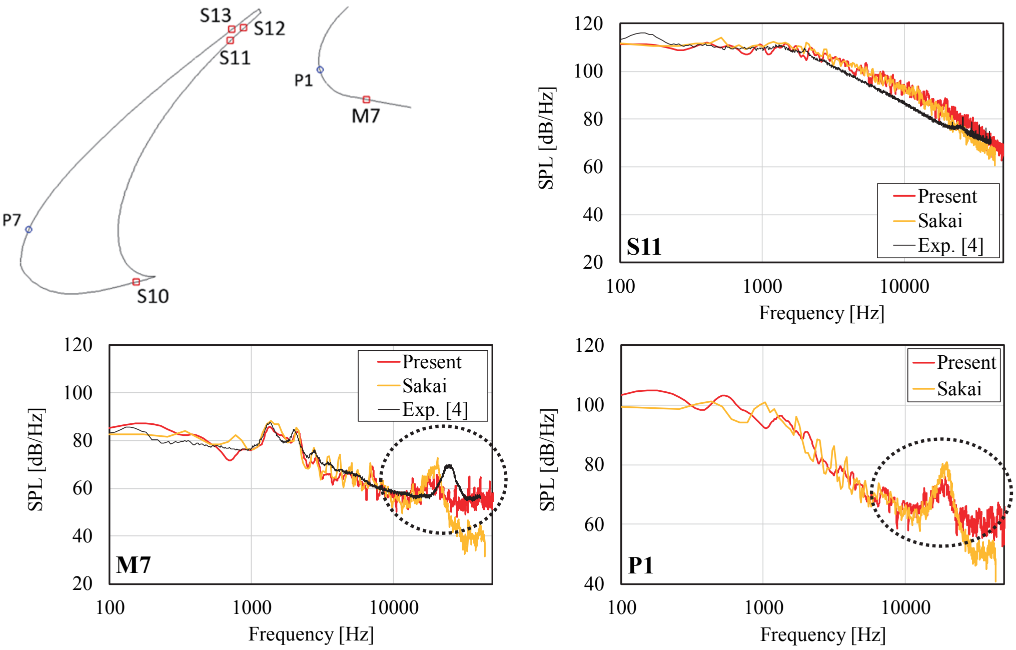
Results: TKE2D distribution



Present (SST IDDES) Dr. Sakai (SA DDES)

- Comparison with Dr. Sakai's data at $\alpha = 5.5$ deg.
- Peak position is moving upstream in present simulation

Results: PSD of surface pressure



- Comparison with Dr. Sakai's data at $\alpha = 5.5$ deg.
- Inflow turbulence affects PSD in high frequency range

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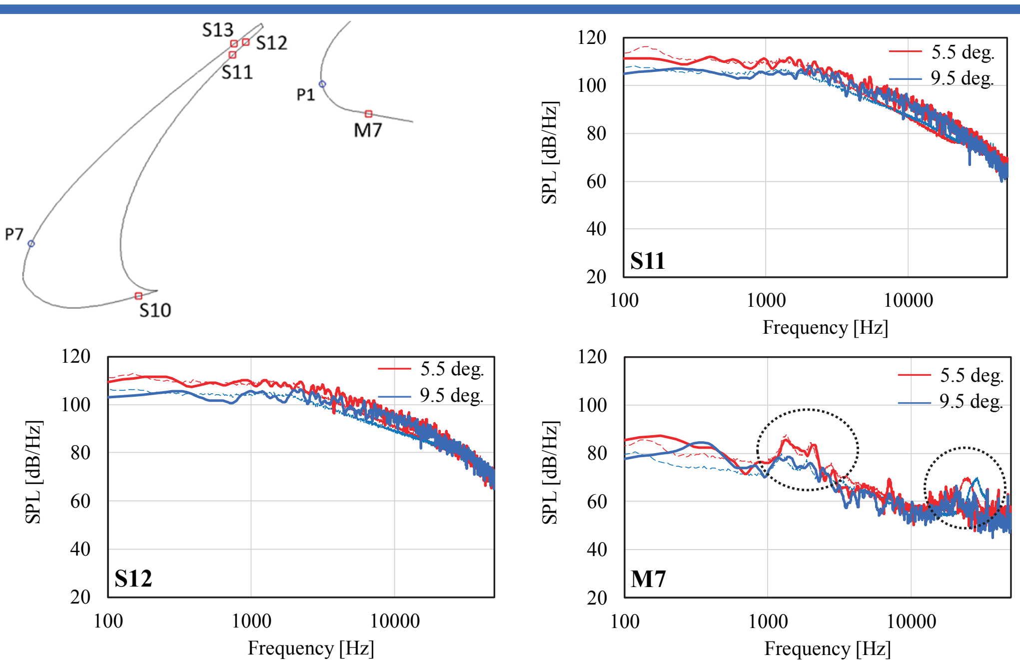
Results: PSD of surface pressure



- Solid line: Simulation, Dotted line: Experiment[4]
- These results are comparatively fitted with exp. data

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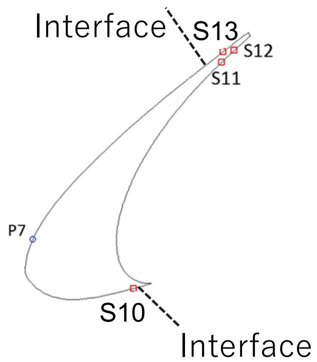
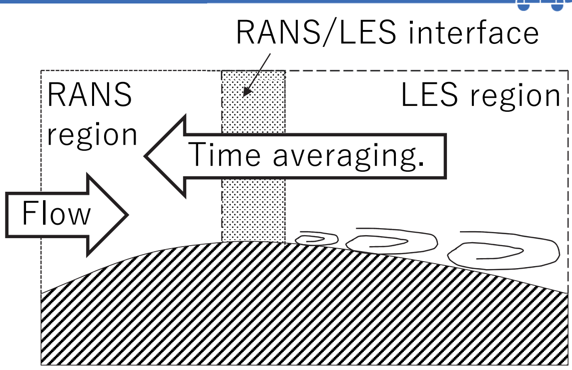
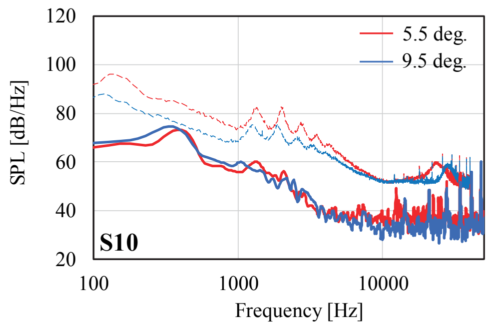
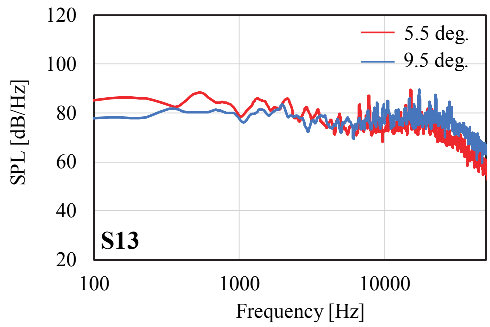
Results: PSD of surface pressure









- Disagreements in S10 and S13 are related to inflow turb.

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Conclusion

- Unsteady flow simulations with ELES was conducted around 30P30N.
- Good agreement with the experiment for Cp distribution.
  - C_L value is consistent with experimental data.
- Peak position of TKE2D in mixing layer is moving upstream.
- PSD of surface pressure is investigated.
  - Inflow turbulence affects PSD in high frequency range.
  - PSD is basically agreement with experiment.
  - Some disagreement is caused by the inflow turbulence.
- Effects of the inflow turbulence should be investigated further.

We are grateful to Dr. Sakai for providing the simulation data.

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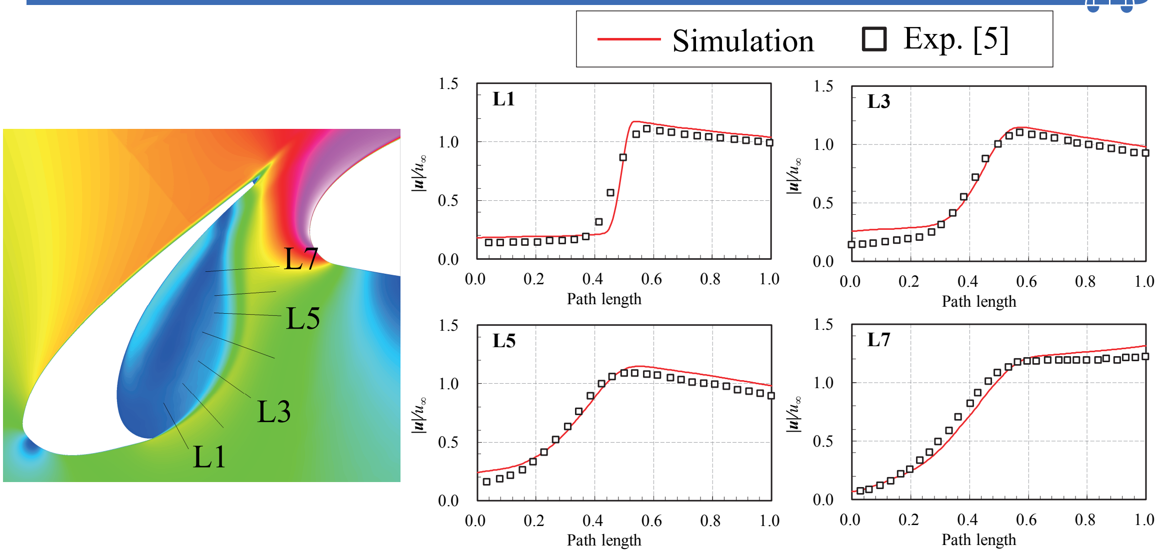
Appendix

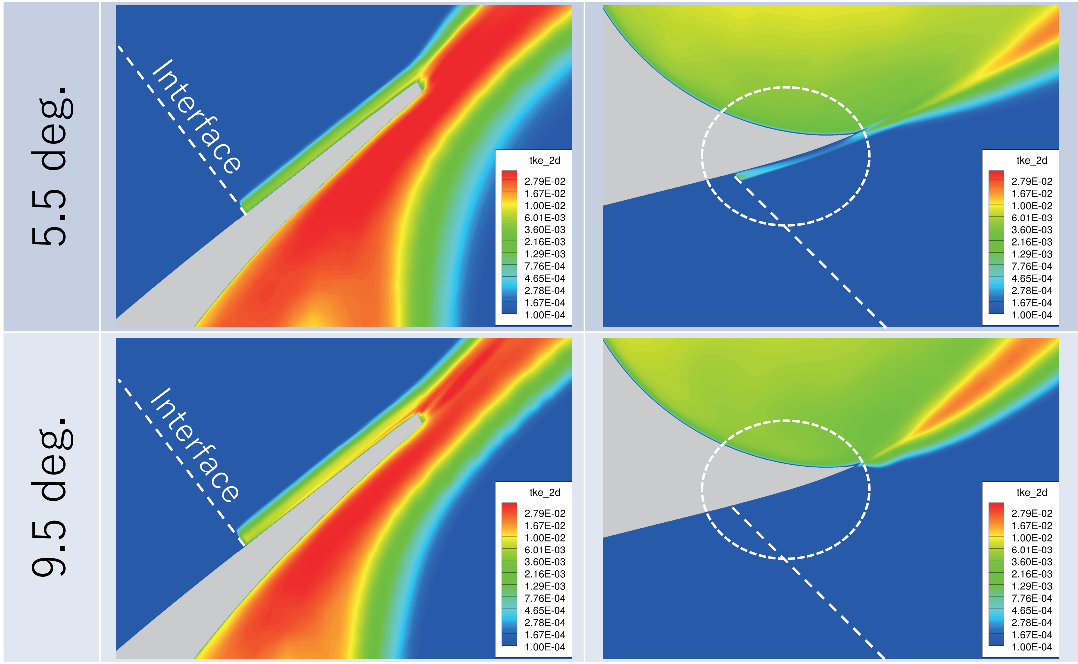
Velocity profiles of mixing layer inside the slat



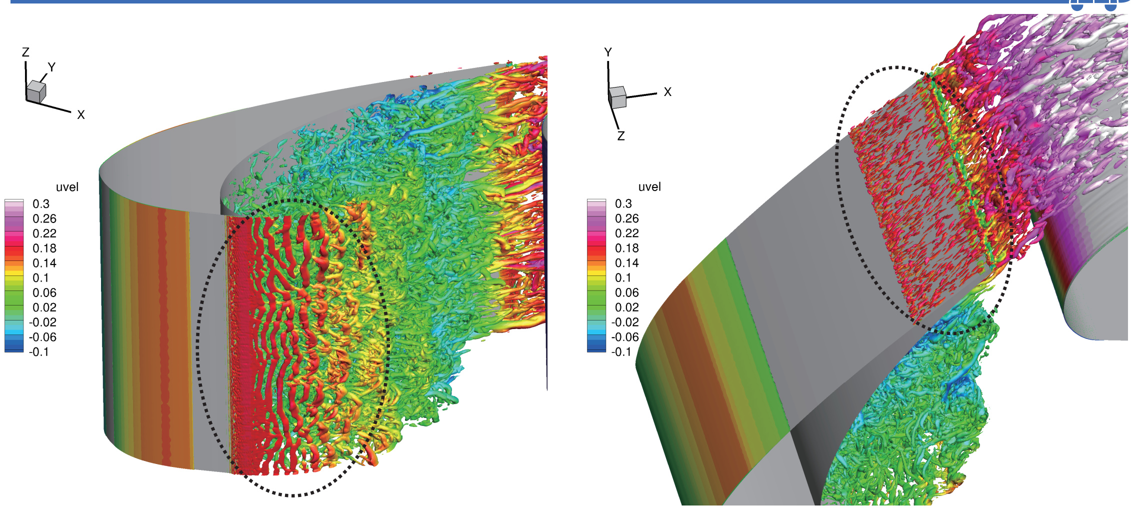
- Velocity magnitude distribution at $\alpha = 5.5$ deg.
- Velocity profile in core region of the mixing layer is well fitted

[5] K. A. Pascioni, L. N. Cattafesta and M. Choudhari, “An Experimental Investigation of the 30P30N Multi-Element High-Lift Airfoil,” *20th AIAA/CEAS Aeroacoustics Conference*, AIAA 2014-3062, 2014, pp. 1–17.

TKE2D distribution around TE and cusp



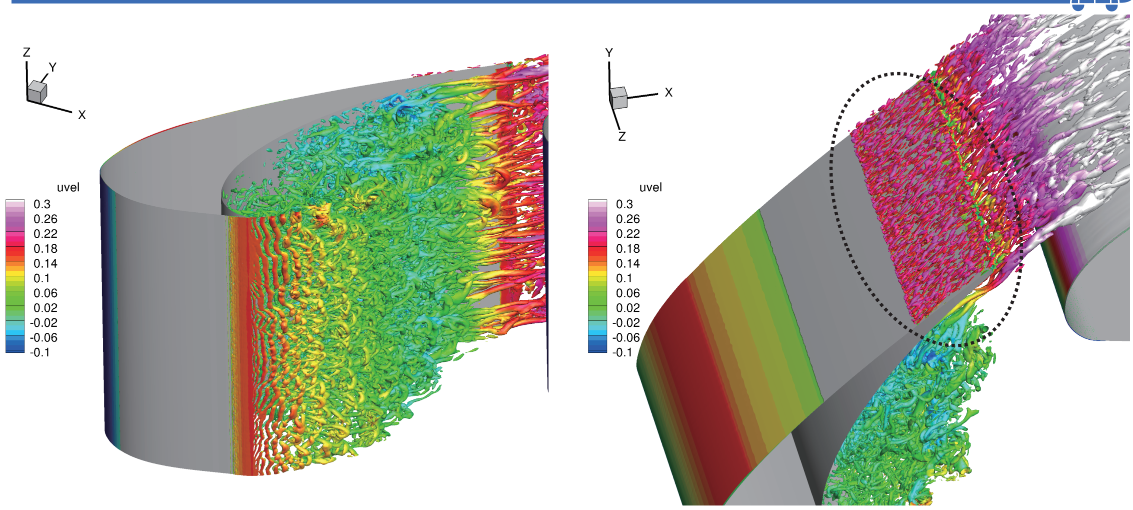
Vortex structure around the slat



$\boldsymbol{\alpha} = \mathbf{5.5}$ **deg.**, $Q = 500a_\infty^2/c^2$, colored by streamwise velocity(u/a_∞)

- a_∞: SoS in the uniform flow, c: chord length
- Turbulent transition of mixing layer is clearly visualized
- Inflow turbulence on the slat TE is observed

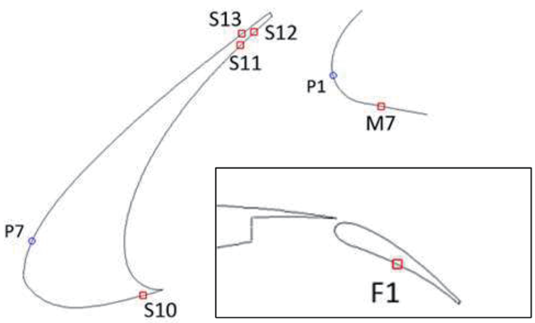
Vortex structure around the slat

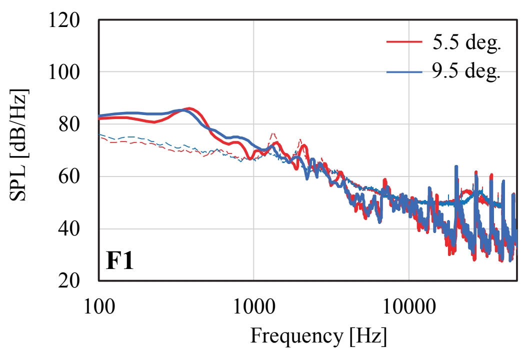


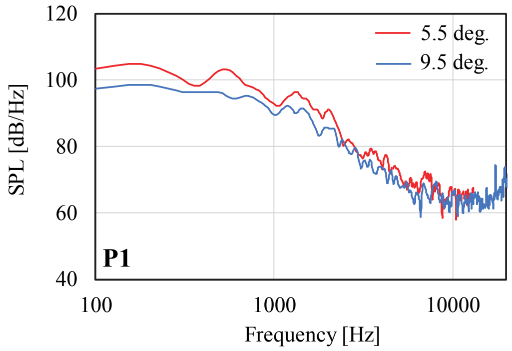
$\boldsymbol{\alpha} = \mathbf{9.5\ deg.}$, $Q = 500a_\infty^2/c^2$, colored by streamwise velocity(u/a_∞)

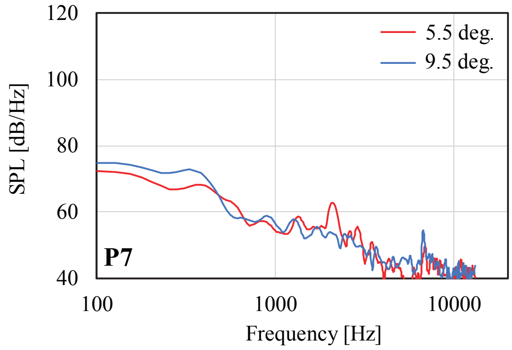
- a_∞: SoS in the uniform flow, c: chord length
- Inflow turbulence on the slat TE is enhanced

PSD of surface pressure

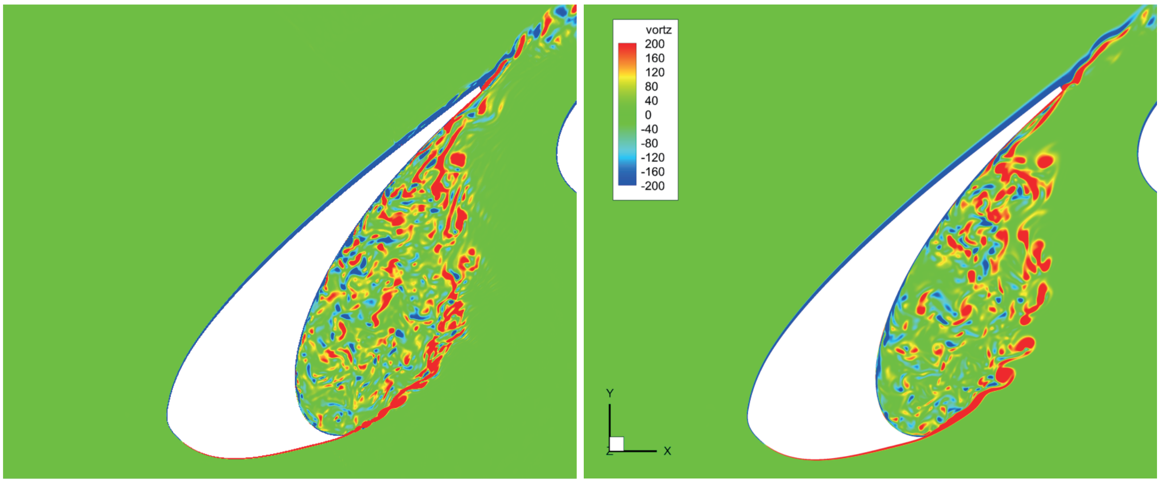








Vorticity-z distribution



Present (L3 Grid, KEP, SST IDDES) Dr. Sakai (L3 Grid, SLAU, SA DDES)

- Comparison with Dr. Sakai's data at $\alpha = 5.5$ deg.

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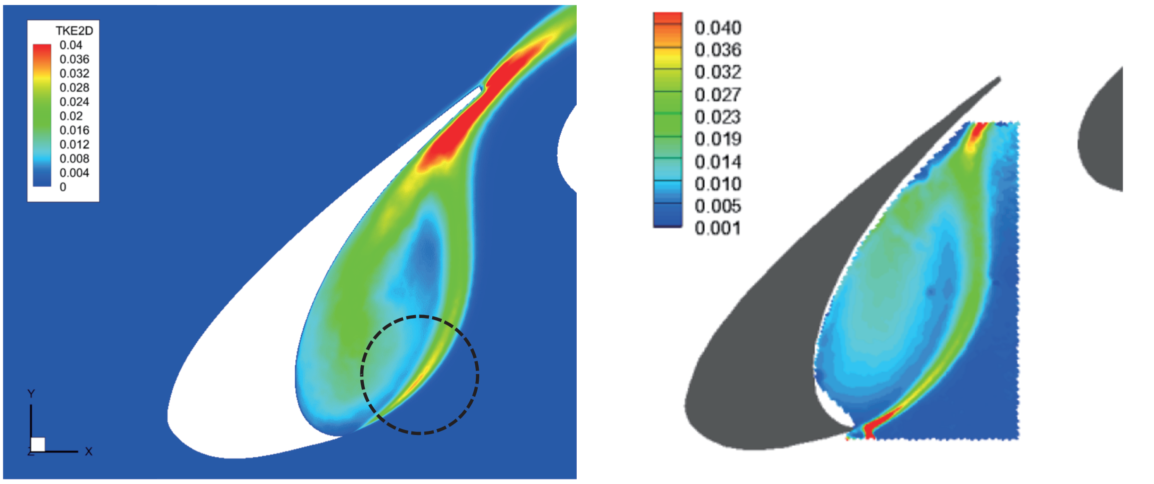
TKE2D distribution



Present (L3 Grid, KEP, SST IDDES) Exp.[6]

- Comparison with Pascioni's exp.[6] at $\alpha = 5.5$ deg.

[6] Choudhari, M., and Lockard, D., "Assessment of Slat Noise Predictions for 30P30N High-Lift Configuration from BANC-III Workshop," *AIAA Aviation 2015*, Reston, Virginia: American Institute of Aeronautics and Astronautics, 2015, pp. 1–41.

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