Analysis using High-Order Schemes in Structured Grid CFD Solver, UPACS

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Objectives

In aerodynamic predictions, to evaluate

- the influence of difference in version of SA model
- the difference between RANS and DDES

In aeroacoustic predictions, to evaluate

- the effect of implemented high-order schemes
  - including the dependency of grid resolution

Numerical Method

UPACS : Unified Platform for Aerospace Computational Simulation (developed in JAXA)

- Flow Solver : UPACS (High-order version)
  - 3-D Compressible N-S Eqs.
  - Multi-block Structured Grid
  - Cell-centered Finite Volume Method
  - DDES w/ S-A model : performed fully turb.
    - SA-noft2
    - SA-noft2-strain : used strain rate instead of vorticity
    - SA-noft2-R (C_{rot}=1)
  - Spatial scheme : performed w/o flux limiter
    - 3rd-order MUSCL SLAU
    - 5th-order upwind Roe / SLAU — ref. FDC/ANSS 3D-10 (Ikeda)
    - 5th-order upwind SLAU + wiggle sensor → AIAA-2018-3784 (Ikeda *et al.*)
      (6th-order centered + 5th-order upwind diffusion w/ wiggle sensor)
      - Kinetic energy preserving, conservative / equivalent skew symmetric form
  - 2nd-order Euler implicit, LU-SGS, 5 sub-iterations
  - Periodic BC for spanwise
- Farfield sound pressure evaluation : UPACS-Acoustics
  - Ffowcs Williams-Hawkings Eq.
    - Solid Surface FW-H

Cases Calculated L2 (Medium) & L3 (Fine)

Scheme	Turb. Model	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2
3rd SLAU	SA-noft2	M/F			M/F				
3rd SLAU	SA-noft2 -strain	M		M/F				M/F	M/F
5th Roe	SA-noft2 -strain			M/F			M	M/F	M/F
5th SLAU	SA-noft2	M/F	F	F				F	F
5th SLAU	SA-noft2 -strain	F	M/F	M/F			M	M/F	M/F
5th SLAU	SA-noft2-R (C_{rot}=1)	F	F	F				F	F
5th SLAU+WS	SA-noft2 -strain		M/F	M/F				M/F	M/F
5th SLAU+WS (skewsym)	SA-noft2 -strain		M/F	M/F				M/F	M/F

Cases Calculated L2 (Medium) & L3 (Fine)

Scheme	Turb. Model	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2
3rd SLAU	SA-noft2	M/F			M/F				
3rd SLAU	SA-noft2 -strain	M		M/F				M/F	M/F
5th Roe	SA-noft2 -strain			M/F			M	M/F	M/F
5th SLAU	SA-noft2	M/F	F	F				F	F
5th SLAU	SA-noft2 -strain	F	M/F	M/F			M	M/F	M/F
5th SLAU	SA-noft2-R (C_{rot}=1)	F	F	F				F	F
5th SLAU+WS	SA-noft2 -strain		M/F	M/F				M/F	M/F
5th SLAU+WS (skewsym)	SA-noft2 -strain		M/F	M/F				M/F	M/F

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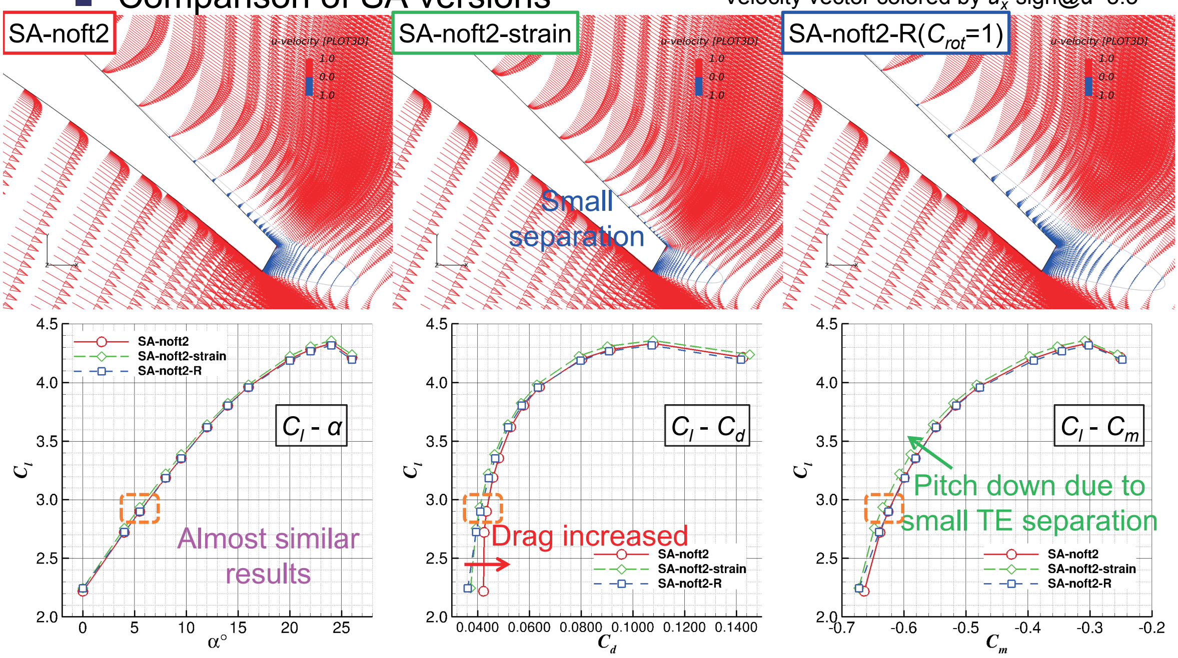
-5-

Aerodynamic Characteristics, 2-D RANS/5th SLAU/L3(Fine)

- Comparison of SA versions

Velocity vector colored by u_x-sign@α=5.5°



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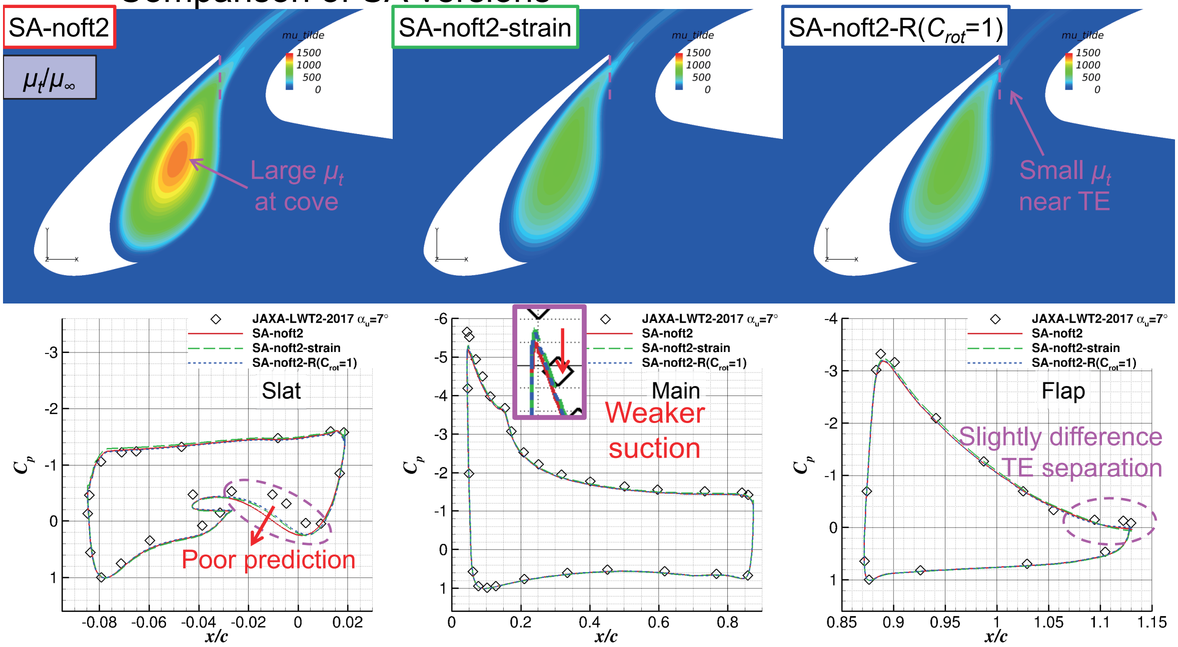
-6-

μ_t/μ_∞ contours & C_p plots@α=5.5° 2-D RANS/5th SLAU/L3(Fine)

- Comparison of SA versions



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Cases Calculated L2 (Medium) & L3 (Fine)

Scheme	Turb. Model	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2
3rd SLAU	SA-noft2	M/F			M/F				
3rd SLAU	SA-noft2 -strain	M		M/F				M/F	M/F
5th Roe	SA-noft2 -strain			M/F			M	M/F	M/F
5th SLAU	SA-noft2	M/F	F	F				F	F
5th SLAU	SA-noft2 -strain	F	M/F	M/F			M	M/F	M/F
5th SLAU	SA-noft2-R (C_{rot}=1)	F	F	F				F	F
5th SLAU+WS	SA-noft2 -strain		M/F	M/F				M/F	M/F
5th SLAU+WS (skewsym)	SA-noft2 -strain		M/F	M/F				M/F	M/F

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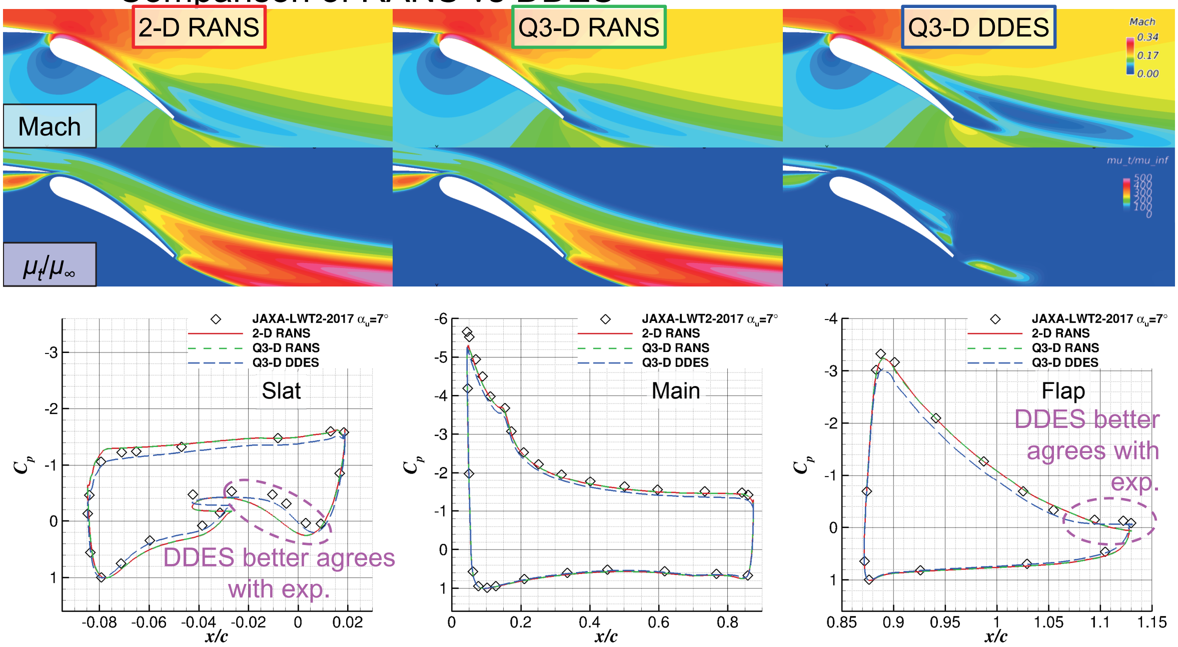
Mach, μ_t/μ_∞ contours & C_p plots@α=5.5° 5th SLAU/SA-noft2-strain/L3(Fine)

- Comparison of RANS vs DDES



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Cases Calculated　　L2 (Medium) & L3 (Fine)

Scheme	Turb. Model	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2
3rd SLAU	SA-noft2	M/F			M/F				
3rd SLAU	SA-noft2 -strain	M		M/F				M/F	M/F
5th Roe	SA-noft2 -strain			M/F			M	M/F	M/F
5th SLAU	SA-noft2	M/F	F	F				F	F
5th SLAU	SA-noft2 -strain	F	M/F	M/F			M	M/F	M/F
5th SLAU	SA-noft2-R (C_{rot}=1)	F	F	F				F	F
5th SLAU+WS	SA-noft2 -strain		M/F	M/F				M/F	M/F
5th SLAU+WS (skewsym)	SA-noft2 -strain		M/F	M/F				M/F	M/F

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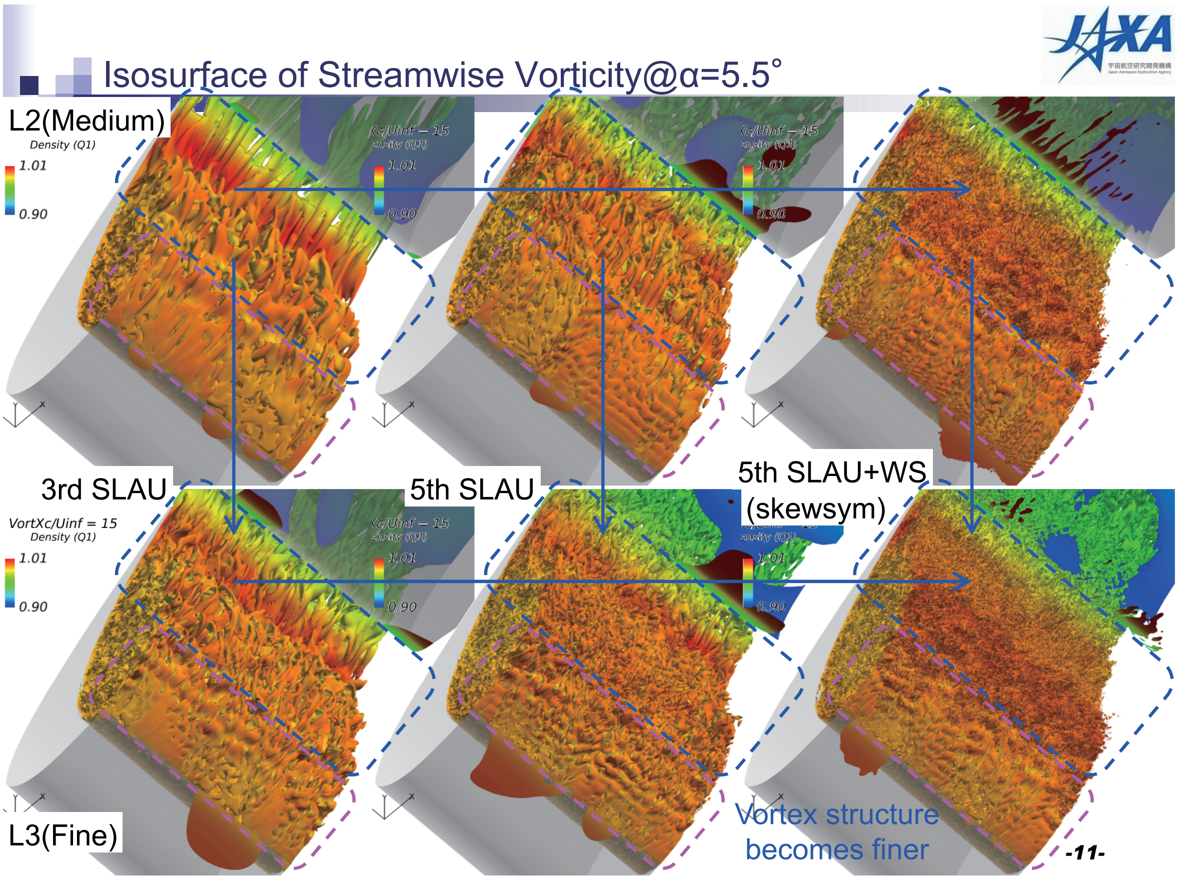
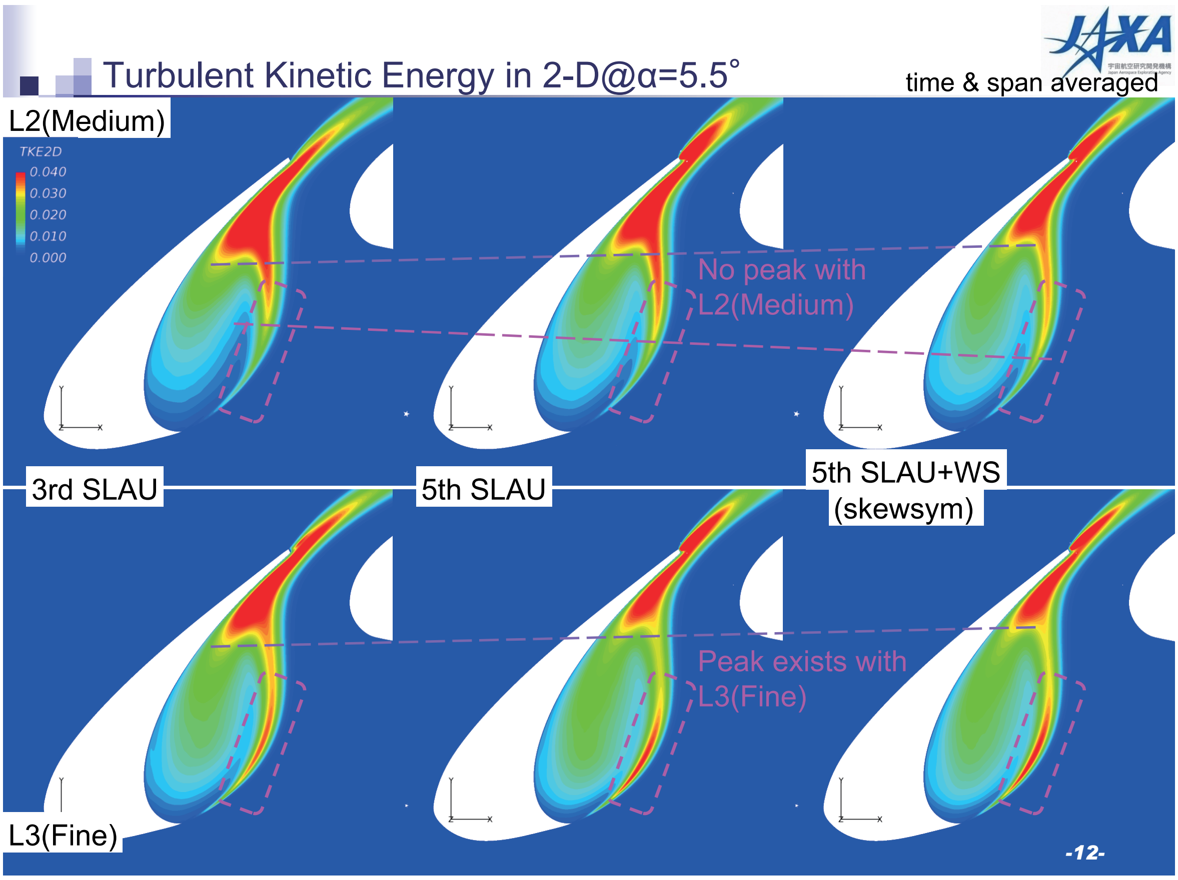
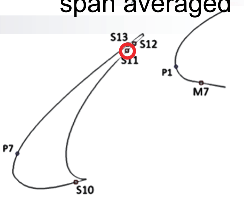

Isosurface of Streamwise Vorticity@α=5.5°
L2(Medium)
Density (Q1)
1.01
0.90
3rd SLAU
5th SLAU
5th SLAU+WS
(skewsym)
VortXc/Uinf = 15
Density (Q1)
1.01
0.90
L3(Fine)
Vortex structure
becomes finer
-11-

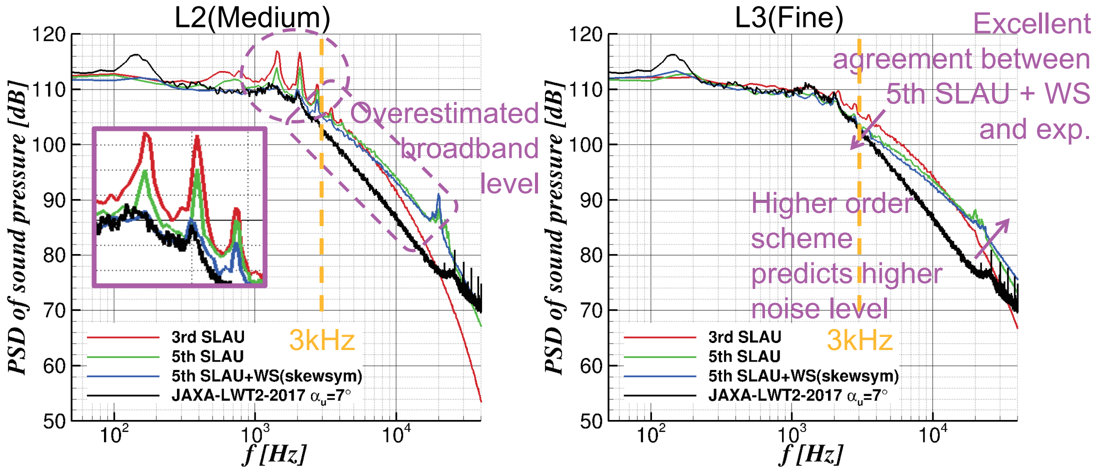

Turbulent Kinetic Energy in 2-D@α=5.5°
time & span averaged
L2(Medium)
TKE2D
0.040
0.030
0.020
0.010
0.000
No peak with
L2(Medium)
3rd SLAU
5th SLAU
5th SLAU+WS
(skewsym)
Peak exists with
L3(Fine)
L3(Fine)
-12-

Surface Pressure Spectra @S11

span averaged



Overestimated NBPs level due to delay in KH instability, but excellent agreement between 5th SLAU + WS and exp.



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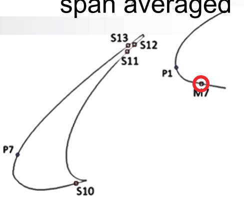
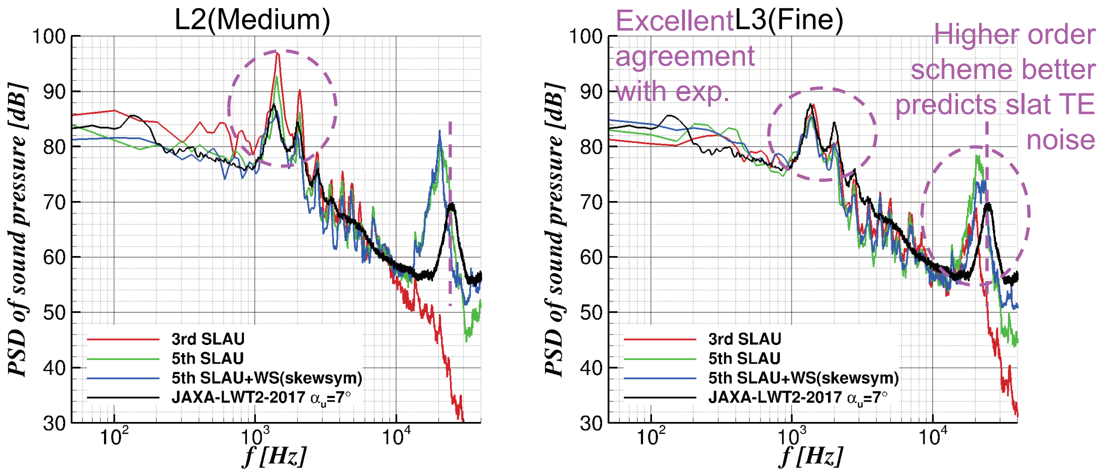
-13-

Surface Pressure Spectra @M7

span averaged



Overestimated NBPs level due to delay in KH instability, but excellent agreement between 5th SLAU + WS and exp.



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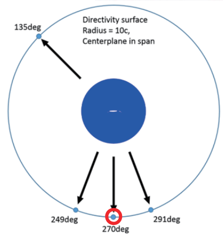
-14-

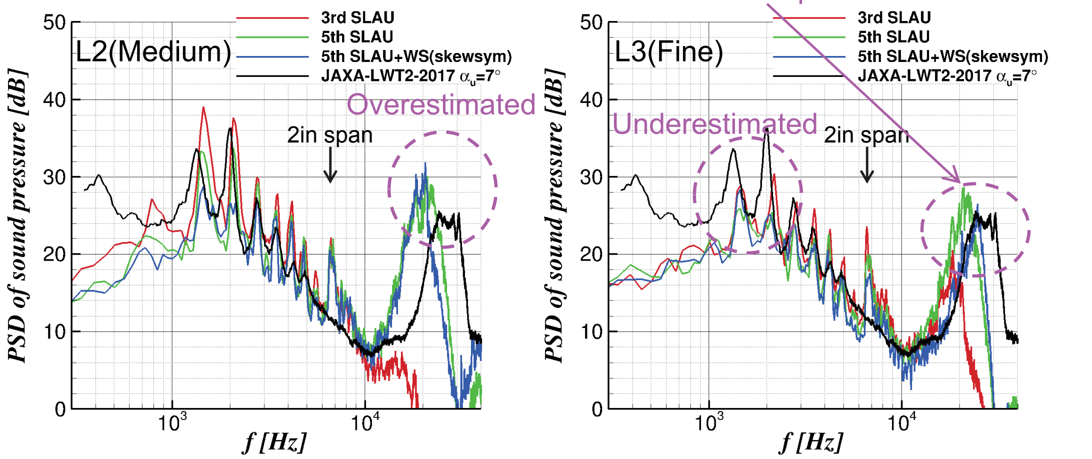
Farfield Acoustic Spectra @270°

- FW-H using solid surface



Excellent agreement between 5th SLAU + WS and exp.

*Normalized to 1inch span



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-15-

Summary

- Three SA models predicted similar aerodynamic characteristics with slight differences.
  - SA-noft2-strain and SA-noft2-R are better than SA-noft2 to suppress excessive growth of eddy viscosity.
- Compared with RANS, DDES better predicted flap TE separation and pressure distribution at slat cove due to the difference in eddy viscosity.
- Higher order schemes better predicted NBPs in nearfield spectra, but underestimated in farfield spectra.
  - Higher order schemes improved the prediction of NBPs at nearfield/farfield spectra even with medium grid.

  → We are also validating the effect of subgrid length scale in DDES to better predict KH instability.

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-16-