JAXA's TAS Code Results for the 7th AIAA CFD Drag Prediction Workshop

Mitsuhiro MURAYAMA and Yasushi ITO (JAXA)

Ryutaro FURUYA (Ryoyu Systems)

Background: JAXA's studies in past DPWs

- JAXA has participated in a series of DPWs since DPW-II
  - Multi-block structured grid solver: UPACS
  - Unstructured grid solvers: TAS code and FaSTAR

Solvers		DPW-II	DPW-III	DPW-IV	DPW-V	DPW-VI
UPACS *Multi-block structured*	NS Eqs	Full/ Thin layer	Full/ Thin layer	Full	Full	
	Turb	SA	SA/SST	SA/SA-QCR	SA/SA-QCR SST/SST-QCR	
	Grids	Gridgen	Gridgen/ Boeing	Gridgen	Gridgen/ Common	
TAS code *Unstructured*	NS Eqs	Full	Full	Full		Full
	Turb	SA	SA	SA		SA-QCR
	Grids	TASMesh (MEGG3D)	MEGG3D	MEGG3D		MEGG3D/ NASA/Boing
FaSTAR *Unstructured*	NS Eqs				Full	Full
	Turb				SA	SA-QCR
	Grids				HexaGrid/ CommonHex	BOXFUN/ NASA

SA = SA-noft2-R

Background: JAXA's studies related past DPWs

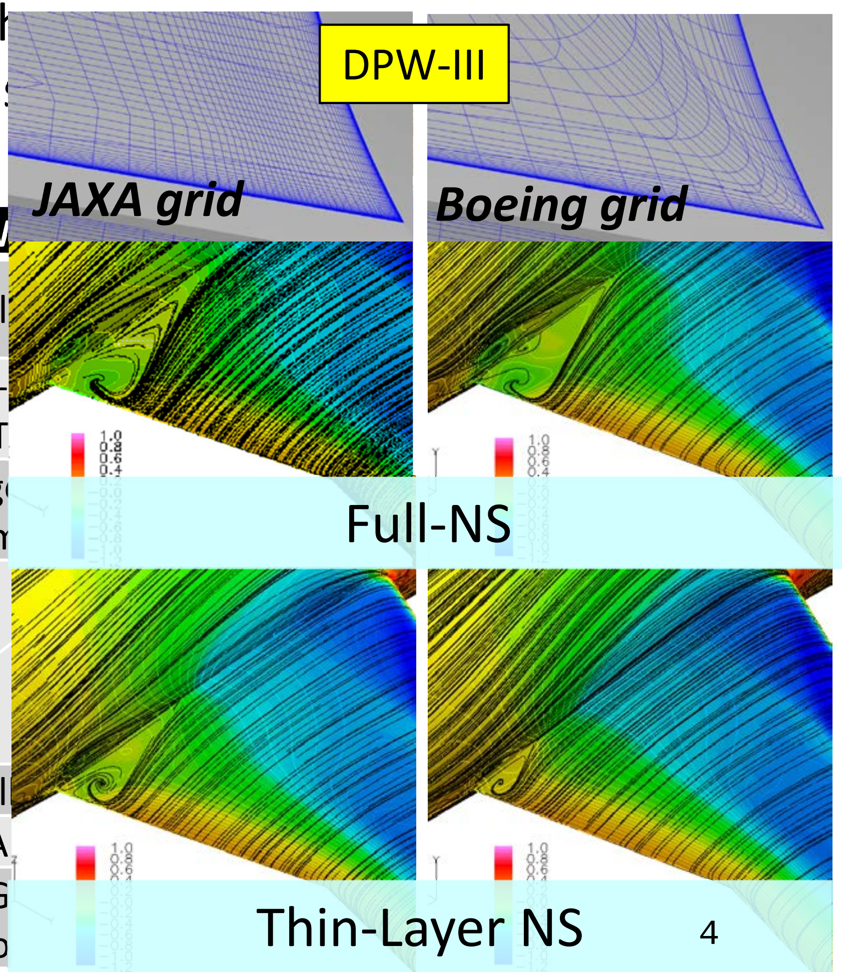
- Lessons Learned
  - Thin-layer NS shows less SOB flow separation and more grid-dependency
  - SA with fine mesh around the corner shows larger SOB flow separation
  - Effect of nonlinear Reynolds stress: Quadratic Constitutive Relation (QCR) improves the prediction of SOB flow separation.
  - Consistent results are obtained between structured grid, UPACS, and unstructured grid, TAS code, with fine mesh
  - Experiences of grid generation were increased based on well-defined DPW gridding guidelines

Solvers		DPW-II	DPW-III	DPW-IV	DPW-V	DPW-VI
UPACS *Multi-block structured*	NS Eqs	Full/ Thin layer	Full/ Thin layer	Full	Full	SA = SA-noft2-R
	Turb	SA	SA/SST	SA/SA-QCR	SA/SA-QCR SST/SST-QCR	
	Grids	Gridgen	Gridgen/ Boeing	Gridgen	Gridgen/ Common	
TAS code *Unstructured*	NS Eqs	Full	Full	Full		Full
	Turb	SA	SA	SA		SA-QCR
	Grids	TASMesh (MEGG3D)	MEGG3D	MEGG3D		MEGG3D/ NASA/Boing
FaSTAR *Unstructured*	NS Eqs				Full	Full
	Turb				SA	SA-QCR
	Grids				HexaGrid/ CommonHex	BOXFUN/ NASA

Background: JAXA's studies related past DPWs

- Lessons Learned
  - Thin-layer NS shows less SOB flow separation and more grid-dependency
  - SA with fine mesh around the corner shows larger SOB flow separation
  - Effect of nonlinear Reynolds stress: Quadratic Constitutive Relation (QCR) improves the prediction of SOB flow separation.
  - Consistent results are obtained between structured grid, UPACS, and unstructured grid, TAS code, with fine mesh
  - Experiences of grid generation were increas DPW gridding guidelines

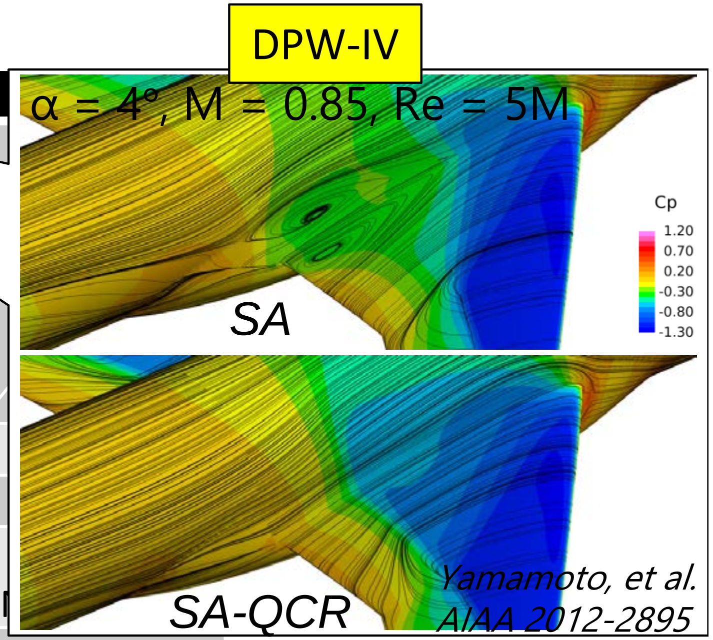
Solvers		DPW-II	DPW-III	DPW-IV	DPW
UPACS *Multi-block structured*	NS Eqs	Full/ Thin layer	Full/ Thin layer	Full	Ful
	Turb	SA	SA/SST	SA/SA-QCR	SA/SA- SST/SST
	Grids	Gridgen	Gridgen/ Boeing	Gridgen	Gridg Comm
TAS code *Unstructured*	NS Eqs	Full	Full	Full	
	Turb	SA	SA	SA	
	Grids	TASMesh (MEGG3D)	MEGG3D	MEGG3D	
FaSTAR *Unstructured*	NS Eqs				Ful
	Turb				SA
	Grids				HexaG Commo



Background: JAXA's studies related past DPWs

- Lessons Learned
  - Thin-layer NS shows less SOB flow separation and more grid-dependency
  - SA with fine mesh around the corner shows larger SOB flow separation
  - Effect of nonlinear Reynolds stress: Quadratic Constitutive Relation (QCR) improves the prediction of SOB flow separation.
  - Consistent results are obtained between structured grid, UPACS, and unstructured grid, TAS code, with fine mesh
  - Experiences of grid generation were increased based on well-defined DPW gridding guidelines

Solvers		DPW-II	DPW-III	DPW-IV	DPW-V	
UPACS *Multi-block structured*	NS Eqs	Full/ Thin layer	Full/ Thin layer	Full		
	Turb	SA	SA/SST	SA/SA-QCR	SA/SA-QC SST/SST-QCR	
	Grids	Gridgen	Gridgen/ Boeing	Gridgen	Gridgen/ Common	
TAS code *Unstructured*	NS Eqs	Full	Full	Full		
	Turb	SA	SA	SA		
	Grids	TASMesh (MEGG3D)	MEGG3D	MEGG3D		
FaSTAR *Unstructured*	NS Eqs				Full	Full
	Turb				SA	SA-QCR
	Grids				HexaGrid/ CommonHex	BOXFUN/ NASA



Background: JAXA's studies related past DPWs

- Lessons Learned
  - Thin-layer NS shows less SOB flow separation and more grid-dependency
  - SA with fine mesh around the corner shows larger SOB flow separation
  - Effect of nonlinear Reynolds stress: Quadratic Constitutive Relation (QCR) improves the prediction of SOB flow separation.
  - Consistent results are obtained between structured grid, UPACS, and unstructured grid, TAS code, with fine mesh
  - Experiences of grid generation were increased based on well-defined DPW gridding guidelines

Solvers		DPW-II	DPW-III	DPW-IV	DPW-V	DPW-VI
UPACS *Multi-block structured*	NS Eqs	Full/ Thin layer	Full/ Thin layer	Full	Full	SA = SA-noft2-R
	Turb	SA	SA/SST	SA/SA-QCR	SA/SA-QCR SST/SST-QCR	
	Grids	Gridgen	Gridgen/ Boeing	Gridgen	Gridgen/ Common	
TAS code *Unstructured*	NS Eqs	Full	Full	Full		Full
	Turb	SA	SA	SA		SA-QCR
	Grids	TASMesh (MEGG3D)	MEGG3D	MEGG3D		MEGG3D/ NASA/Boing
FaSTAR *Unstructured*	NS Eqs				Full	Full
	Turb				SA	SA-QCR
	Grids				HexaGrid/ CommonHex	BOXFUN/ NASA

JAXA's studies using TAS code for DPW-VII

- To leverage experiences from past DPWs
  - Grid generation of a series of unstructured grids by MEGG3D: JAXA_Grids.REV00
  - Full-NS with SA-noft2-R-QCR on JAXA's grids
  - Some comparisons with SA-noft2-R
- Test cases
  - Case 1a&b Grid Convergence Study at Re=20M & 5M
  - Case 2a&b Alpha Sweep at Re=20M & 5M
  - Case 3 Reynolds Number Sweep At Constant C_L

Solvers		DPW-II	DPW-III	DPW-IV	DPW-V	DPW-VI	DPW-VII
UPACS *Multi-block structured*	NS Eqs	Full/ Thin layer	Full/ Thin layer	Full	Full		
	Turb	SA	SA/SST	SA/SA-QCR	SA/SA-QCR SST/SST-QCR	SA = SA-noft2-R	
	Grids	Gridgen	Gridgen/ Boeing	Gridgen	Gridgen/ Common		
TAS code *Unstructured*	NS Eqs	Full	Full	Full		Full	Full
	Turb	SA	SA	SA		SA-QCR	SA/SA-QCR
	Grids	TASMesh (MEGG3D)	MEGG3D	MEGG3D		MEGG3D/ NASA/Boing	MEGG3D
FaSTAR *Unstructured*	NS Eqs				Full	Full	Full, linearized URANS
	Turb				SA	SA-QCR	SA/SA-QCR/AMM-QCR
	Grids				HexaGrid/ CommonHex	BOXFUN/ NASA	MEGG3D

Flow solver and solution strategies

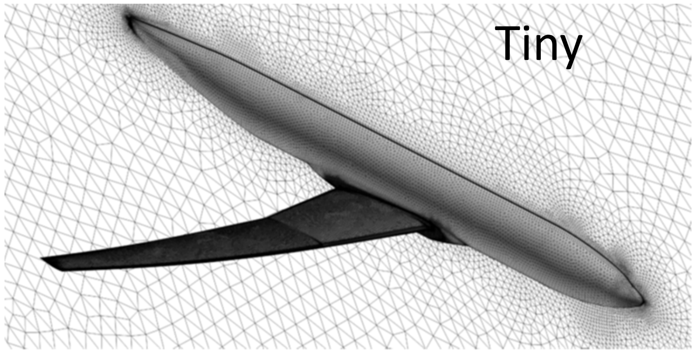
- Flow solver: unstructured TAS-code
  - Solving full compressible Navier-Stokes equations
  - SA-noft2-R (C_{rot}=1)-QCR2000 with our experience in DPWs
  - Fully turbulent
  - Computations at higher α with warm start: restart from previous solution at lower α with velocity vector rotation to accelerate solution convergence

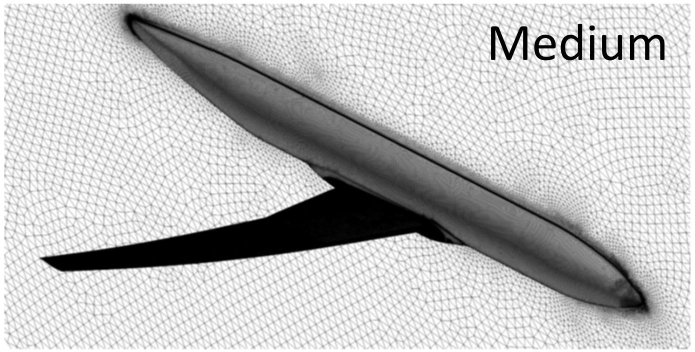
	TAS-code
Discretization	Cell-vertex finite volume
Convection flux	HLLEW 2nd-order UMUSCL w/ Venkatakrishnan's limiter (K=5)
Time integration	LU-symmetric Gauss-Seidel
Turbulence model	SA-noft2-R(C_{rot}=1)-QCR2000, SA-noft2-R(C_{rot}=1)

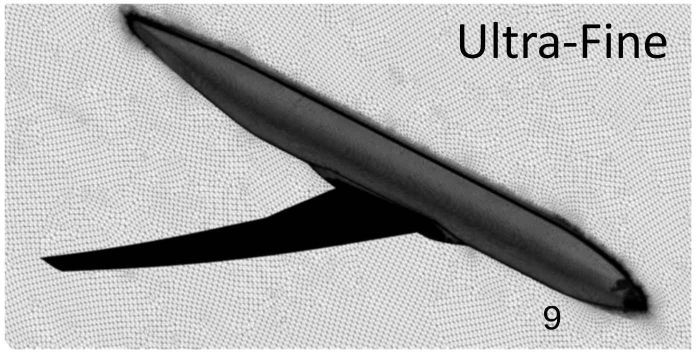
Computational Grids: JAXA_Grids.Rev00 in DPW-7 website

- Grid generation software
  - MEGG3D –Mixed Element Grid Generator in 3D
    - Unstructured hybrid surface/volume grid generator
      - Surface: Triangle & rectangle, Volume: Prism, hexa, tetra & pyramid
- Grid generation method with wing deformation
  - Baseline grid for config. w/o deformation was generated, then the grid was deformed based on the wing deformation

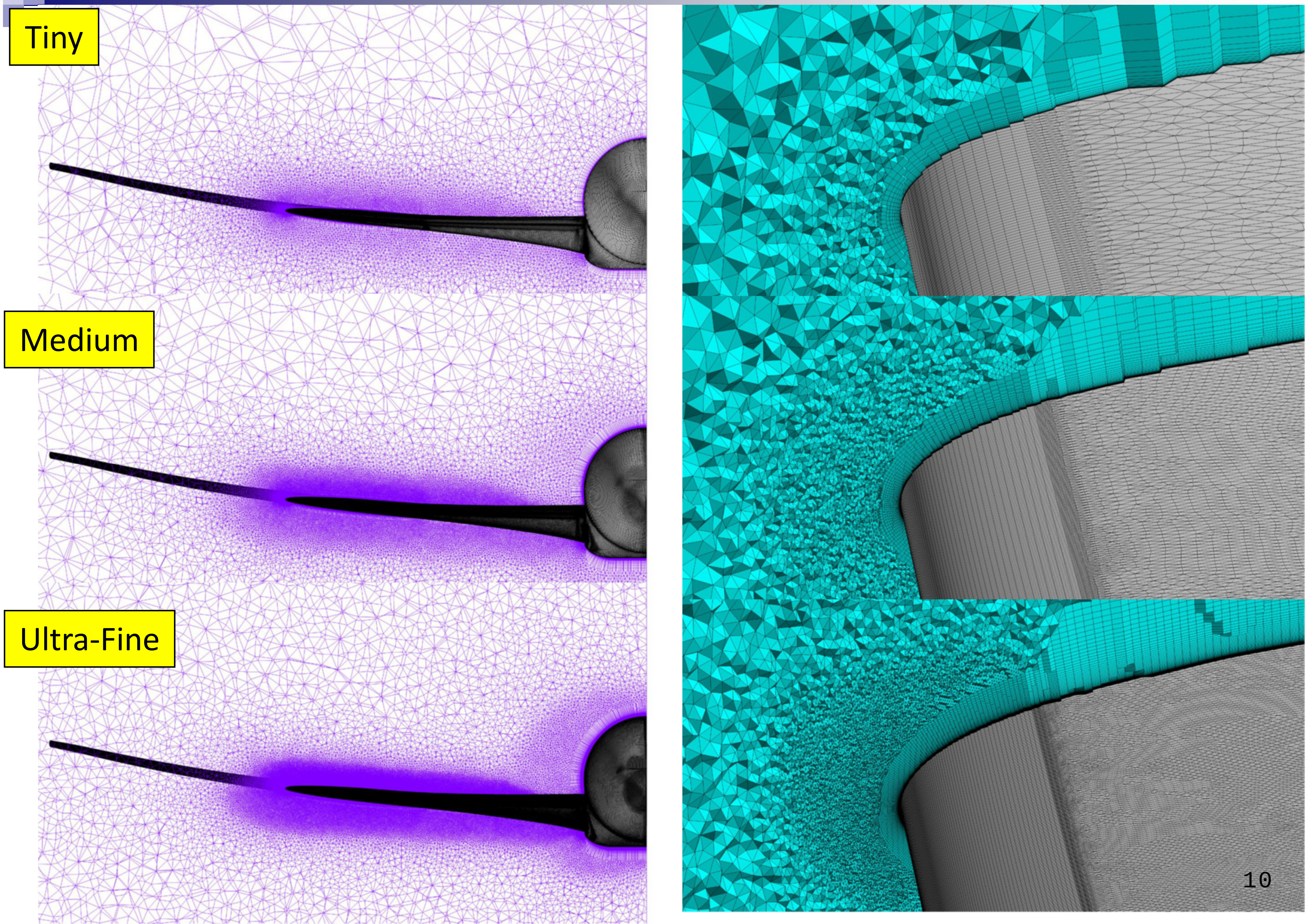
	Tiny	Coarse	Medium	Fine	Extra-Fine	Ultra-Fine
Nodes	9 M	27 M	60 M	112 M	184 M	291 M
Cells	25 M	76 M	164 M	295 M	476 M	739 M
Target Y^+	1.00	0.67	0.50	0.40	0.33	0.29







Computational Grids: JAXA_Grids.Rev00 in DPW-7 website



Computational Results

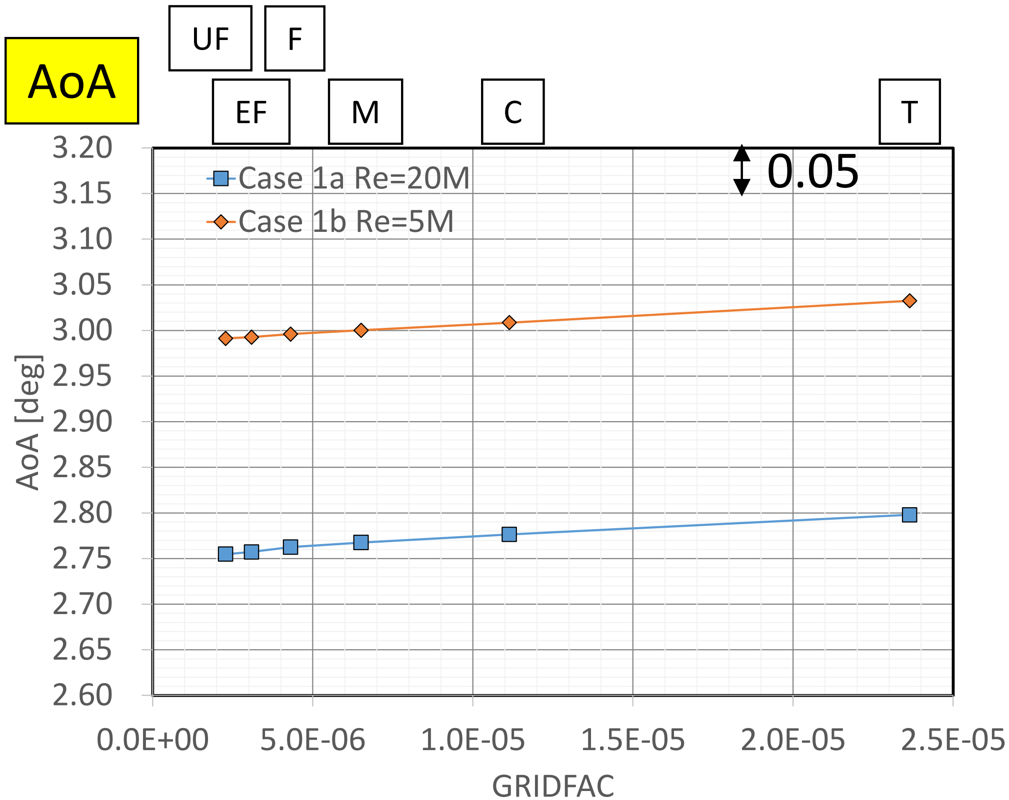
- Case 1a&b: Grid Convergence Study at Re=20M & 5M
- Case 2a&b: Alpha Sweep at Re=20M & 5M
- Case 2a+: Comparison of turbulence models at Re=20M
  - SA-noft2-R(Crot=1)-QCR2000 vs SA-noft2-R(Crot=1)
- Case 3: Reynolds Number Sweep At Constant C_L

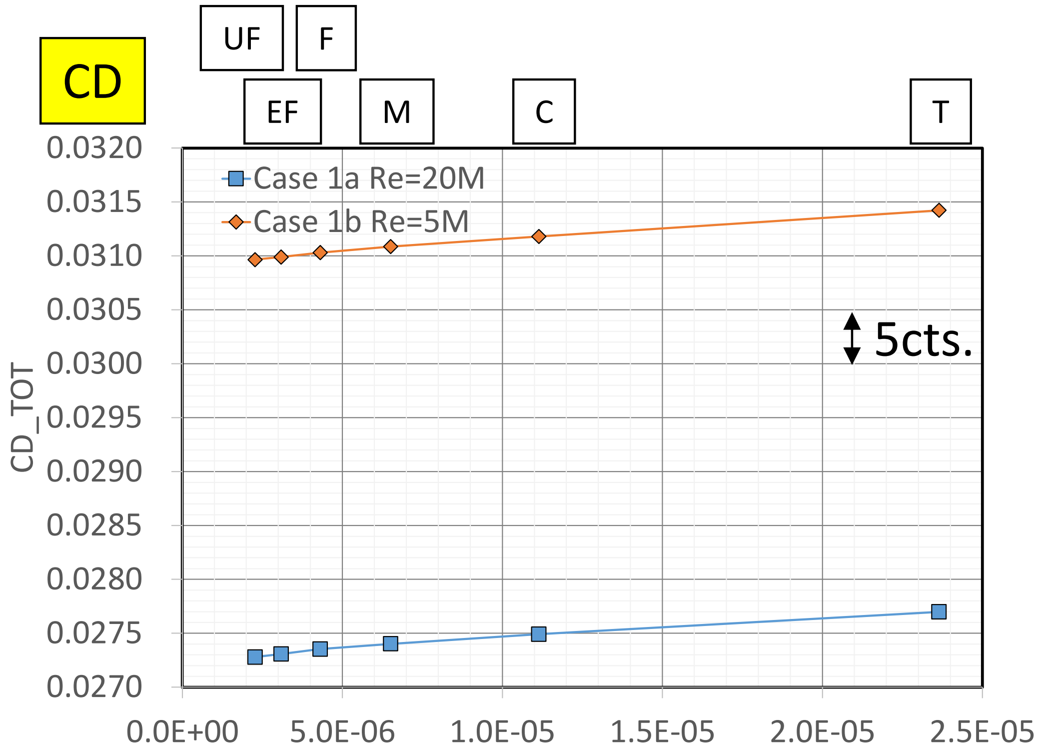
Computational Results

- Case 1a&b: Grid Convergence Study at Re=20M & 5M
- Case 2a&b: Alpha Sweep at Re=20M & 5M
- Case 2a+: Comparison of turbulence models at Re=20M
  - SA-noft2-R(Crot=1)-QCR2000 vs SA-noft2-R(Crot=1)
- Case 3: Reynolds Number Sweep At Constant C_L

Case 1a&b: Grid Convergence Study at Re=20M & 5M

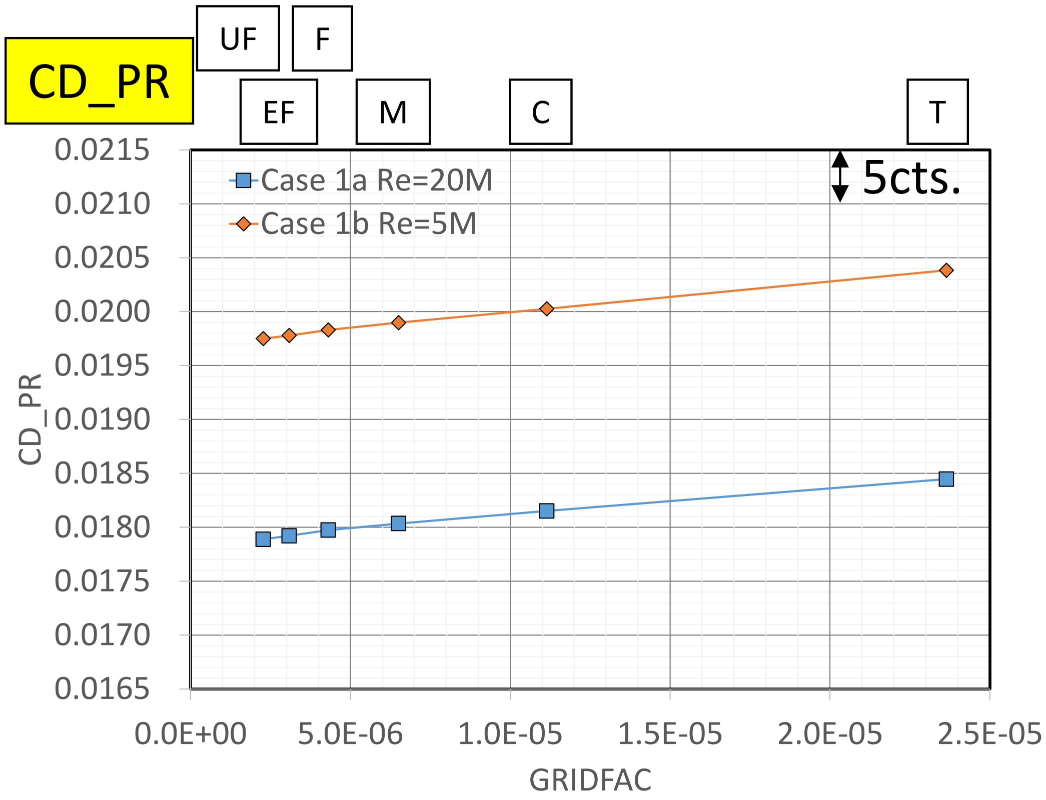
- Almost straight grid convergence from Tiny to Ultra-Fine
  - AoA: Variations with grid size < 0.05deg
  - CD: Variations with grid size < 5cts. (CD 1cts. = 0.0001)
- Almost constant difference between result of two Re conditions at each grid level

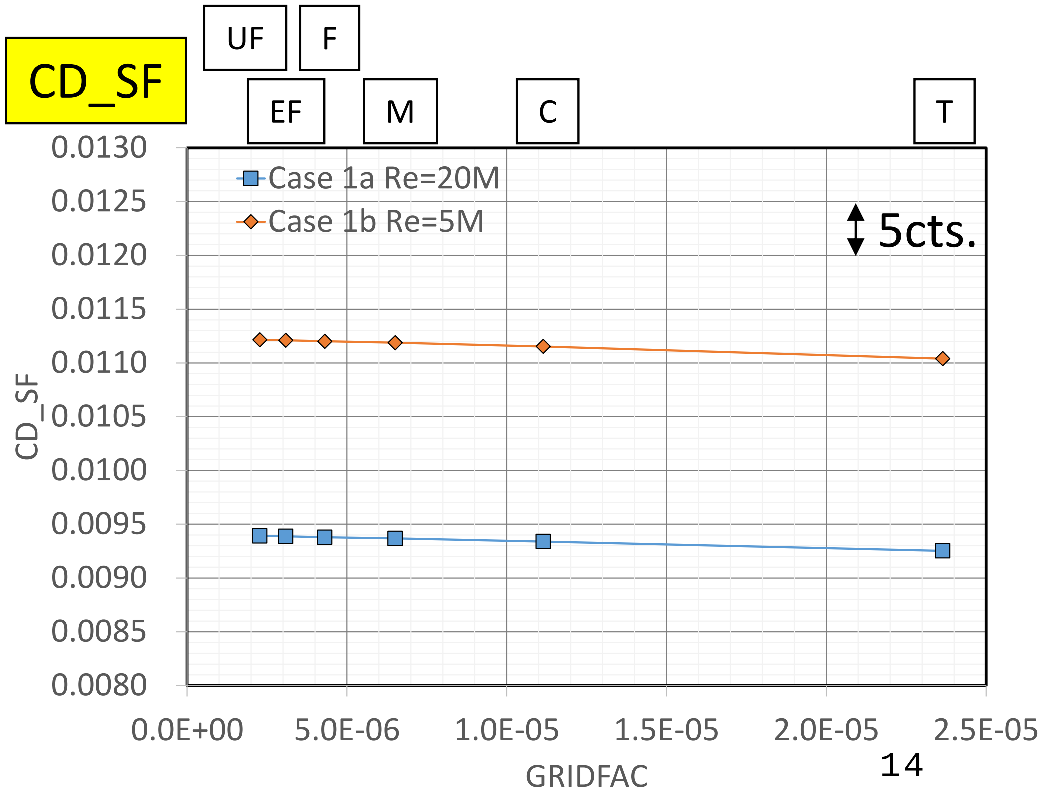




Case 1a&b: Grid Convergence Study at Re=20M & 5M

- Almost straight grid convergence from Tiny to Ultra-Fine
  - CD_SF
    Less variations with grid size < 2cts.
    Tendency to increase with grid size
- Almost constant difference between result of two Re conditions at each grid level



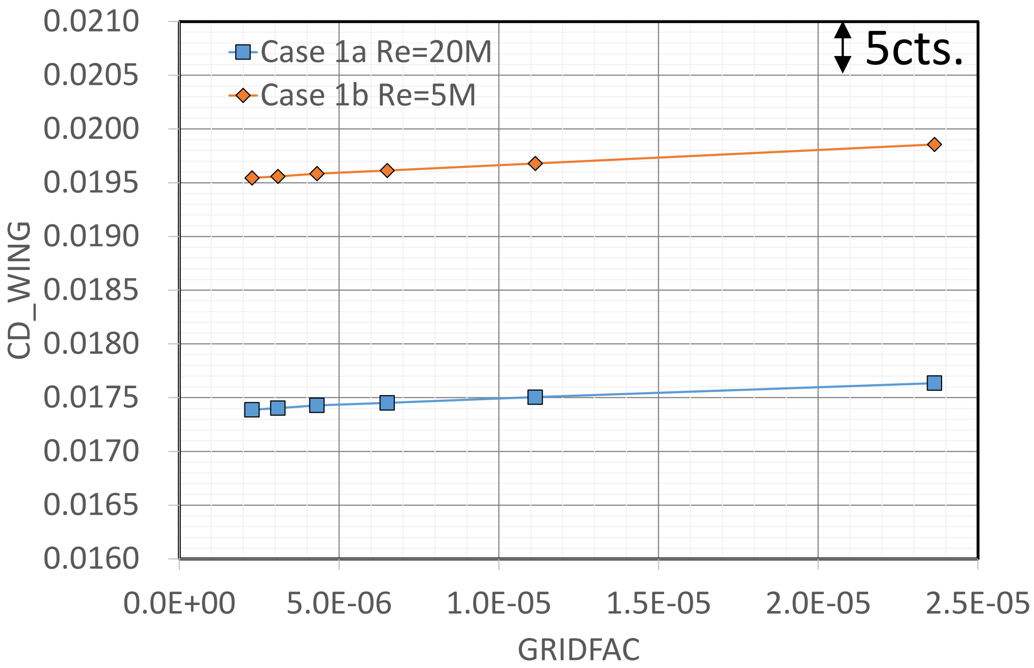


Case 1a&b: Grid Convergence Study at Re=20M & 5M

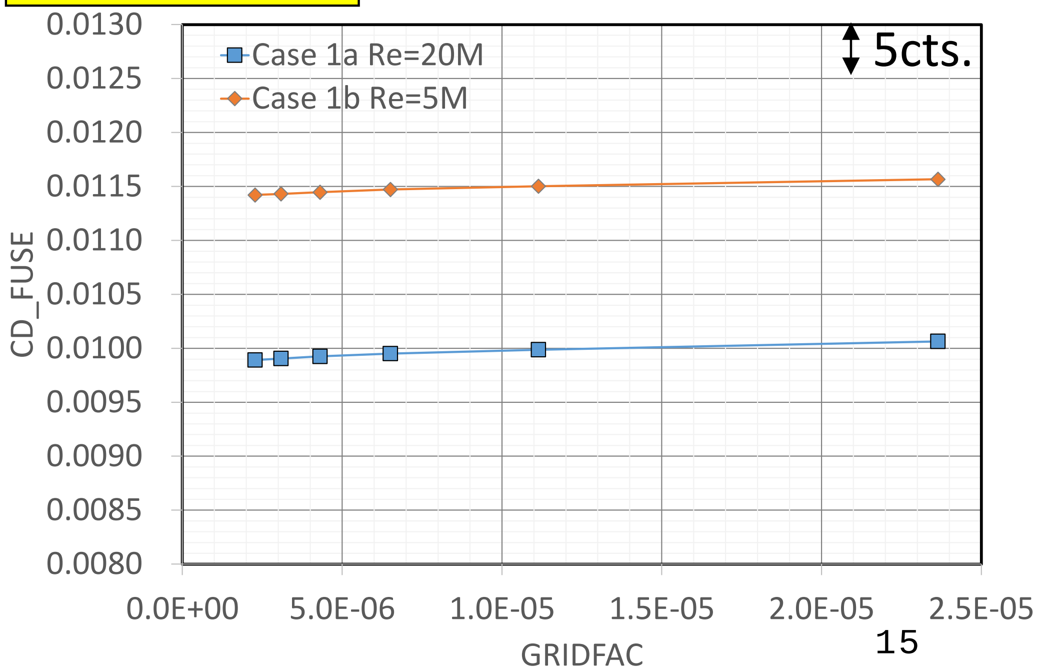
- Almost straight grid convergence from Tiny to Ultra-Fine
  - CD_FUSELAGE: Less variations with grid size < 2cts.

- Almost constant difference between result of two Re conditions at each grid level

CD_WING

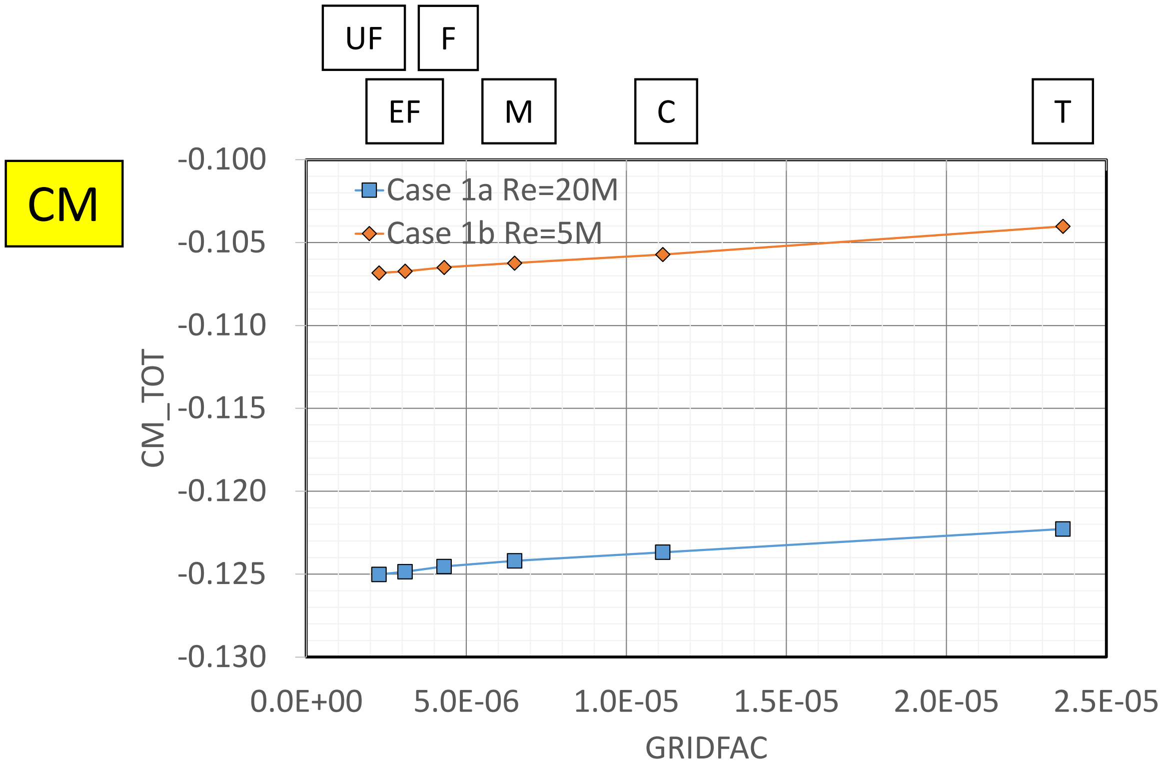


CD_FUSELAGE



Case 1a&b: Grid Convergence Study at Re=20M & 5M

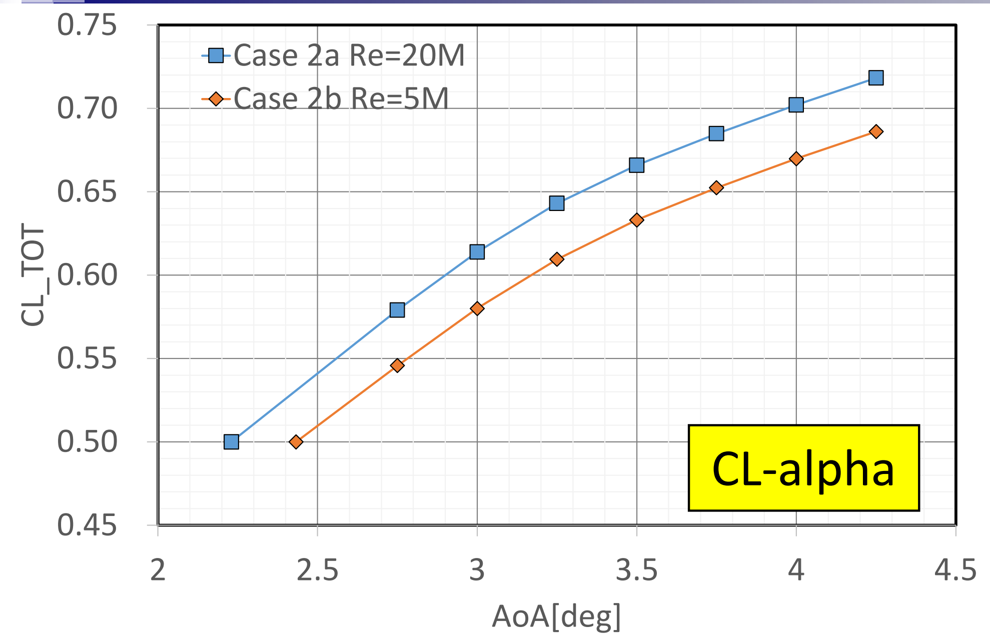
- Almost straight grid convergence from Tiny to Ultra-Fine
- Almost constant difference between result of two Re conditions at each grid level

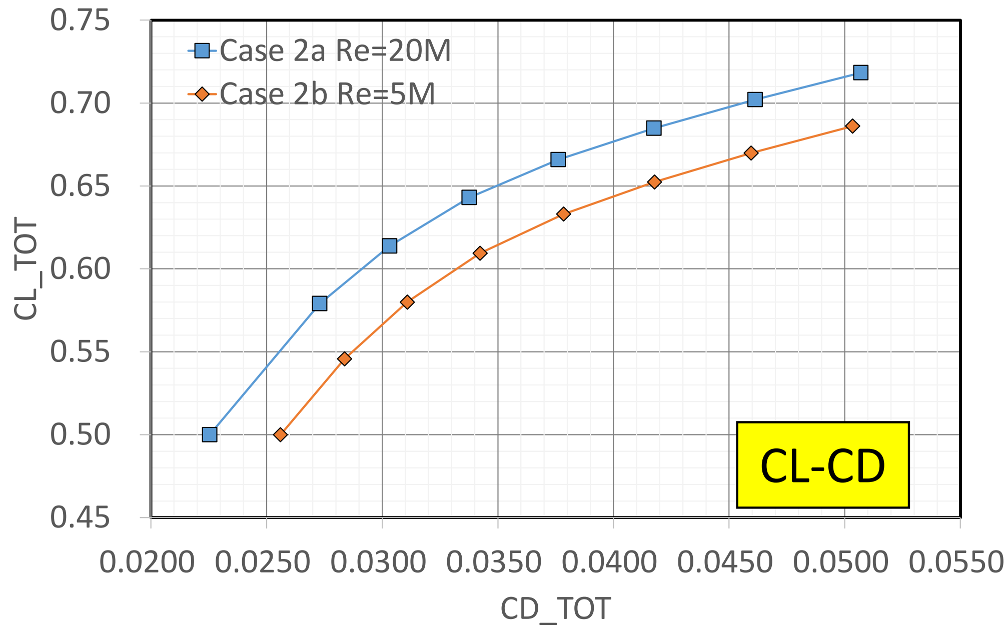


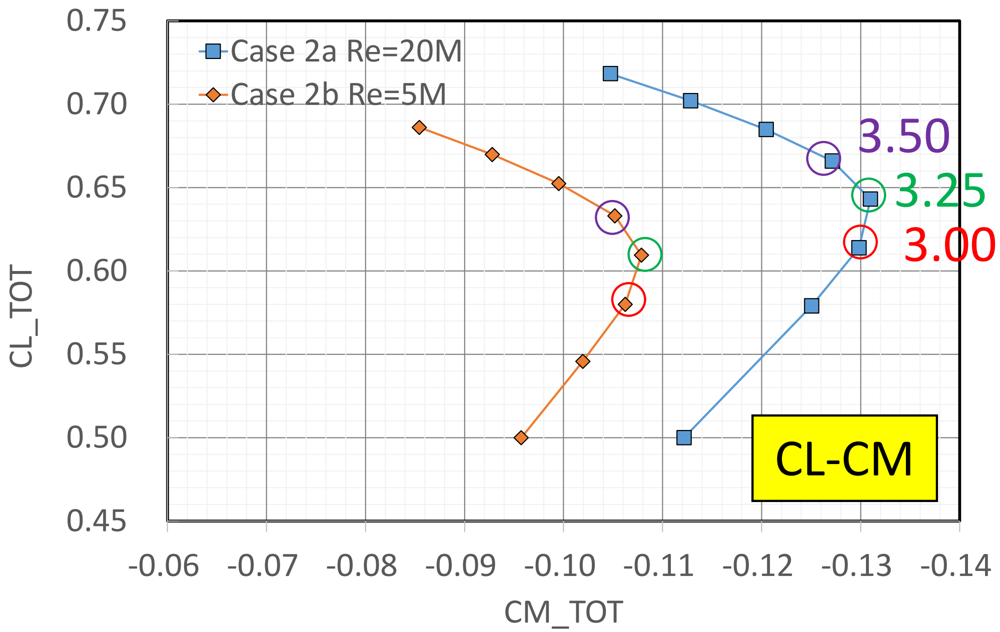
Computational Results

- Case 1a&b: Grid Convergence Study at Re=20M & 5M
- Case 2a&b: Alpha Sweep at Re=20M & 5M
- Case 2a+: Comparison of turbulence models at Re=20M
  - SA-noft2-R(Crot=1)-QCR2000 vs SA-noft2-R(Crot=1)
- Case 3: Reynolds Number Sweep At Constant C_L

Case 2a&b: Alpha Sweep at Re=20M & 5M



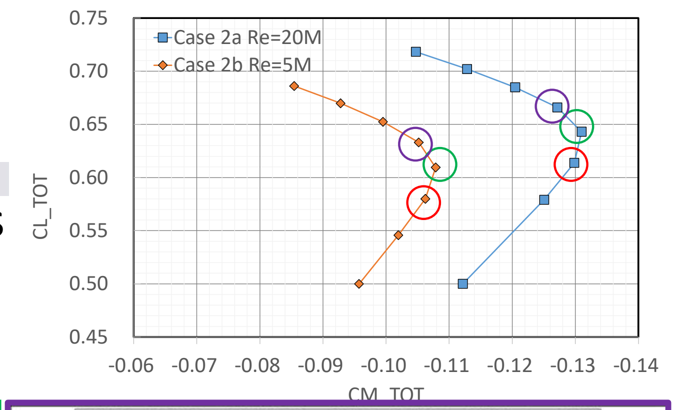


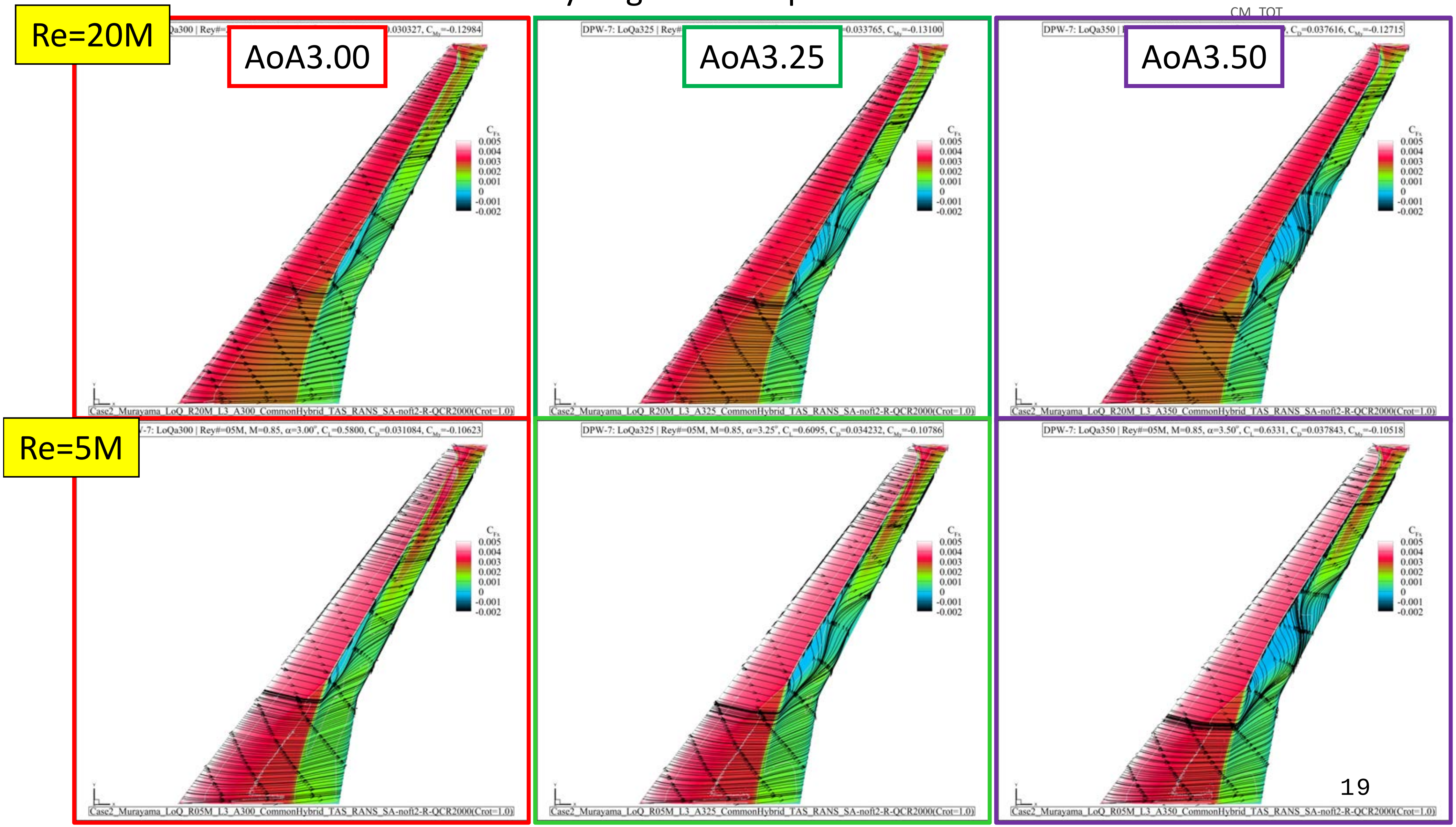


- Almost constant shift between results of two Re, but some differences after pitching-moment break
- The break of curve is observed around AoA=3.25

Case 2a&b: Alpha Sweep at Re=20M & 5M

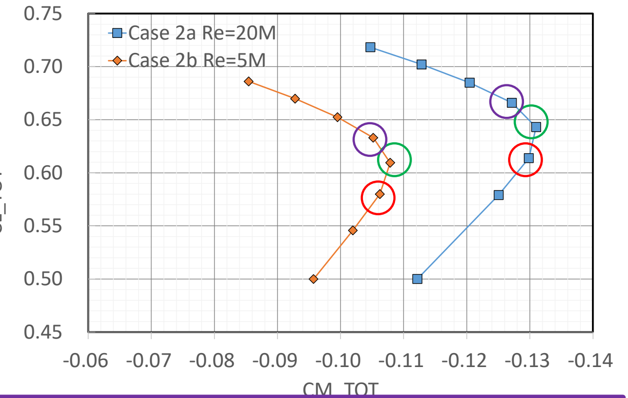
- Shock-induced flow separation around mid-span expands at higher AoAs
- Results at 5M show relatively larger flow separation

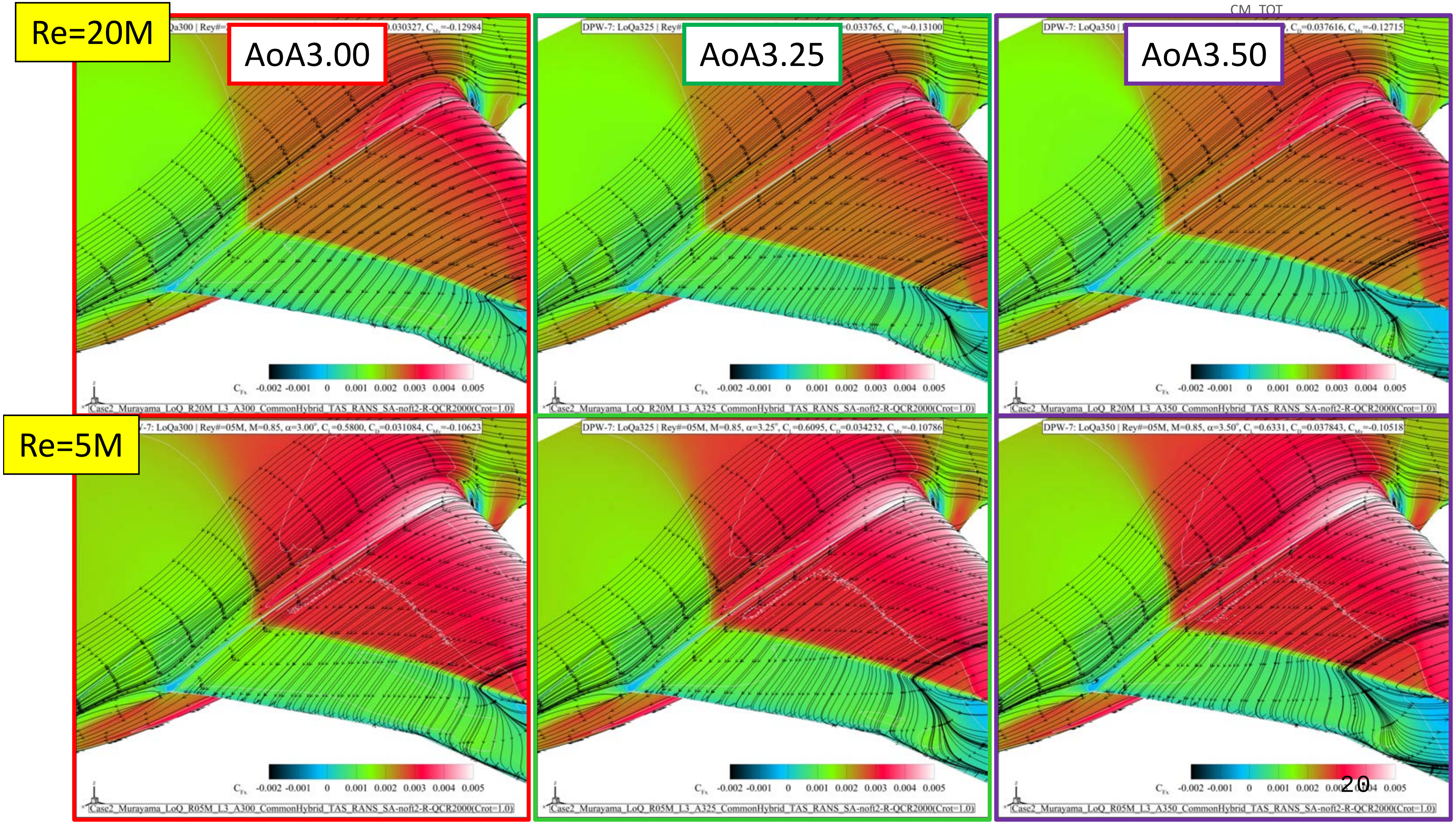




Case 2a&b: Alpha Sweep at Re=20M & 5M

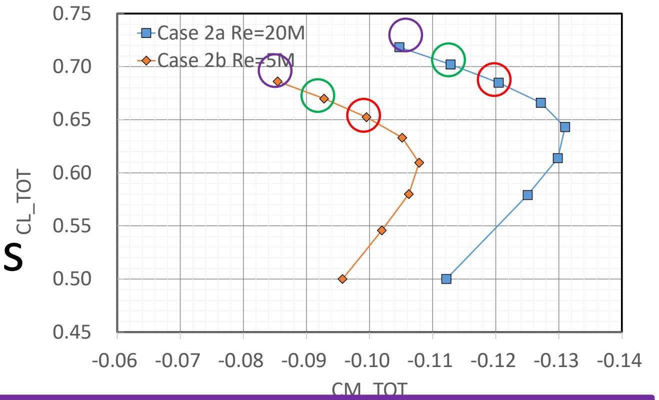
- No large SOB flow separation at both Re conditions

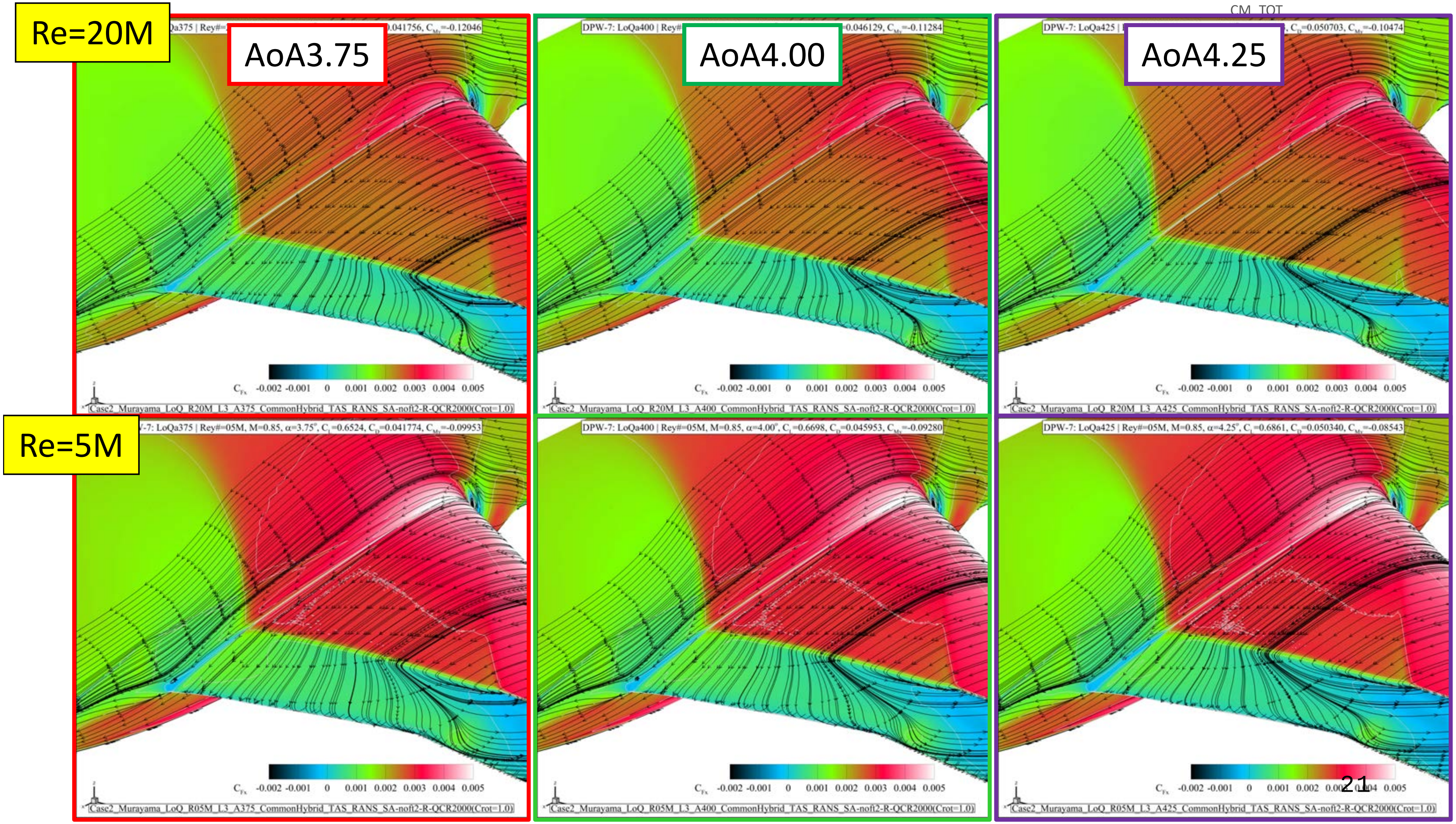




Case 2a&b: Alpha Sweep at Re=20M & 5M

- No large SOB flow separation at both Re conditions



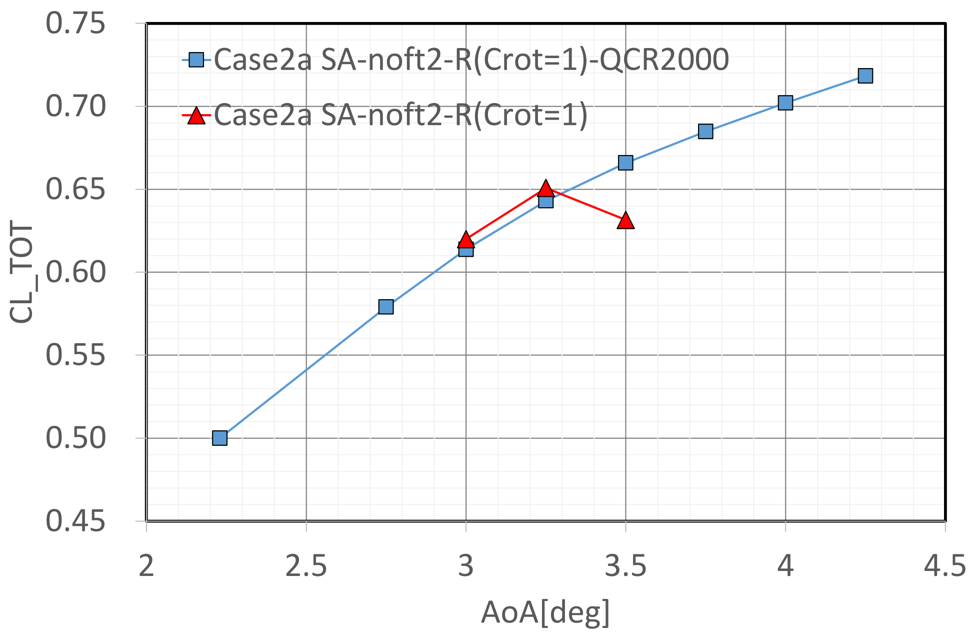


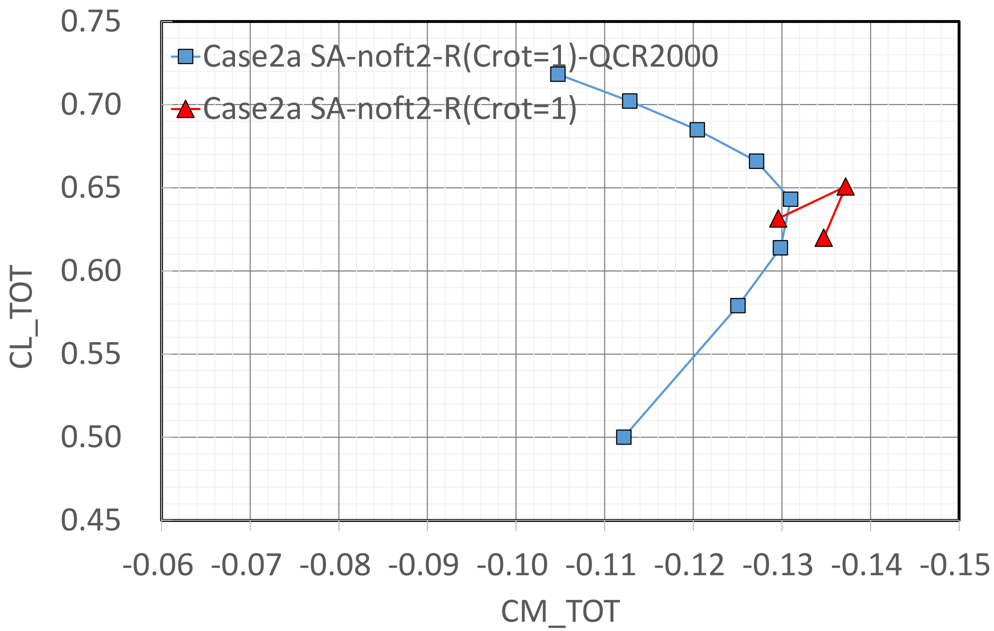
Computational Results

- Case 1a&b: Grid Convergence Study at Re=20M & 5M
- Case 2a&b: Alpha Sweep at Re=20M & 5M
- Case 2a+: Comparison of turbulence models at Re=20M
  - SA-noft2-R(Crot=1)-QCR2000 vs SA-noft2-R(Crot=1)
- Case 3: Reynolds Number Sweep At Constant C_L

Case 2a+: SA-noft2-R-QCR2000 vs SA-noft2-R

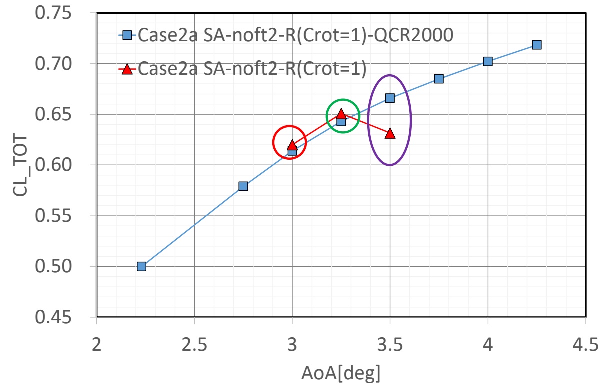
- w/o QCR
  - Lift and pitching moment curves break at AoA=3.5deg

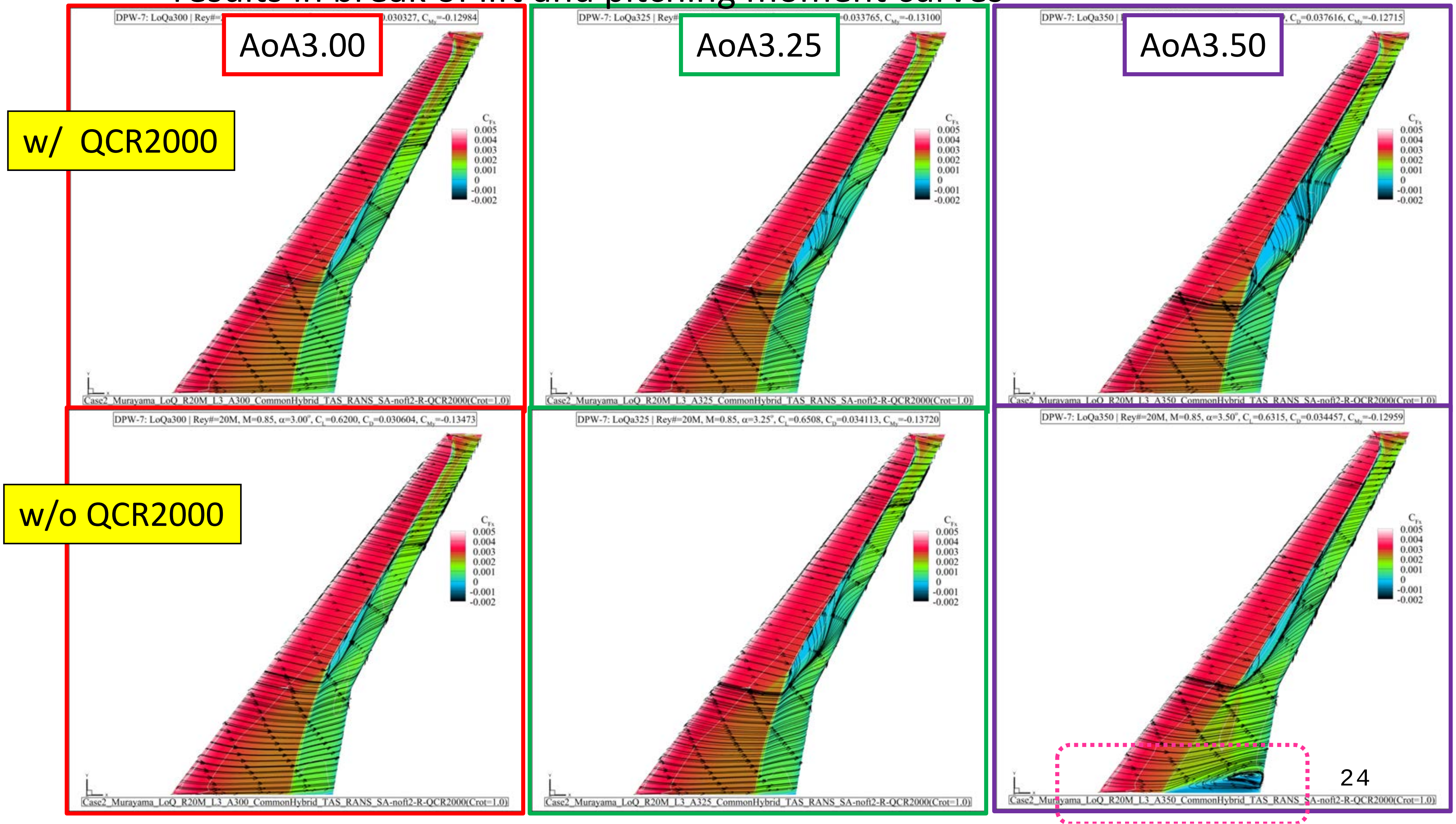




Case 2a+: SA-noft2-R-QCR2000 vs SA-noft2-R

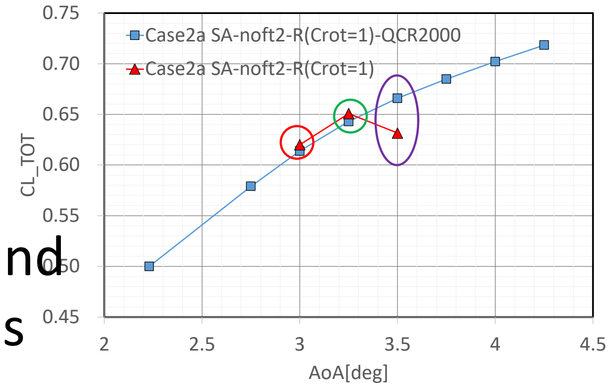
- w/ QCR: shock slightly shifts forward
- w/o QCR: SOB separation occurs at AoA=3.5 and it results in break of lift and pitching moment curves

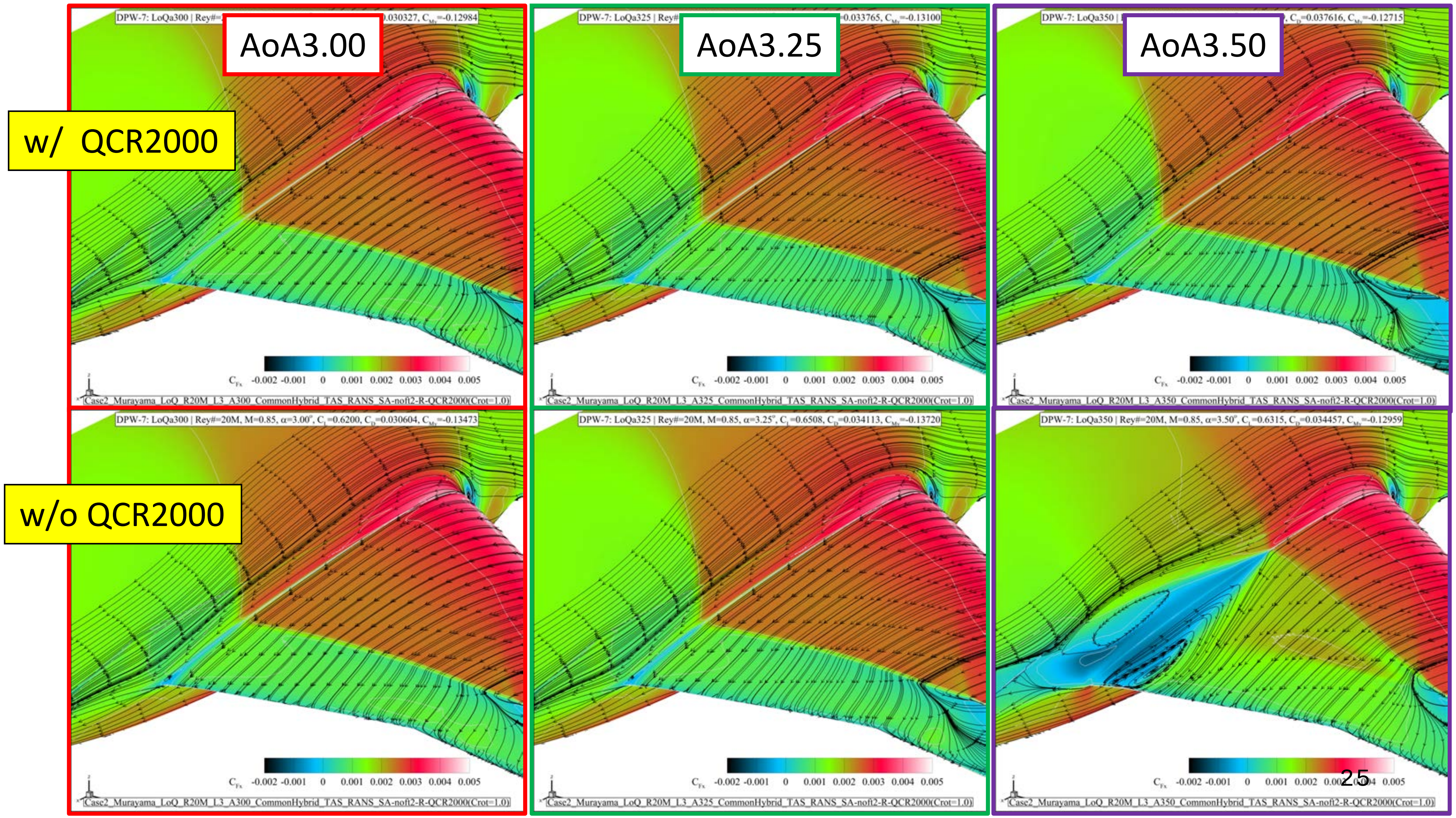




Case 2a+: SA-noft2-R-QCR2000 vs SA-noft2-R

- w/o QCR: large SOB separation occurs at AoA=3.5 and it results in break of lift and pitching moment curves

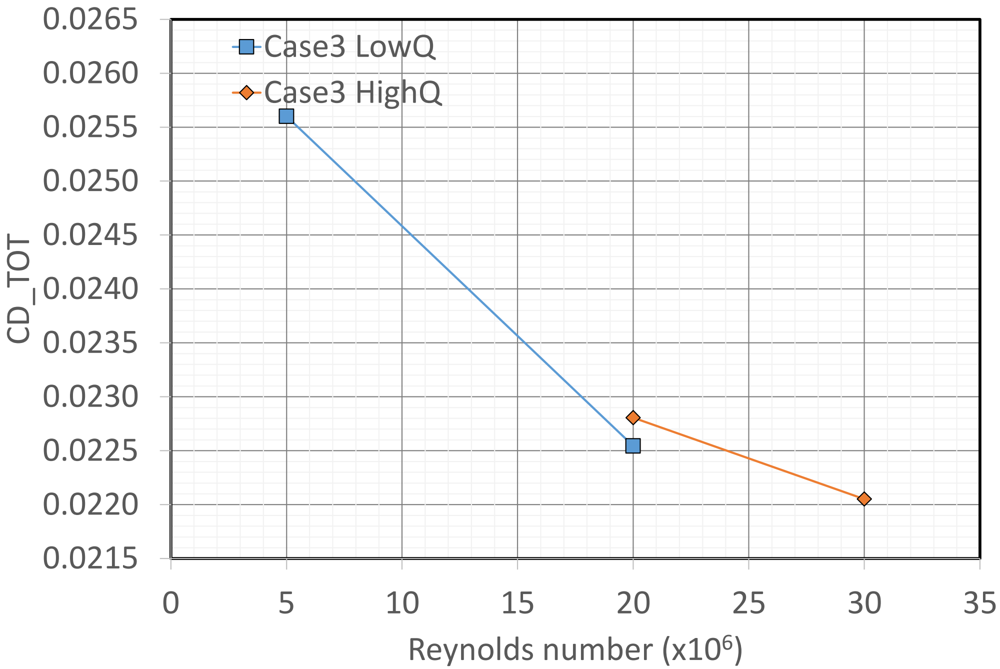


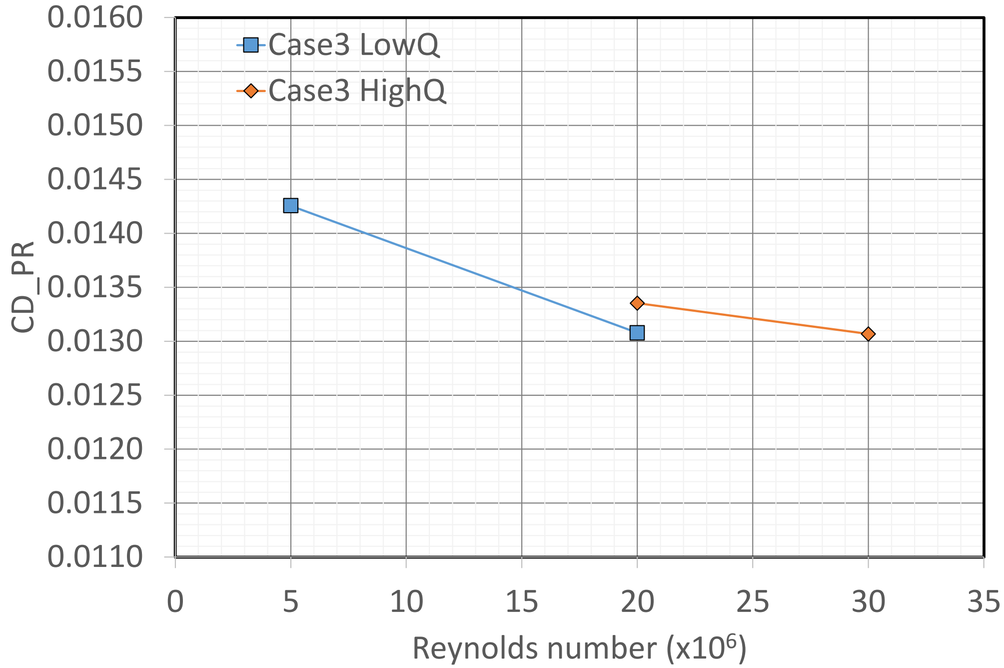


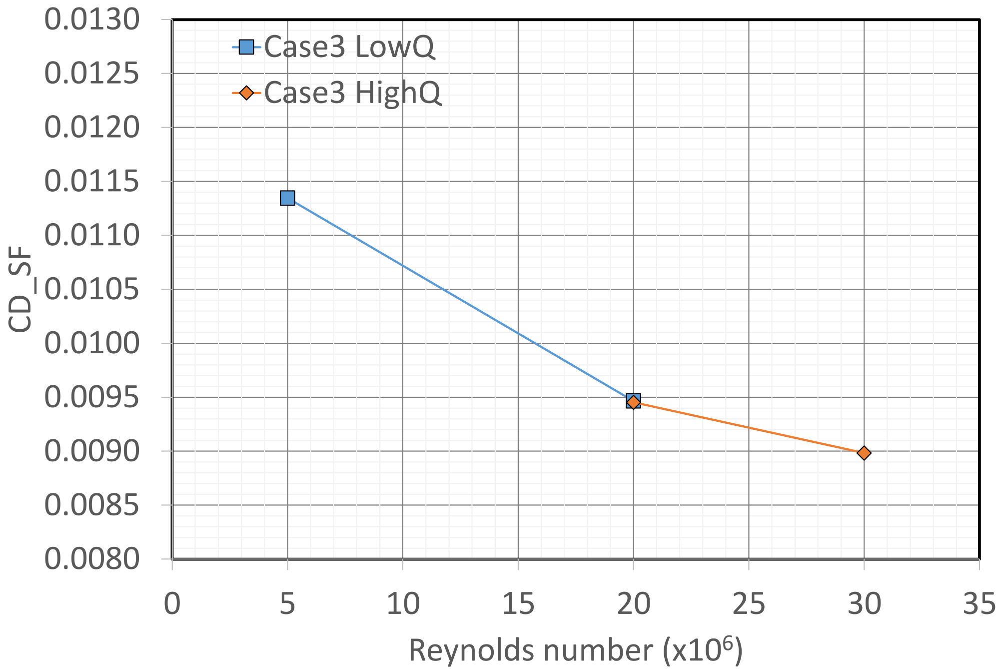
Computational Results

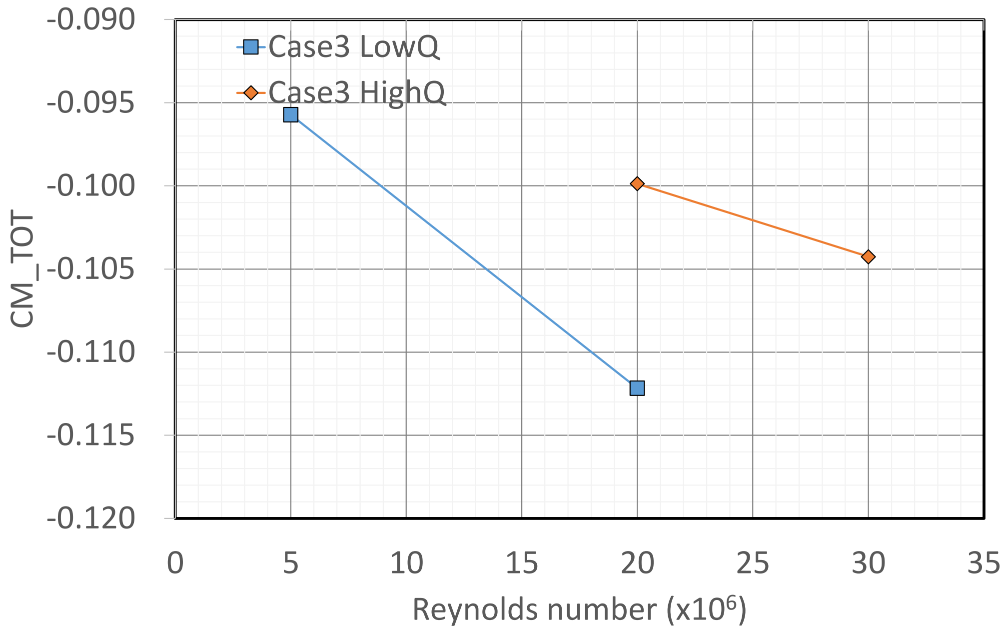
- Case 1a&b: Grid Convergence Study at Re=20M & 5M
- Case 2a&b: Alpha Sweep at Re=20M & 5M
- Case 2a+: Comparison of turbulence models at Re=20M
  - SA-noft2-R(Crot=1)-QCR2000 vs SA-noft2-R(Crot=1)
- Case 3: Reynolds Number Sweep At Constant C_L

Case 3: Reynolds Number Sweep At Constant C_L









Some jumps are found at Re=20M by the difference of Q especially for CD_PR and CM

Concluding Remarks

- JAXA's TAS Code Results for DPW-VII were shown
  - Case 1a&b Grid Convergence Study at Re=20M & 5M
    - Straight grid convergence from Tiny to Ultra-Fine and constant difference between result of two Re conditions at each grid level
  - Case 2a&b Alpha Sweep at Re=20M & 5M
    - Shock-induced flow separation expands around mid-span from AoA=3.00
    - No large SOB flow separation is found at both Re conditions with QCR2000
    - w/ QCR: shock slightly shifts forward
    - w/o QCR: Large SOB flow separation suddenly occurs at AoA=3.5 and it results in break of lift and pitching moment curves
  - Case 3 Reynolds Number Sweep At Constant C_L
    - Some jump at Re=20M by the difference of Q and deformation especially for CD_PR and CM

Case 2a&b: Alpha Sweep at Re=20M & 5M

- Shock-induced flow separation around mid-span expands at higher AoAs
- Results at 5M show relatively larger flow separation