NASA-CRM飛行条件の微小変化に対するシミュレーション結果の検討

Study on Simulations Slightly Changing Flight Conditions for NASA-CRM Plane

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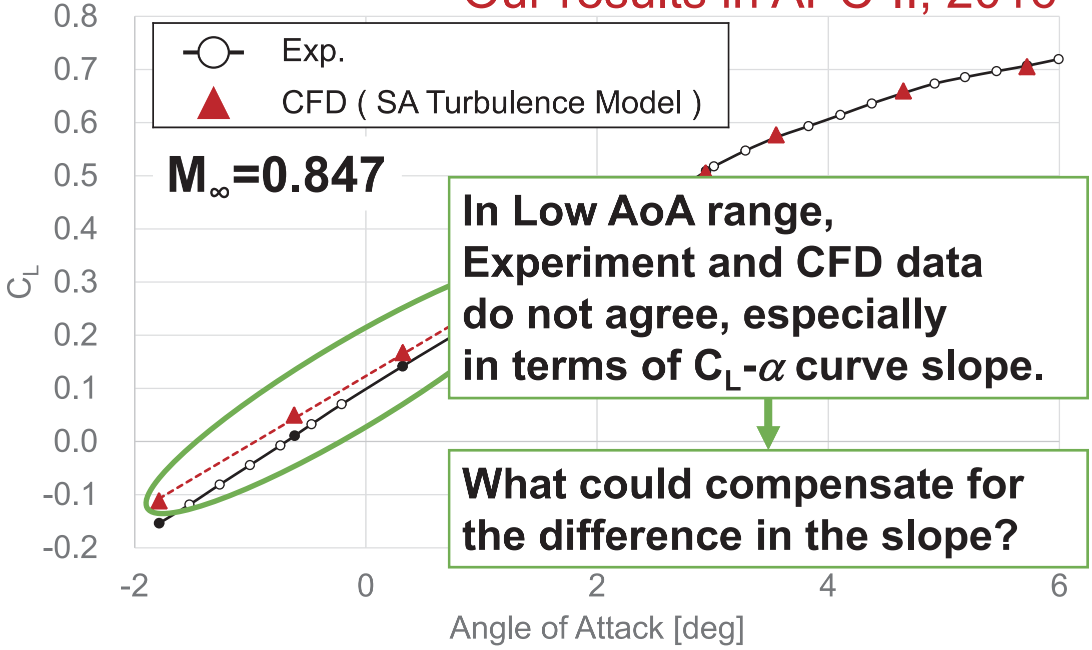
Motivations

Our results in APC-II, 2016



Objectives

What could compensate for the difference in the slope?

We think about flight conditions.

Wind Tunnel Experiments	CFD simulations
● Tunnel walls exist. ● A sting to hold a model plane exists.	● The model geometry is accurate? ● Discretization errors ● Numerical errors ● Physical models are fully appropriate? (e.g. a turbulence model)

Then, we think

➢AoA of 2° for a WT experiment might not correspond to AoA of 2° for CFD.

➢M_∞ of 0.847 for a WT experiment might not correspond to M_∞ of 0.847 for CFD.

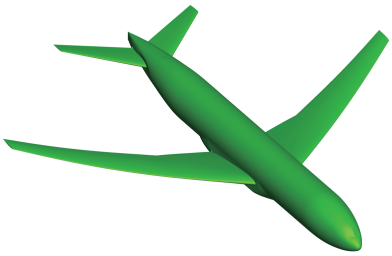
Therefore, we are going

To conduct **CFD** study whether the variation of Turbulence Model, AoA and M_∞ values could cover above difference from experiments and give corresponding results to experiments.

Numerical method

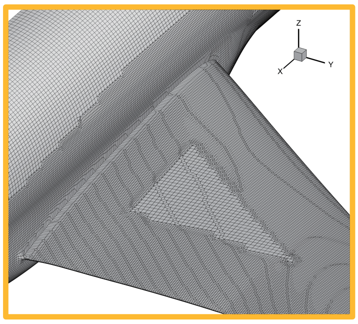
- Grid … Unstructured Cartesian type mesh (provided by JAXA)
  Mesh generated by '**Hexa Grid**'
- Navier-Stokes Solver … **FaSTAR** ©JAXA
  - Discretization in Space … **cell-centered FVM**
  - Scheme for advection terms (third order accuracy)
    - **TVD** with **HLLEW** flux evaluation
    - **GLSQ** gradient calculation
    - **Hishida** (van Leer type) slope limiter
    - **U-MUSCL**
  - Scheme for viscous terms (second order accuracy)
    - GLSQ gradient calculation
  - Time integration(first order accuracy in time)
    - **LU-SGS** (local time-stepping)
  - Turbulence model … **SST-2003 model**

Numerical method



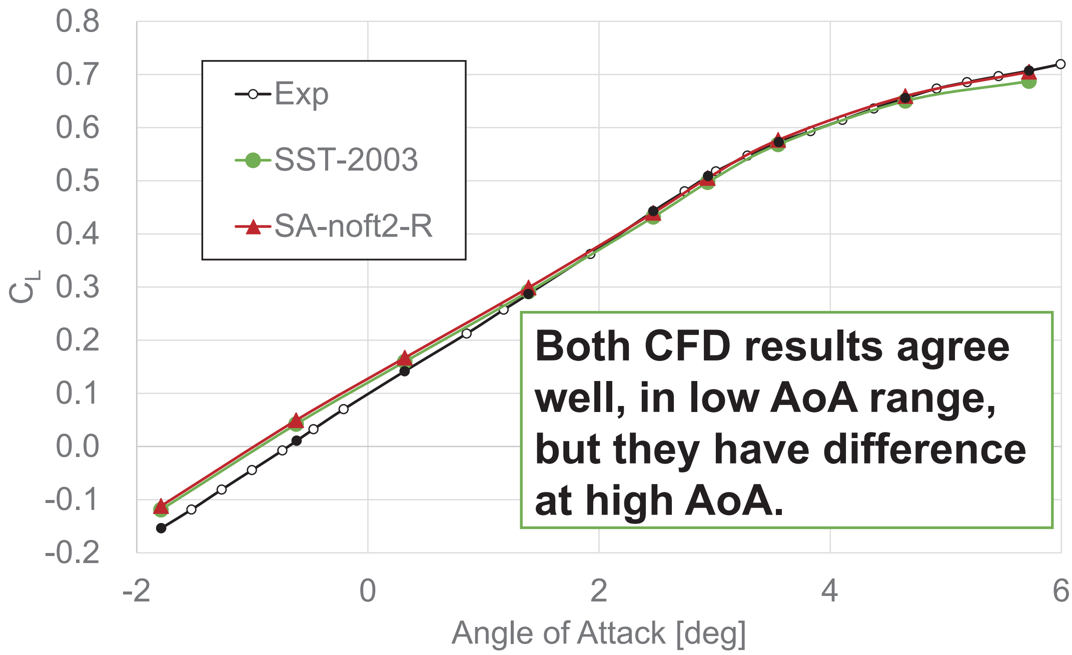
- wing + body + tail (**without a sting**)
  The model plane shape for each AoA contains geometrical deformation due to aerodynamic forces measured in the WT experiment.

Medium Grid

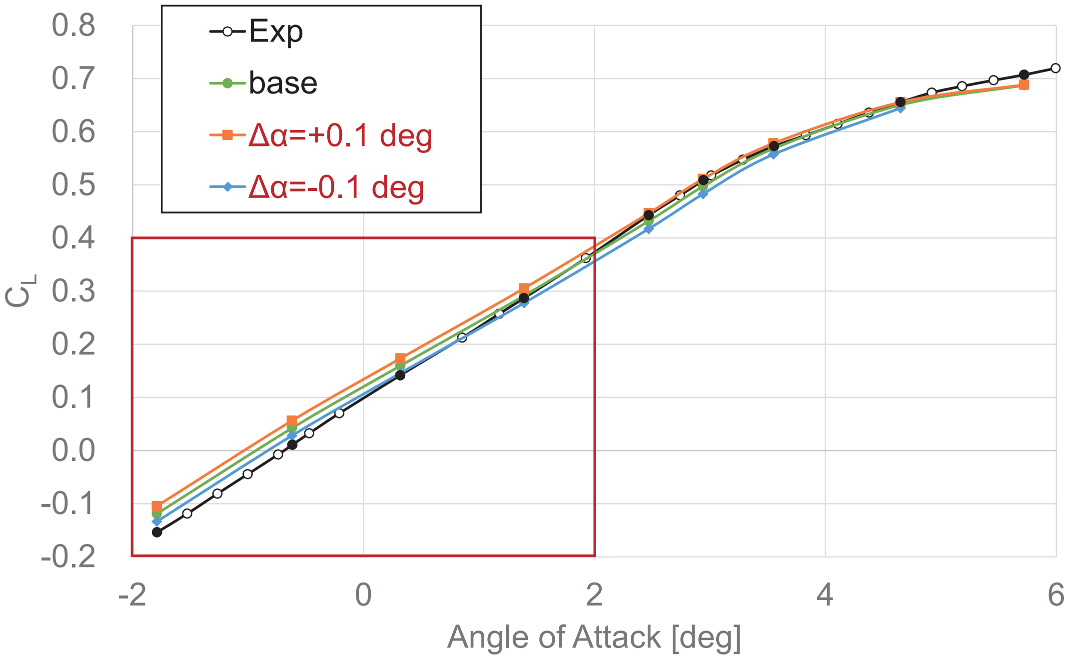


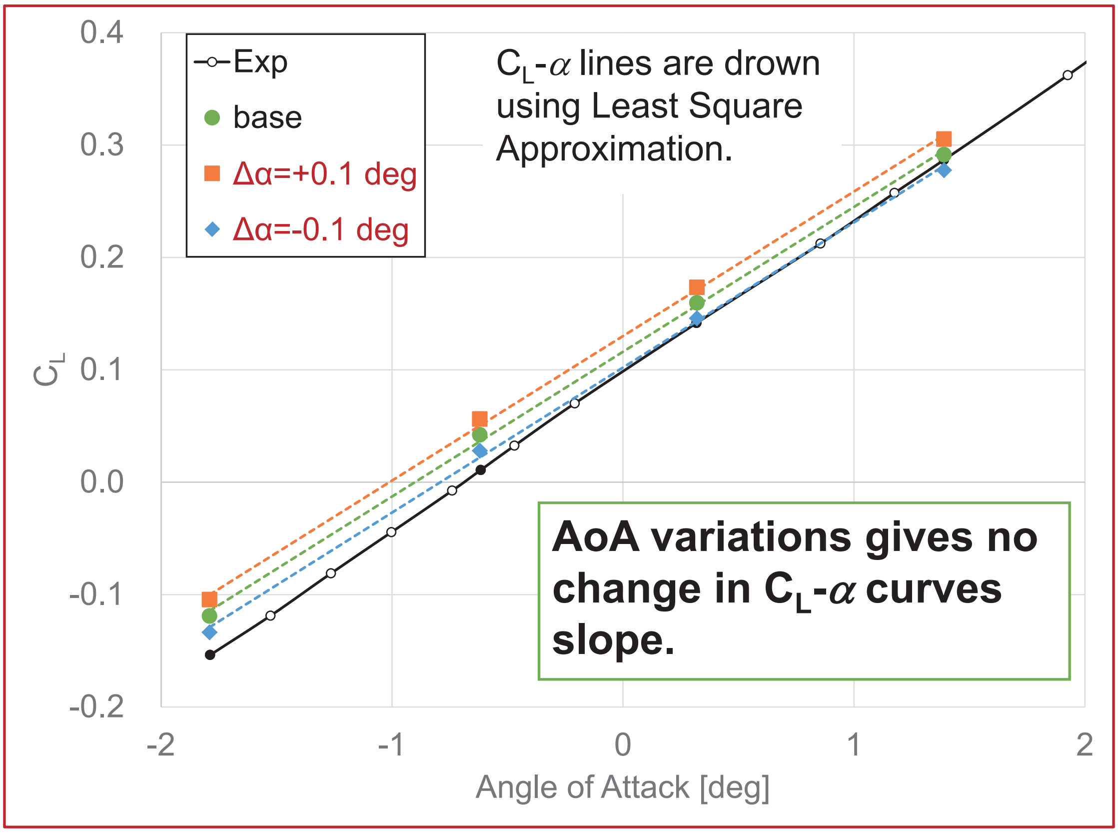
- About 13M nodes (15M cells)

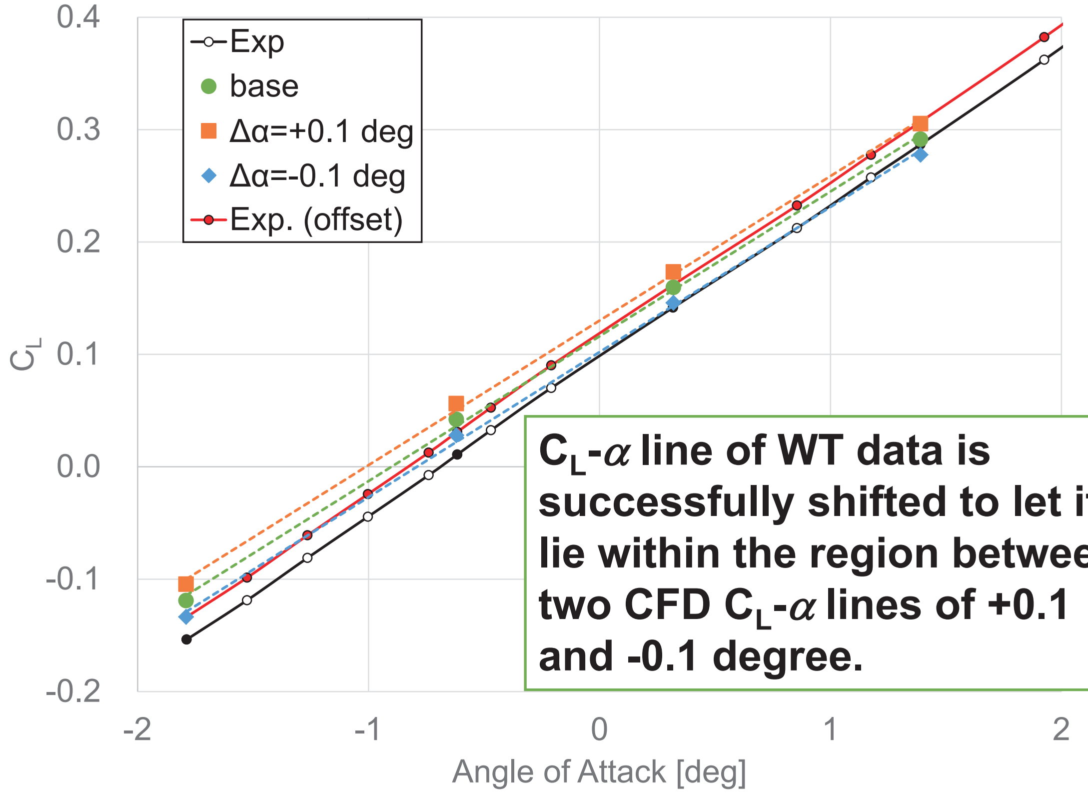
Results #1 – To Change a Turbulence Model



Results #2 – AoA Variation

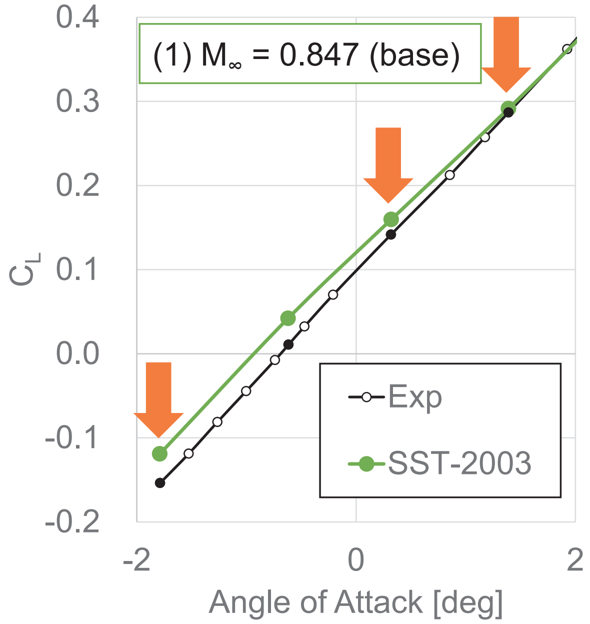






C_L-α line of WT data is successfully shifted to let it lie within the region between two CFD C_L-α lines of +0.1 and -0.1 degree.

Results #3-1 – M_∞ Variation



- Angle of Attack [deg] :

  -1.79, 0.32, 1.39

- Free-Stream Mach number:

  (1) M_∞ = 0.847 (Base)

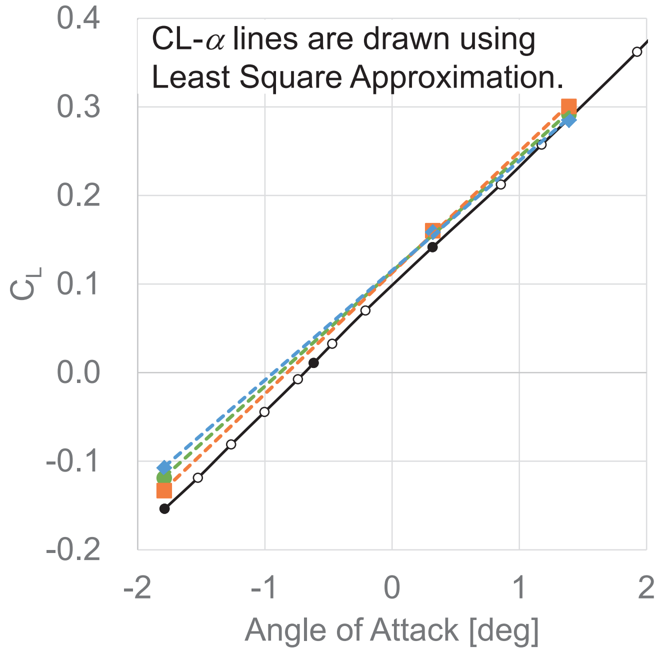
  (2) M_∞ = 0.864 (+2%)

  (3) M_∞ = 0.830 (−2%)

- Turbulence model:

  SST – 2003

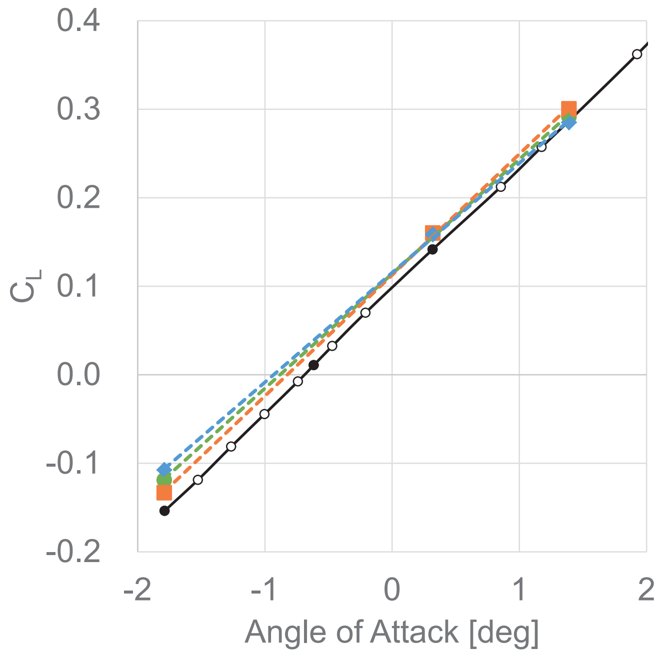
Results #3-2 – M_∞ Variation



	$\frac{dC_L}{d\alpha}$
Exp.	0.139
M_∞ = 0.847 (base)	0.130
M_∞ = 0.864 (+2%)	0.137
M_∞ = 0.830 (−2%)	0.124

The higher the M_∞ is, the steeper the slope is.

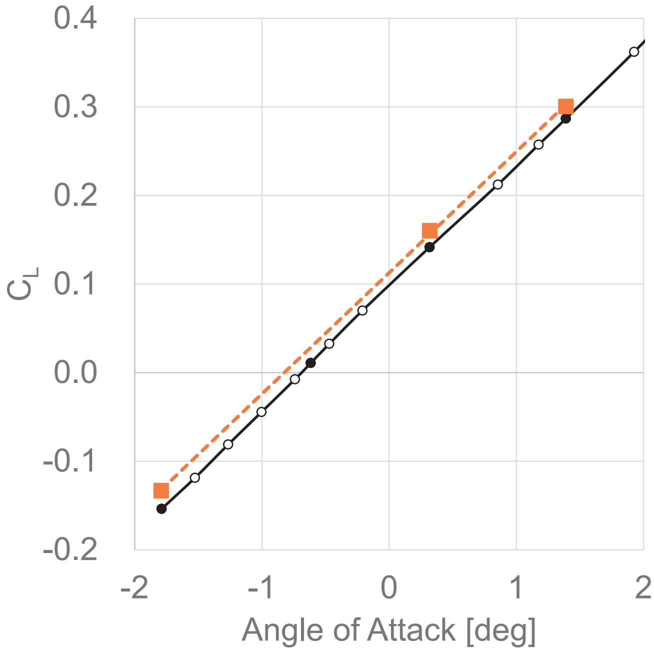
Results #3-3 – M_∞ Variation



	$\frac{dC_L}{d\alpha}$
Exp.	0.139
M_∞ = 0.847 (base)	0.130
M_∞ = 0.864 (+2%)	0.137
M_∞ = 0.830 (−2%)	0.124

CFD Lift curve of Slope of M_∞ 0.864 is the closest to that of Exp.

Results #3-3 – M_∞ Variation



	$\frac{dC_L}{d\alpha}$
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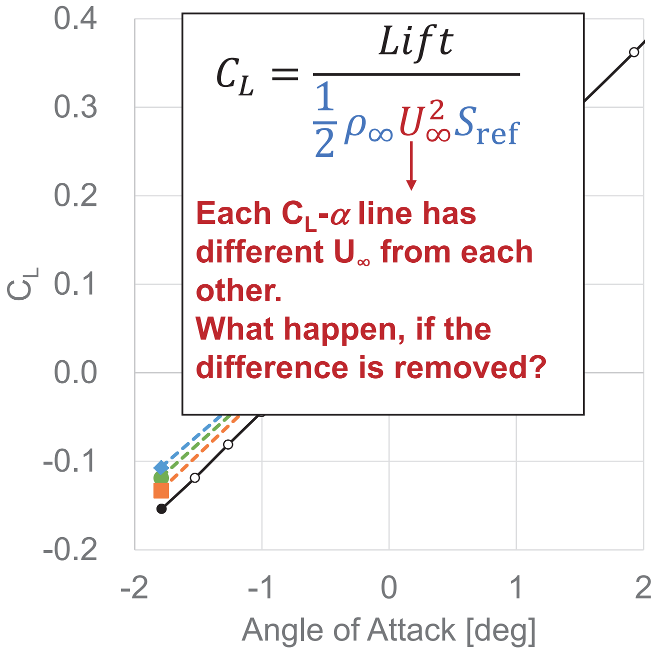


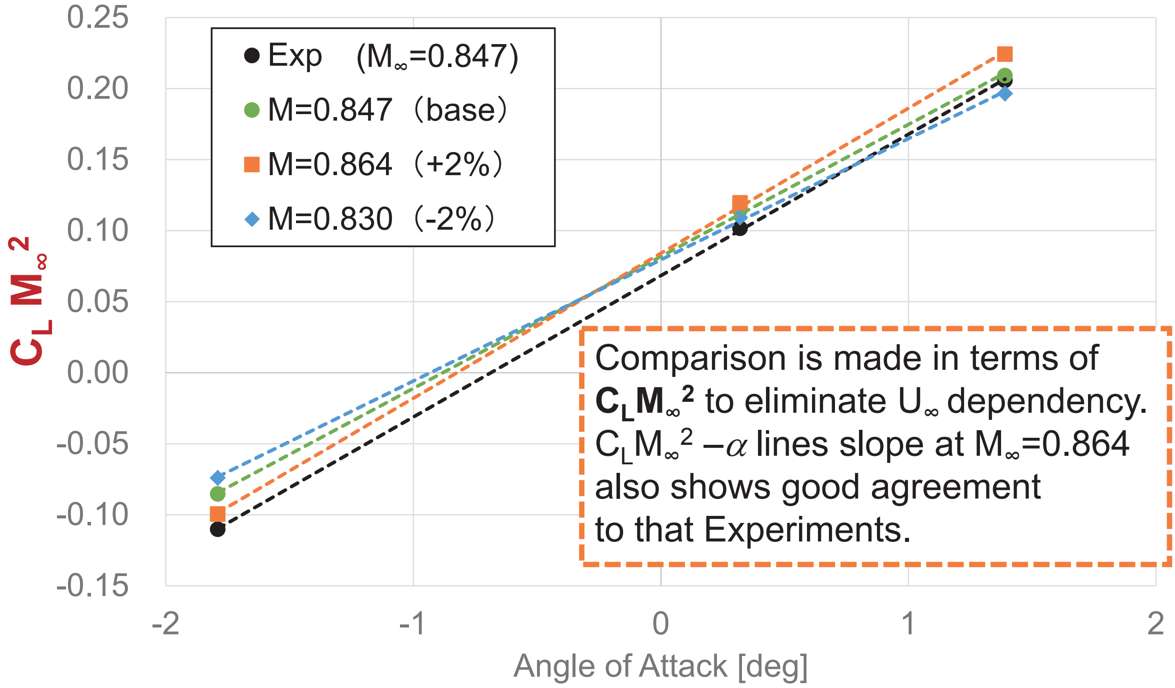
$$C_L = \frac{Lift}{\frac{1}{2}\rho_\infty U_\infty^2 S_{ref}}$$

Each C_L-α line has different U_∞ from each other.
What happen, if the difference is removed?

	$\frac{dC_L}{d\alpha}$
Exp.	0.139
M_∞ = 0.847 (base)	0.130
M_∞ = 0.864 (+2%)	0.137
M_∞ = 0.830 (−2%)	0.124

CFD Lift curve of Slope of M_∞ 0.864 is the closest to that of Exp.

Results #3-4 – M_∞ Variation



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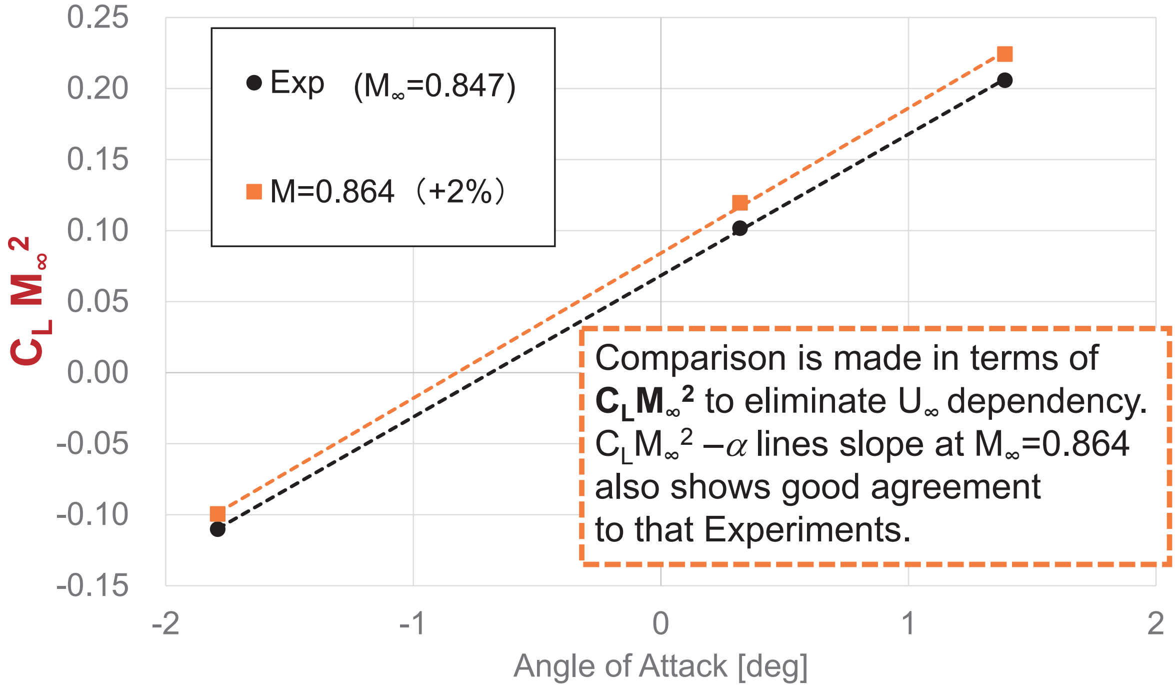
Results #3-4 – M_∞ Variation



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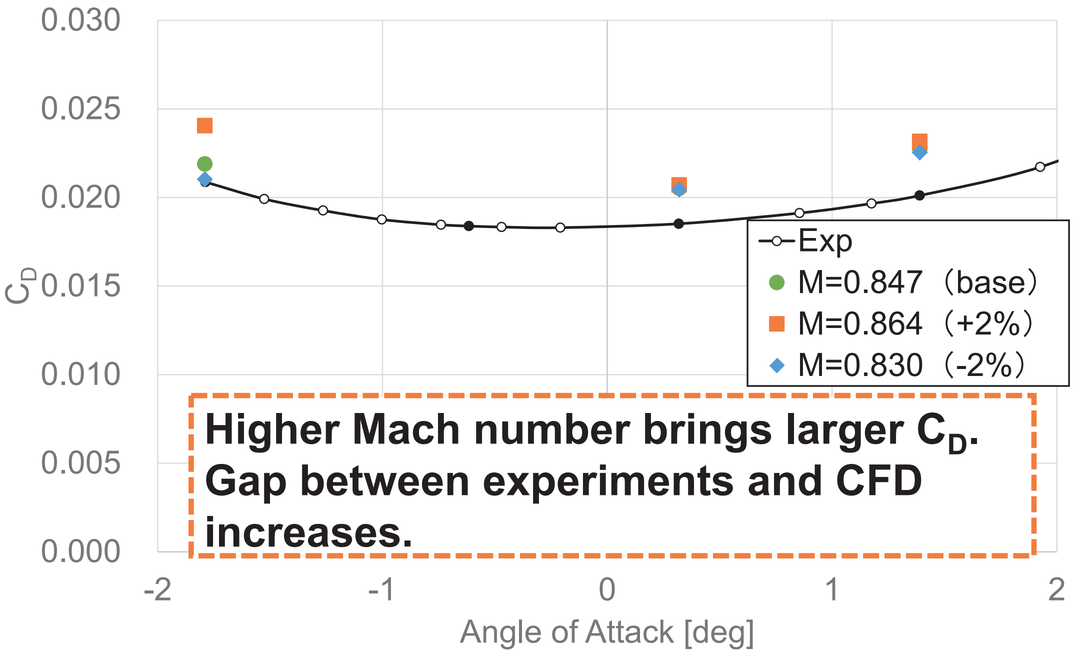
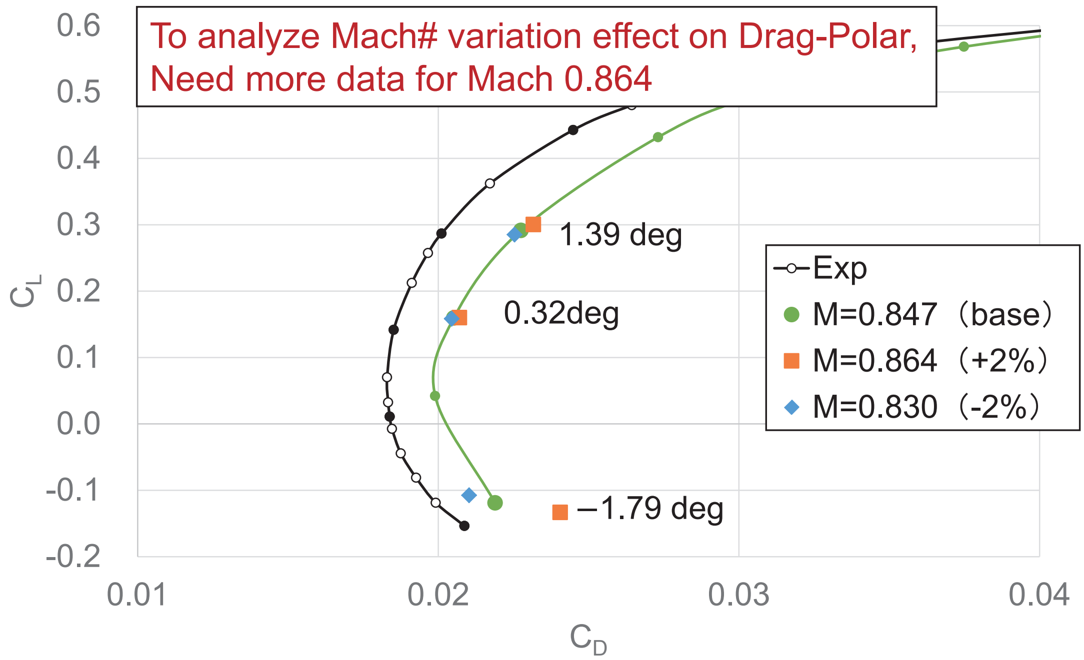
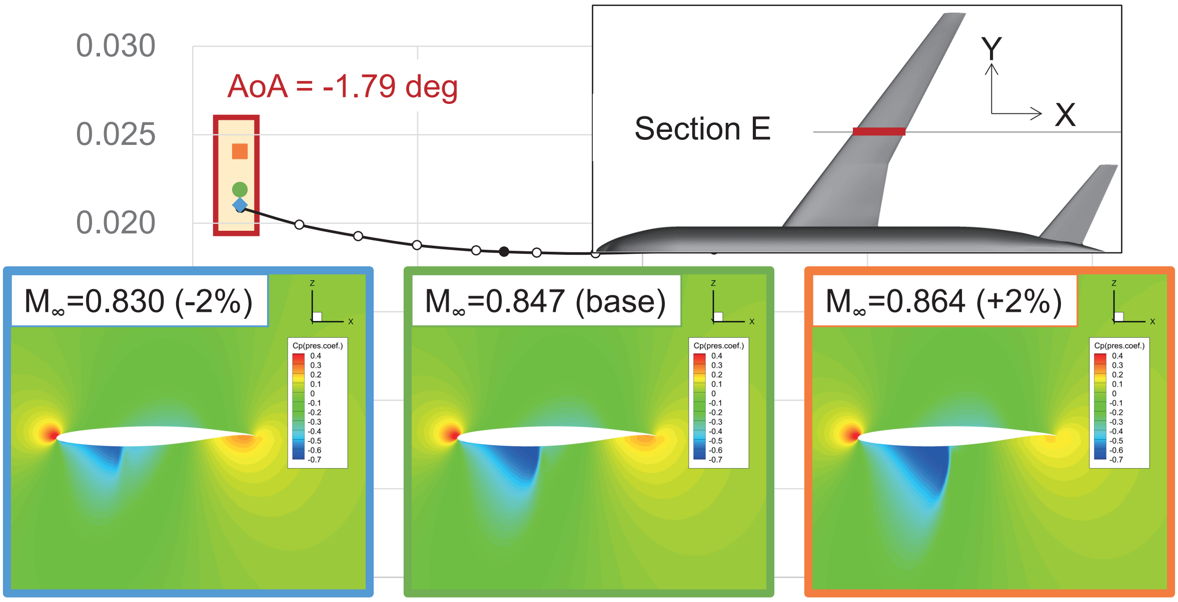
Results #3-5 – M_∞ Variation　C_D-α curve



Results #3-6 – M_∞ Variation　C_L-C_D (Drag Polar) curve

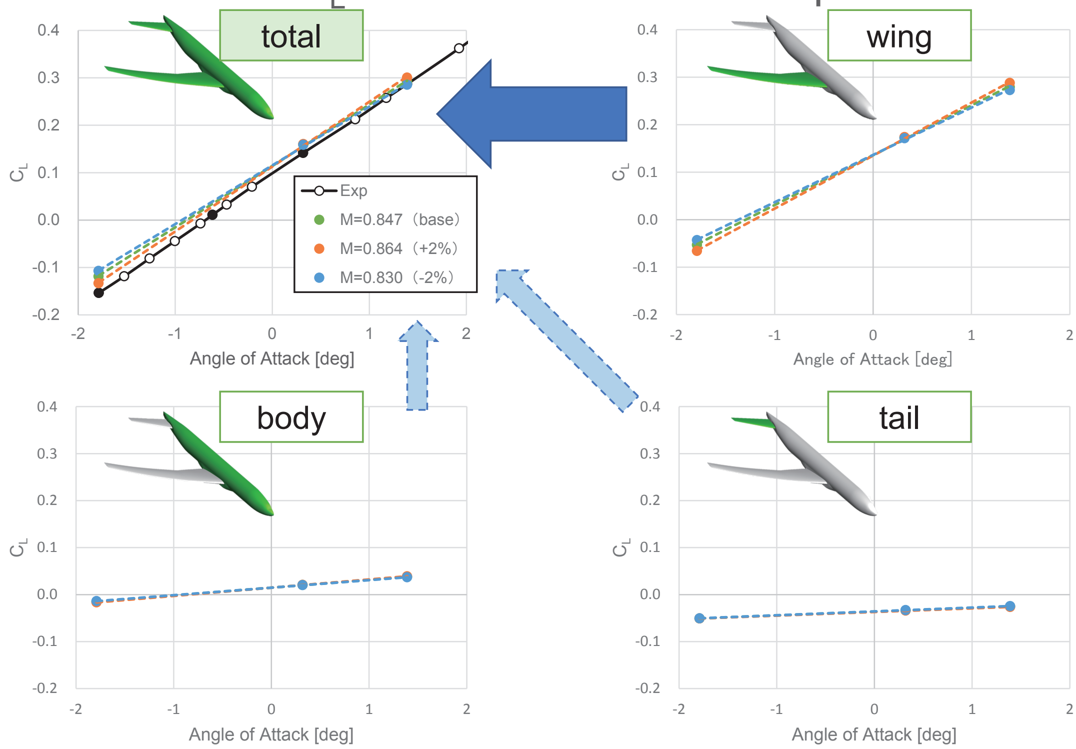


Results #3-7 – M_∞ Variation　C_D and Shock Wave

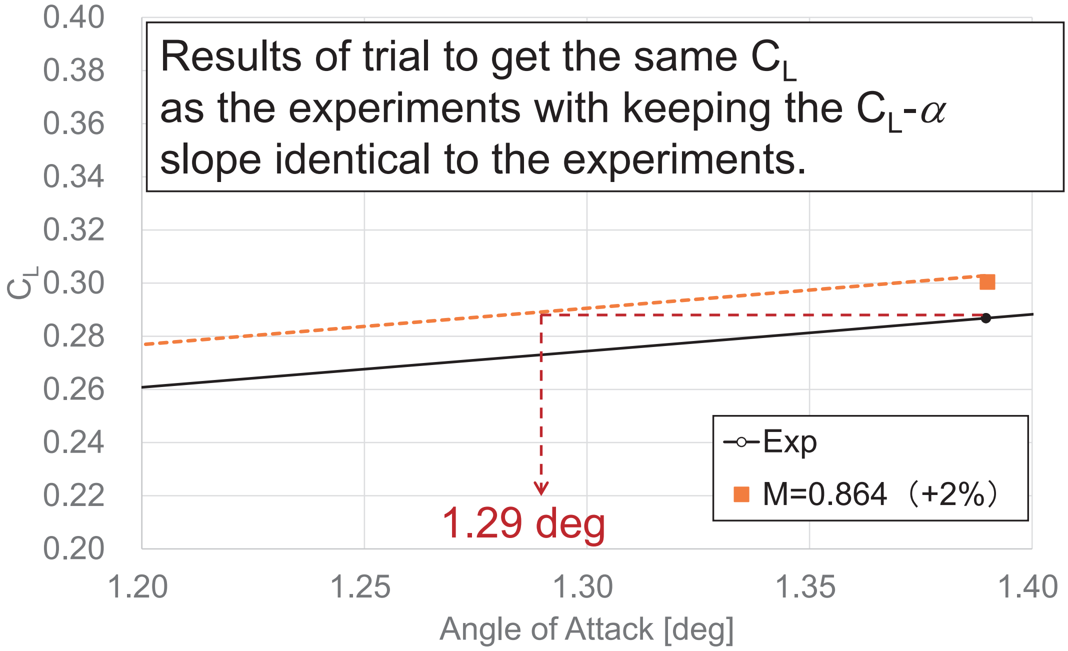


C_D values are largely depend on Shock wave strength which increases when Mach number becomes higher.

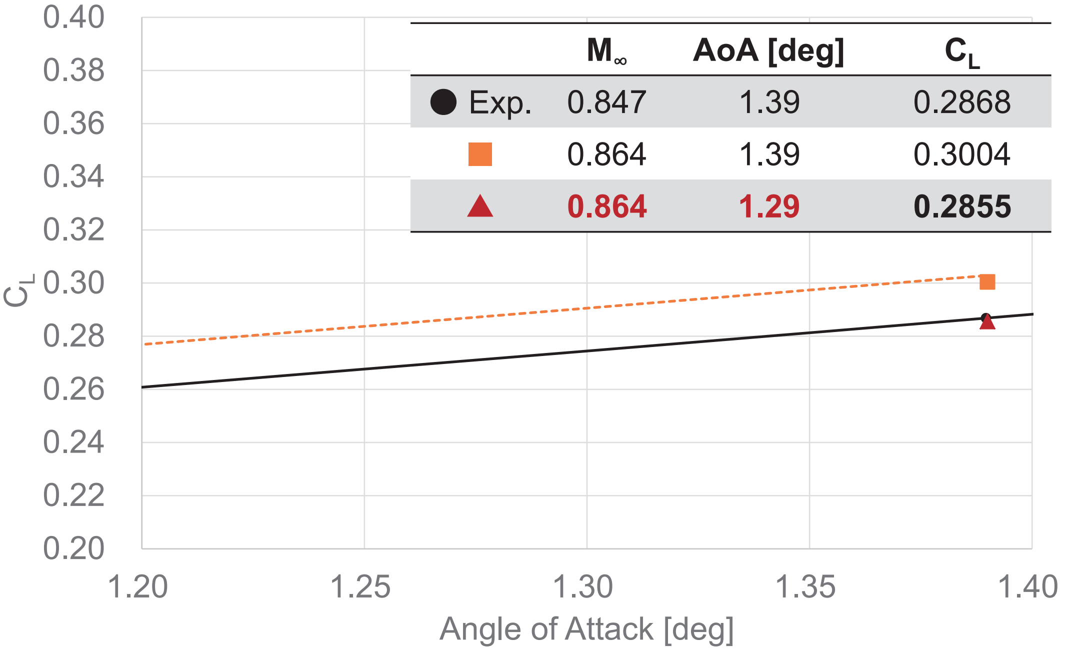
Results #3-8 – M_∞ Variation
C_L-α Curves of Each Component



Results #4-1 – Trial to Get the Same C_L

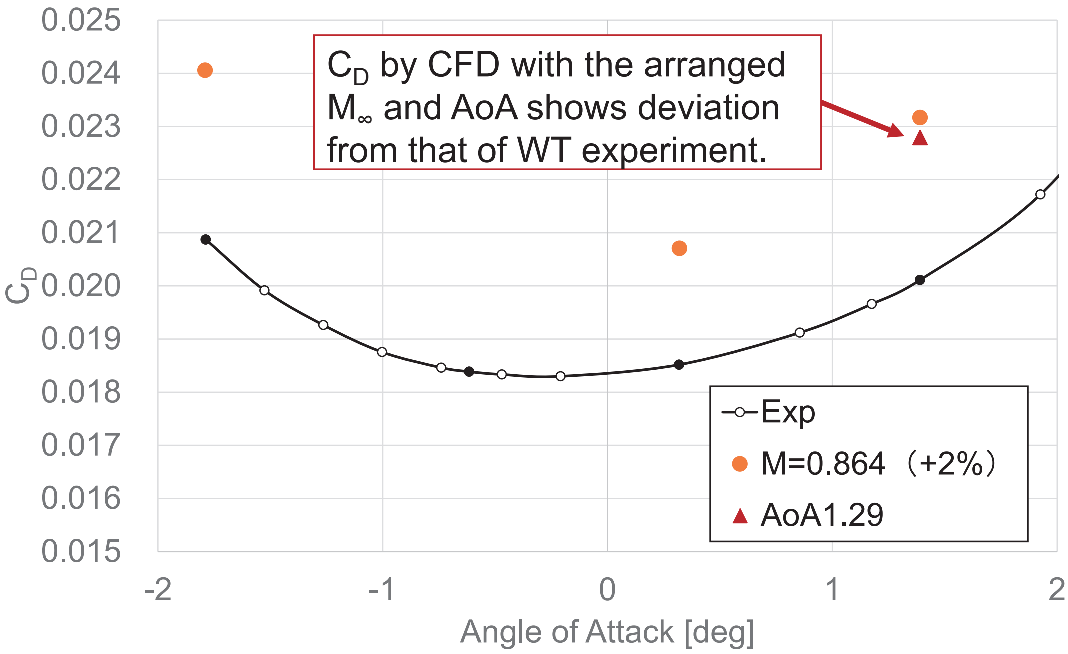


Results #4-2 – Trial to Get the Same C_L



	M_∞	AoA [deg]	C_L
● Exp.	0.847	1.39	0.2868
■	0.864	1.39	0.3004
▲	**0.864**	**1.29**	**0.2855**

Results #4-3 – Trial to Get the Same C_L



Conclusions

- The results of CFD simulations using the **SST-2003** turbulence model are almost same as that using the **SA** one, except the case flows are separated.
- CFD simulations with **AoA variation** do not bring promising effect on shaping C_L-α curve slope identical to that of the WT experiment.
- **Mach number variation** promisingly affects lift curve slope.
- The lift curve slope by the higher Mach number CFD simulations becomes steeper than that of base Mach number same as the experiment. Consequently, the slope is closer to experimental data when setting the higher Mach number for CFD simulation.
- To get C_L and C_L-α slope identical to the experiments, Mach variation combined with AoA adjustment would work.
  To perform it systematically, more investigation is needed.

Calculation costs

Terminal specifications of PC type Work Stations

Type 1

- CPU: Intel(R) Xeon(R) CPU E5-2697 v4 2.30GHz (18 cores) X 2CPU
- OS: CentOS 6.7

Type 2

- CPU: Intel(R) Xeon(R) CPU E5-2687W 3.10GHz (8 cores) X 2CPU
- OS: CentOS 6.3

Calculation conditions

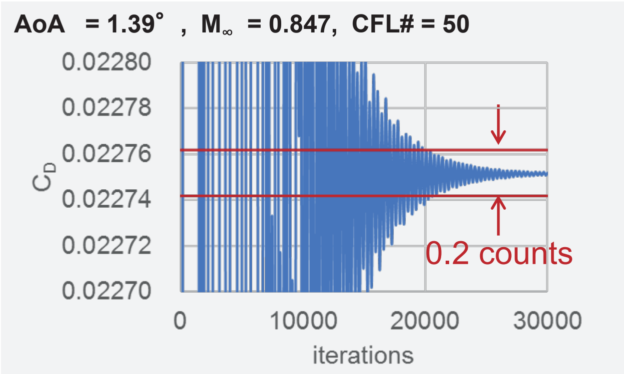
- 13M grid points
- 30000 iterations

Calculation time

- **Type 1 : 18 hours** (36 parallels)
- **Type 2 : 35 hours** (16 parallels)

Memory

- **24GB**



Thank you for your kind attention.