Wind Tunnel Walls Effects on the NASA High Lift Common Research Model in RANS Calculations using FaSTAR・Uchida Kosuke, Matsuzaki Tomoaki, Kojima Yoimi, Sansica Andrea, Zauner Markus, Hashimoto Atsushi (JAXA)

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Outline

Introduction

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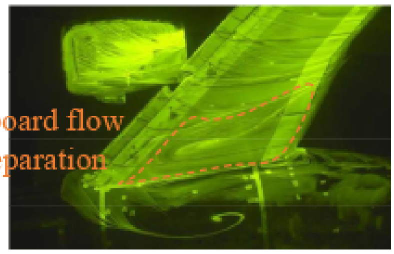
Discussions in APC-8 indicate that
Wind tunnel walls affect the inboard flow separation



Tasks and Goals

- Solving the Reynolds-Averaged Navier-Stokes (RANS) equations to characterize aerodynamic performance of the NASA High Lift Common Research Model
- Investigating the wind tunnel interference effects
- Determining turbulence model sensitivity

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Case1 : Verification case (RANS)

Case1 : Methodology

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Numerical approach and Flow conditions

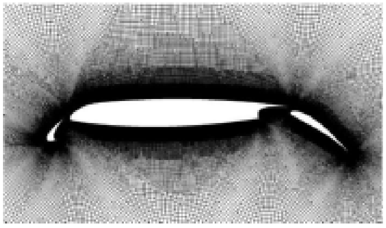
Numerical method
Solving RANS equations
CFD solver : FaSTAR
Turbulence model : SA-noft2, SA-noft2-R
Convection flux : HLLEW 2nd-order U-MUSCL
Time integration : LU-SGS

Flow conditions	
Mach number	$Ma = 0.20$
Reynolds number	$Re = 5.00 \times 10^6$
Reference temperature	$T_{ref} = 272.1$ [K]
Angle of attack	$\alpha = 16^\circ$

[1] https://turbmodels.larc.nasa.gov/multielementverif_grids.html

Geometry and Grids

3-elements 2D CRM-HL airfoil



Family 1 unstructured grids[1]

Grid Level	Nodes
L1 (coarsest)	173958
L2	294161
L3	508099
L4	930671
L5	1679982
L6	3227904
L7 (finest)	5980721

Case1 : Aerodynamic Coefficients

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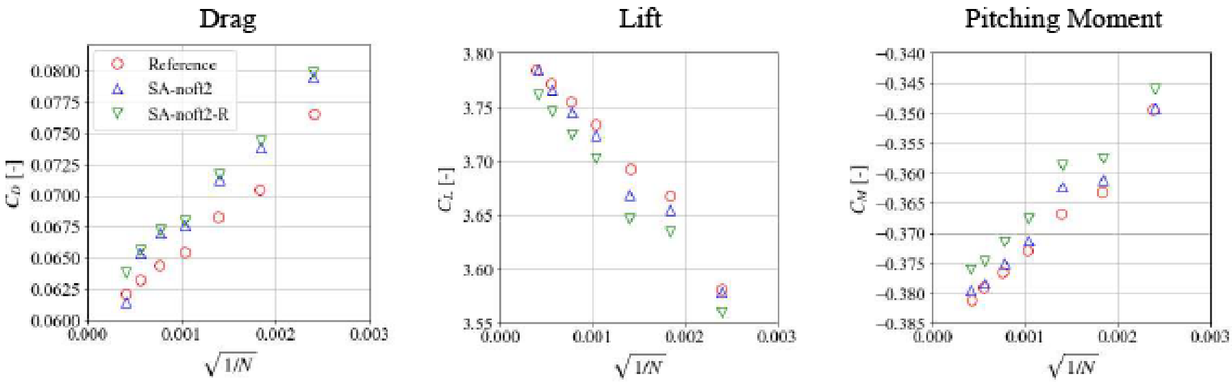
Comparisons with reference data

Reference data : FUN3D using 2nd-order advection for turbulence model(SA-neg)[2]

- Predicted C_D values are close for both SA-noft2 and SA-noft2-R
- SA-noft2 has better agreement than SA-noft2-R for C_L and C_M predictions



[2] https://turbmodels.larc.nasa.gov/multielementverif_saneg.html

Case1 : C_p and $C_{f,x}$ distributions

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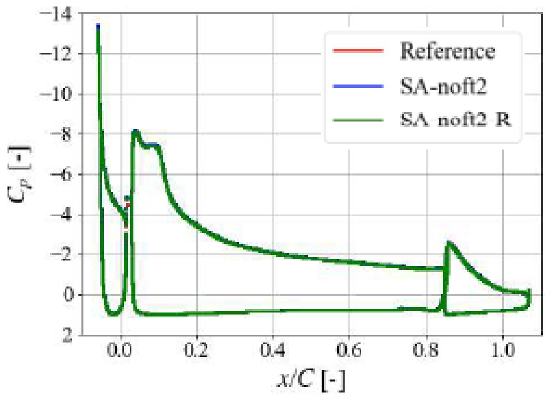
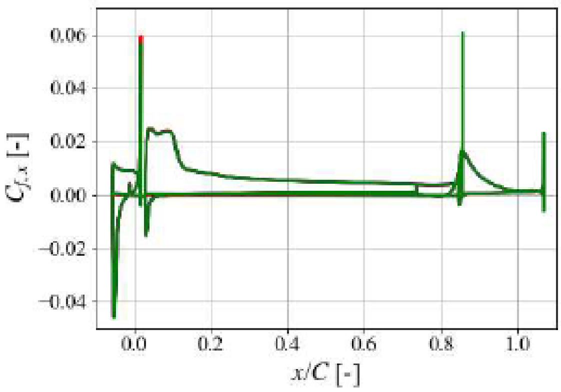
Comparisons with reference data

C_p and $C_{f,x}$ values extracted from the finest L7 grid

- Both SA-noft2 and SA-noft2-R results agree nearly perfectly with reference data





Case1 : Some Profiles

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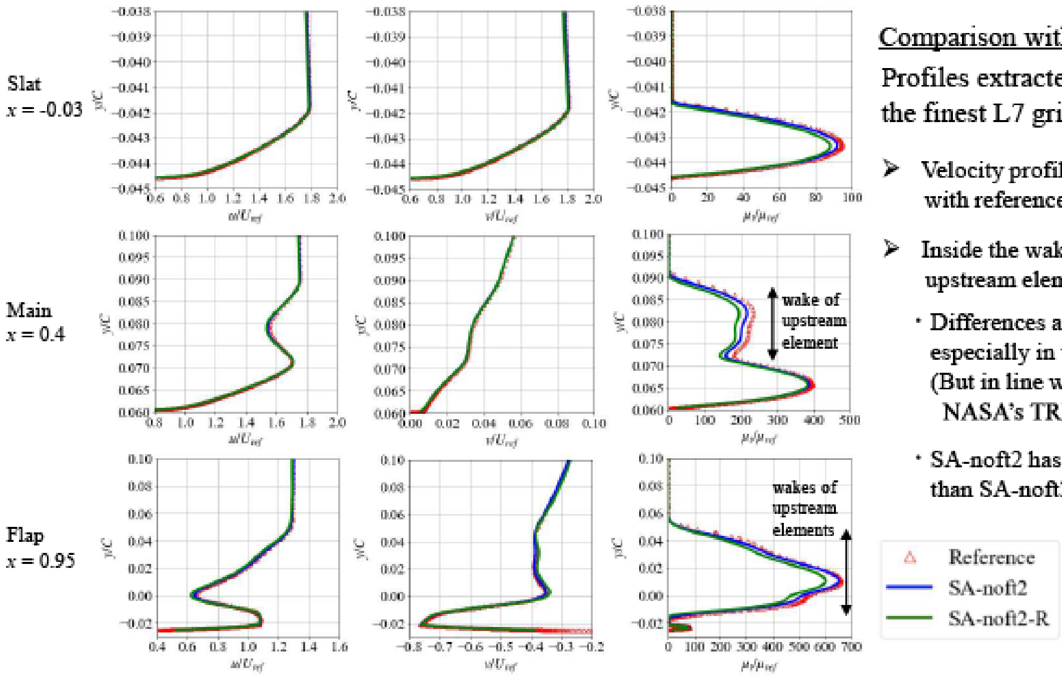

Comparison with reference data

Profiles extracted from the finest L7 grid

- Velocity profiles agree well with reference data
- Inside the wake region of the upstream elements
  - Differences are apparent, especially in the eddy viscosity (But in line with what seen on NASA's TRM website)
  - SA-noft2 has better agreement than SA-noft2-R

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Case2 : In-Tunnel RANS simulations

Case2 : Methodology

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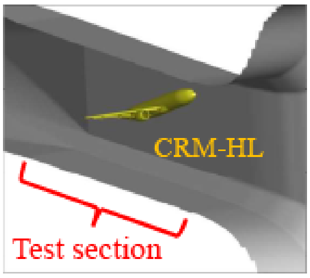
Geometry

Half span of the High-Lift configuration of NASA's Common Research Model (CRM-HL)

QinetiQ wind tunnel is also modelled



Numerical approach and Flow conditions

Numerical method
Solving RANS equations
CFD solver : FaSTAR
Discretization : Cell-vertex finite volume
Turbulence model : SA-noft2, SA-noft2-R
Convection flux : HLLEW 2nd-order U-MUSCL
Time integration : LU-SGS
CFL number : 10

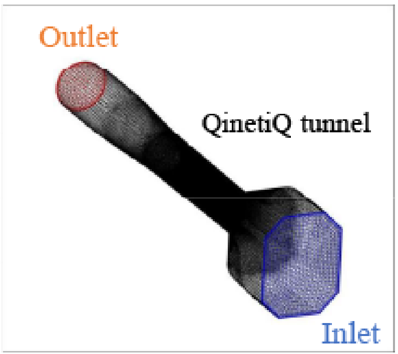
Flow conditions	
Mach number	$Ma = 0.20$
Reynolds number	$Re = 5.49 \times 10^6$
Reference temperature	$T_{ref} = 289.44$ [K]
Angle of attack	$\alpha = 5.98, 15.48, 17.98, 19.98$ deg

Case2 : Methodology

<u>Computational grid</u>

105T-ANSA-Unstractured-Yplus1 (Level B)[3]

- The grid contain 156 million cells
- Minimum y+ = approx. 1



<u>Boundary conditions</u>

- Wind tunnel walls : No-slip condition
- Inlet : Fixed static pressure, static temperature, and velocity
- Outlet : Fixed static pressure

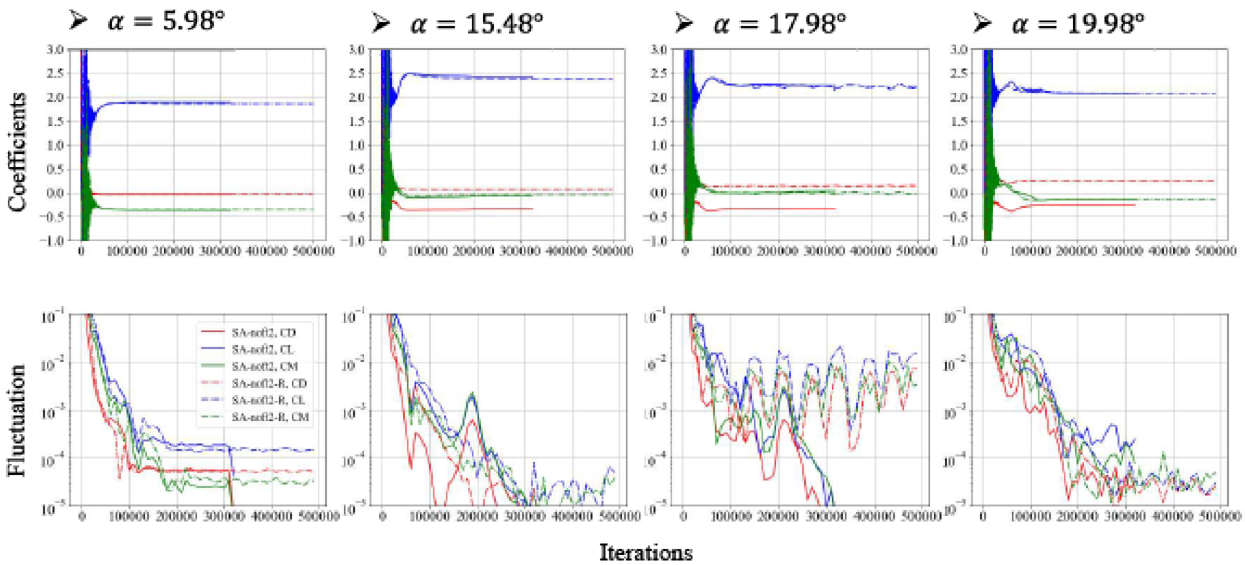
In order to obtain the targeted Mach number in the test section *(M_{test})*, the inlet and outlet static pressure values are determined using isentropic flow relations

AoA	p_i	T_i	U_i	p_o	M_{test}
5.98	17712.04	292.18	8.9941	17585.97	0.2022
15.48	17713.11	292.19	9.0019	17586.80	0.2020
17.98	17718.43	292.21	9.0410	17590.99	0.2018
19.98	17728.08	292.26	9.1113	17598.57	0.2016

[3] https://hiliftpw.larc.nasa.gov/Workshop4/grids_downloads.html

Case2 : Convergence

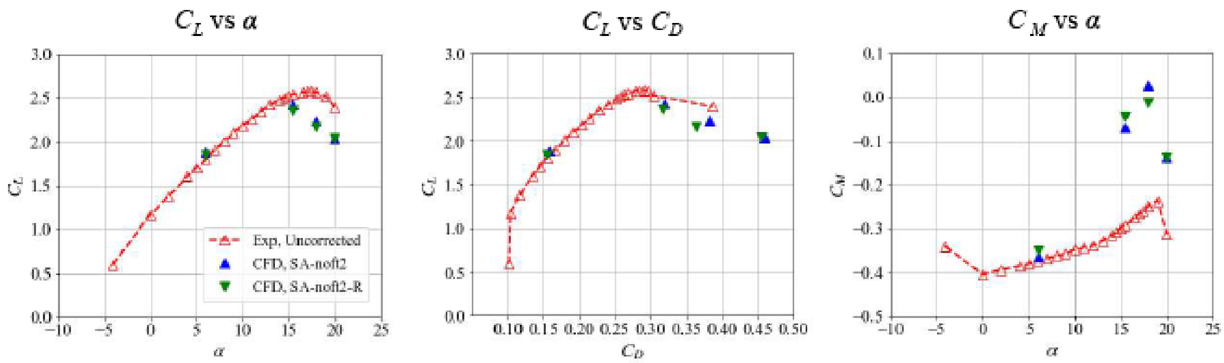
<u>Aerodynamic coefficients convergence</u>



Case2 : Aerodynamic Coefficients

Aerodynamic coefficients compared to the experimental data[4]

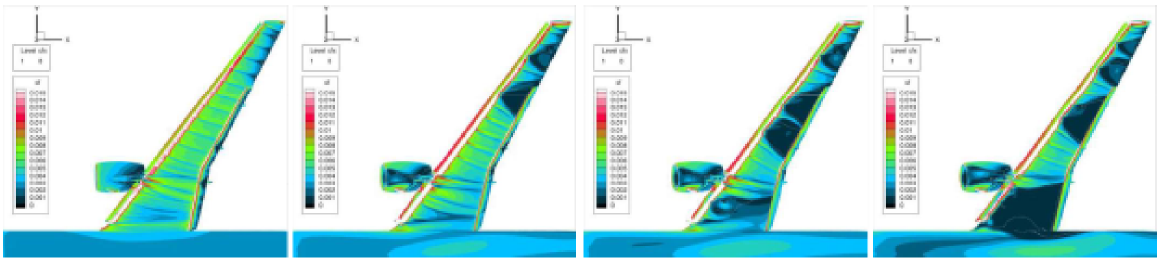
- Near stall, CFD results under-predict C_L with respect to the experimental data
- Predicted C_L and C_D values are close between SA-noft2 and SA-noft2-R
- C_M values have striking differences over $\alpha = 15.48°$



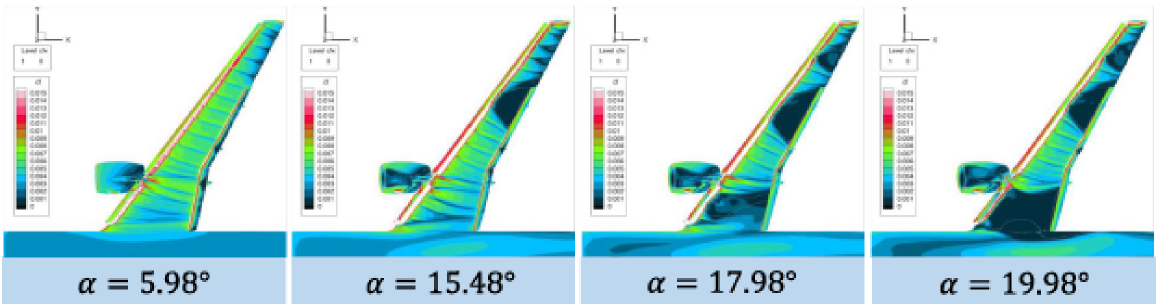
[4] https://hiliftpw.larc.nasa.gov/Workshop4/windtunneldata.html

Case2 : Skin Friction

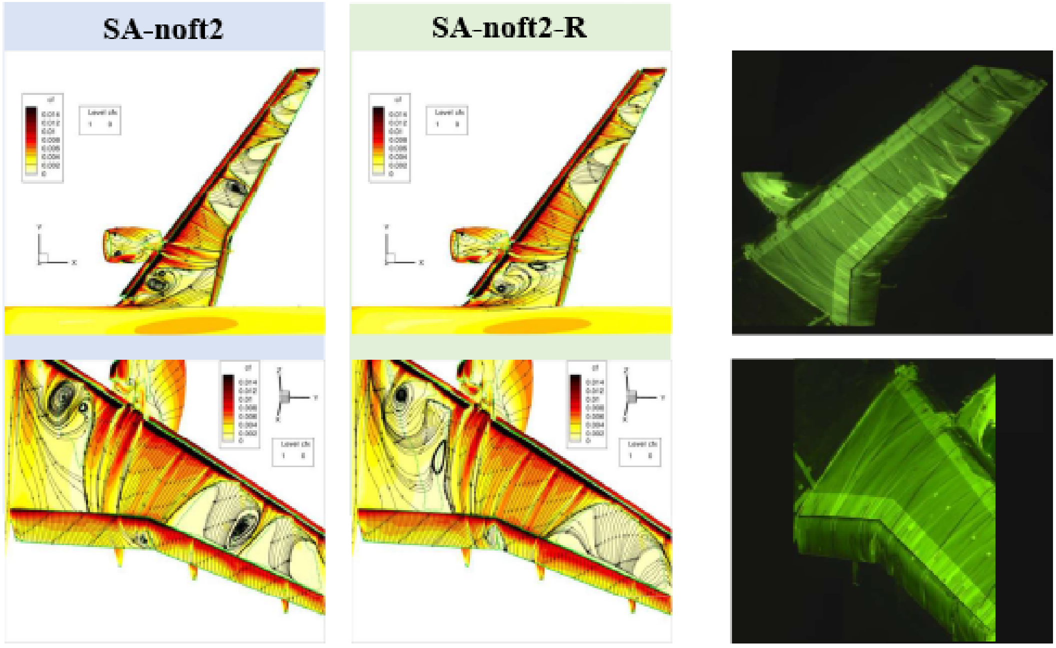
- SA-noft2



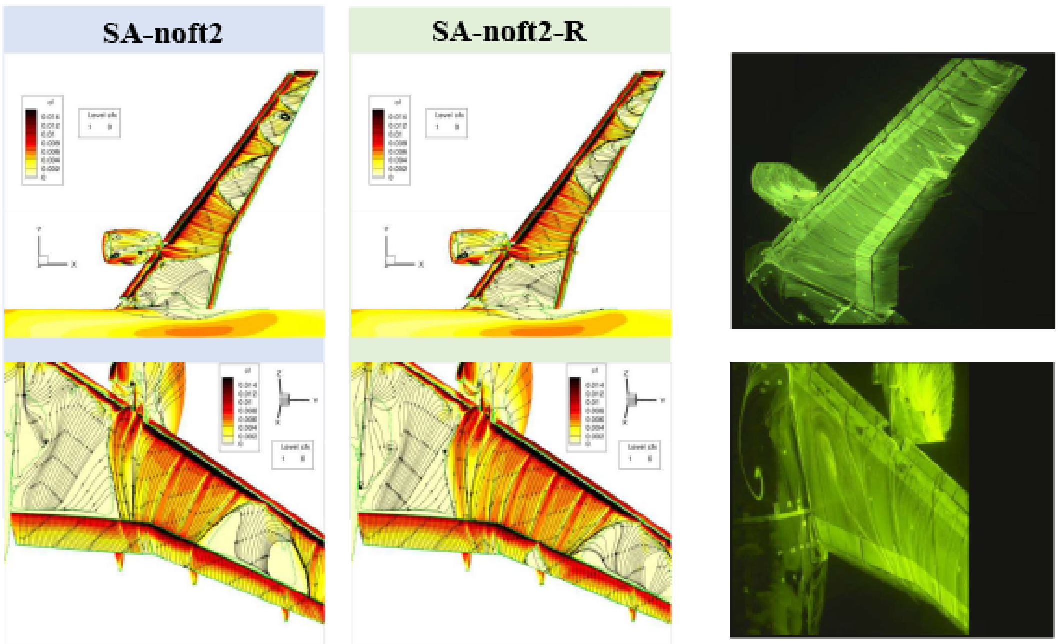
- SA-noft2-R



Case2 : Streamlines ($\alpha = 17.98$) 17/19



Case2 : Streamlines ($\alpha = 19.98$) 18/19



Conclusions

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- CFD under-predicted C_L values near stall
- CFD results predicted larger flow separation on the nacelle and in the inboard and outboard regions
- The inclusion of the wind tunnel walls does not improve the RANS CFD predictions and the same problems seen in the Free-air RANS predictions persist
- Although there were differences in the magnitude and location of separation among turbulence models, no significant differences were observed in the prediction of aerodynamic characteristics

Thank you for your attention