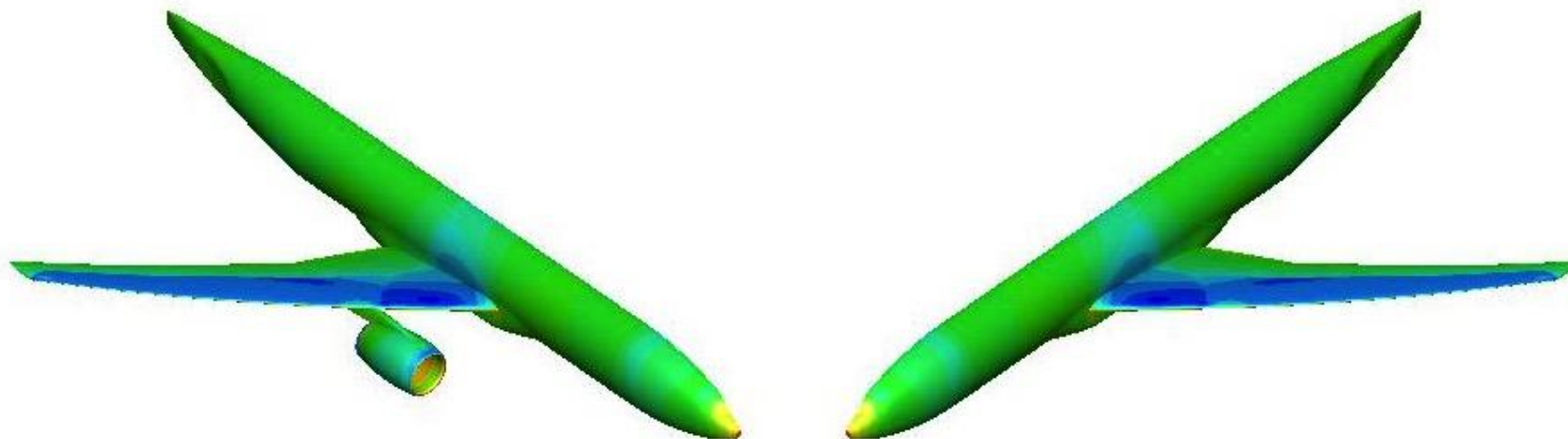# DPW 6 Summary of Participant Data
Case 1: Code Verification

Chris Roy (Virginia Tech)

and the DPW Organizing Committee

Outline:

- **Motivation for Case #1**

- **Problem description**

- **Participant data**

  - **Forces and moments**

  - Pressure and shear stress distributions

- **Effects to examine**

  - **Turbulence model**

  - **Grid type**

  - Order of accuracy of turbulence equations
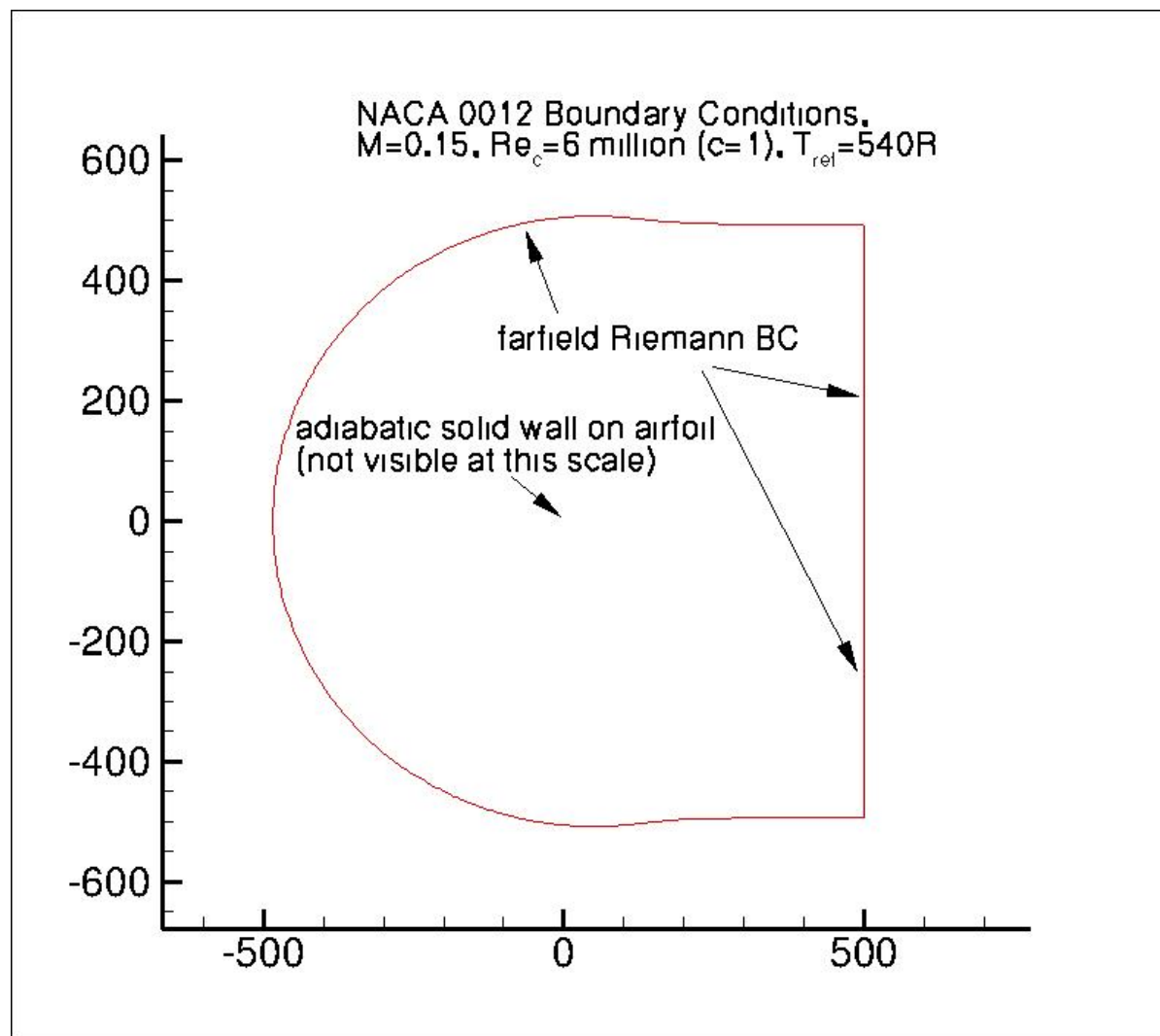
- **Conclusions**

Motivation for Case #1:

- **Past DPW Workshops had many instances of (ostensibly) the same turbulence model converging to different results with mesh refinement**

- **There should only be a single asymptotic answer for each model**

- **These problems could be attributed to a number of sources:**
    - Coding mistakes
    - Inconsistent algorithms or boundary conditions
    - Variations in the version of the turbulence model
    - Effects of grid type (structured, unstructured, etc.)
    - Ad hoc limiters on the turbulence equations (e.g., production)
    - Insufficient iterative convergence

- **Case #1 was designed to help identify contributions which suffered from these issues**
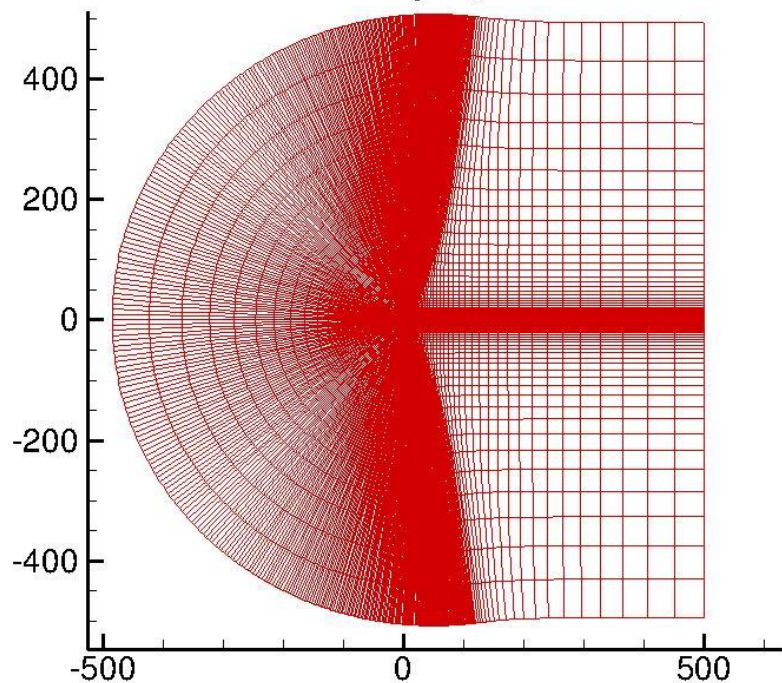
Problem description: boundary conditions

- **NACA 0012 airfoil**
- **Mach 0.15**
- **Re_c = 6M**
- **Fixed Riemann BCs at ~500 chords**
- **Problem definition and grids supplied by the NASA Langley TurbModels web site:**

http://turbmodels.larc.nasa.gov/naca0012numerics_val.html

NACA 0012 Boundary Conditions.
$M=0.15$, $Re_c=6$ million (c=1), $T_{ref}=540R$

farfield Riemann BC
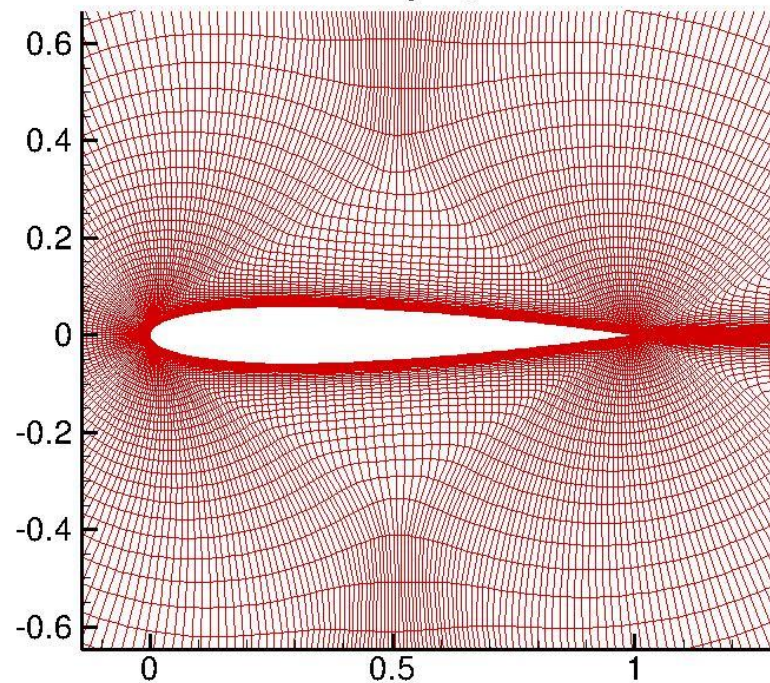
adiabatic solid wall on airfoil (not visible at this scale)

Problem description: C-grids

449 x 129 grid, far view

449 x 129 grid, near view

Problem description: primary grids used

Family I
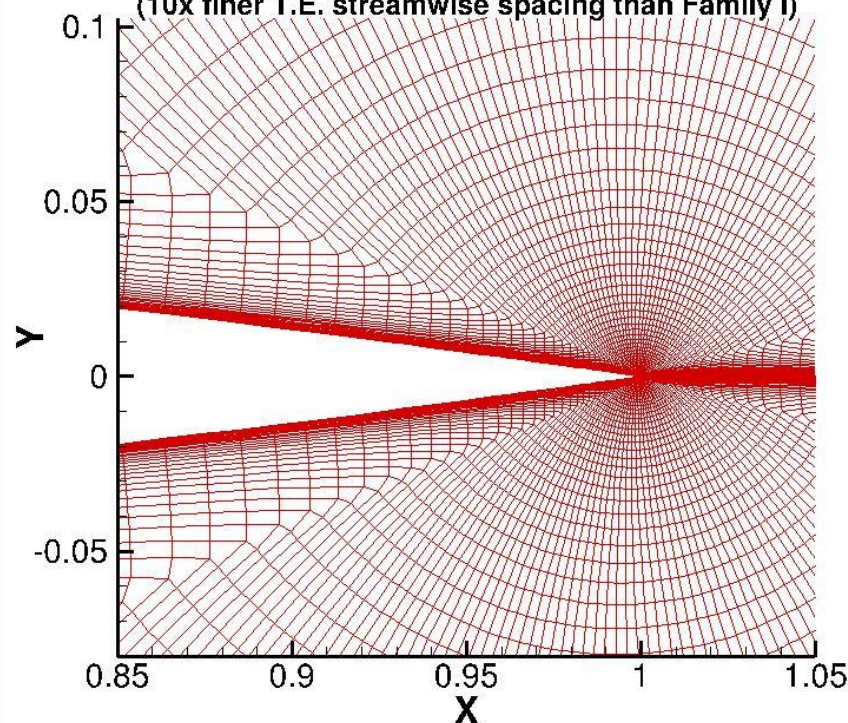
Family II (recommended)

Participant data summary for Case #1:

- **30 Data Total Data Submittals**
- **15 Teams/Organizations**
- **Turbulence Models:**
    - 22 SA (all types)
    - 4 SST
    - 1 k-kl, 1 k-e Lam, 1 EARSM, 1 LBM-VLES
- **Grid Types:**
    - 4   Structured Grid Family I (2 teams)
    - 21   Structured Grid Family II (11 teams) ← recommended grids
    - 1   O-Grid
    - 2   Cartesian (2 teams)
    - 1   Unstructured
    - 1   Adapted Unstructured

Organisation	Name	Soln ID	Code	Turbulence Model	Case 1							
					Family	113x33	225x65	449x129	897x257	1793x513	3585x1025	7169x2049
Boeing, BCA Advanced Concepts, Long Beach CA	John Vassberg	A1	Overflow v2.2k	SA-RC	II	X	X	X	X	X		
		A2	Overflow v2.2k	SA-RC-QCR2000	II	X	X	X	X	X		
NASA Langley Research Center, FUN3D	Khaled S. Abdol-Hamid	B2	FUN3D 12.8	k-kL-MEAH2015	II	X	X	X	X	X	X	
CARDC	Jiangtao Chen	D1	Mflow	SA	II	X	X	X	X	X		
		D3	Mflow	SST	II	X	X	X	X	X		
	Yan Sun	T1	TRIP	SA	I	X	X	X	X	X		
		T2	TRIP	SST-2003	I	X	X	X	X	X		
JAXA (FaSTAR Code), Ryoyu Systems	Atsushi Hashimoto	E1	FaSTAR	SA-noft2	II	X	X	X	X	X	X	X
		E2	FaSTAR	SA-noft2	II	X	X	X	X	X	X	X
		E3	FaSTAR	SA-noft2	I	X	X	X	X	X	X	X
		E4	FaSTAR	SA-noft2	I		X	X	X	X	X	
EXA Powerflow	Benedikt König	G1	PowerFLOW	LBM-VLES	Cartesi	o	o	o	o	o	o	o
CFMS, Zenotech, ARA	Andrei Cimpoeru	H2	Edge	EARSM	II	X	X	X	X	X	X	
Mentor Graphics	Chris Watson	I2	FloEFD	k-e Lam-Bremhorst	Cartesian			o	o	o		
MetaComp	Uriel Goldberg	J1	CFD++	SA	II	X	X	X	X	X	X	X
		J2	CFD++	SST	II	X	X	X	X	X	X	X
Kawasaki Heavy Industries, Ltd., Aerospace	Taku Nagata	K1	Cflow: 2nd order	SA-noft2 (1st)	II	X	X	X	X	X	X	X
		K2	Cflow: 3rd order	SA-noft2-QCR (1st)	II	X	X	X	X	X	X	X

Organisation	Name	Soln ID	Code	Turbulence Model	Case 1							
					Family	113x33	225x65	449x129	897x257	1793x513	3585x1025	7169x2049
CAd Lab, IIS, Bangalore, S&I Engineering Solutions	Balakrishnan	N1	HiFUN	SA (1st)	O-Grid	X	X	X	X	X	X	X
ONERA	David Hue	O1	elsA	SA	II		X		X		X	X
Boeing, St. Louis	Mori Mani	P1	BCFD	SA	Unstr		X	X	X			
		P2	GGNS	SA-neg	Adapt	Adapted Mesh						
MDOlab, University of Michigan	Joaquim R. R. A. Martins	Q1	SUMad	SA 1stOrder	II	X	X	X	X	X	X	
		Q2	SUMad	SA	II	X	X	X	X	X	X	
Embraer S/A	Rodrigo Felix de Souza	V1	CFD++	SA	II	X	X	X	X	X	X	X
		V2	CMSoft-AERO	SA	II	X	X	X	X	X	X	X
		V3	CFD++	SST	II	X	X	X	X	X	X	X
JAXA, Ryoyu Systems	Yasushi Ito	Z1	TAS	SA-noft2-R-QCR-K1	II	X	X	X	X	X	X	X
		Z2	TAS	SA-noft2-R-QCR-K5	II	X	X	X	X	X	X	
		Z3	TAS	SA-noft2-R-QCR-K10	II	X	X	X	X	X	X	X

Results:
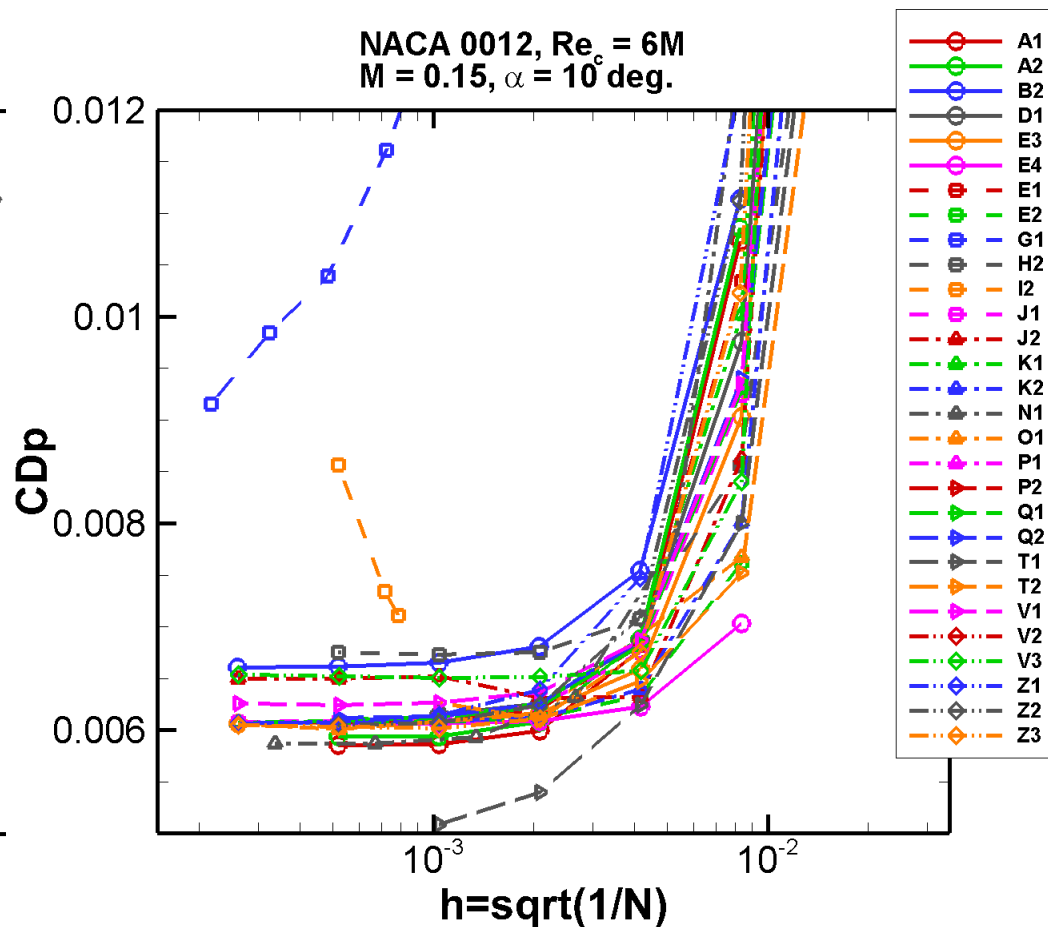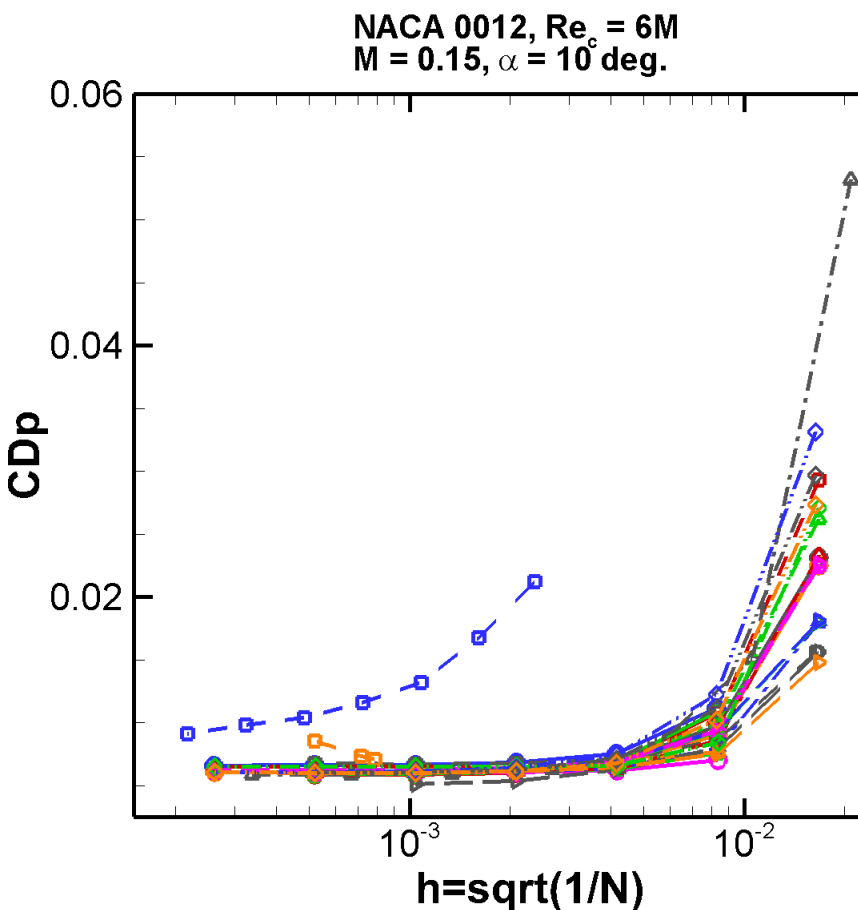

NACA 0012, Re$_c$ = 6M
M = 0.15, α = 10 deg.
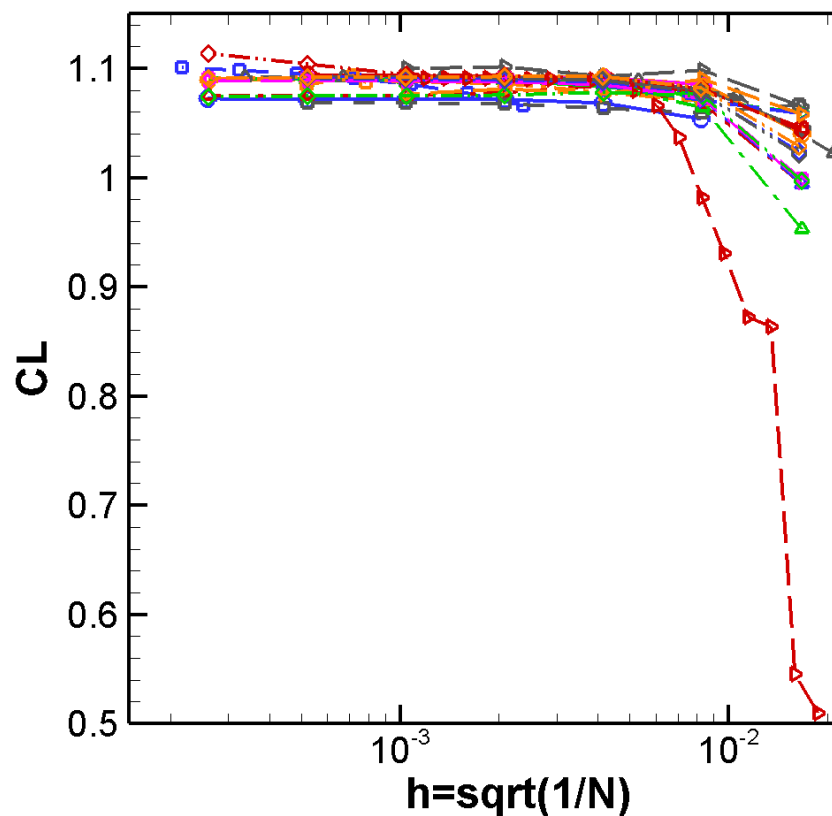
Results:

Results:

NACA 0012, Re_c = 6M
M = 0.15, α = 10° deg.
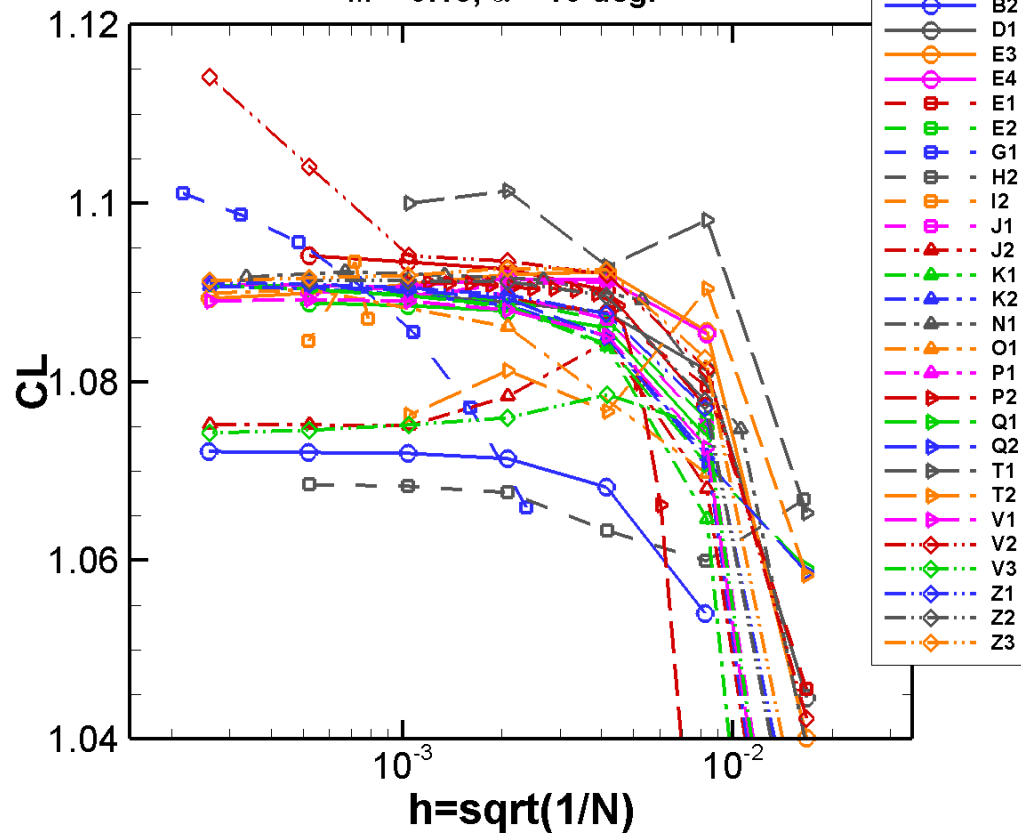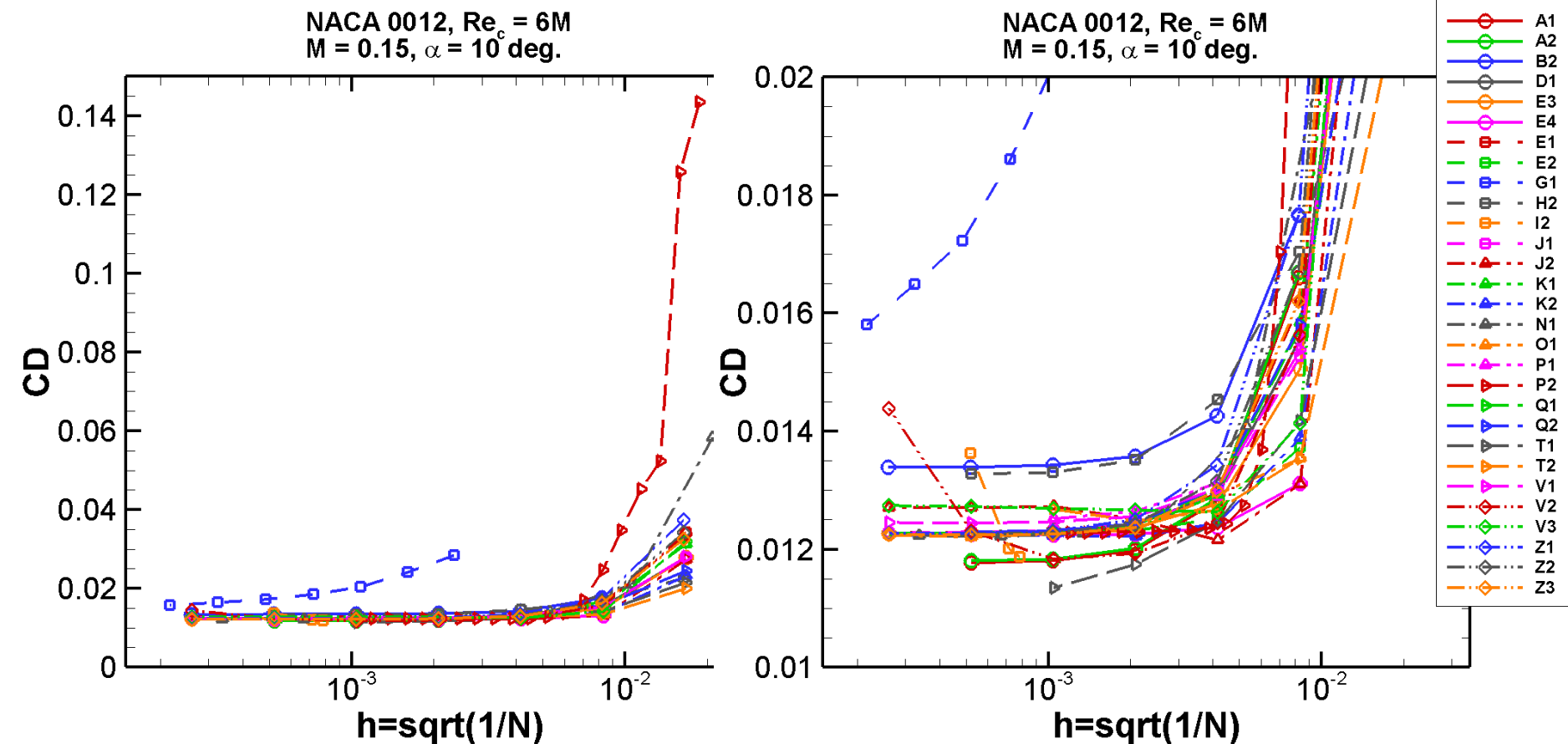
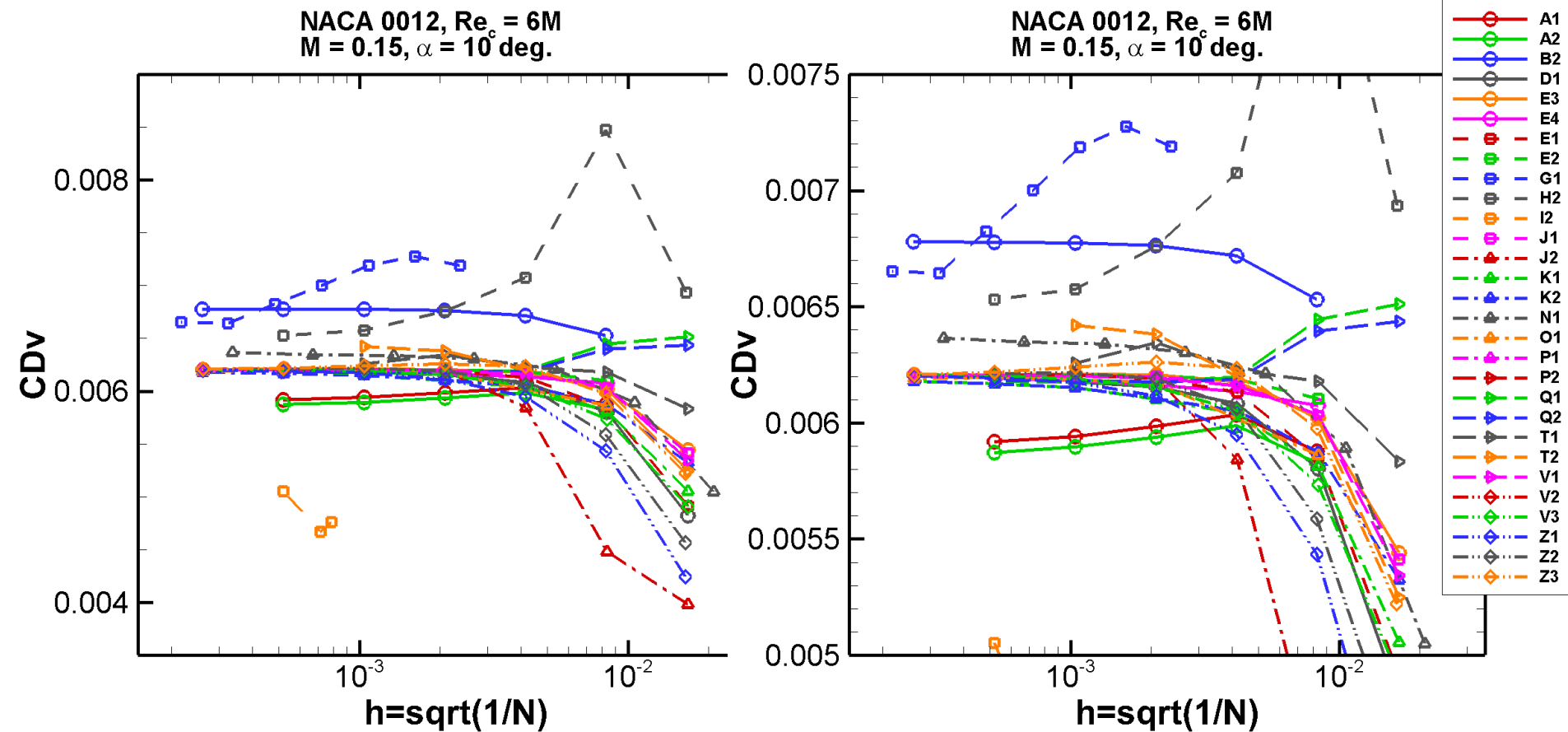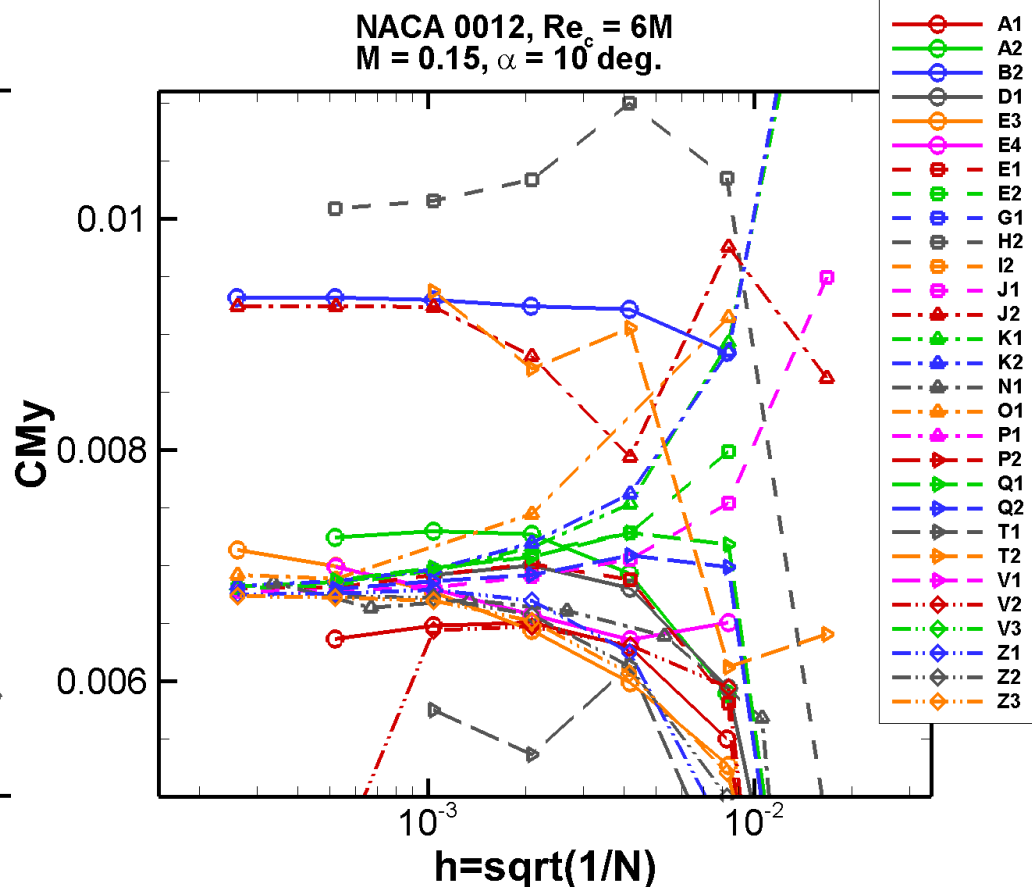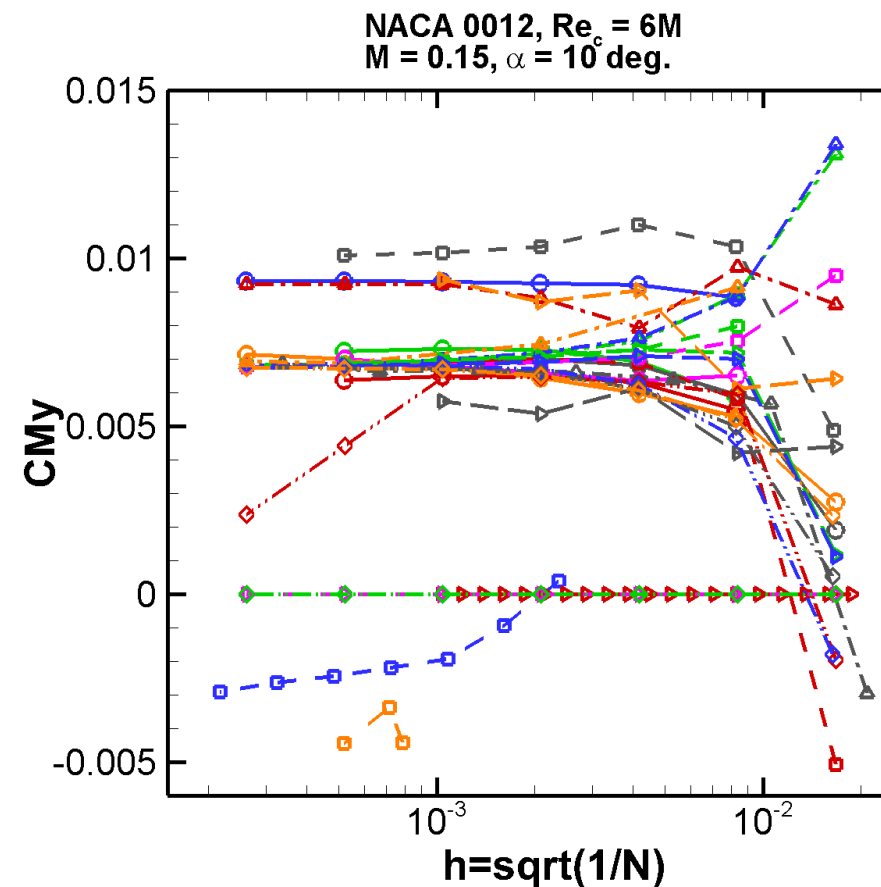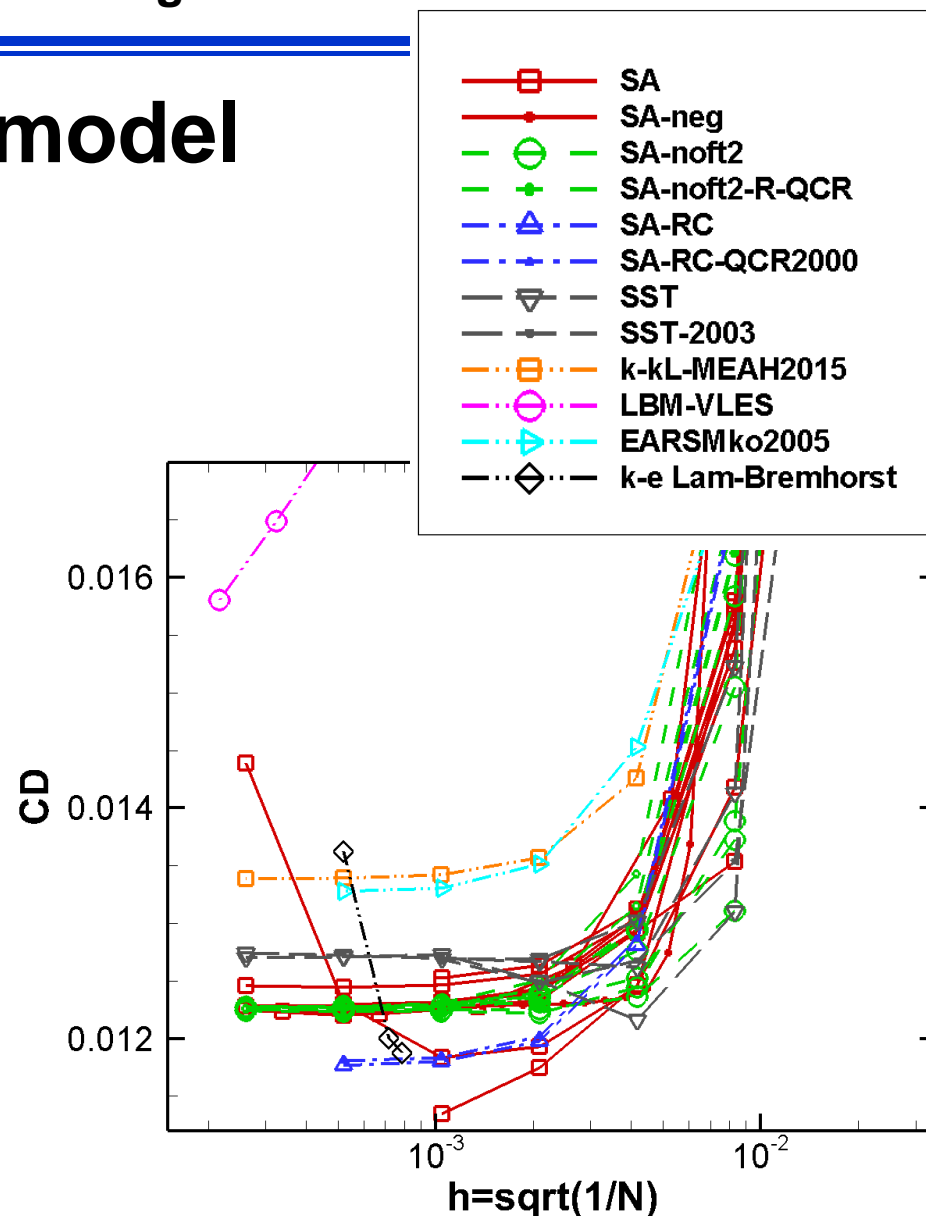## Results:

Results:

Effects of turbulence model

NACA 0012, $Re_c = 6M$
$M = 0.15$, $\alpha = 10$ deg.

Legend:
- SA
- SA-neg
- SA-noft2
- SA-noft2-R-QCR
- SA-RC
- SA-RC-QCR2000
- SST
- SST-2003
- k-kL-MEAH2015
- LBM-VLES
- EARSMko2005
- k-e Lam-Bremhorst
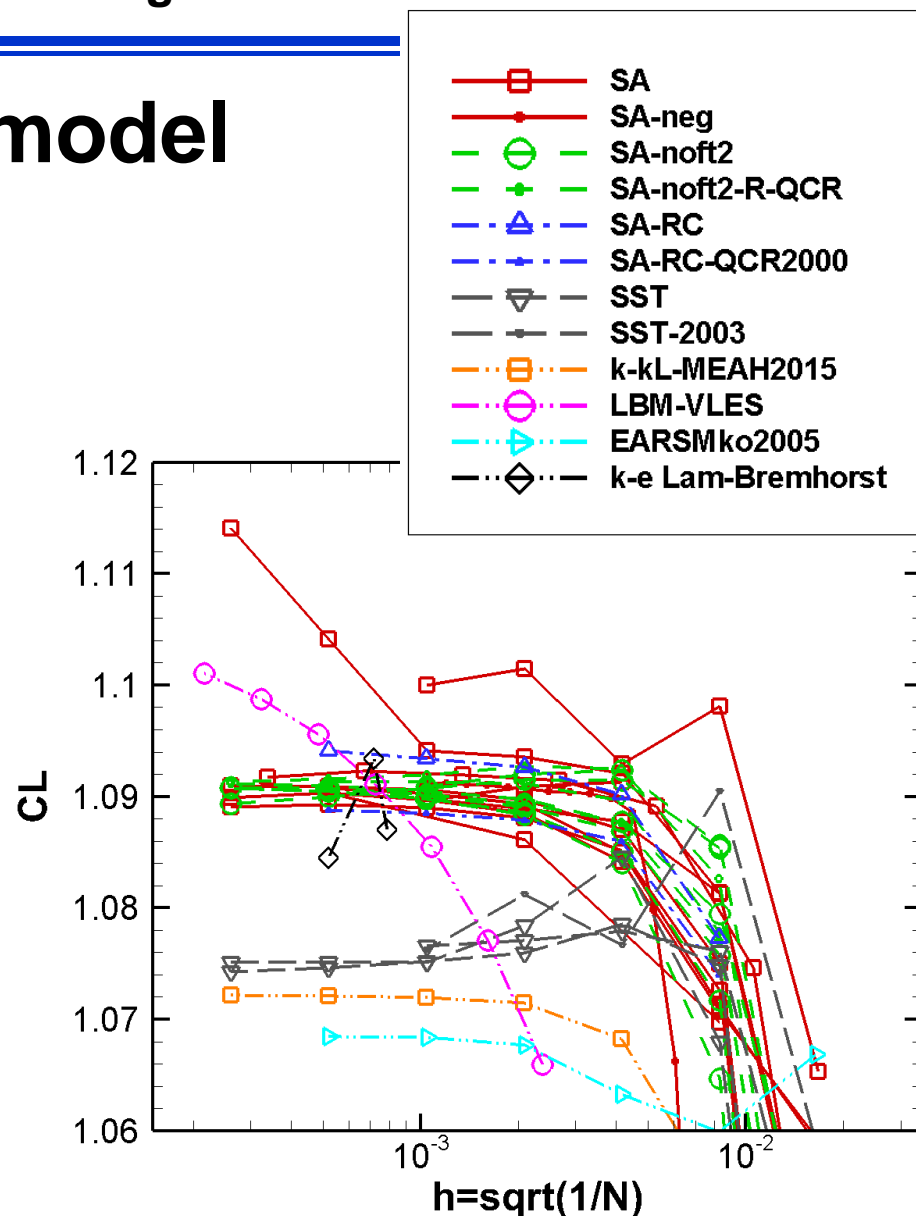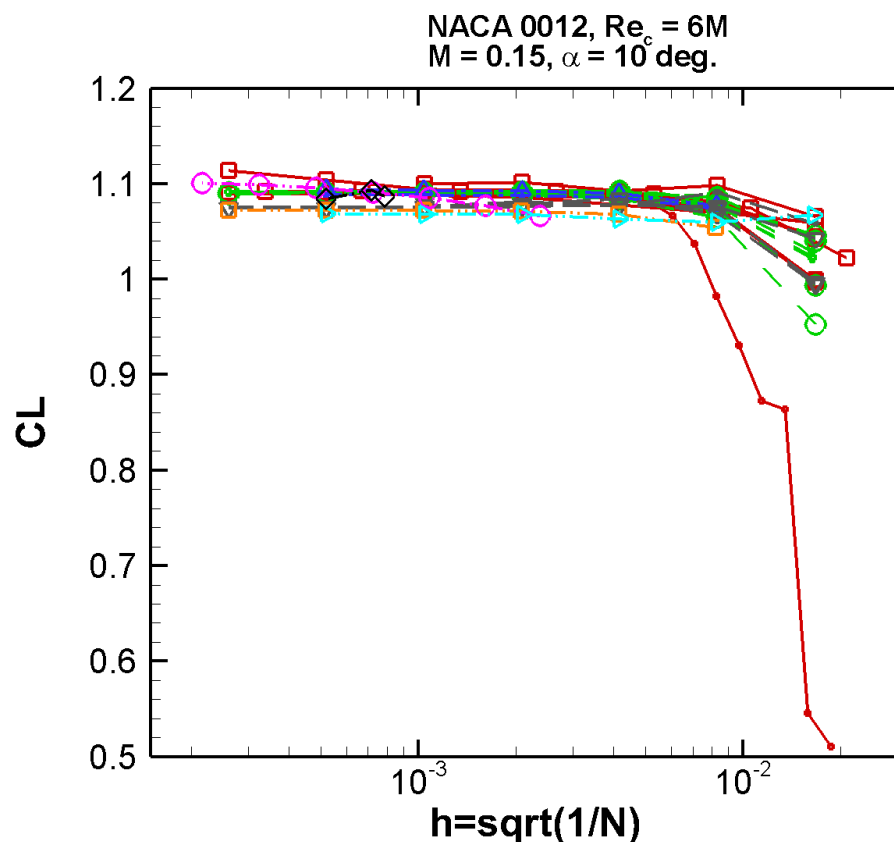
Effects of turbulence model

Effects of turbulence model
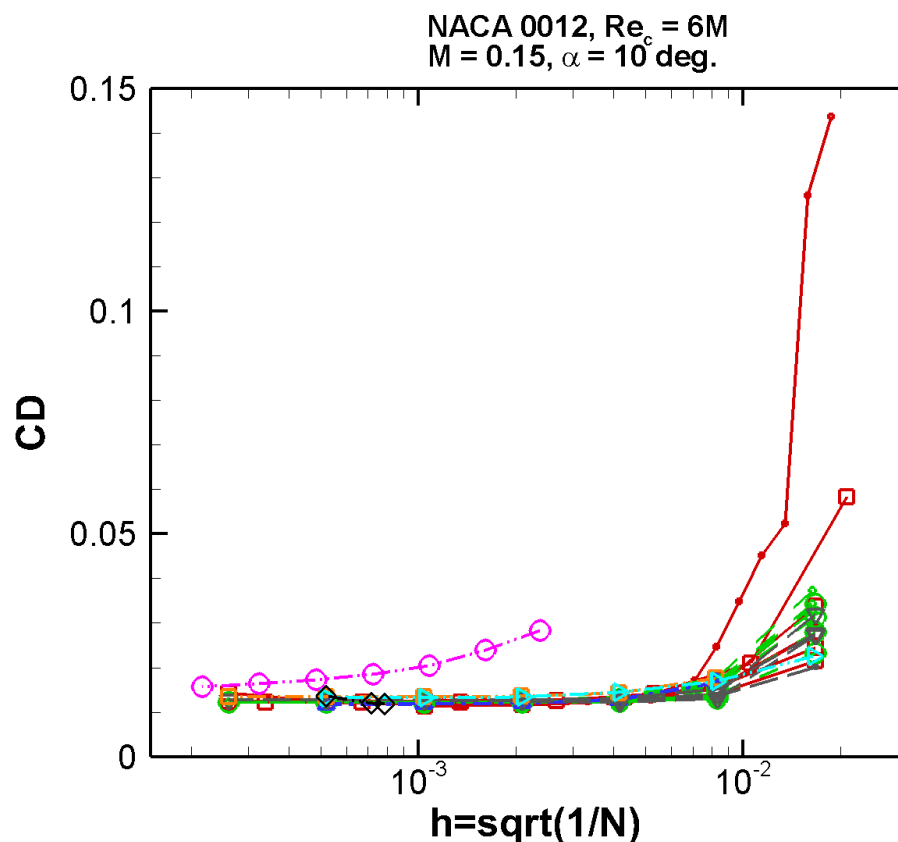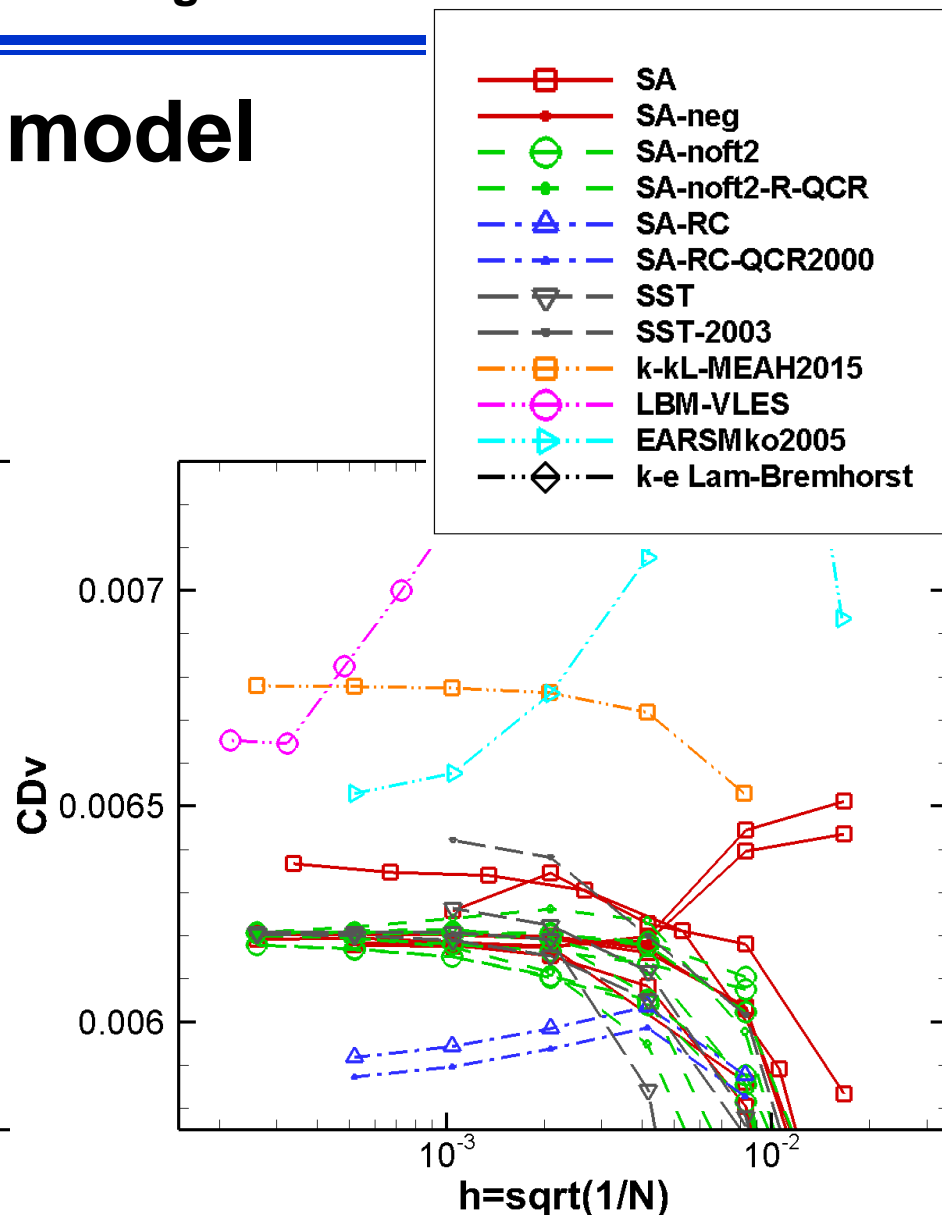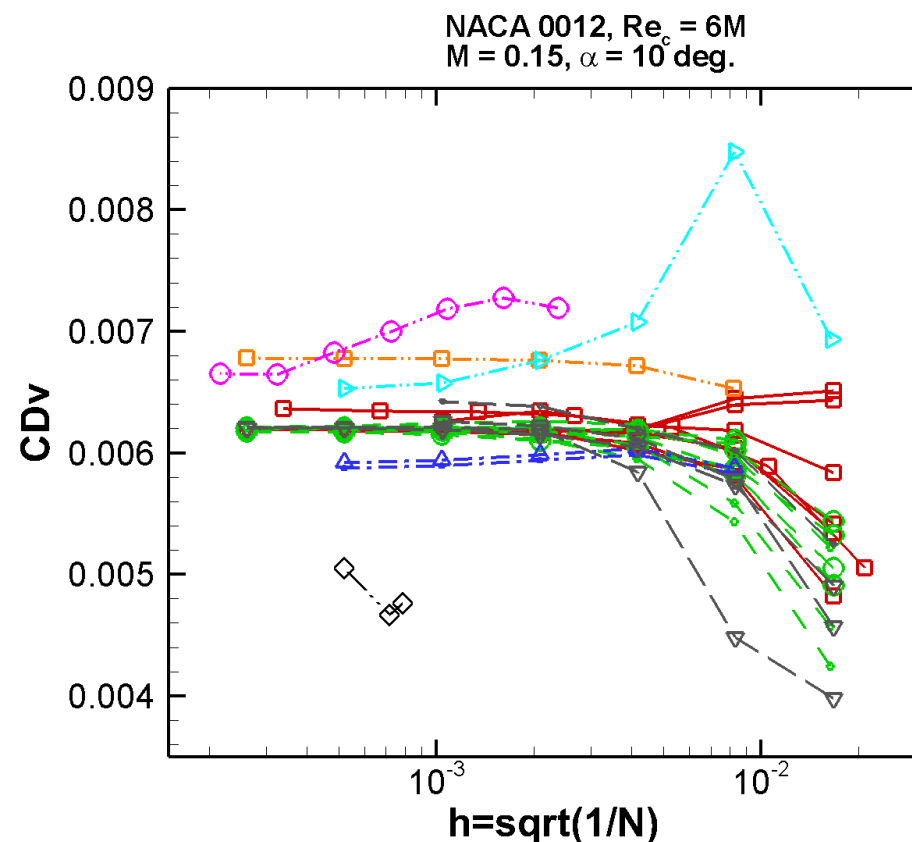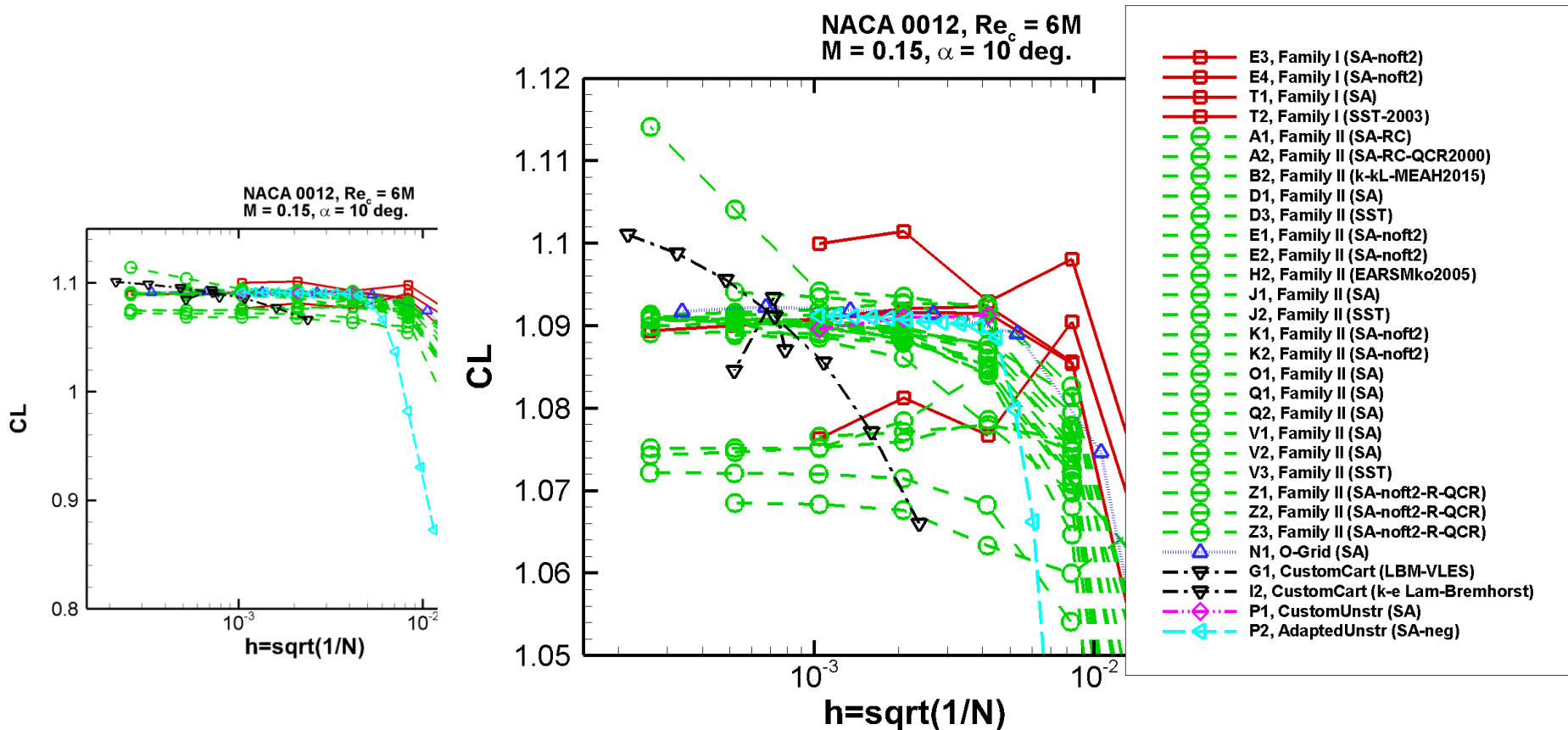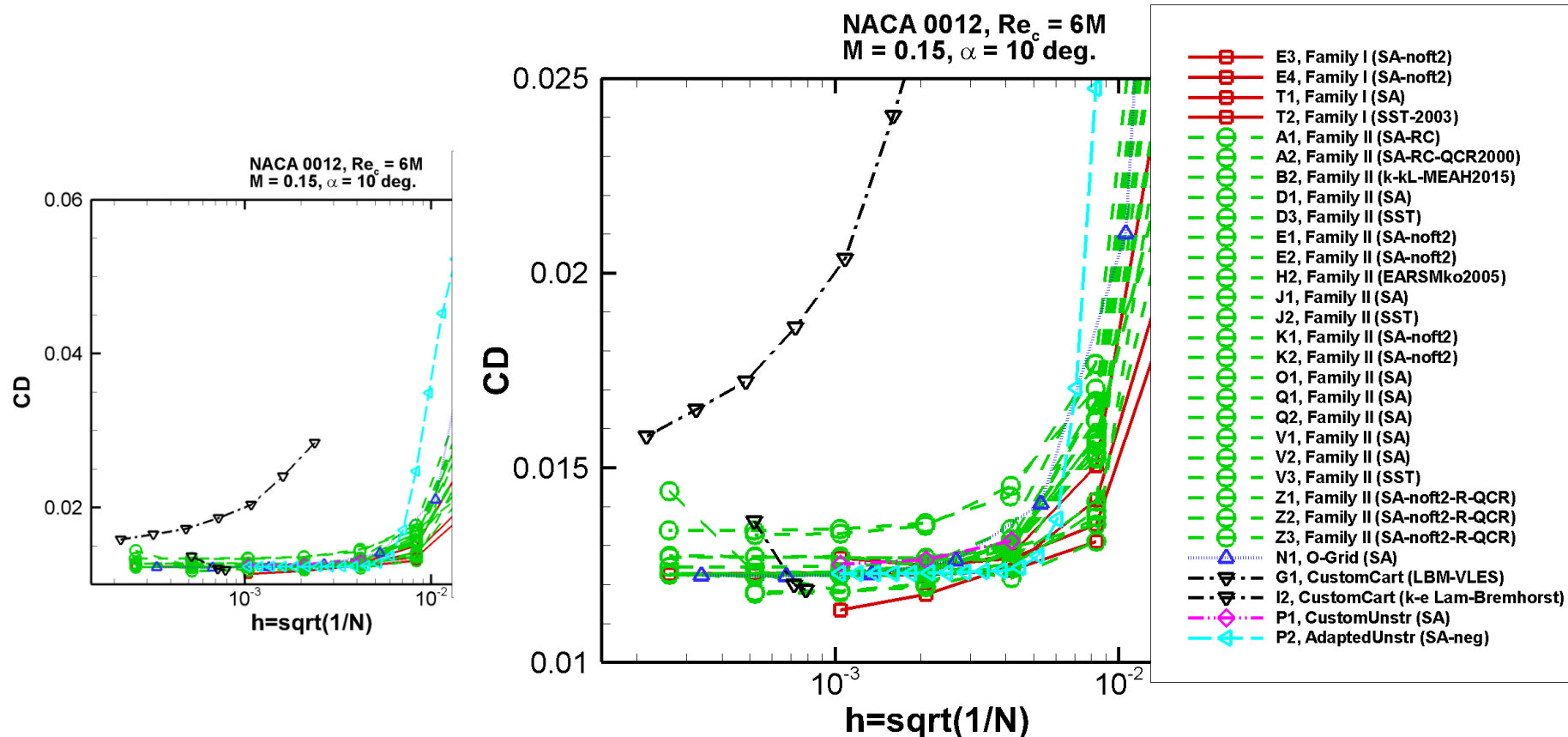

NACA 0012, Re_c = 6M
M = 0.15, α = 10 deg.
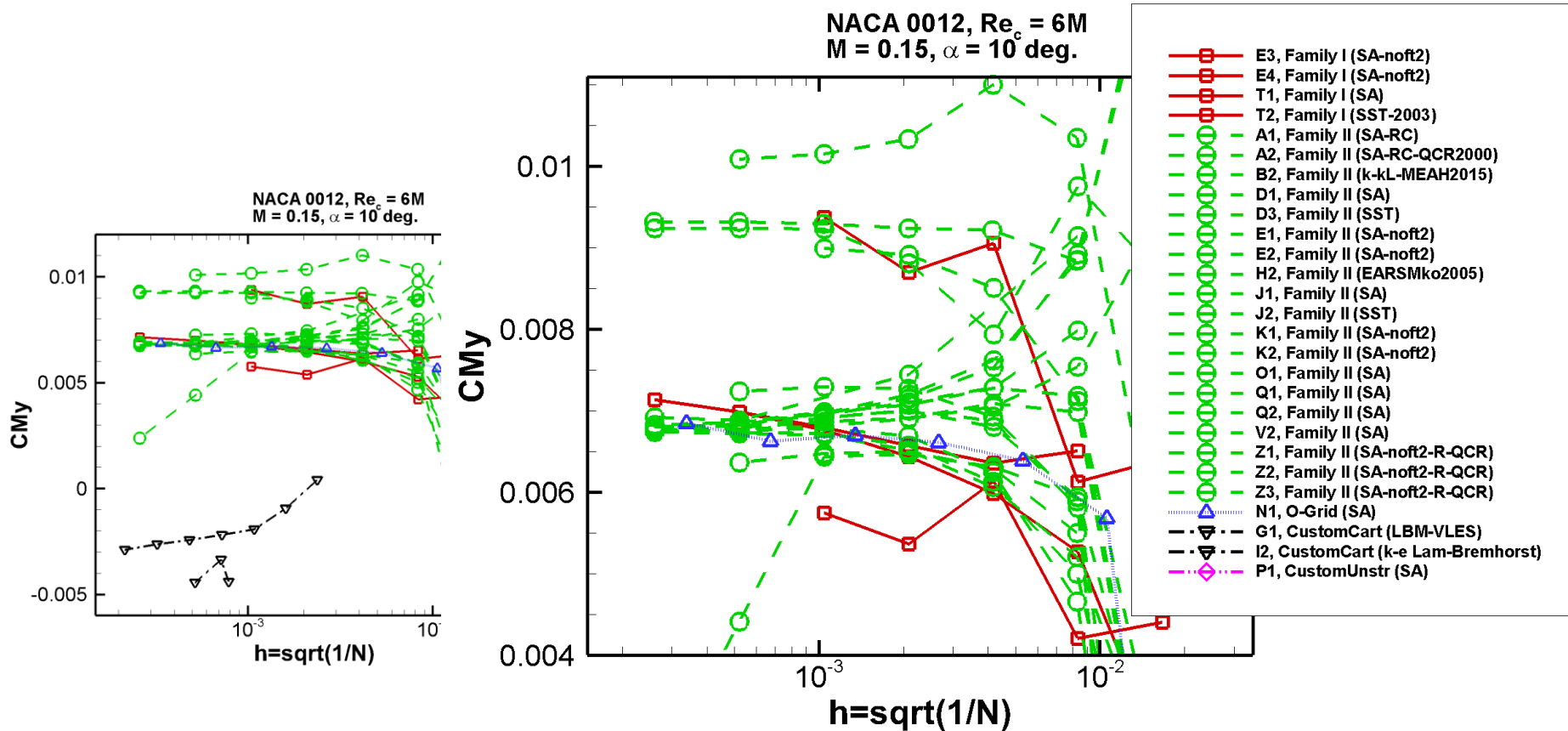
Effects of grid type

Effects of grid type

Effects of grid type

NACA 0012, Re_c = 6M
M = 0.15, α = 10 deg.

Effects of grid type: SA only

Effects of grid type: SA only

NACA 0012, $Re_c = 6M$
$M = 0.15$, $\alpha = 10$ deg.

Correct Value

Legend:
- Family I (SA)
- Family I (SA-noft2)
- Family I (SA-noft2)
- Family II (SA)
- Family II (SA)
- Family II (SA)
- Family II (SA)
- Family II (SA)
- Family II (SA)
- Family II (SA)
- Family II (SA-noft2)
- Family II (SA-noft2)
- Family II (SA-noft2)
- Family II (SA-noft2)
- Family II (SA-noft2-R-QCR)
- Family II (SA-noft2-R-QCR)
- Family II (SA-noft2-R-QCR)
- O-Grid (SA)
- CustomUnstr (SA)
- AdaptedUnstr (SA-neg)
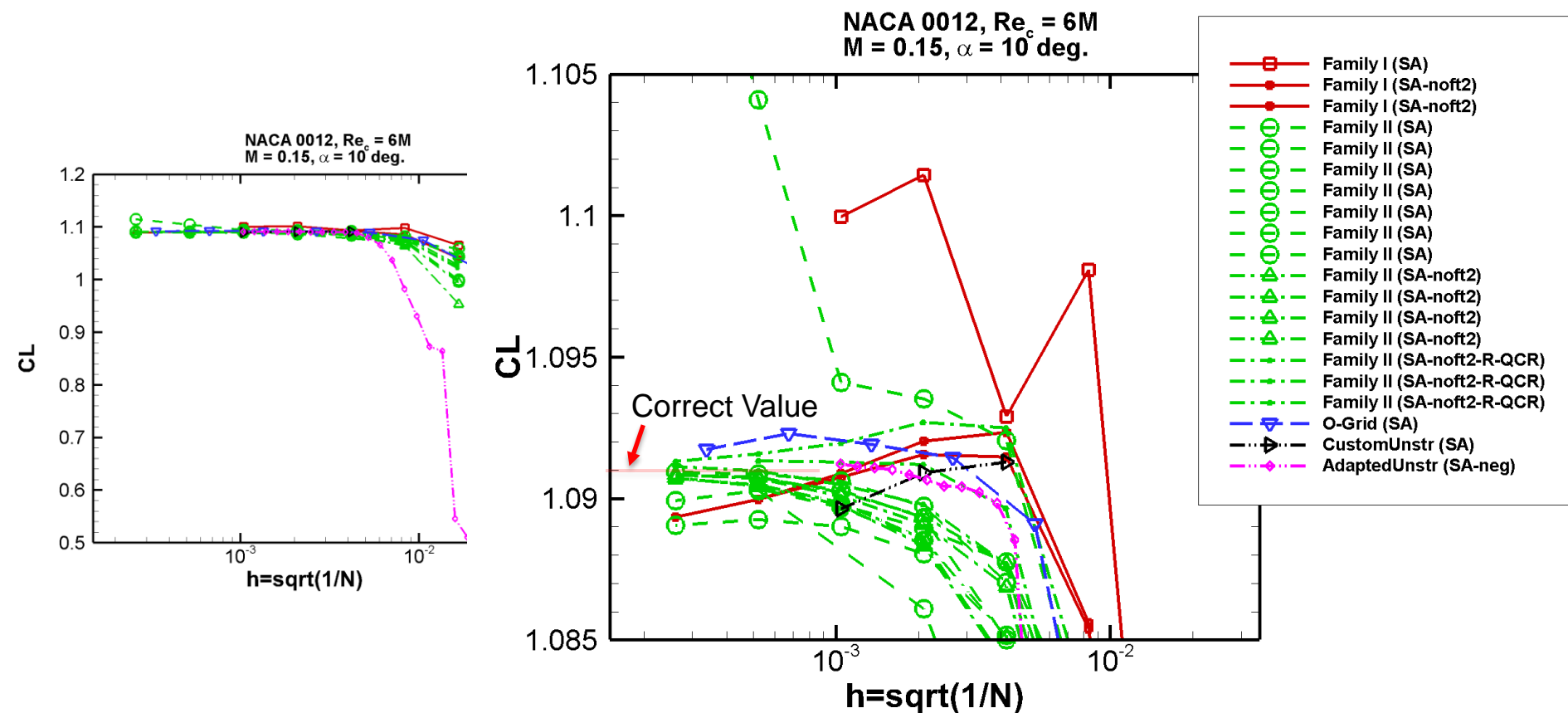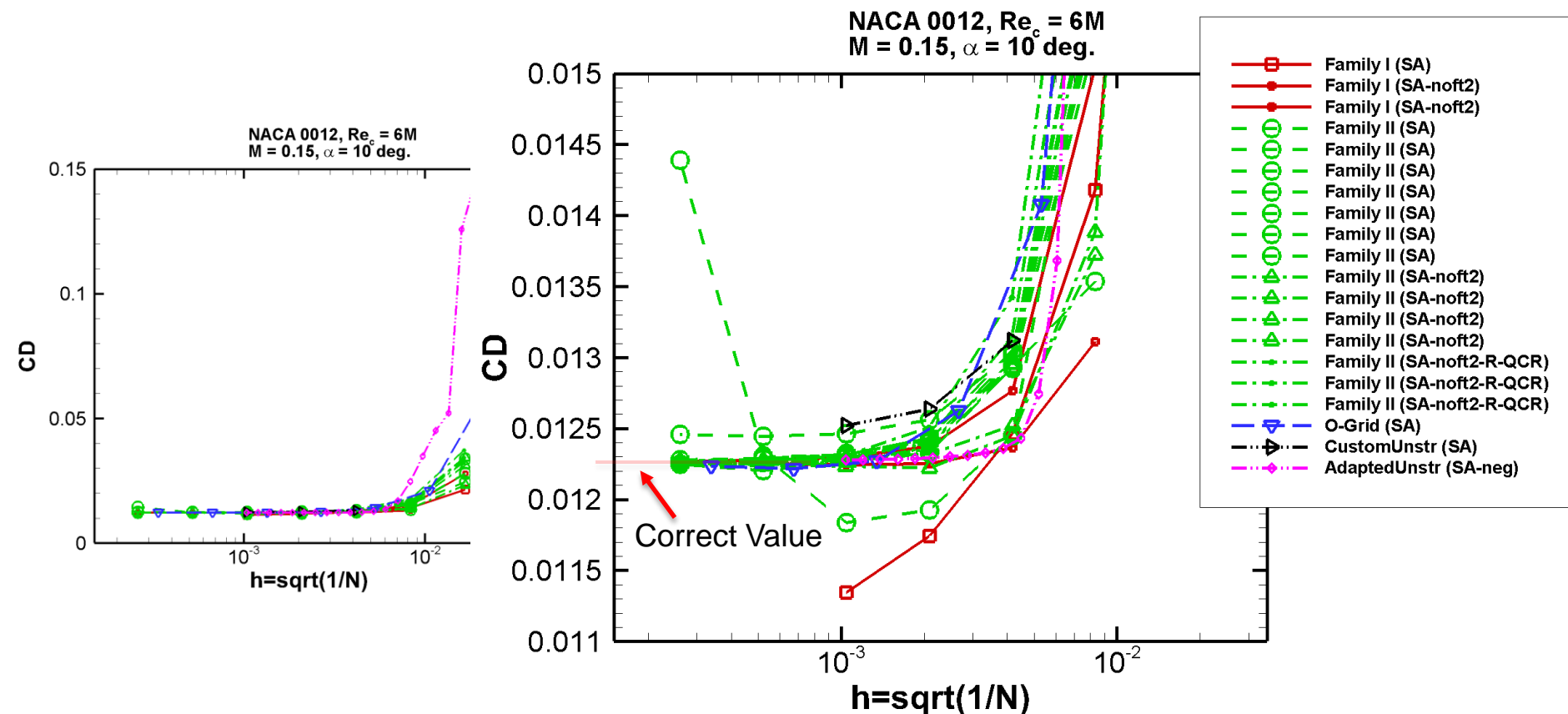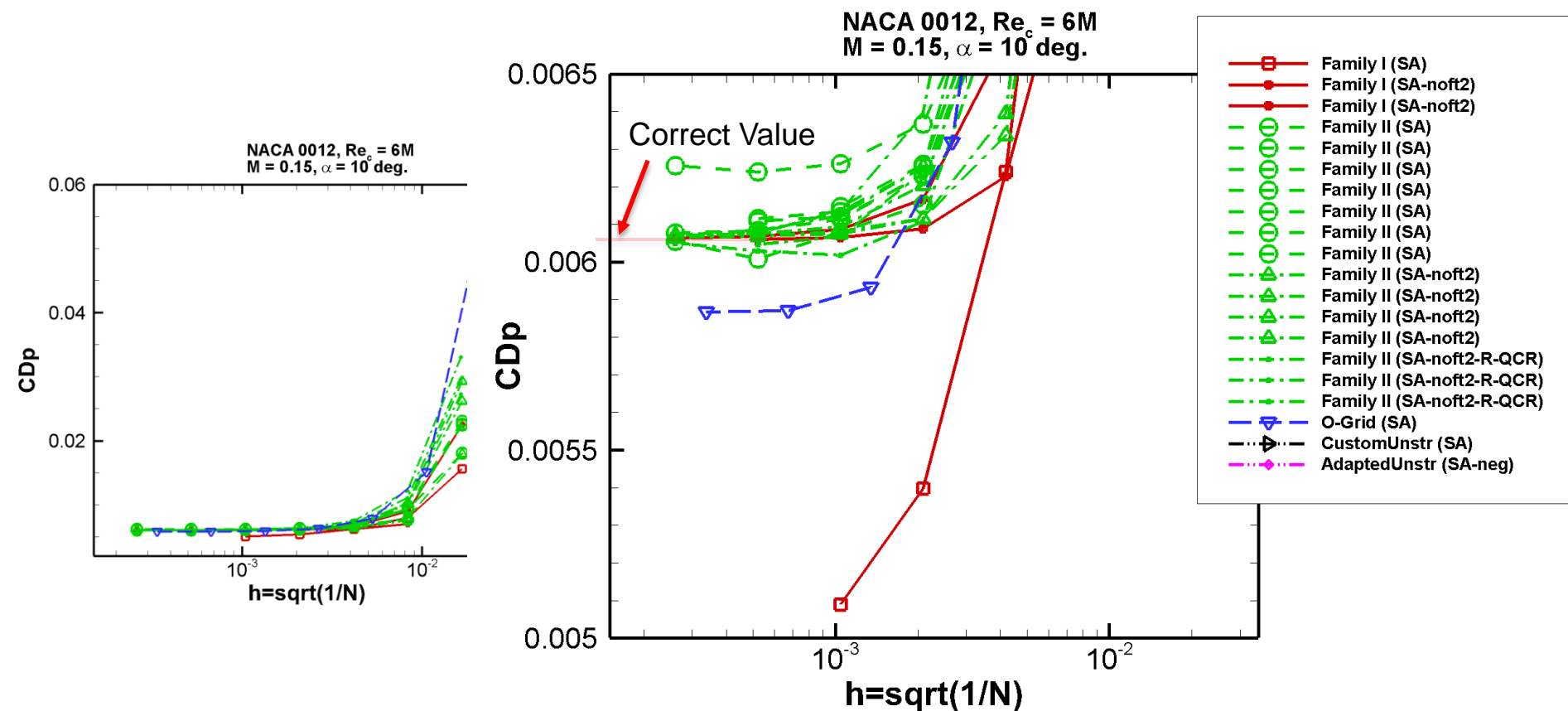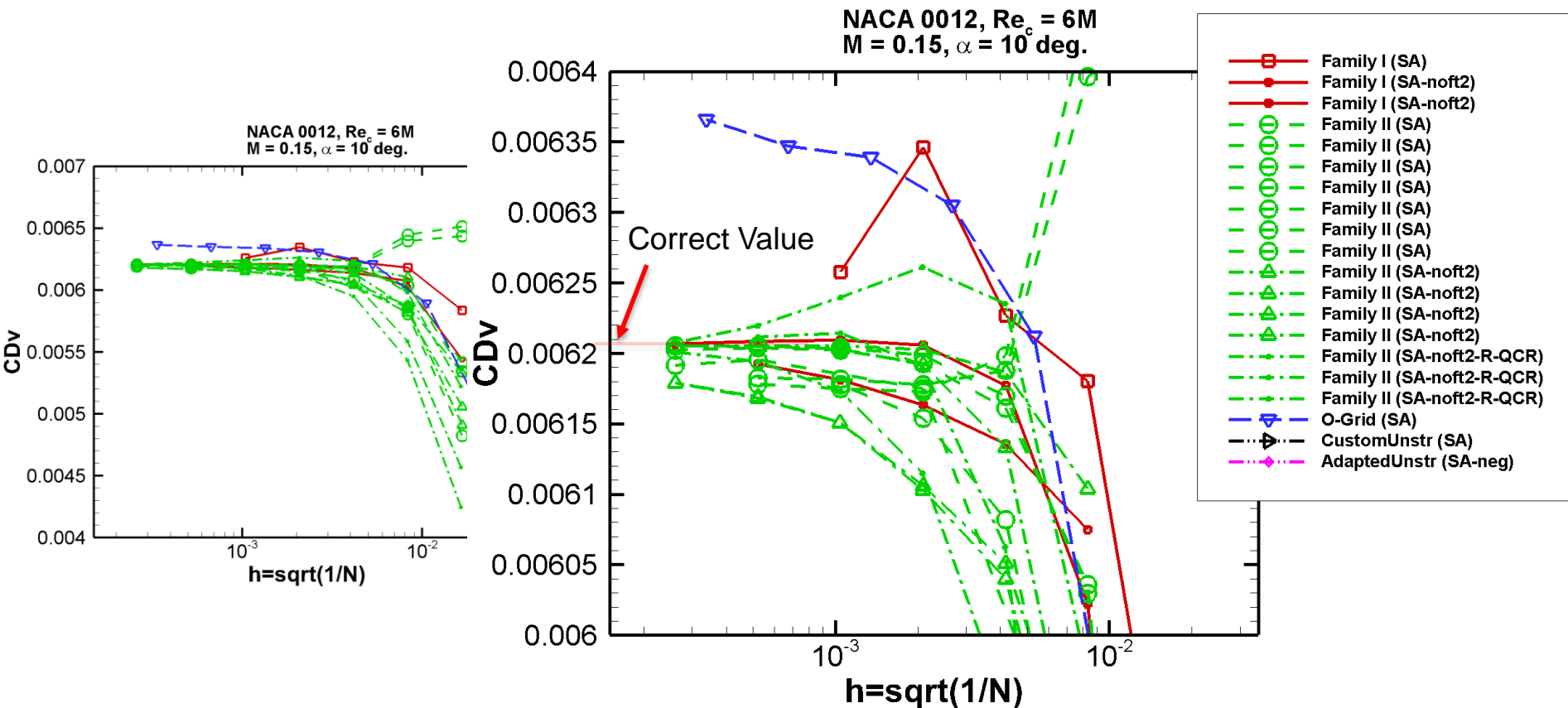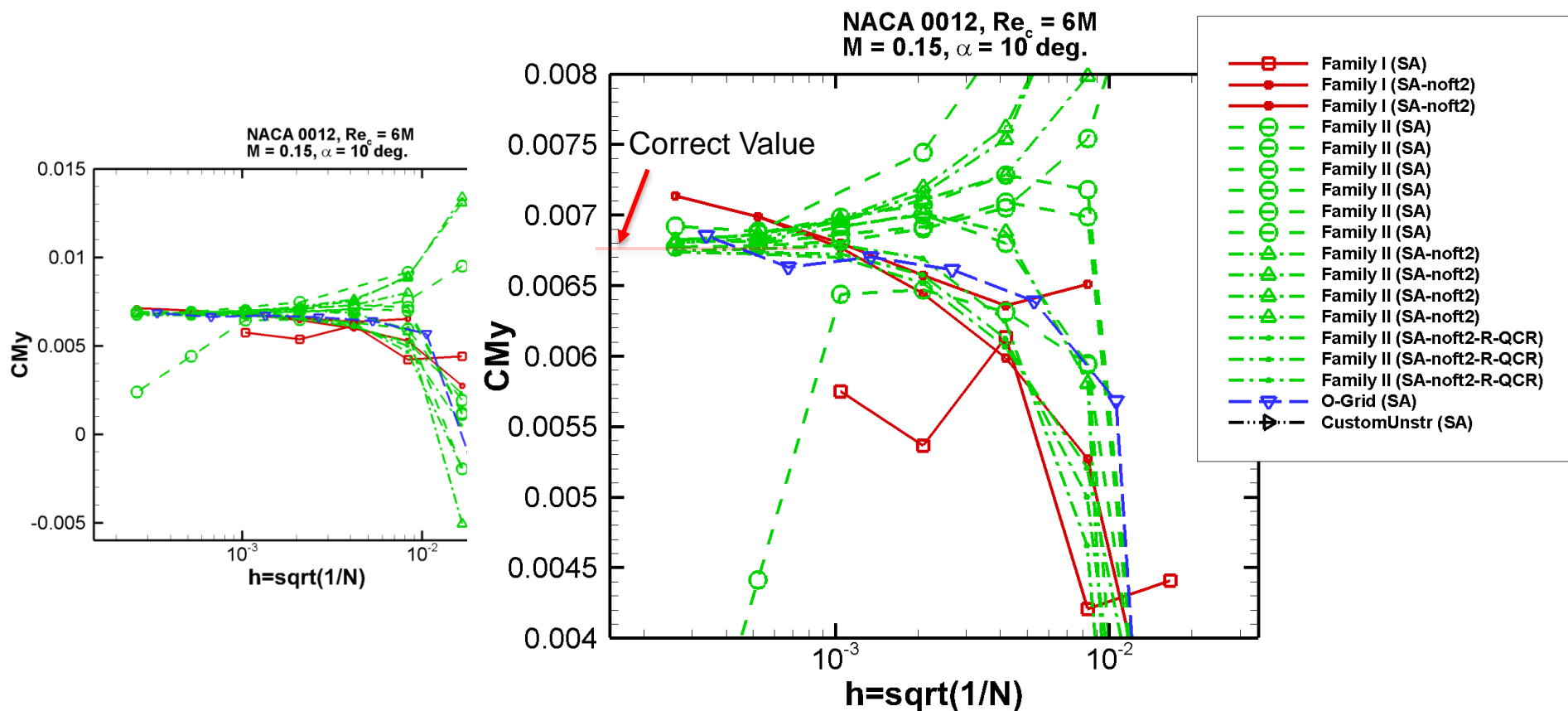
Effects of grid type: SA only

Effects of grid type: SA only

Effects of grid type: SA only

Conclusions for Case #1

- **Grid effects and other numerical issues (iterative convergence?) are still polluting the results**
- **Grid type is important**
    - Cartesian methods appear to either converge slowly or not converge
- **Grid adaptation helps: the single adapted grid case honed in on the (correct) converged values at much lower cell counts**
- **Adequate code verification is still not being done**
    - Ideal approach is to demonstrate order of accuracy using Manufactured Solutions
    - This numerical benchmark allows an easier path to code verification
- **Errors that occur for this simple 2D case are expected to be (much) larger for the more complex 3D cases**
- **Code verification should be a prerequisite for application of a code to analysis, model validation, etc.**

Thanks go to:

- **Chris Rumsey of NASA Langley for helping with formatting for data files**

- **Ed Tinoco for doing the initial screening of the Case 1 data**

- **All of the DPW-6 participants**

Extra Slides

Effects of order of accuracy of turbulence models

- **TBD**
    - TBD

To Be Updated

Pressure distributions:

- **TBD**
  - TBD

To Be Updated

Skin friction distributions:

- **TBD**
  - TBD

To Be Updated

Order of accuracy plots for SA models