



# Flexcompute Contribution to the VII<sup>th</sup> AIAA Drag Prediction Workshop

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- 1. Flow360 Solver
- 2. Grids
- 3. Cases
- 4. Case 1 Grid Convergence Study
- 5. Case 2 Alpha Sweep Study
- 6. Case 3 Reynolds Number and Q Effect Study
- 7. Conclusions

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- Hardware/Software co-design with emerging hardware computing
- Node-centered
- Unstructured solver
- 2<sup>nd</sup> order finite volume method
- Roe inviscid fluxes
- Central difference viscous fluxes
- MUSCL Extrapolation
- SA, SA-RC, SA-QCR, kw-SST turbulence models (DDES, transition also available)





## JAXA grids were used for Flow360 simulations

Mesh Statistics	Number of Nodes	BL 1 <sup>st</sup> cell size (non. dim by c_ref)	BL growth rate
Tiny	8,687,830	8.455E-07	1.323
Coarse	26,891,512	5.638E-07	1.205
Medium	60,184,023	4.228E-07	1.150
Fine	111,843,367	3.383E-07	1.118



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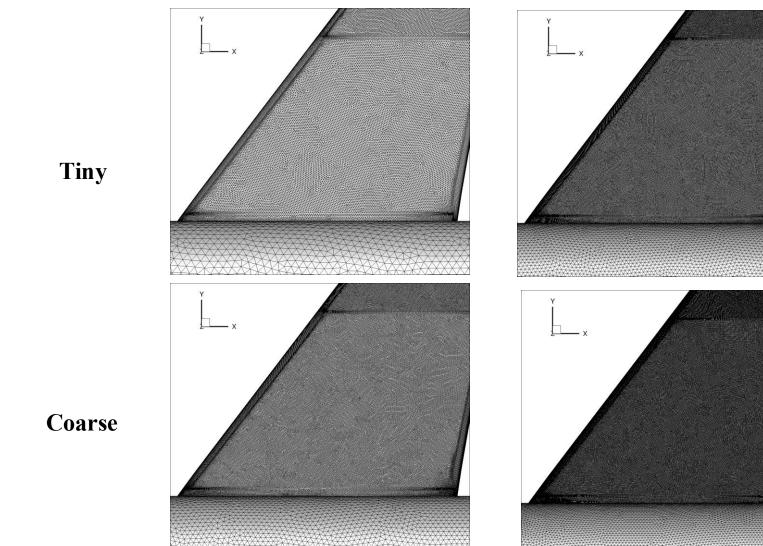
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JAXA grids – Root region



Medium

Fine



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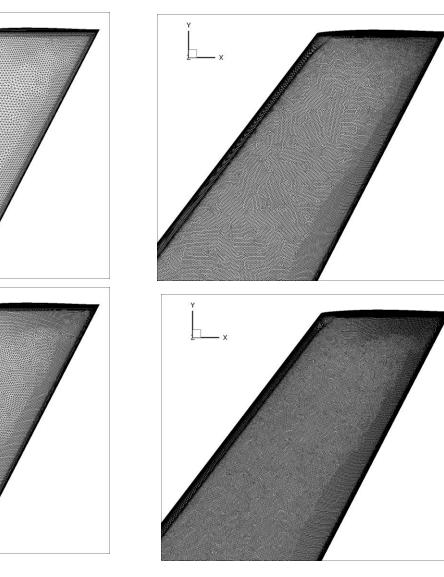
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JAXA grids – Tip region

Tiny





Medium

Fine





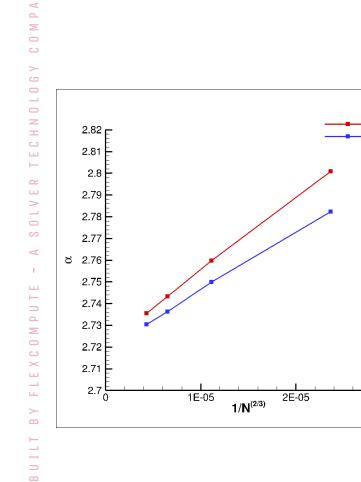
## 4 different turbulence models used: SA, SA-QCR, SA-RC-QCR and k $\omega$ -SST

Case 1	Case 2	Case 3
Grids:	Grids:	Grids:
Tiny – Fine	Medium	Medium
Turbulence	Turbulence models:	Turbulence models:
models:	SA, SA-QCR, SA-	SA, kω-SST
SA, kω-SST	RC-QCR and kω-SST	

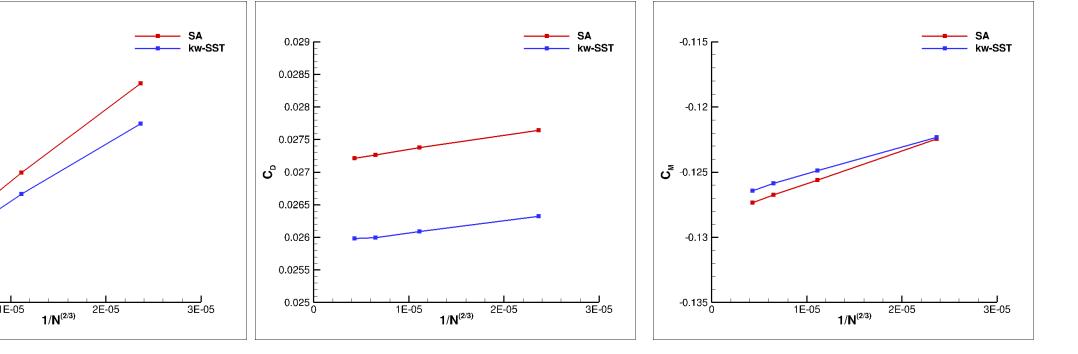








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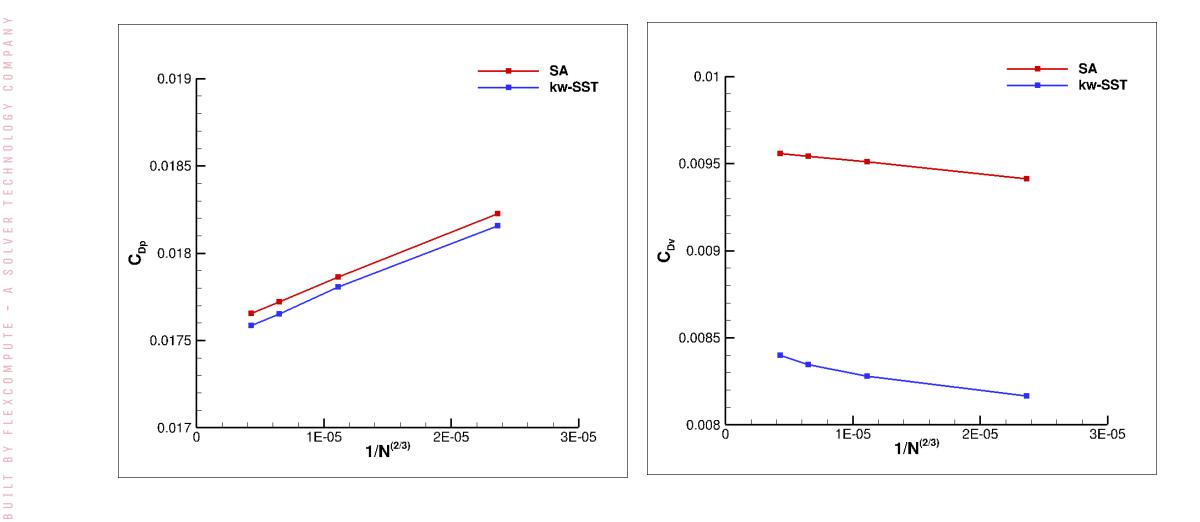
Alpha

CD

CM

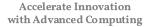






CDp

CDv







-0.2

0

0.2

0.4

0.6

0.8

0

0.2

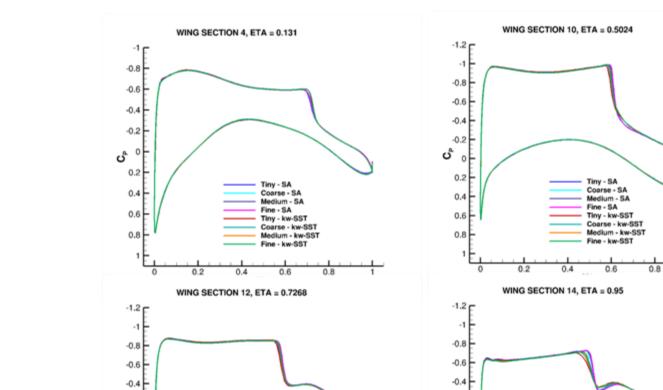
0.4

X/c

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Surface pressure curves at 4 locations along the wing





Tiny - SA

Fine - SA

Coarse - SA

Medium - SA

Tiny - kw-SST

Fine - kw-SST

0.6

0.8

1

Coarse - kw-SST

Medium - kw-SST

-0.2

0

0.2

0.4

0.6

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X/c

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Tiny - SA

Fine - SA

Coarse - SA

Medium - SA

Tiny - kw-SST

Fine - kw-SST

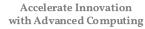
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1

Coarse - kw-SST

Medium - kw-SST





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#### Tip surface pressure contours

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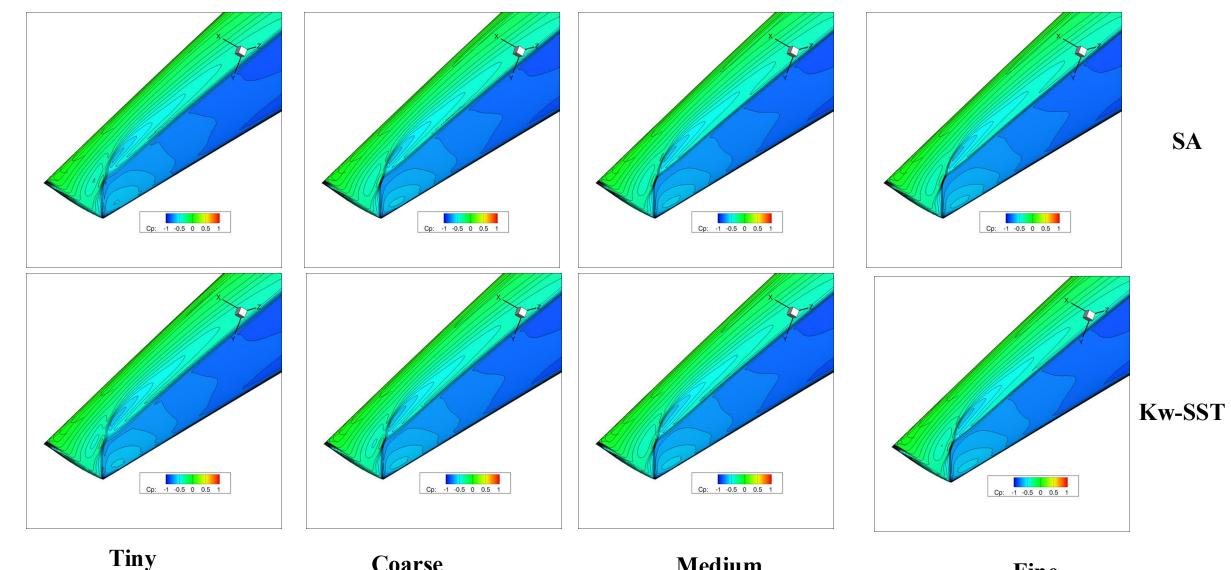
- $\sim$ 4

111 а.  $\geq$ 

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Tiny

June 25, 2022

Coarse

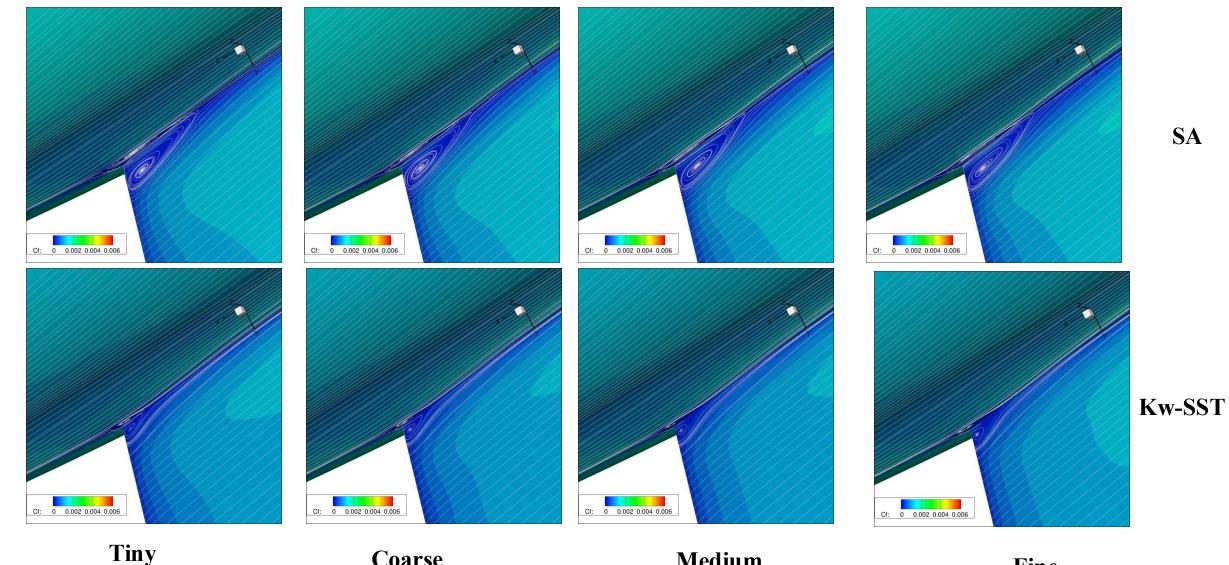
#### Medium

Fine





#### Corner separation at root



Tiny

Z  $\triangleleft$ а.  $\geq$ 

June 25, 2022

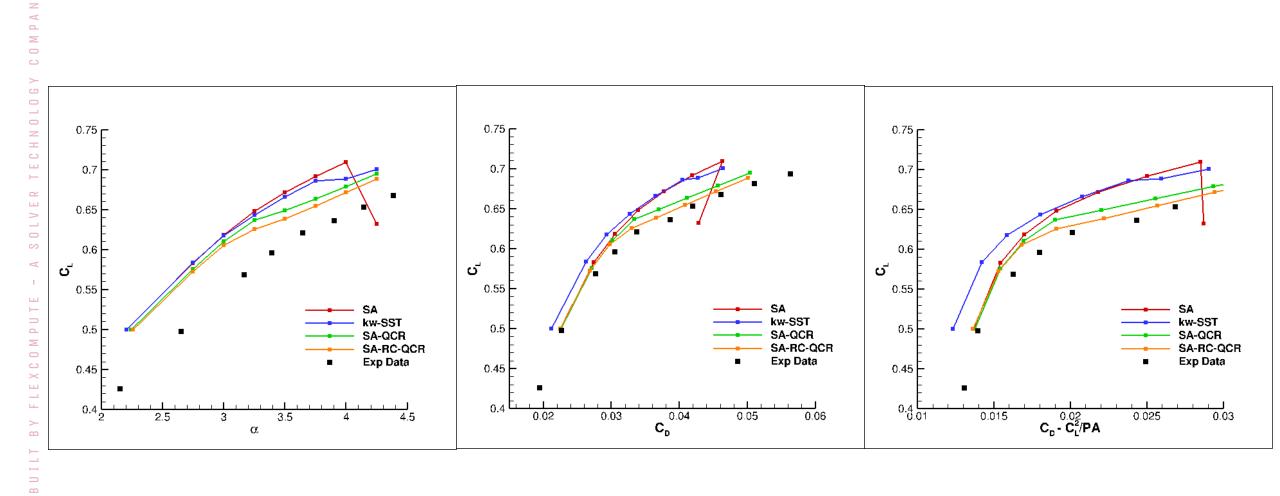
Coarse

#### Medium









CL

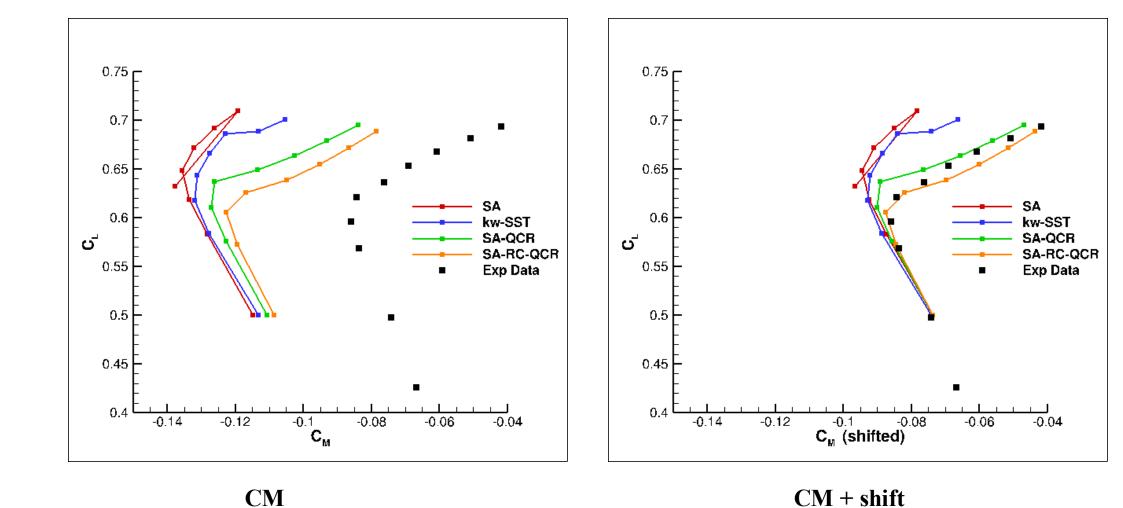
CD

**CD** Trim

#### t197R165 experimental data



# **Case 2 – Alpha Sweep Study**



t197R165 experimental data

Z 4  $\geq$ 

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Surface CP - eta = 0.131t197R242 experimental data alpha = 3.0, WING SECTION 4, ETA = 0.131 alpha = 4.0, WING SECTION 4, ETA = 0.131 -1 --1.2 -0.8 -1 -0.8 -0.6 -0.6 -0.4 -0.4 -0.2 **α**= 4.0 -0.2 °° ပံ α= 3.0 0 0.2 0.2 Experimental data Experimental data 0.4 SA SA 0.4 kw-SST kw-SST SA-QCR SA-QCR 0.6 SA-RC-QCR 0.6 SA-RC-QCR 0.8 0.8 0.2 0.4 0.6 0.8 0.4 0.2 0.6 0.8 1 V/a X/c alpha = 3.5, WING SECTION 4, ETA = 0.131 alpha = 4.25, WING SECTION 4, ETA = 0.131 -1.2 -1.2 Г -1 F -1 -0.8 -0.8 -0.6 -0.6 -0.4 -0.4  $\alpha = 4.25$ -0.2 -0.2  $\alpha = 3.5$ ບົ ບື 0 0 0.2 0.2 Experimental data Experimental data SA 0.4 SA kw-SST 0.4 kw-SST SA-QCR 0.6 SA-RC-QCR SA-QCR 0.6 SA-RC-QCR 0.8 0.8 0 0.2 0.4 0.6 0.8 X/c 0 0.2 0.4 0.6 0.8 X/c

Z



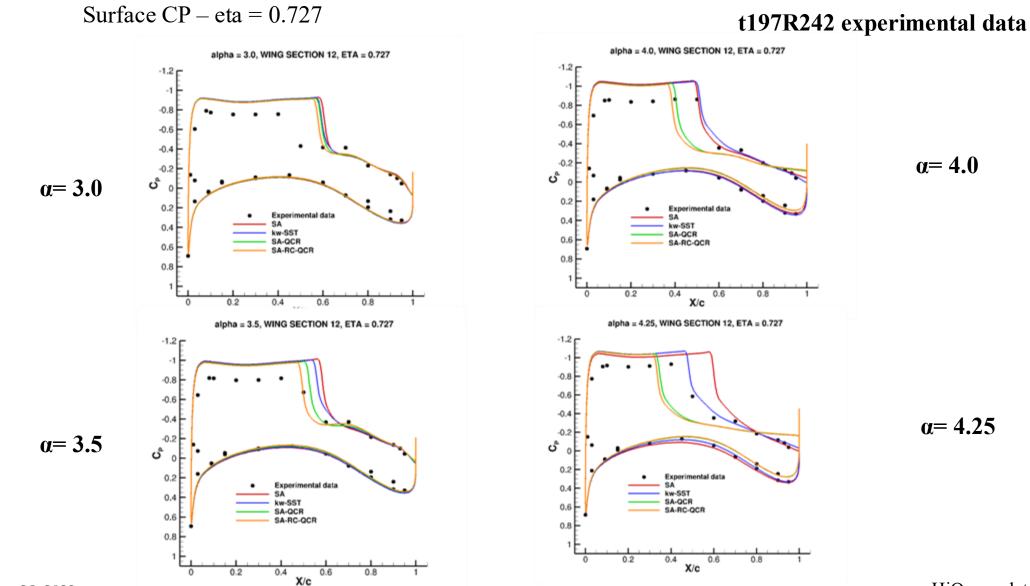


Surface CP - eta = 0.5024t197R242 experimental data alpha = 4.0, WING SECTION 10, ETA = 0.5024 alpha = 3.0, WING SECTION 10, ETA = 0.502 -1.2 -1.2 -11 -1 -0.8 -0.8 -0.6 -0.6 -0.4 -0.4 **α**= 4.0 -0.2 -0.2 ပံ ບື ٠. α= 3.0 0 01 0.2 0.2 Experimental data Experimental data SA 0.4 kw-SST 0.4 kw-SST SA-QCR SA-QCR 0.6 SA-RC-QCR 0.6 SA-RC-QCR 0.8 8.0 0.2 0.4 0.6 0.8 X/c 0.4 0.6 0.2 0.8 alpha = 4.25, WING SECTION 10, ETA = 0.502 alpha = 3.5, WING SECTION 10, ETA = 0.5024 -1.2 -1.2 -1 -1 E •• -0.8 -0.8 -0.6 -0.6 -0.4 -0.4  $\alpha = 4.25$ -0.2 .... -0.2  $\alpha = 3.5$ ບົ ບື 0 0 0.2 Experimental data 0.2 Experimental data SA 0.4 kw-SST 0.4 SA-QCR kw-SST 0.6 SA-RC-QCR SA-QCR 0.6 SA-RC-QCR 0.8 0.8 0 0.2 0.4 0.6 0.8 X/c 0 0.2 0.4 0.6 0.8 X/c June 25, 2022

Z





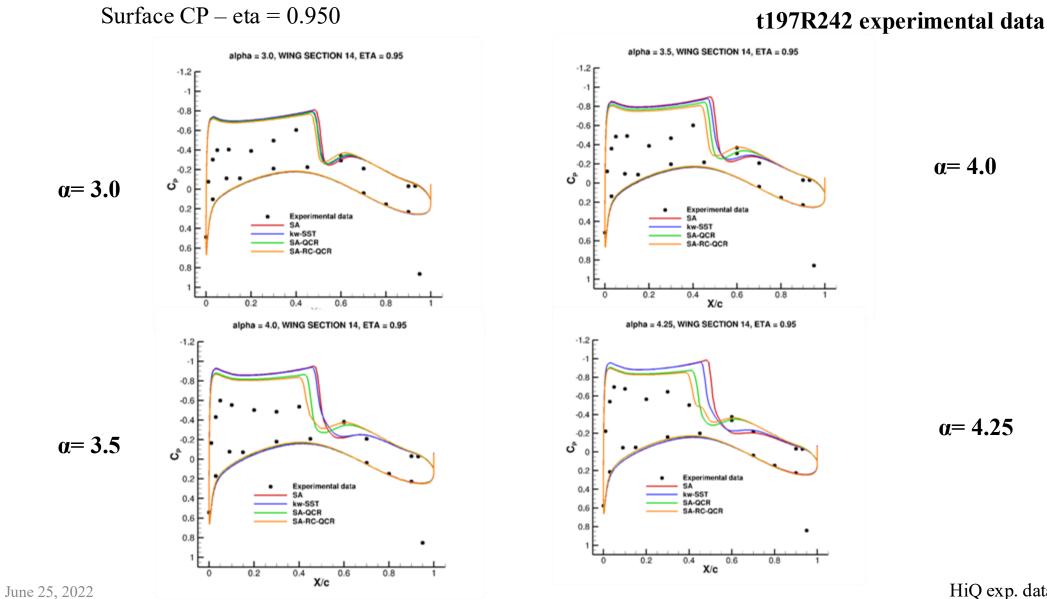


Z

HiQ exp. data 17







Z

HiQ exp. data 18





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Z 4 а.  $\geq$ 

> Z -

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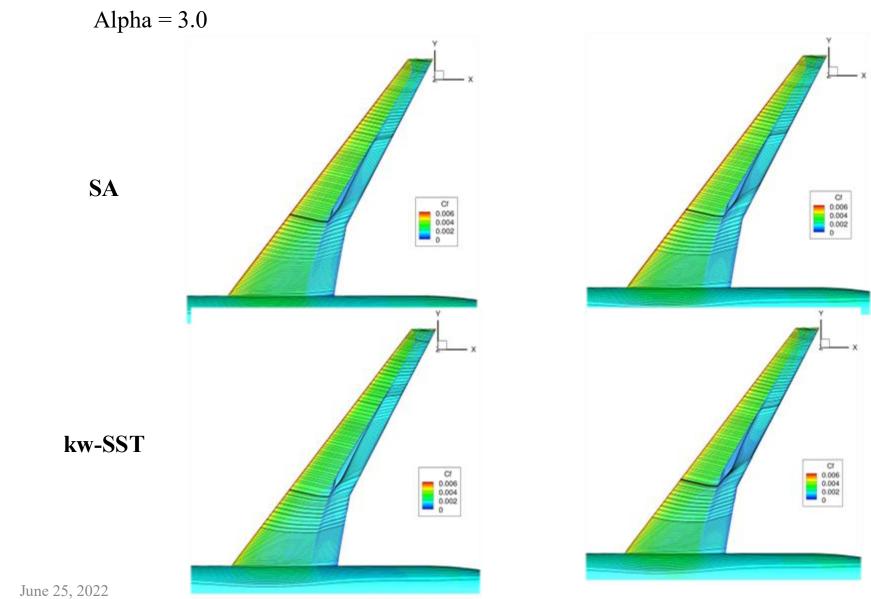
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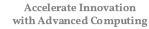
 $\mathbf{\omega}$ 

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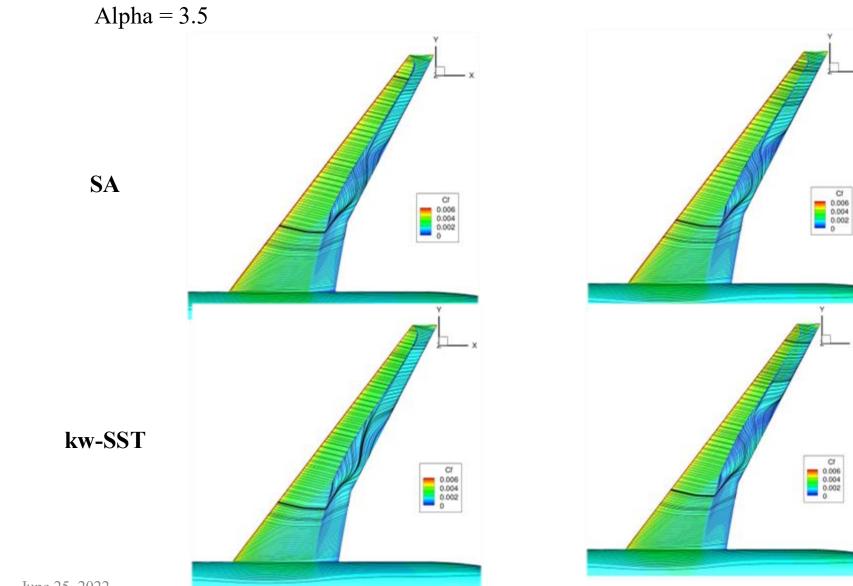
**SA-QCR** 

**SA-RC-QCR** 









SA-QCR

**SA-RC-QCR** 

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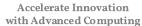
Z H

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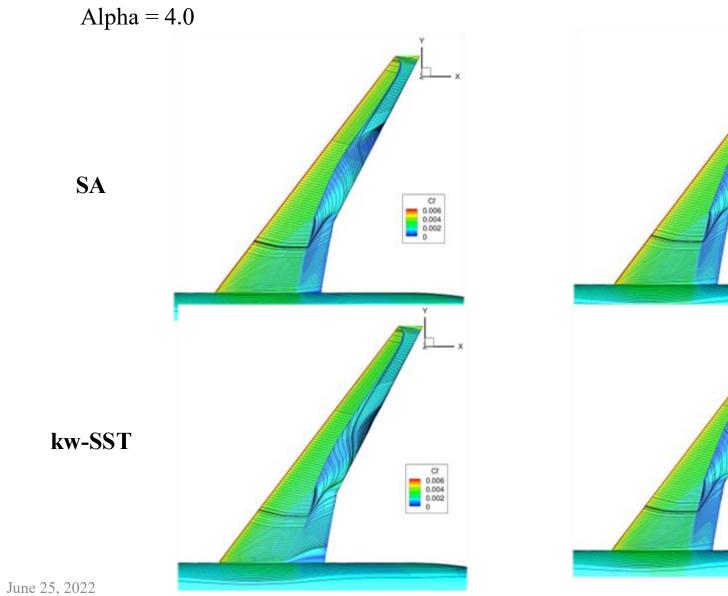
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**SA-QCR** 

Cf 0.006 0.004 0.002 0

Cf 0.006 0.004 0.002 0



Z 4 а.  $\geq$ 

> Z -

> $\geq$

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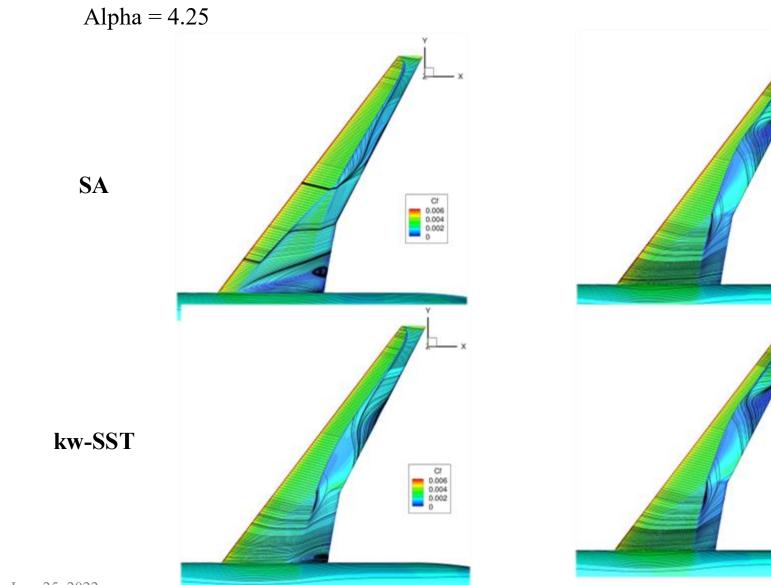
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SA-QCR

Cf 0.006 0.004 0.002 0

Cf 0.006 0.004 0.002 0 **SA-RC-QCR** 

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Z H

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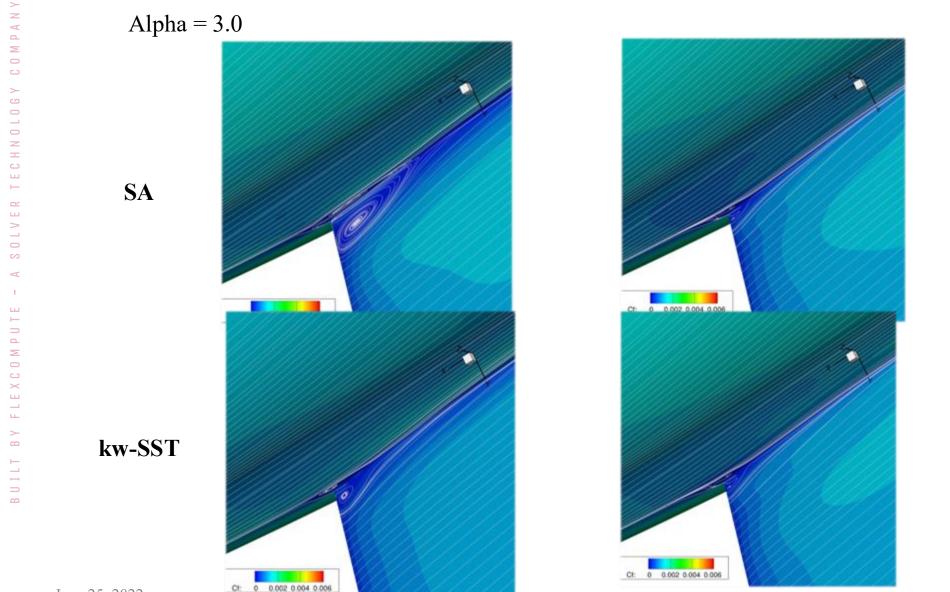
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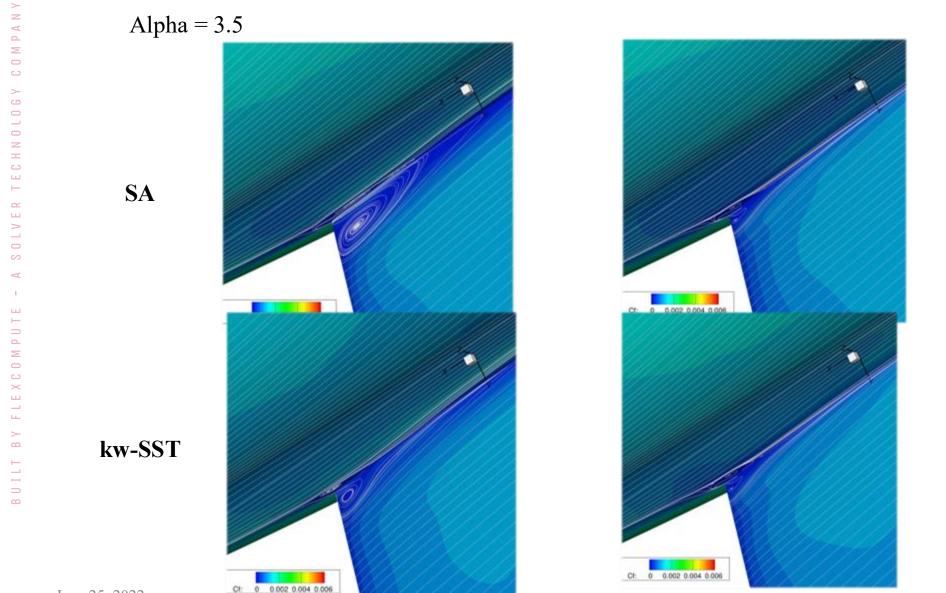


SA-QCR

SA-RC-QCR





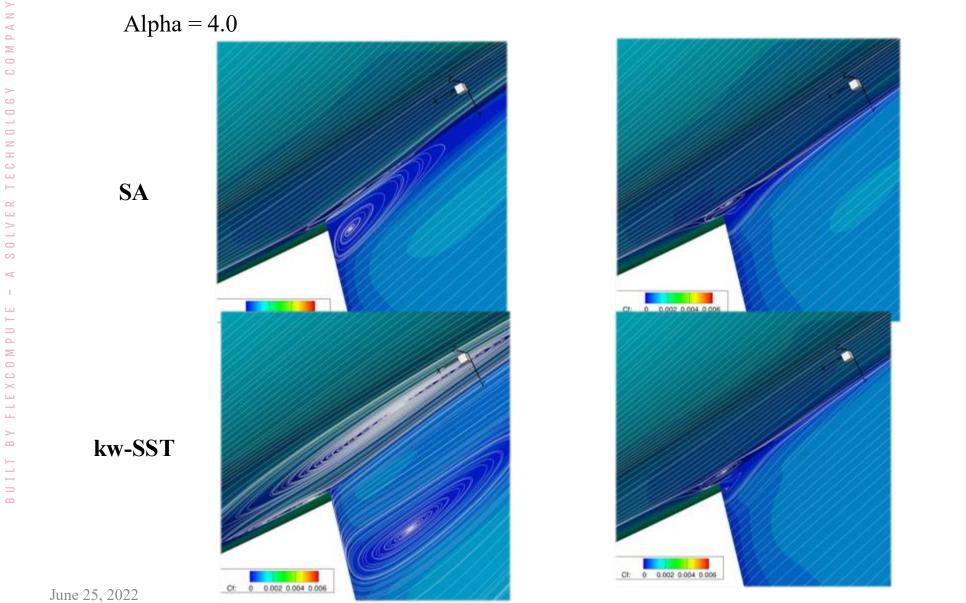


SA-QCR

SA-RC-QCR





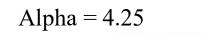


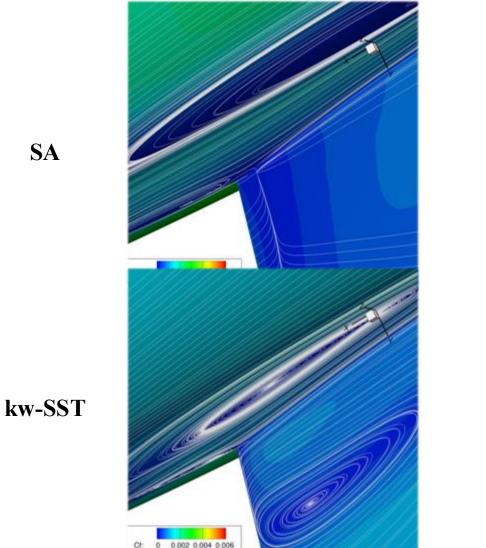
SA-QCR

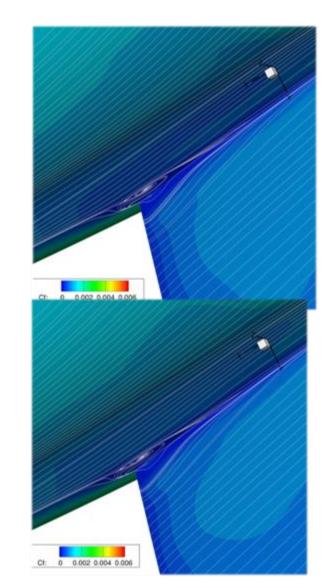
SA-RC-QCR









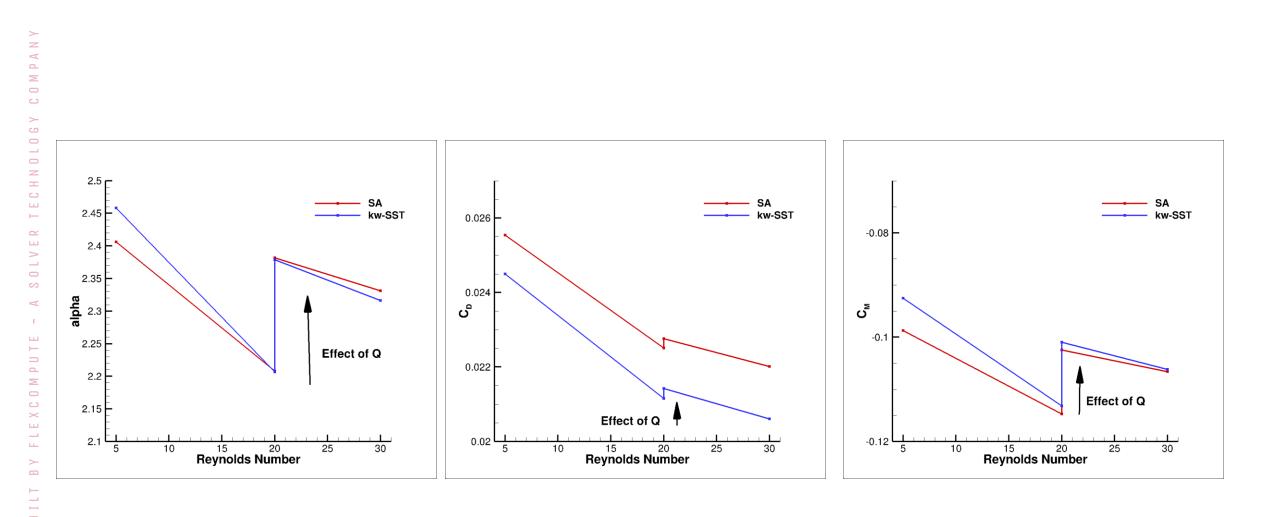


#### SA-QCR

SA-RC-QCR

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# Case 3 – Reynolds number and Q effect study



Alpha

CM

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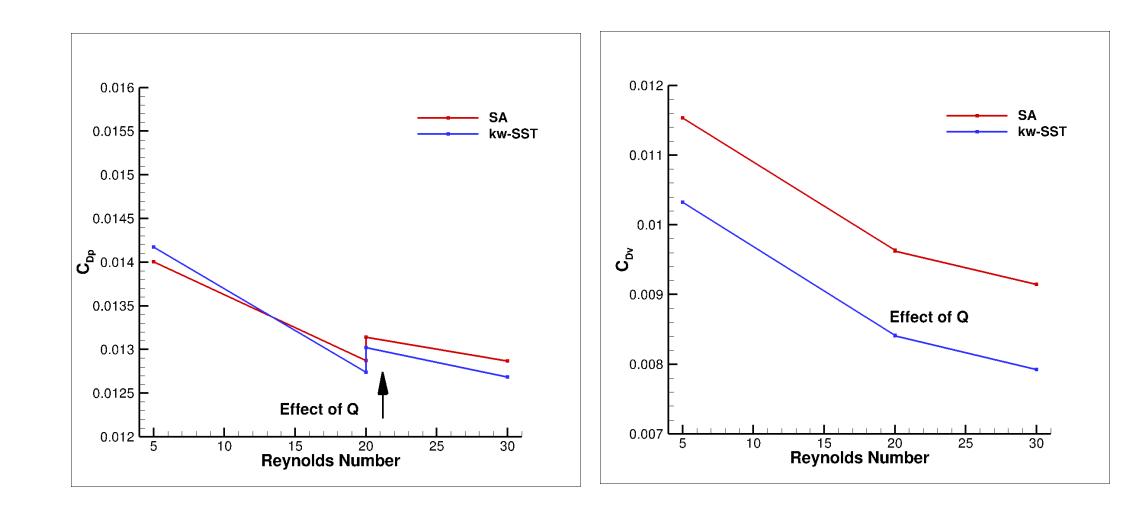
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## Case 3 – Reynolds number and Q effect study



CDp

CDv

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- The grid convergence study shows good convergence properties, with grid refinement primarily affecting the shock position and resolution.
- The alpha sweep study showed a strong sensitivity of turbulence modelling on the result. The QCR-correction was found to significantly improve the unphysical strong separation at the root, whereas the RC-correction, shifts the shock aft.
- The Reynolds number study showed reduced drag and alpha with increasing Re. whereas the Q primarily increased the alpha and reduced the negative pitching moment.

## Potential further investigations:

- Mesh sensitivity study -> repeat study on ultra-fine grids/ grids of a different family
- Warm-started alpha sweep (each grid needs exactly the same number of nodes)
- Scale-resolving simulations