Sixth Aerodynamics Prediction Challenge (APC-6)

Flow simulations around NASA-CRM with Reynolds stress model

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Objective

Assess the prediction accuracy and practical capability of SSG/LRR-ω RSM in the prediction of NASA Common Research Model (CRM), by comparing with k-ω SST model.

Reynolds stress model

SSG/LRR-ω RSM: Reynolds stress model proposed by Eisfield et al. [2005]

Governing equation:

$$\frac{\partial(\bar{\rho}\hat{u}_i)}{\partial t}+\frac{\partial(\hat{u}_j\bar{\rho}\hat{u}_i)}{\partial x_j}=-\frac{\partial\bar{p}}{\partial x_i}+\frac{\partial\bar{\sigma}_{ij}}{\partial x_j}+\frac{\partial\bar{\tau}_{ij}}{\partial x_j}$$

$\bar{\tau}_{ij}$

Turbulence model:

Six Reynolds stress equations and a length-scale equation are given by

$$\frac{\partial\bar{\rho}\hat{R}_{ij}}{\partial t}+\frac{\partial\bar{\rho}\hat{u}_l\hat{R}_{ij}}{\partial x_l}=\bar{\rho}P_{ij}+\bar{\rho}\Pi_{ij}-\bar{\rho}\epsilon_{ij}+\bar{\rho}D_{ij}\qquad(\bar{\tau}_{ij}=-\bar{\rho}\hat{R}_{ij})$$

$$\frac{\partial\bar{\rho}\omega}{\partial t}+\frac{\partial(\bar{\rho}\hat{u}_l\omega)}{\partial x_l}=\frac{\alpha_\omega\omega}{\hat{k}}\frac{\bar{\rho}P_{ll}}{2}-\beta_\omega\omega+\frac{\partial}{\partial x_l}\left[\left(\bar{\mu}+\sigma_\omega\frac{\bar{\rho}\hat{k}}{\omega}\right)\frac{\partial\omega}{\partial x_l}\right]+\sigma_d\frac{\bar{\rho}}{\omega}\max\left(\frac{\partial\hat{k}}{\partial x_j}\frac{\partial\omega}{\partial x_j},0\right)$$

P_{ij}: production Π_{ij}: pressure-strain ϵ: dissipation D_{ij}: Dissipation

3

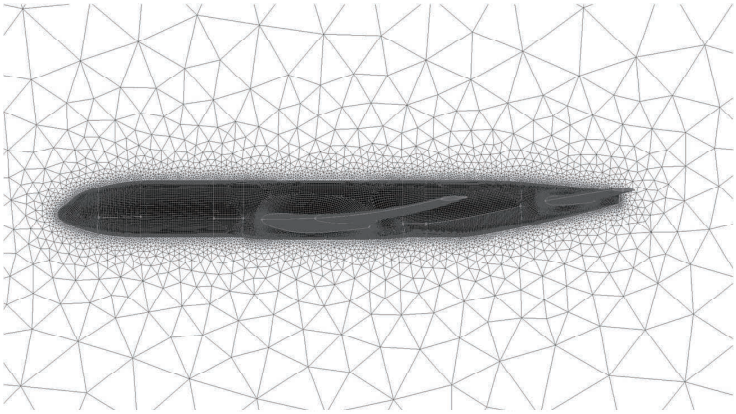
Subject 1: steady case

Flow condition	
Mach number M_∞	0.168
Reynolds number Re	1.06×10^6
Reference temperature T_{ref}	310 K
Angle of attack α	$-3.22\sim18.08$ degree
Turbulent intensity Tu_∞	0.07%
Eddy viscosity ratio μ_t/μ	10.0

Numerical method	
Discretization	Cell-centered finite volume
Inviscid flux	SLAU with 3rd-order U-MUSCL
Viscous flux	2nd order central approximation
Time integration	LU-SGS

4

CRM grid



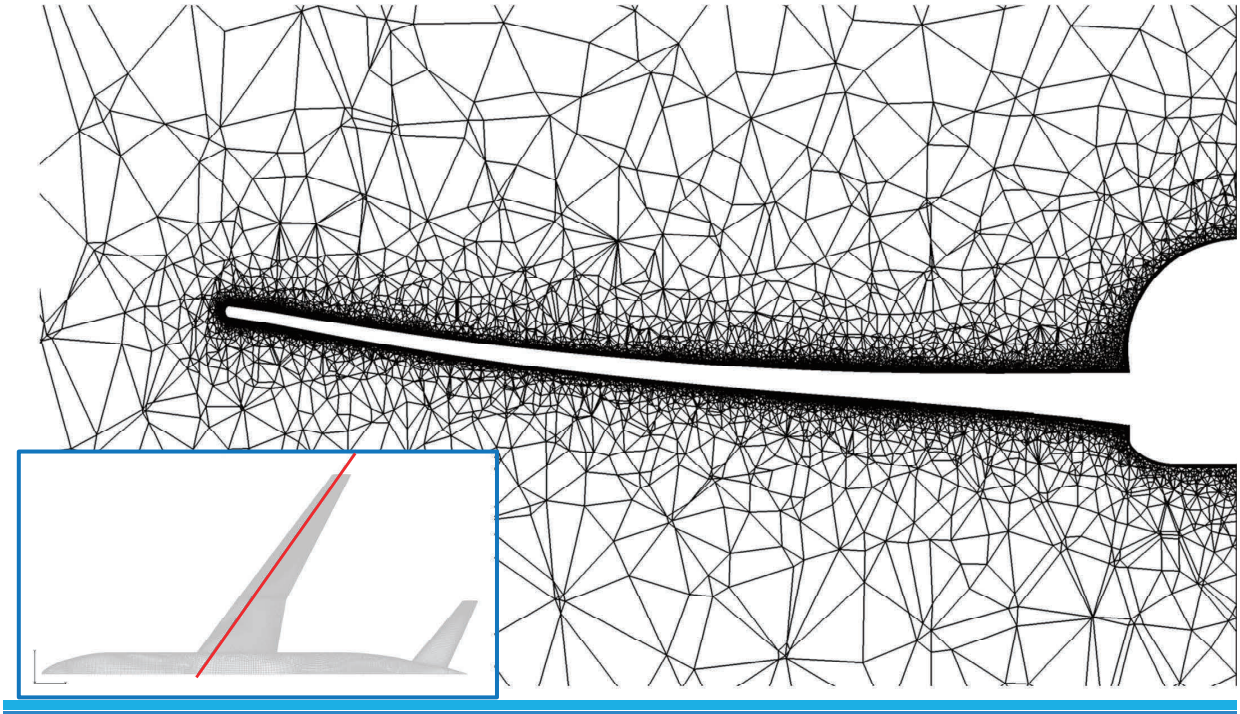
Cell type	Amount
Tetrahedral	1,791,861
Pyramids	65,569
Prism	14,225
Hexahedral	1,639,225
All	3,510,880

Number of points = 2,081,695

$y^+ \leq 0.7$ (AoA = 0 deg)

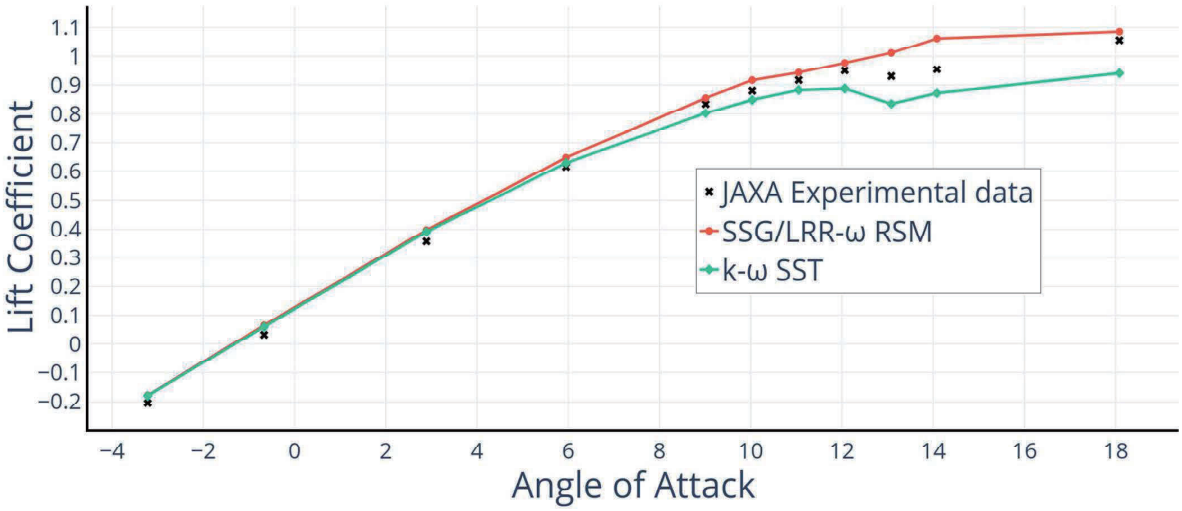
5

CRM grid (2)



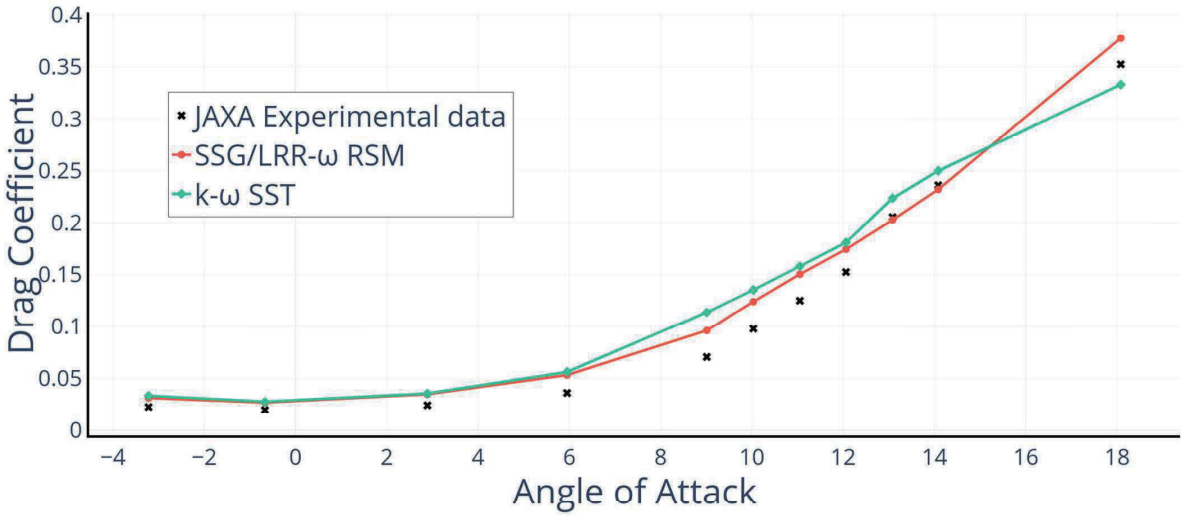
6

Comparison of lift coefficient



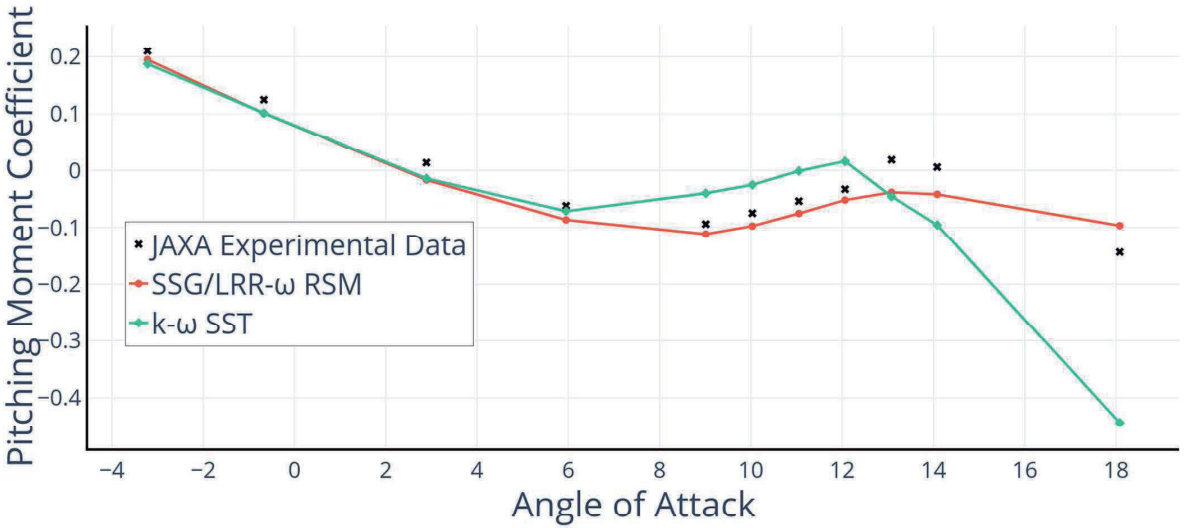
7

Comparison of drag coefficient



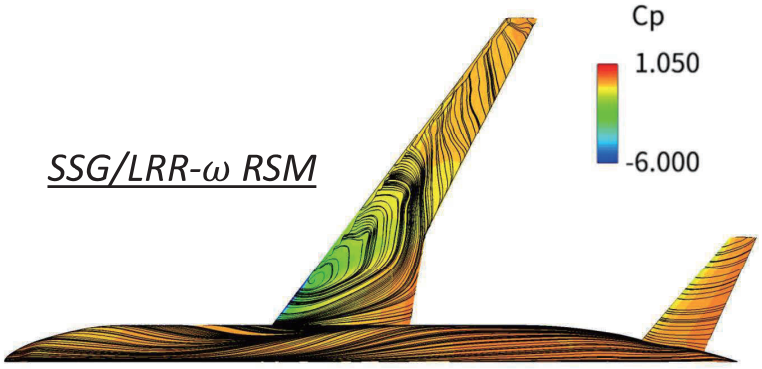
8

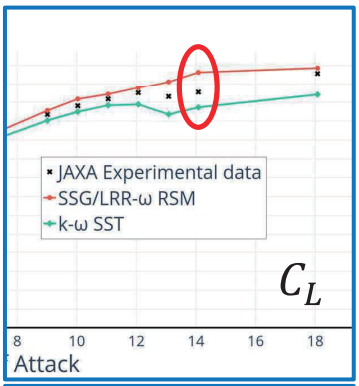
Comparison of pitching moment coefficient

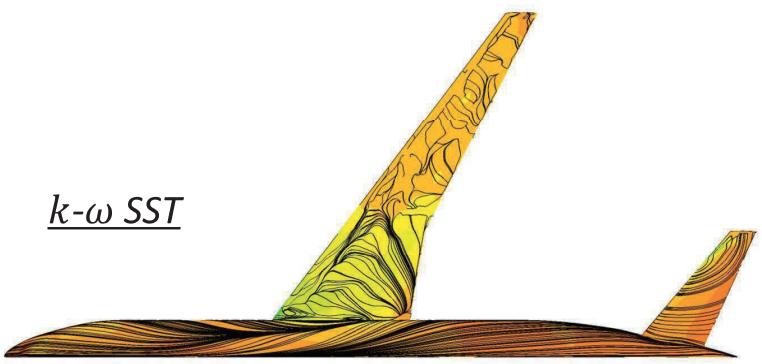


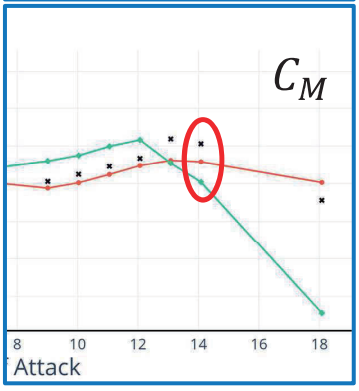
9

Pressure coefficient distribution at AoA of 14.08 deg



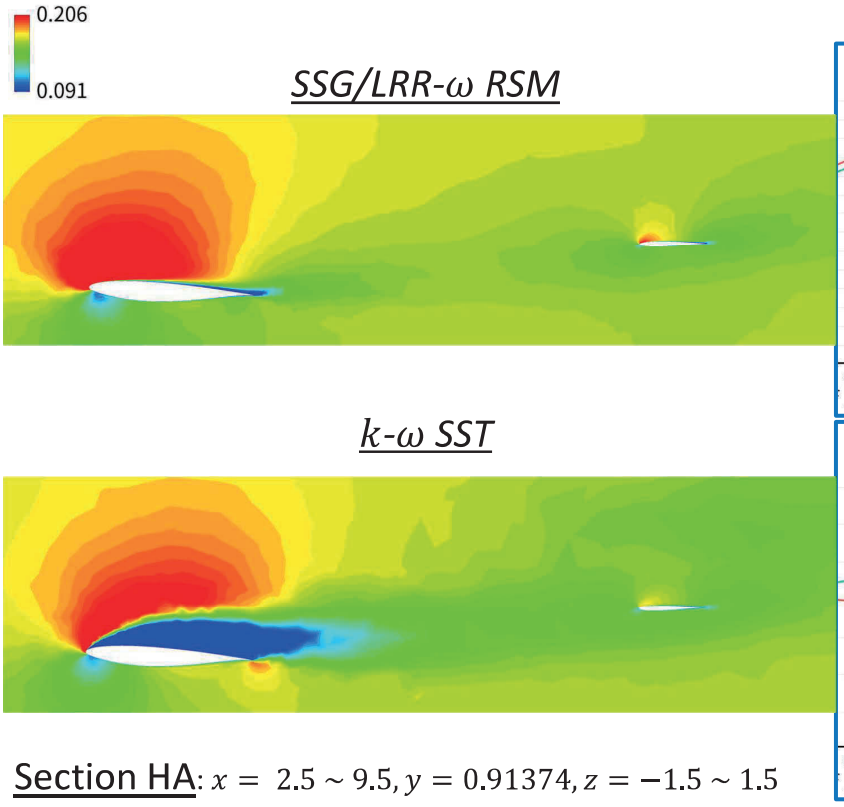


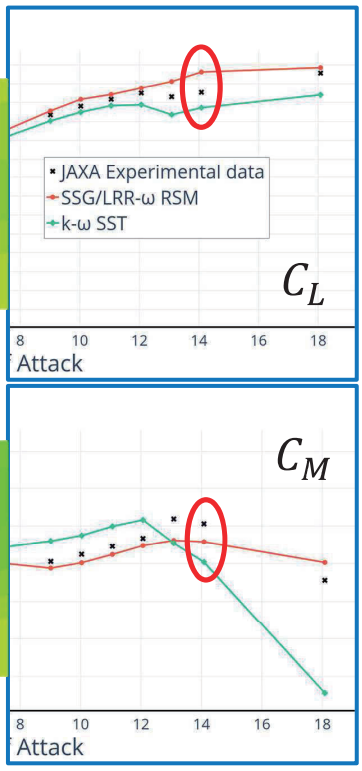




10

Mach number distribution at AoA of 14.08 deg

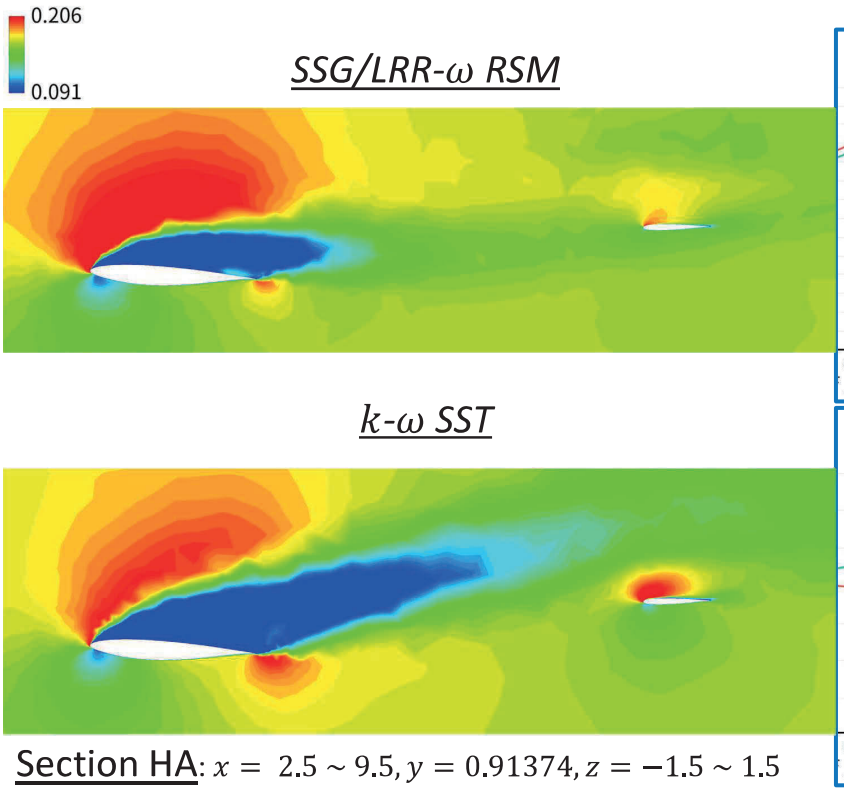


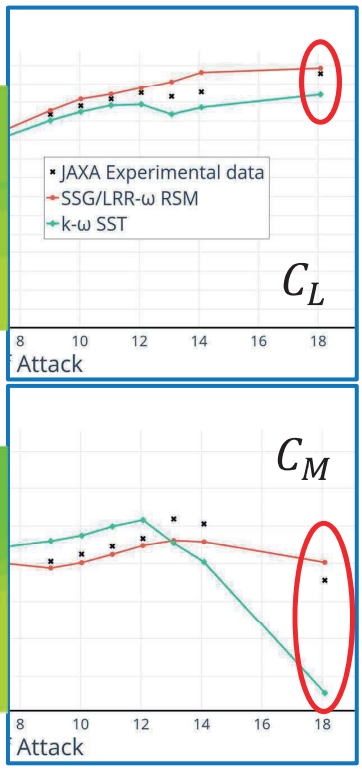


Section HA: $x = 2.5 \sim 9.5, y = 0.91374, z = -1.5 \sim 1.5$

11

Mach number distribution at AoA of 18.08 deg





Section HA: $x = 2.5 \sim 9.5, y = 0.91374, z = -1.5 \sim 1.5$

12

Conclusion

- The SSG/LRR-ω model shows better agreement than the k-ω SST model according to experimental data from JAXA.
- SSG/LRR-ω RSM gives relatively smaller separated region on the main wing and the horizontal tail is still in the wing wake to give smaller lift which result in larger pitch up moment at AOA of 18 deg, if compared to that given by k-ω SST
- SSG/LRR-ω RSM can be a practical tool for aeronautical flow computations
  - The computational cost of SSG/LRR-ω RSM is roughly less than double, compared to k-ω SST model.
  - The current computations were conducted stably by SSG/LRR-ω RSM .