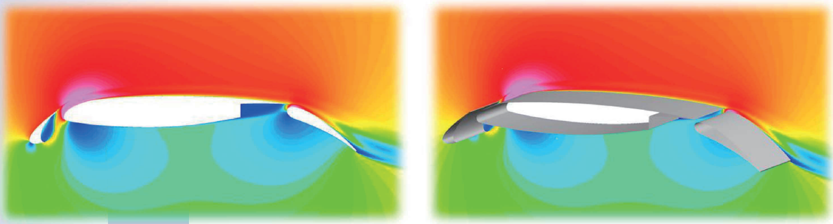
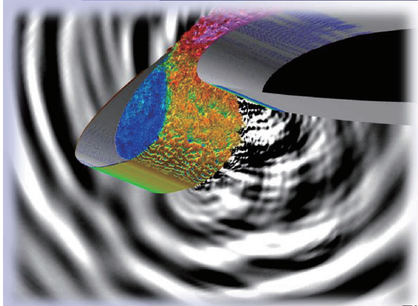


Aerodynamics and Aeroacoustics Prediction Using High-Order Schemes in Structured Grid CFD Solver, UPACS

高次精度スキームを用いた構造格子UPACSによる空力・音響予測



TANAKA Kentaro (Ryoyu Systems)
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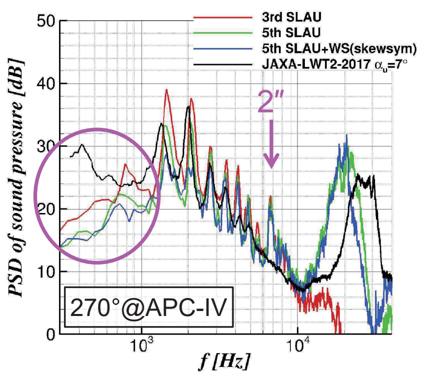
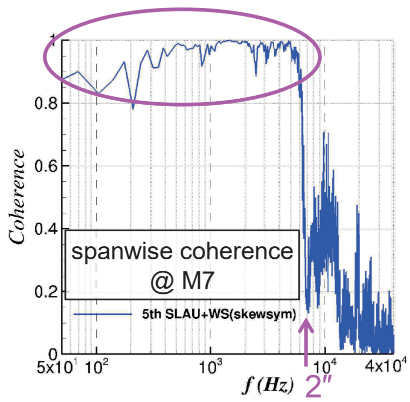
Fifth Aerodynamics Prediction Challenge (APC-V)
Jul. 1, 2019 @ WASEDA Univ.

-1-

Objectives

- Aerodynamic simulations:
  - → **To evaluate turbulence and transition models other than SA**
- Aeroacoustic simulations:
  - → **To evaluate the influence of span width of computational domains**
    - Previous predictions did not capture the noise level of exp. below about 1 kHz
      - Possibilities were explored other than fluctuations from main-cove
        - → Provided grids could not resolve it because of insufficient resolutions
    - Influence of periodic BC with 2″ span width at lower frequency
      - → May not be enough span width 2″





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Numerical method

▪ Flow solver: **UPACS** (developed in JAXA)

	Aerodynamic simulations	Aeroacoustic simulations
Governing Eq.	3-D compressive NS Eq.	
Discretization	Multi-block structured grid Cell-centered finite volume method	
Convection term	SLAU 3rd-order MUSCL	SLAU 5th-order upwind + wiggle sensor (skew symmetric form) → Ikeda et al., AIAA-2018-3784
Flux limiter	w/o limiter	
Turbulence model (performed fully turb.)	• SA-noft2 • SA-noft2-R (C_{rot} = 1) • SA-noft2-strain • SST-V	DDES based on SA-noft2-strain (used strain rate instead of vorticity)
Transition model	• SST-V-LM2009 (γ-Re_θ)	
Time integration	LU-SGS implicit, local timestep	2nd-order Euler implicit (sub-iter = 5)

- Farfield sound pressure evaluation: **UPACS-Acoustics**

Governing Eq.	Ffowcs Williams-Hawkings Eq.
FW-H surface	Solid surface of airfoil

Fifth Aerodynamics Prediction Challenge (APC-V)
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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
SLAU 3rd	SA-noft2	M,F			M,F				
	SA-noft2-R (C_{rot}=1)	M							
	SA-noft2-strain	M							
	SST-V	M,F			M				
	SST-V-LM2009	M,F							
SLAU 5th + wiggle sensor	SA-noft2-strain		M (1″)					M (1″)	
			M,F (2″)					M,F (2″)	
			M (4″)					M (4″)	
			M (6″)					M (6″)	

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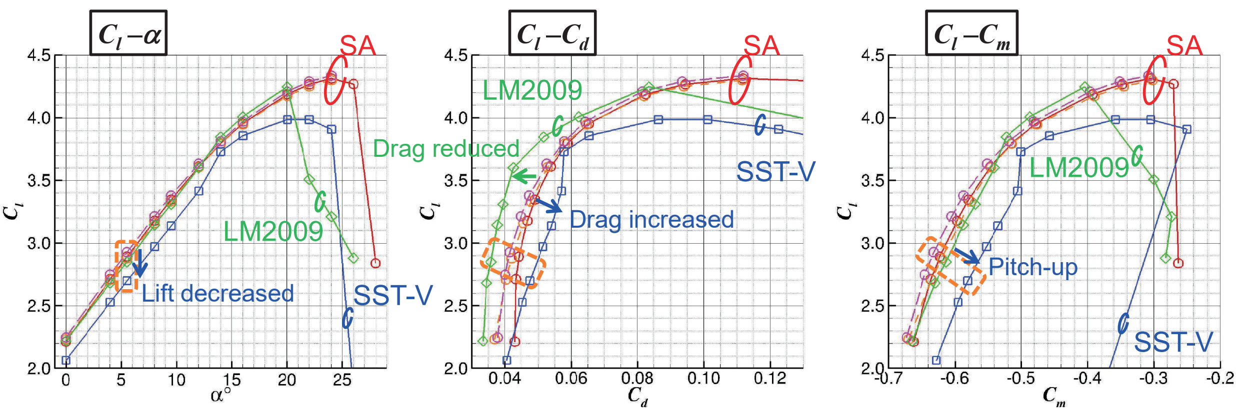
Cases calculated L2 (Medium) & L3 (Fine)

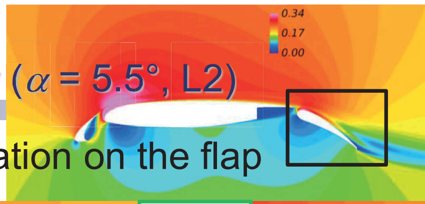
Scheme	Turb. Model	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2
SLAU 3rd	SA-noft2	M,F			M,F				
	SA-noft2-R (C_{rot}=1)	M							
	SA-noft2-strain	M							
	SST-V	M,F			M				
	SST-V-LM2009	M,F							
SLAU 5th + wiggle sensor	SA-noft2-strain		M (1″)					M (1″)	
			M,F (2″)					M,F (2″)	
			M (4″)					M (4″)	
			M (6″)					M (6″)	

Forces & moment (L2)

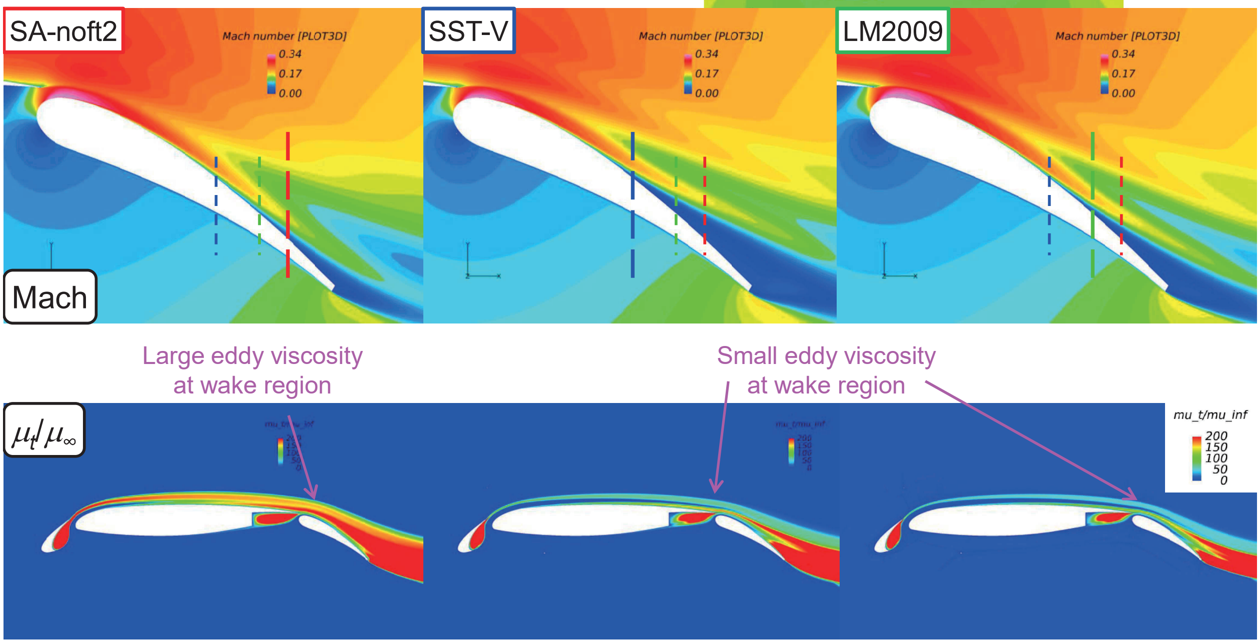
- SA variants predicted similar results
  - Excluding drag at α < 10°
- SST-V predicted different results with SA variants
  - Lower lift, higher drag, lower stall angle
    - Oscillating results at $\alpha \leq$ 12°
- SST-V-LM2009 predicted good agreement in lift curve with SA at $\alpha \leq$ 20°
  - Lower drag, lower stall angle
    - Oscillating results the whole of α-sweep



Contours of Mach & eddy viscosity (α = 5.5°, L2)

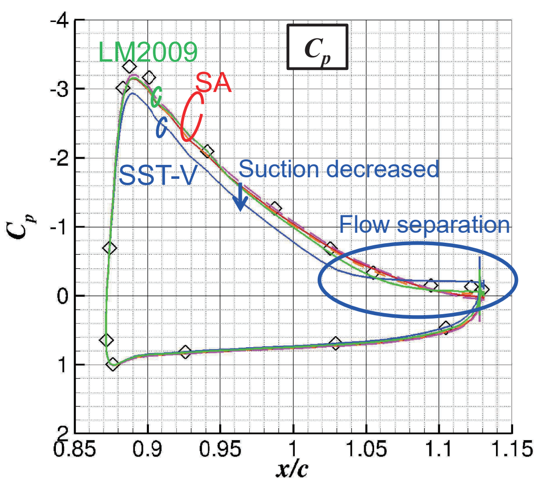


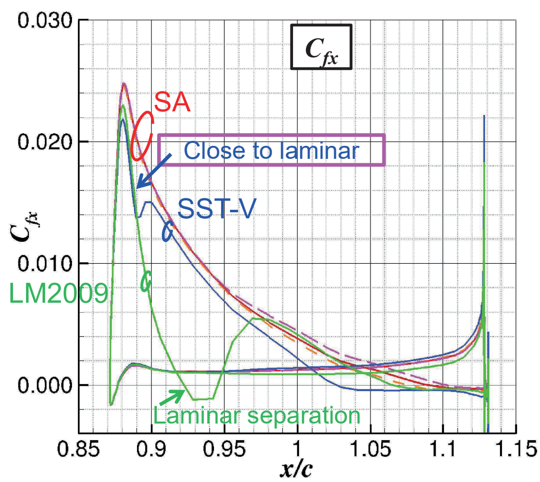
- SST-V predicted large flow separation on the flap



Surface pressure & skin friction distributions on the flap (α = 5.5°, L2)

- Surface pressure:
  - SST-V predicted large flow separation on the flap
- Skin friction:
  - LM2009 predicted laminar separation and transition to turbulence
  - SST-V predicted similar distribution to laminar (LM2009) at x/c < 0.89

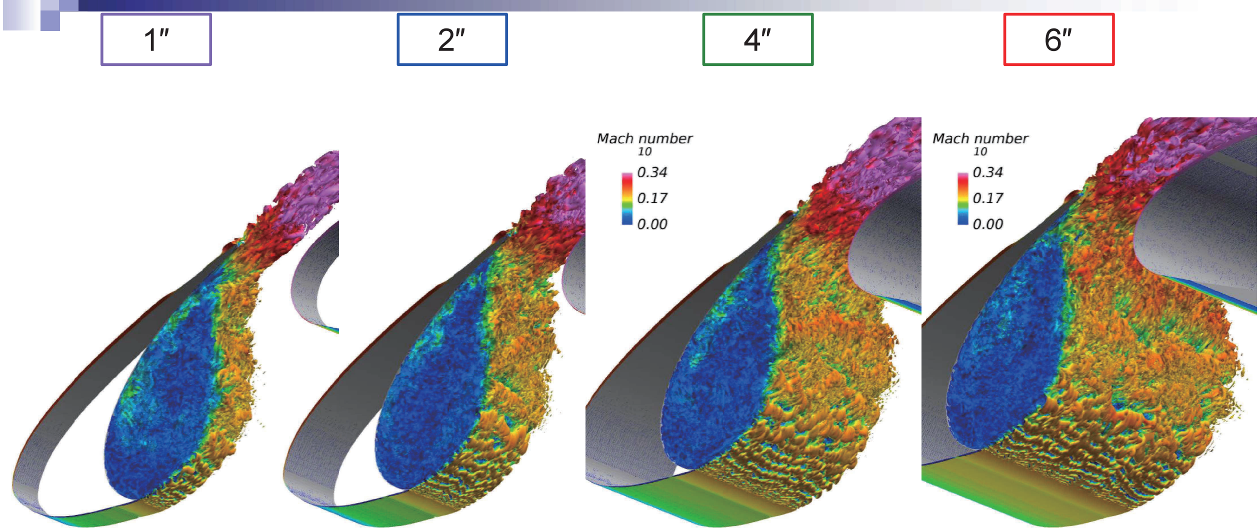




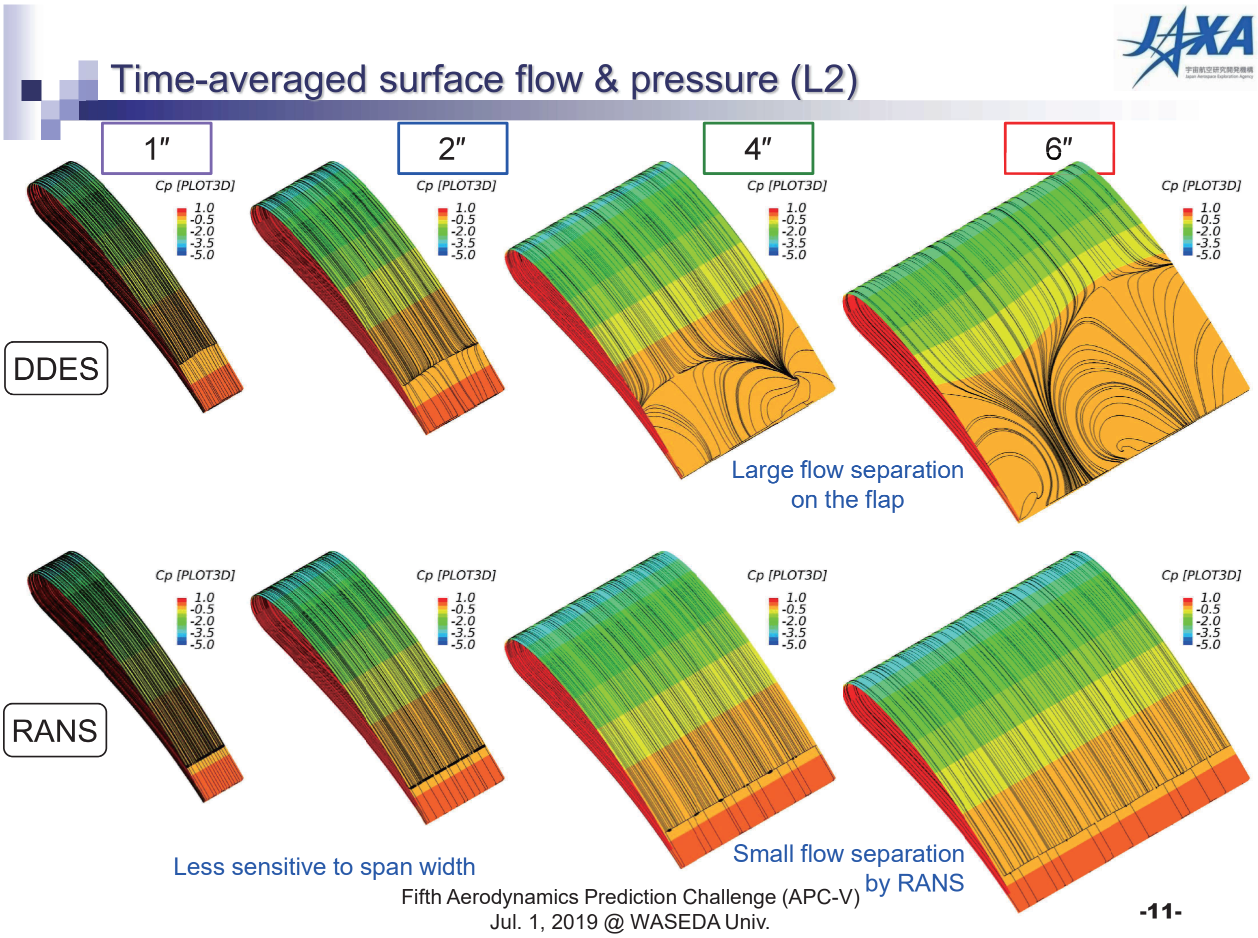
Cases calculated　L2 (Medium) & L3 (Fine)

Scheme	Turb. Model	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2
SLAU 3rd	SA-noft2	M,F			M,F				
	SA-noft2-R (C_{rot}=1)	M							
	SA-noft2-strain	M							
	SST-V	M,F			M				
	SST-V-LM2009	M,F							
SLAU 5th + wiggle sensor	SA-noft2-strain		M (1″)					M (1″)	
			M,F (2″)					M,F (2″)	
			M (4″)					M (4″)	
			M (6″)					M (6″)	

Instantaneous snapshots of Q-criterion isosurface colored by Mach (L2)



- Similar flow structures were obtained



Time-averaged surface flow & pressure (L2)
1″
2″
4″
6″
Cp [PLOT3D]
1.0
-0.5
-2.0
-3.5
-5.0
DDES
Large flow separation on the flap
RANS
Less sensitive to span width
Small flow separation by RANS
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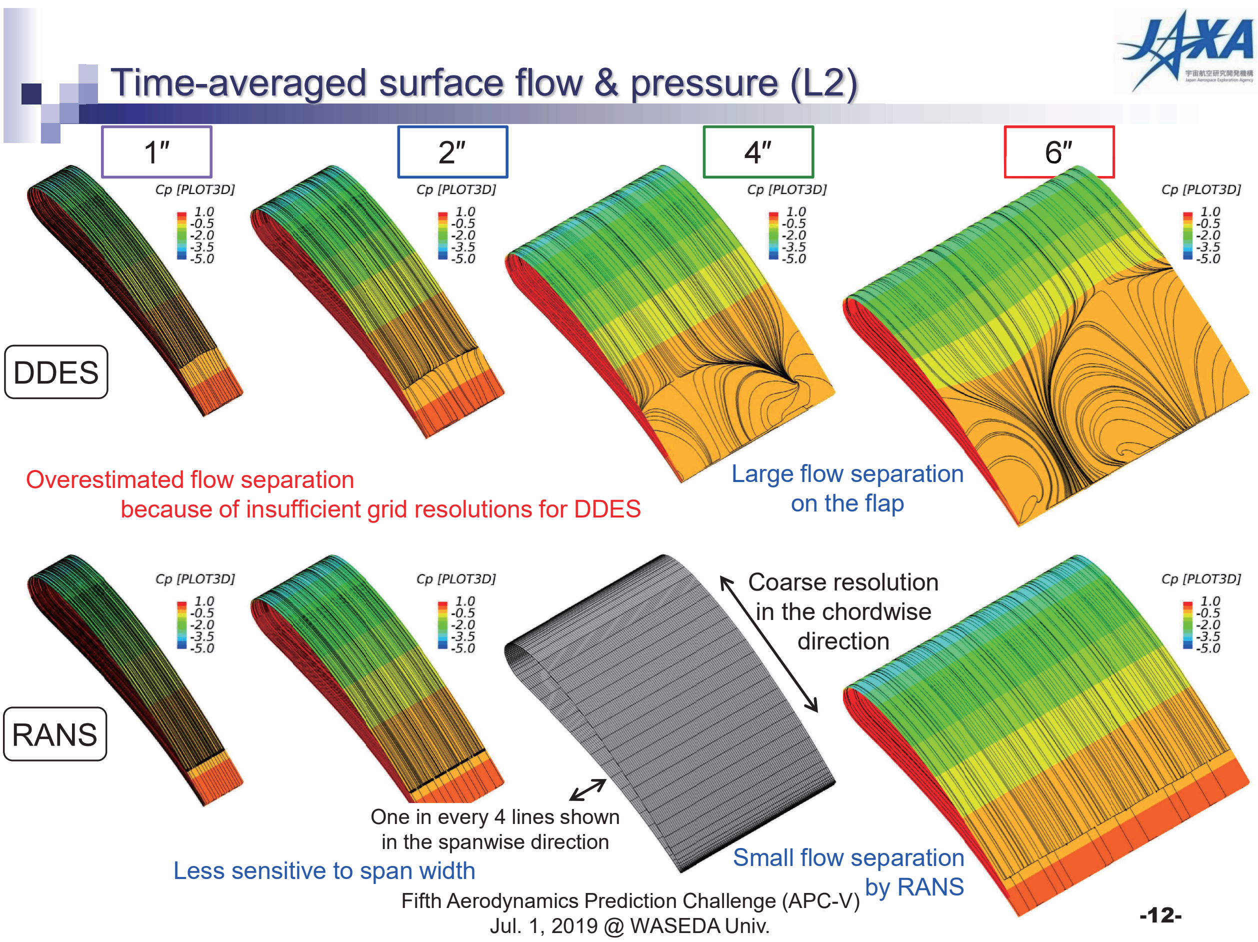

Time-averaged surface flow & pressure (L2)
1″
2″
4″
6″
Cp [PLOT3D]
1.0
-0.5
-2.0
-3.5
-5.0
DDES
Overestimated flow separation because of insufficient grid resolutions for DDES
Large flow separation on the flap
RANS
Coarse resolution in the chordwise direction
One in every 4 lines shown in the spanwise direction
Less sensitive to span width
Small flow separation by RANS
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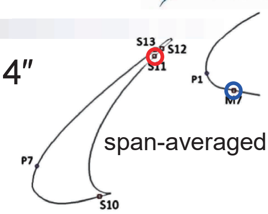
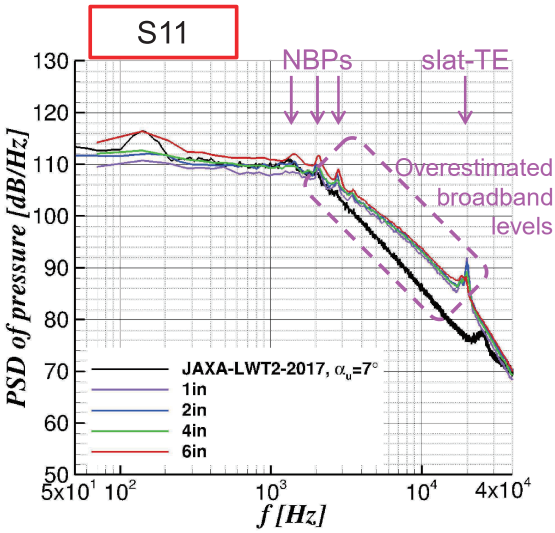
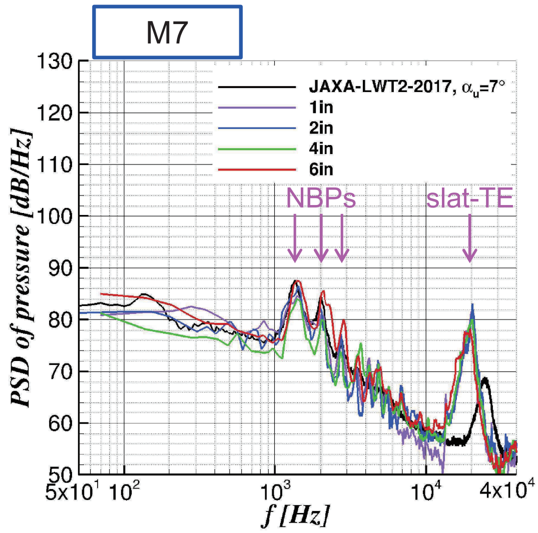
Surface pressure spectra (L2)

- Similar results were obtained among the cases of 1″ to 4″
- Predicted PSD levels with the case of 6″ were higher than those with the cases of 1″ to 4″
  → Because of flow separation on the flap

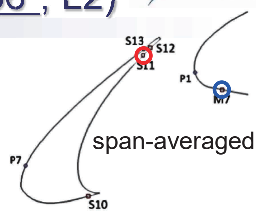


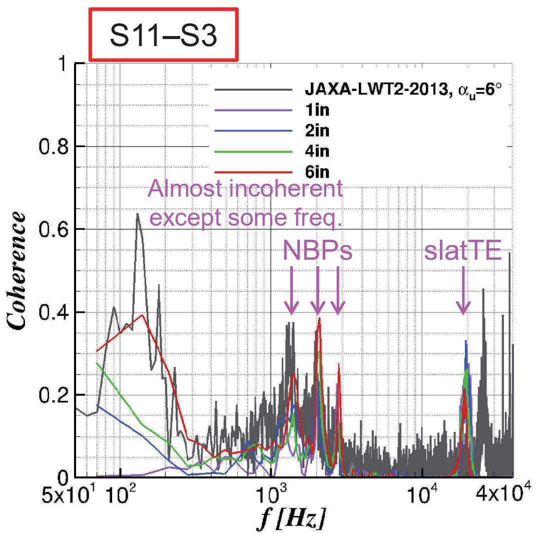


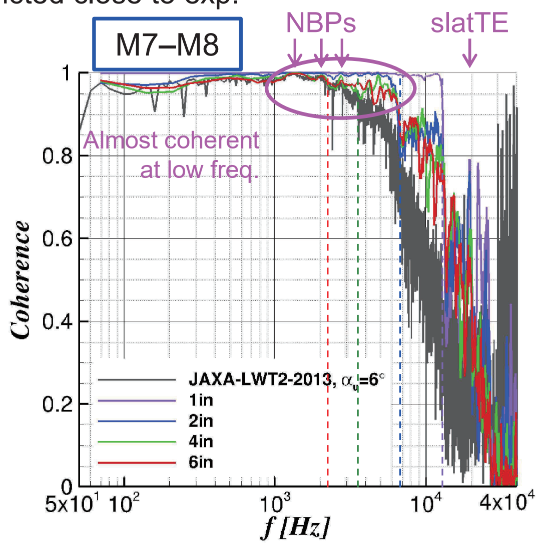


Spanwise coherence of surface pressure (Δz = 0.156″, L2)

- S11–S3: Almost incoherent except NBPs & slat-TE peaks
- M7–M8:
  - Almost coherent in the range lower than frequencies corresponding to one acoustic wavelength across the periodic span width
  - A simulation with a wider span predicted close to exp.

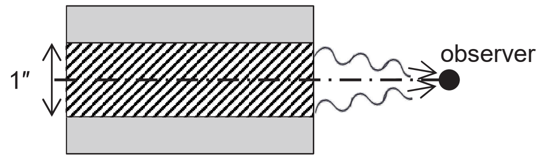


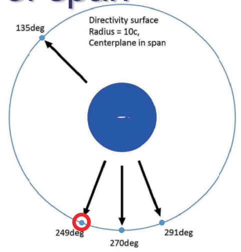




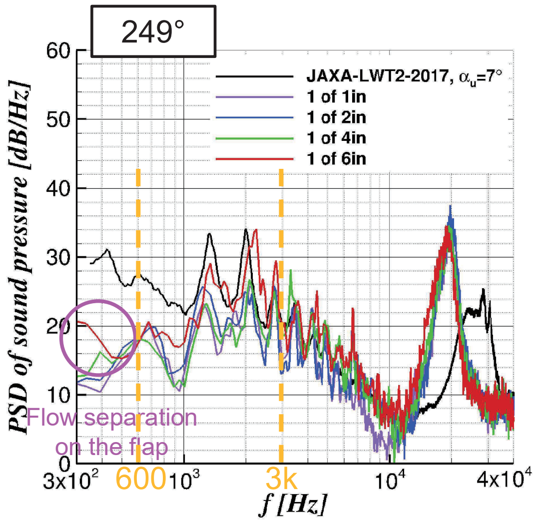
Acoustic spectra, FW-H using 1″ width data at center of span

(submitted data)



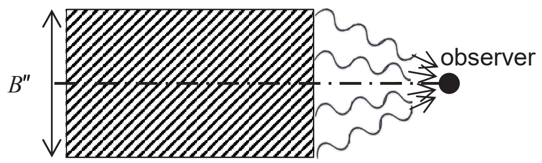


- Predicted PSD levels were lower than exp. in the range lower than 3 kHz
- Predicted levels by 6″ were higher than the others
  → Attributed to decrease of effective angle of attack due to flow separation on the flap
- The influence of fluctuations due to flow separation on the flap appears in the range lower than 600 Hz

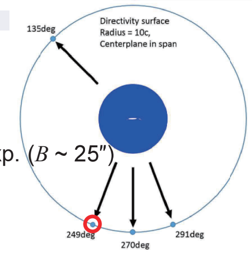


Acoustic spectra, FW-H using full-span data

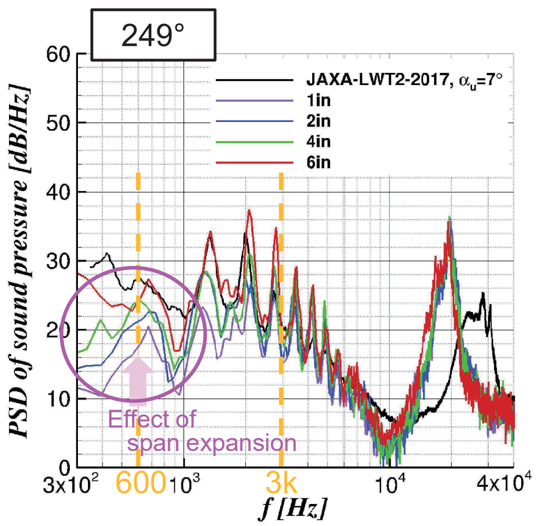
(not submitted data)



- Normalized to 1″
  - span width → power ratio
    - Same procedure with exp. ($B \sim 25''$)
  - $SPL(B'') = SPL(1'') + 10 log B$



- NBPs: 1″ ~ 2″ < 4″ < 6″
  - Including the influence of flow separation on the flap
- A simulation with a wider span predicted higher PSD levels in the range lower than 3 kHz



Summary

- Aerodynamic simulations:
  - SST-V predicted significantly different characteristics with SA because of large flow separation on the flap
  - SST-V-LM2009 predicted similar characteristics to SA, except near-stall conditions, because flow separation on the flap was suppressed
- Aeroacoustic simulations:
  - As the span of the computational domain was larger,
    - flow separation on the flap became prominent if grid resolutions were insufficient for DDES
    - predicted spanwise coherence of surface pressure on the lower surface of the main-LE became close to that of experiment
    - predicted farfield PSD levels became close to experimental results at lower frequencies

Future work

- Aerodynamic simulations:
  - Continue evaluation of SST turbulence & transition models
- Aeroacoustic simulations:
  - Evaluation of results by zonal DDES/RANS
    - to remove influences of flow separation on the flap (especially 6″ span width)

Acknowledgments

- The authors would like to thank
  - *Dr. Junichi KAZAWA (JAXA) and Mr. Susumu KATO (VINAS)*

    for their technical support in analysis using SST turbulence & transition models.

- These calculations were performed on JAXA Supercomputer System generation 2 (JSS2).

Thank you for your attention!