DPW-8/AePW-4 Scatter Working Group:

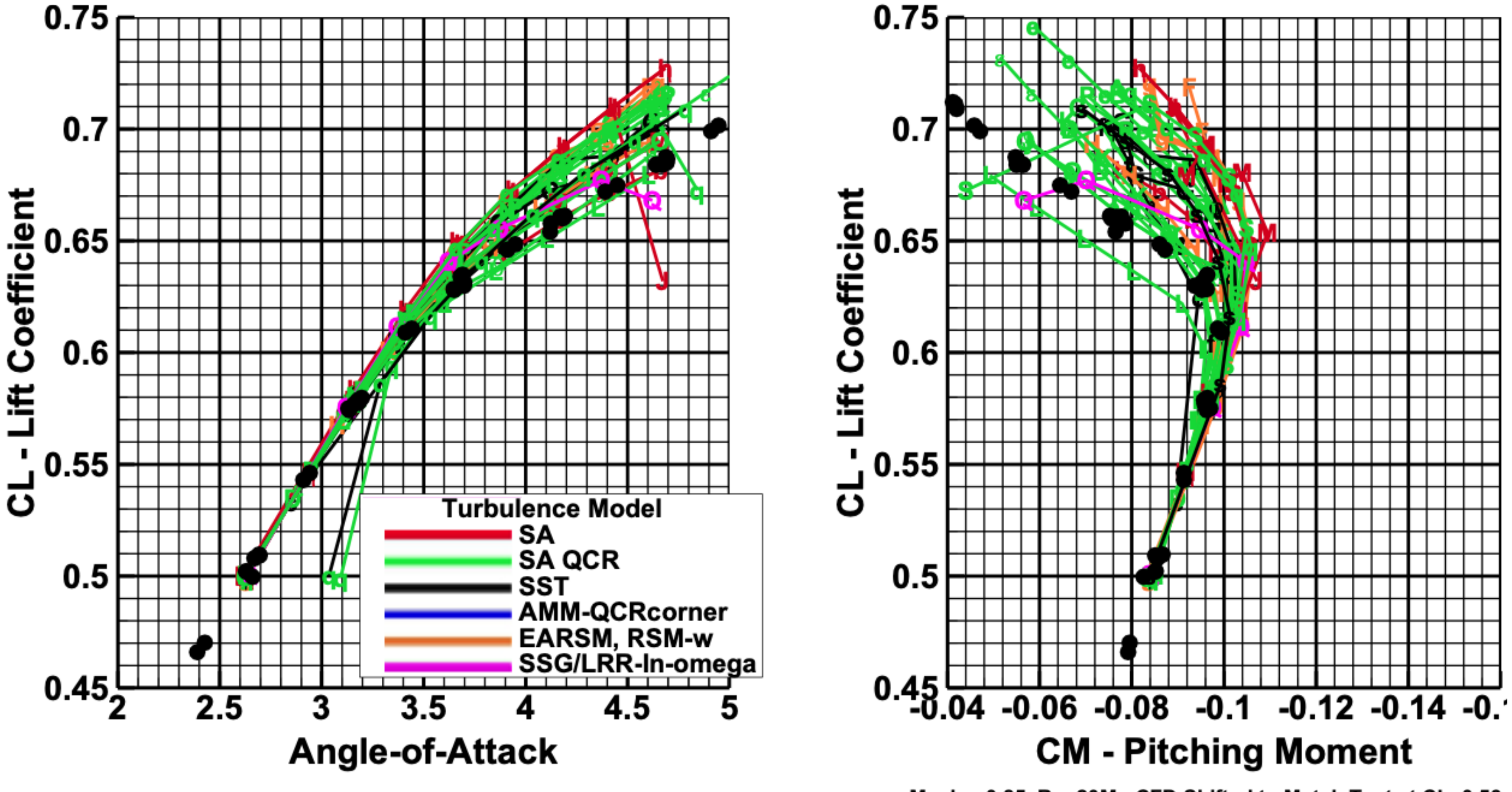
An Overview of Mini Workshops 1 and 2

AIAA Aviation 2025
July 21

https://www.aiaa-dpw.org

Source of Scatter – Motivation

- **Seek to identify deviations in DPW-7 CRM data**
- **Significant spread in solvers post pitchup (all submissions plotted)**



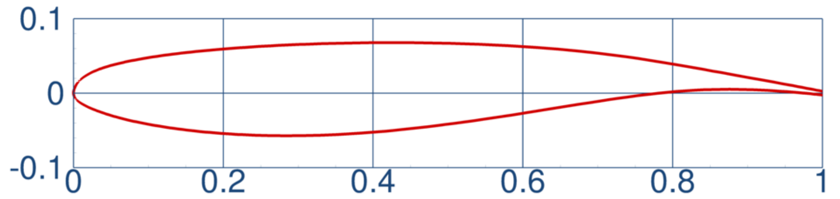
Curves collapsed to match experimental data near cruise point

Image source:
Tinoco, E., et al., "Summary Data from the Seventh AIAA CFD Drag Prediction Workshop," AIAA 2023-3492

Sources of Scatter – Overview

- **Three test cases examined so far**
  - Test Case 1a: ONERA OAT15A
    - Establish initial level of scatter
  - Test Case 1b: Joukowksi Airfoil
    - Order of accuracy check
  - Test Case 1c: ONERA OAT15A
    - Reduced scatter
- **Future test case**
  - Test Case 2: CRM Wing/Body Cruise
    - Examine scatter for 3D and QCR2000
- **Sustained meeting cadence and structure**
  - Approx 20 people on distribution list
  - Average 10 attendees in each meeting
  - Meeting Tuesdays 10am ET on 2nd and 4th week of the month

Test Case 1a: Workshop-Wide Validation

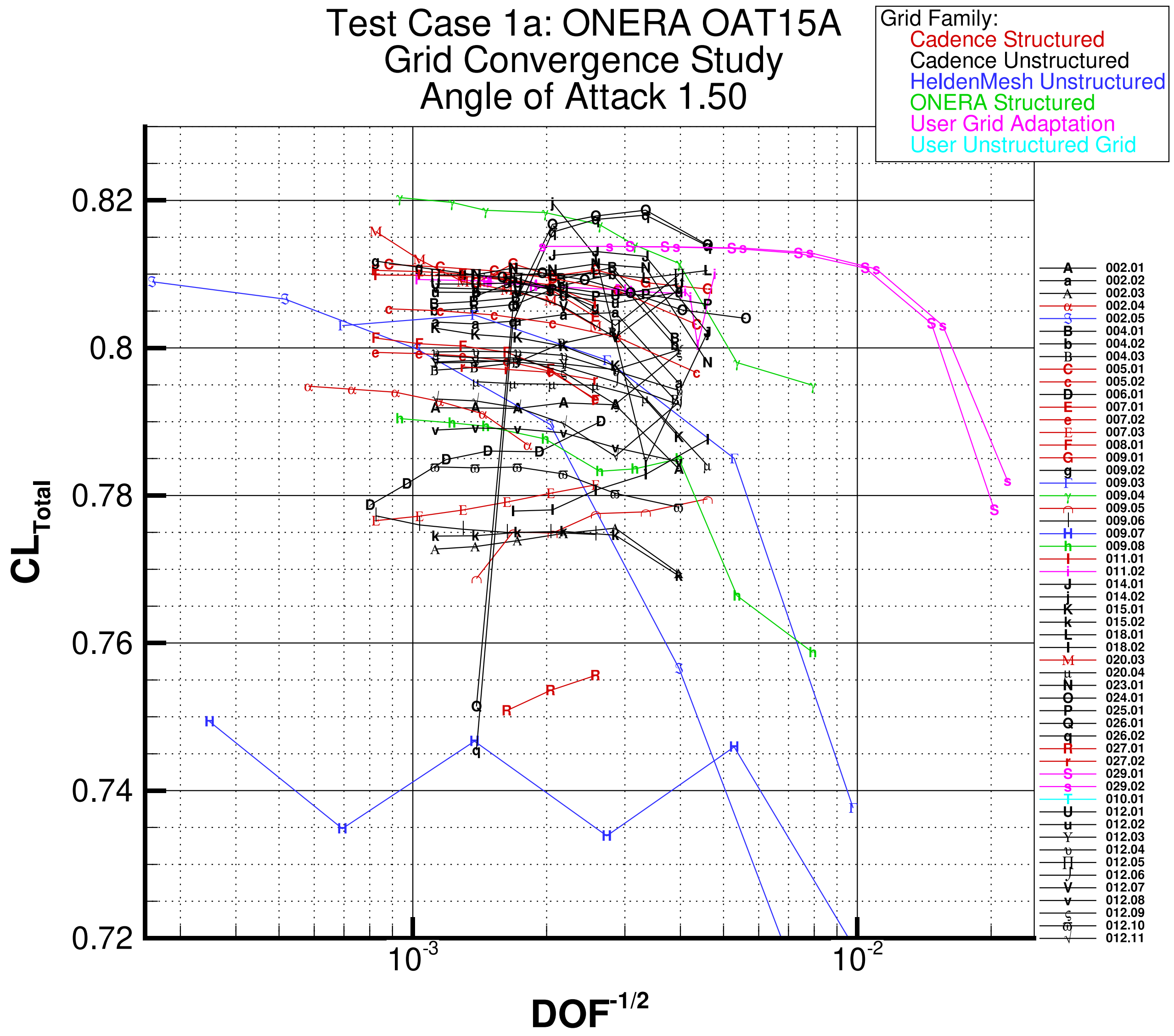


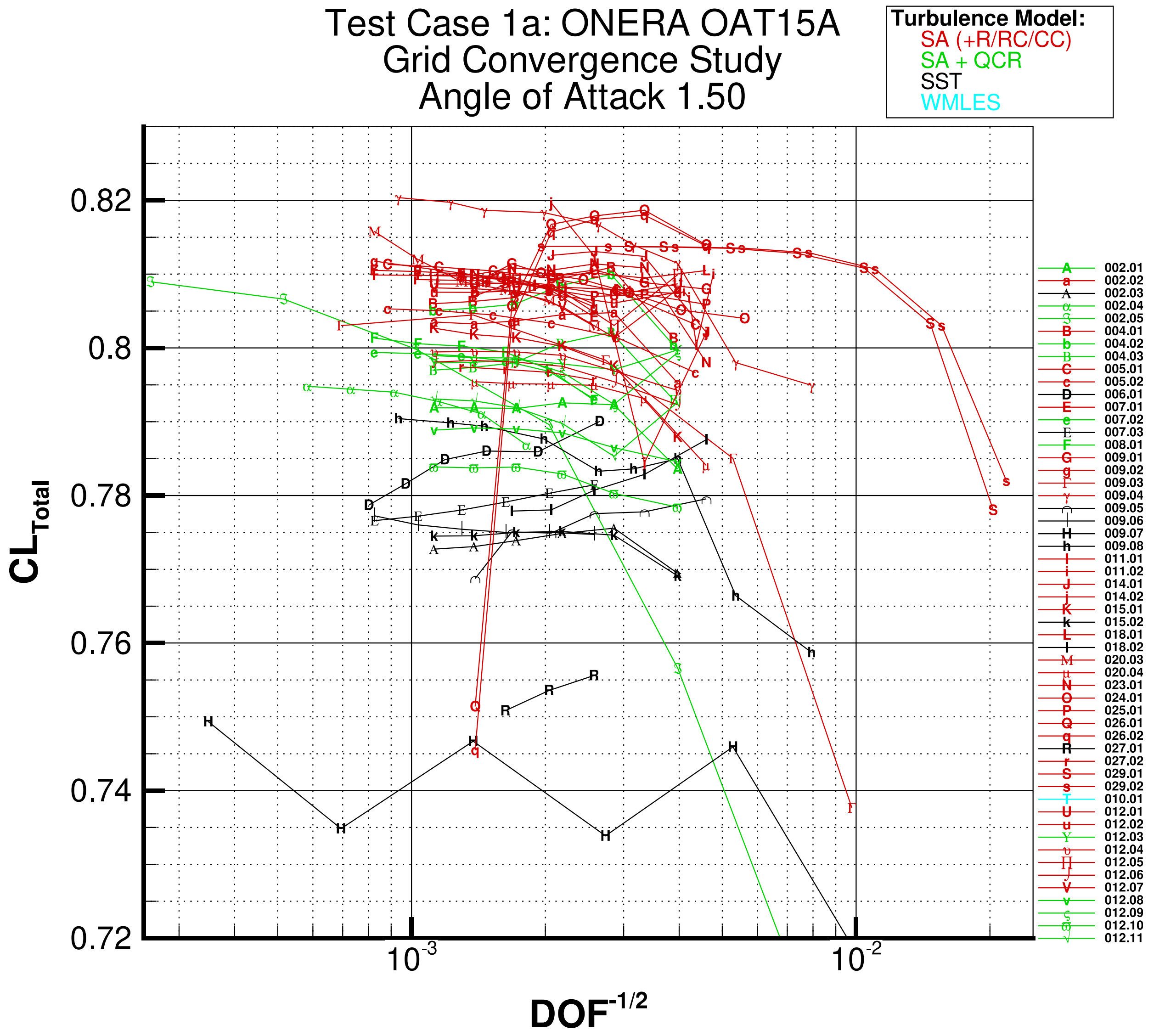
ONERA OAT15A Transonic Airfoil

- **Validation of steady CFD analysis, required**
- **Users are encouraged to employ best practices**
- **Settings**
  - Steady CFD (e.g., RANS)
  - Prefer some version of SA, multiple turbulence models can be submitted
  - Purely 2D simulations (one cell wide)
- **Grids**
  - Six-member RANS grid family; four are required, six are desirable
  - Encourage use of committee-supplied grids; user-generated grids are acceptable
  - Committee-supplied grid is one cell wide with a 230mm chord (same as experiment) and follows RANS best practices
- **Conditions**
  - Mach 0.73, Re_C=3m (based on chord length), T_{static}= 271 K (487.8 R)
  - Alpha: 1.36, 1.50, 2.50, 3.00, 3.10

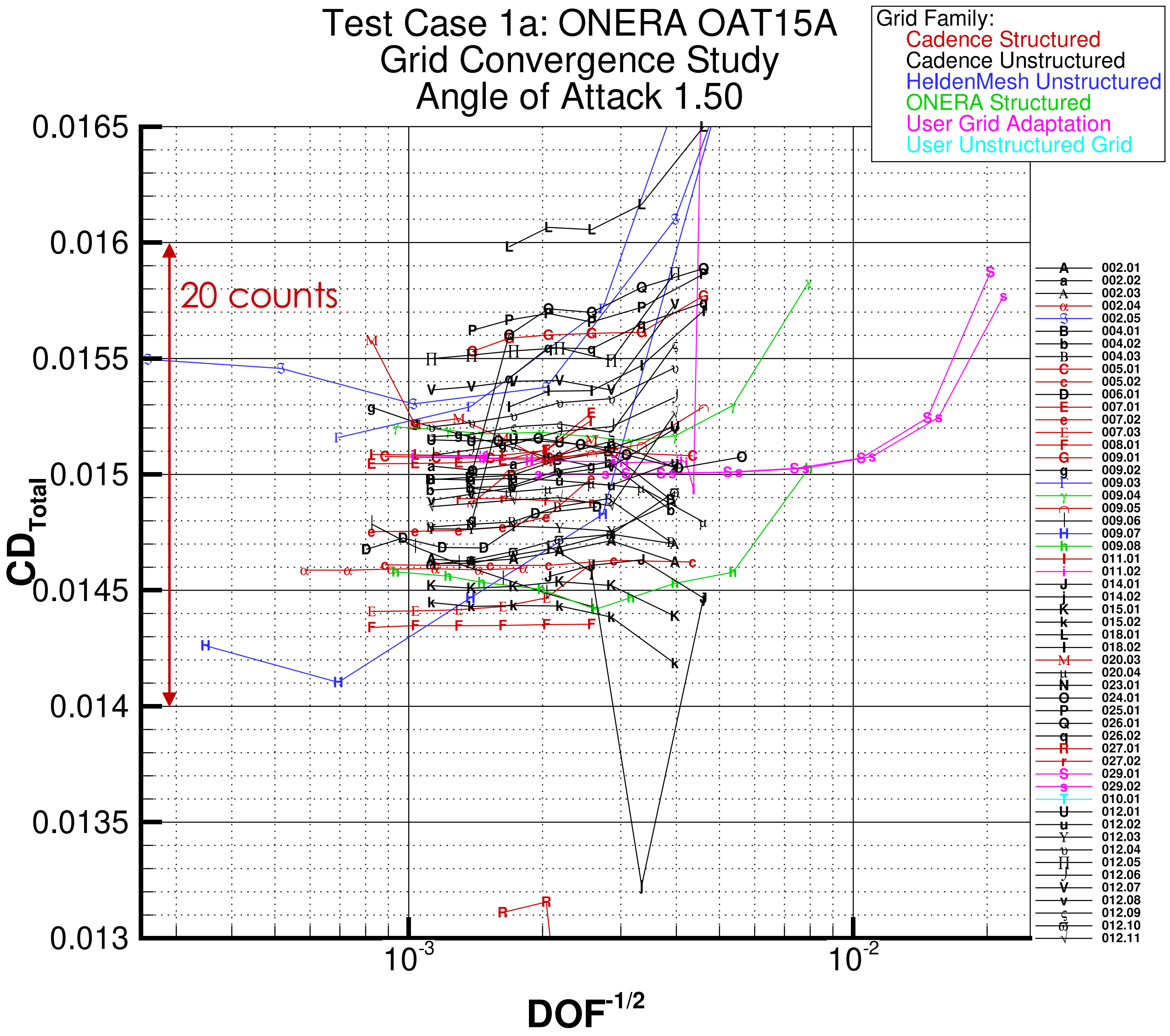
Jaquin, et al. "Experimental Study of Shock Oscillation over a Transonic Supercritical Profiles." AIAA Journal, Vol. 47, No. 9, 2009. Pages 1985-1994.

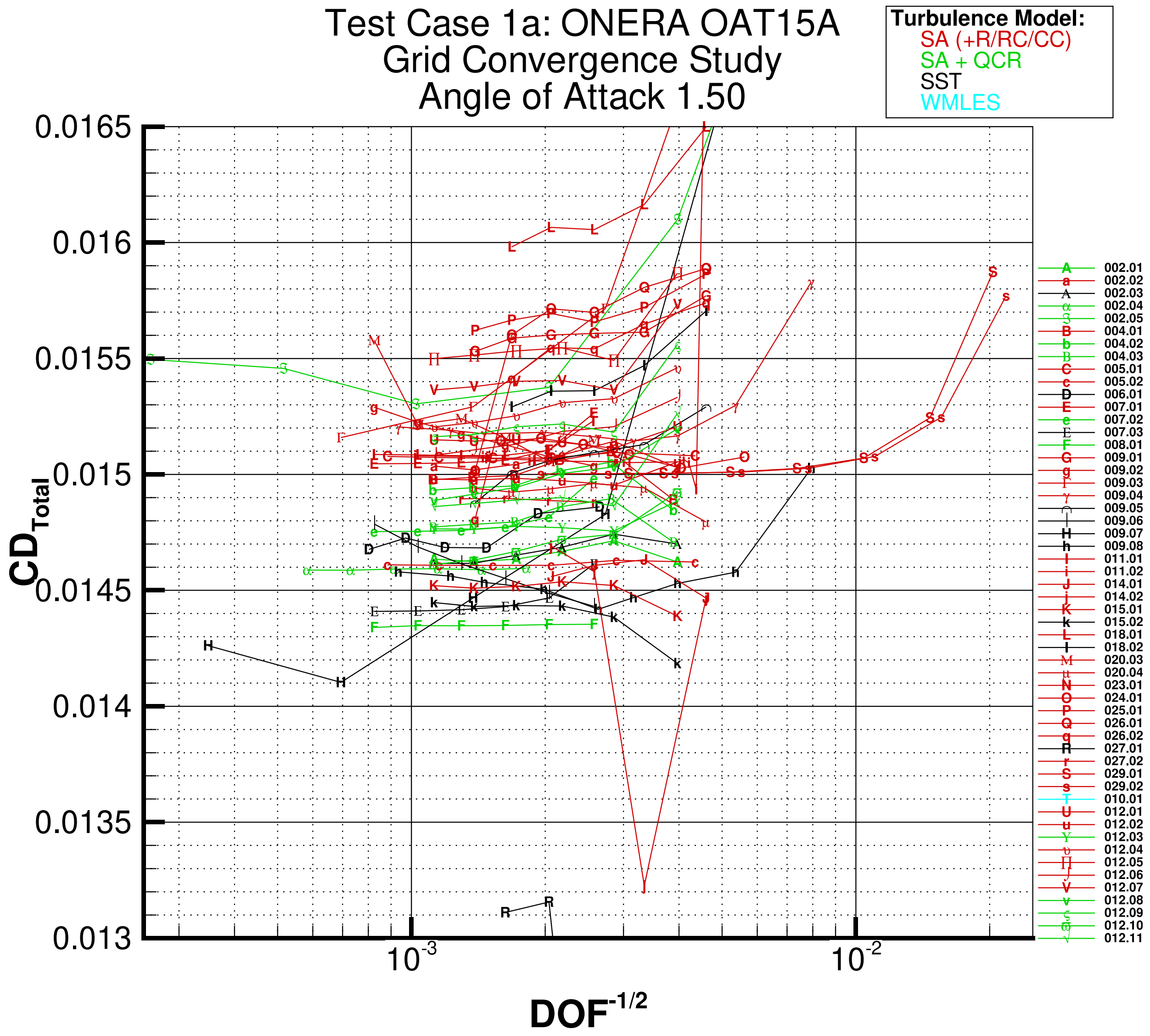
ONERA OAT15A C_L Convergence: $\alpha = 1.5°$



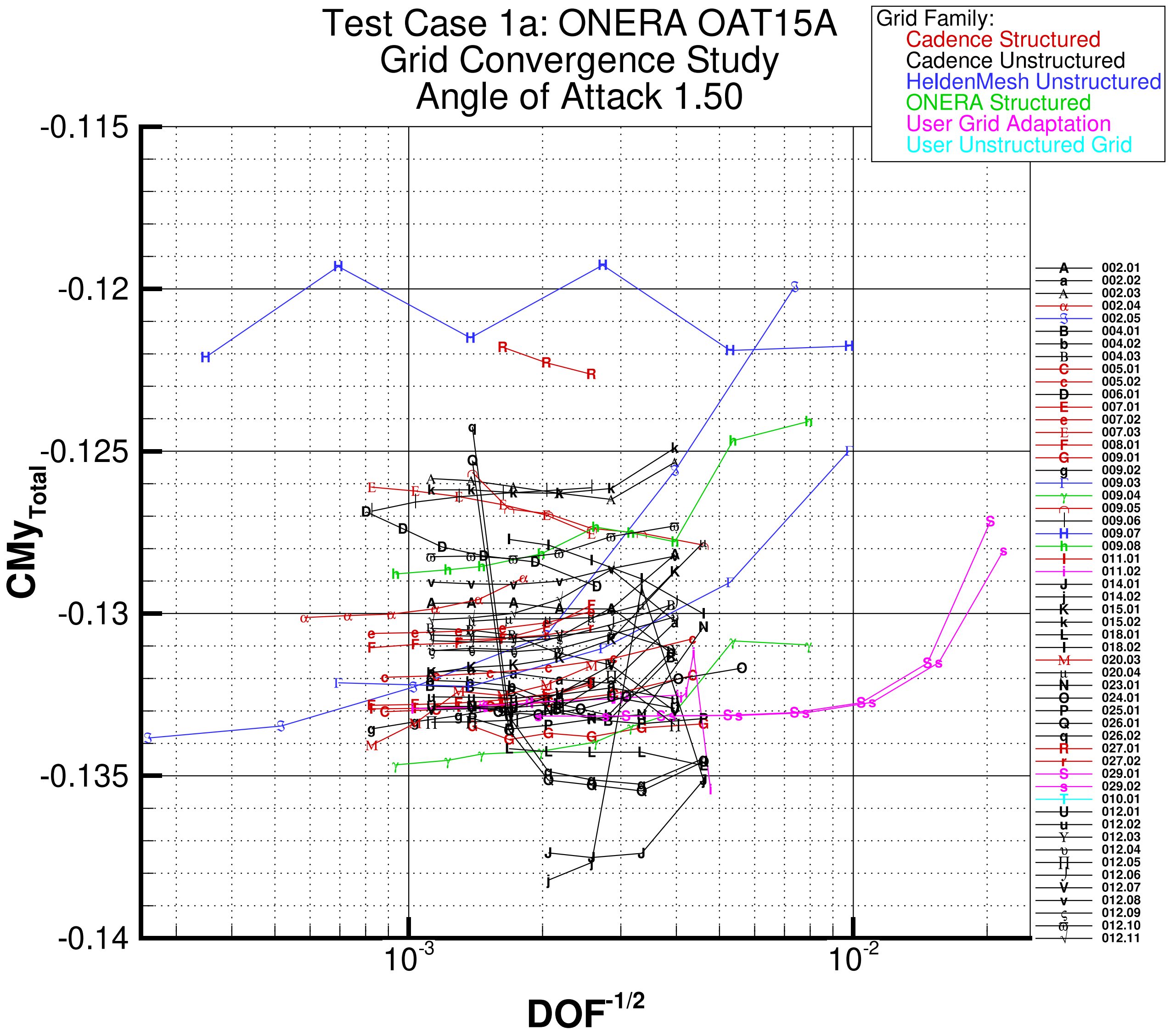


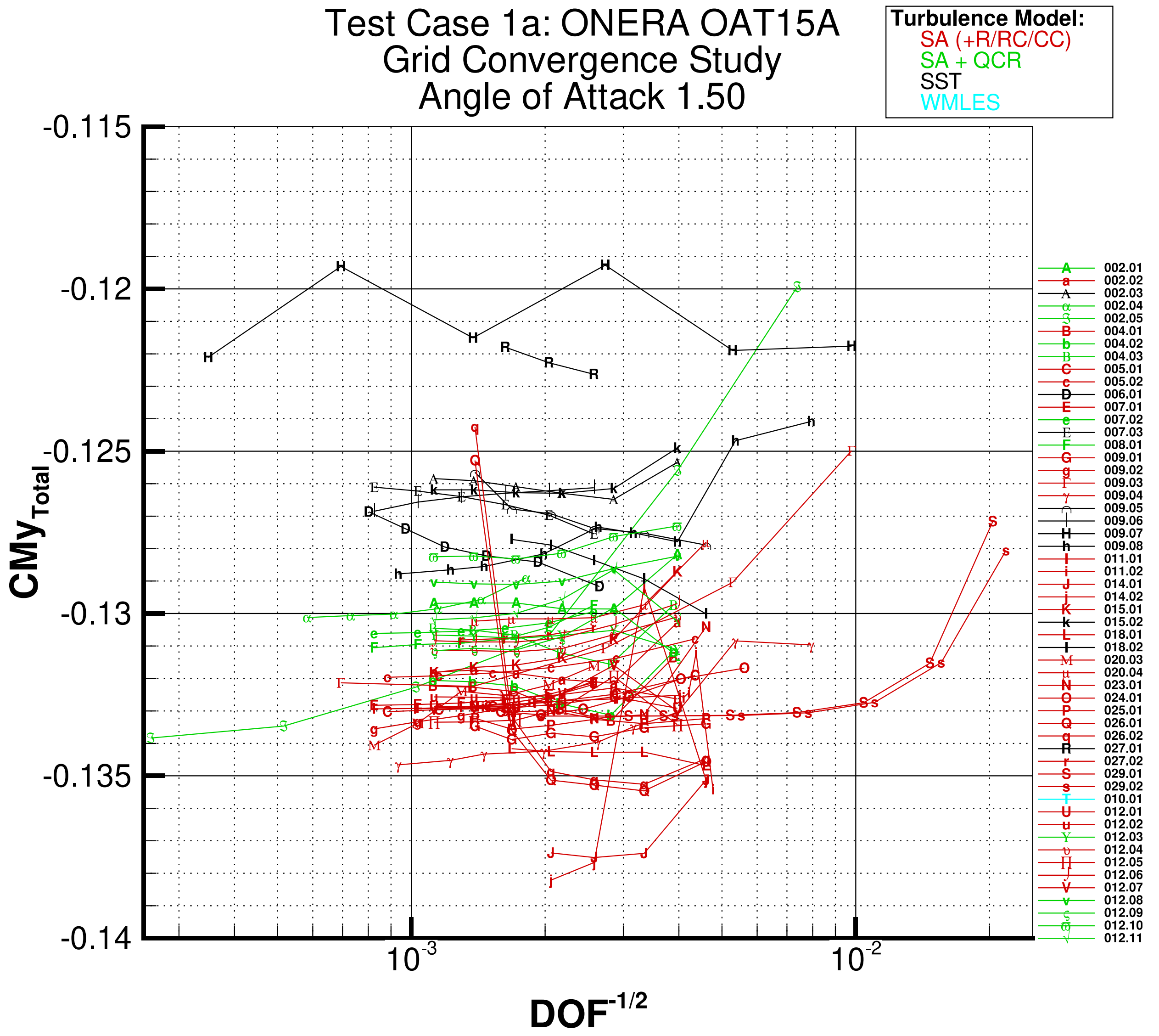
ONERA OAT15A C_D Convergence: $\alpha = 1.5°$



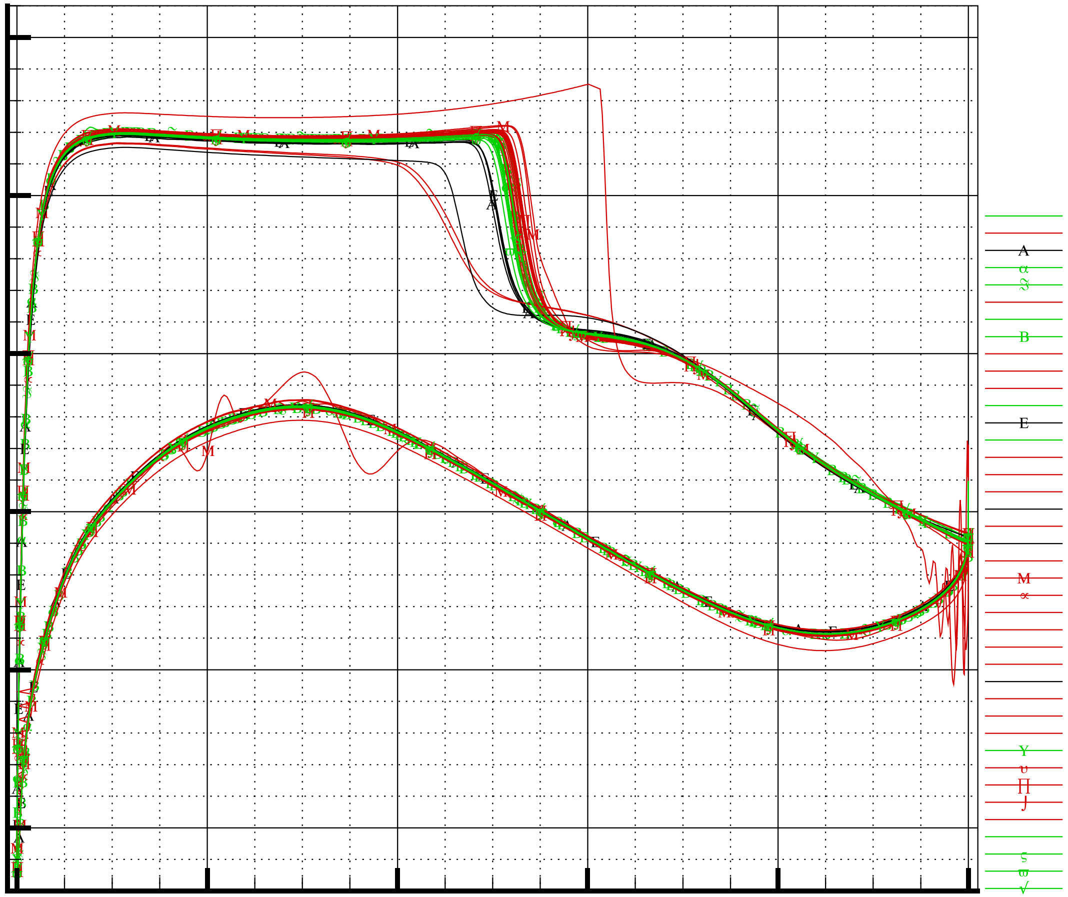


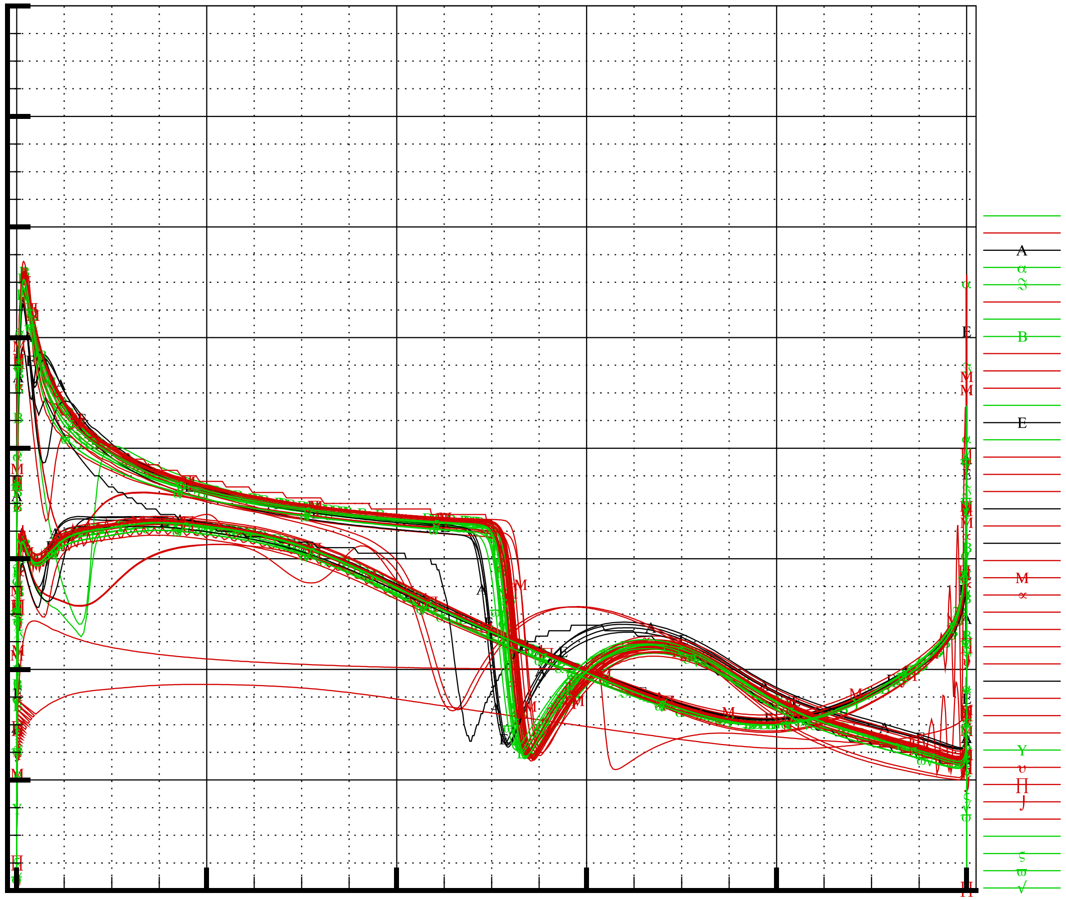
ONERA OAT15A C_M Convergence: $\alpha = 1.5°$





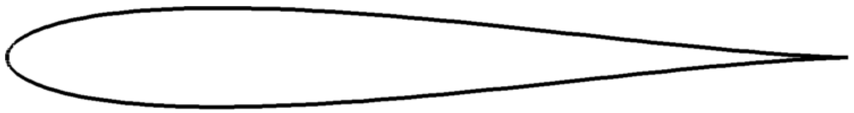
ONERA OAT15A C_p and C_f: $\alpha = 1.5°$





Test Case 1b: Joukowski Airfoil

- **Validation of steady CFD analysis, required**
  - https://github.com/Drag-Prediction-Workshop/DPW8-Scatter/blob/main/TestCase1b/Joukowski.pdf
- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg] (All terms!)**
    - Adiabatic Wall (not isothermal)
    - Characteristic Farfield (***100 chords away - no circulation***)
    - Use periodic boundary conditions for sidewall boundary conditions
  - Converge residuals to machine precision (~1e-10)



- **Grids**
  - Committee-supplied grid family (High-Fidelity CFD Verification Workshop 2024)
- **Conditions**

Mach	Re_c	T_{static}	α	γ	Pr	Pr_t	Farfield $\chi = \tilde{\nu}/\nu$
0.15	6×10^6	520.0 R	$0.0°$	1.4	0.72	0.9	3

- **Sutherland's Law**

$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right)$$

$$\mu_0 = 1.716 \times 10^{-5} \frac{\text{kg}}{m\ s}$$

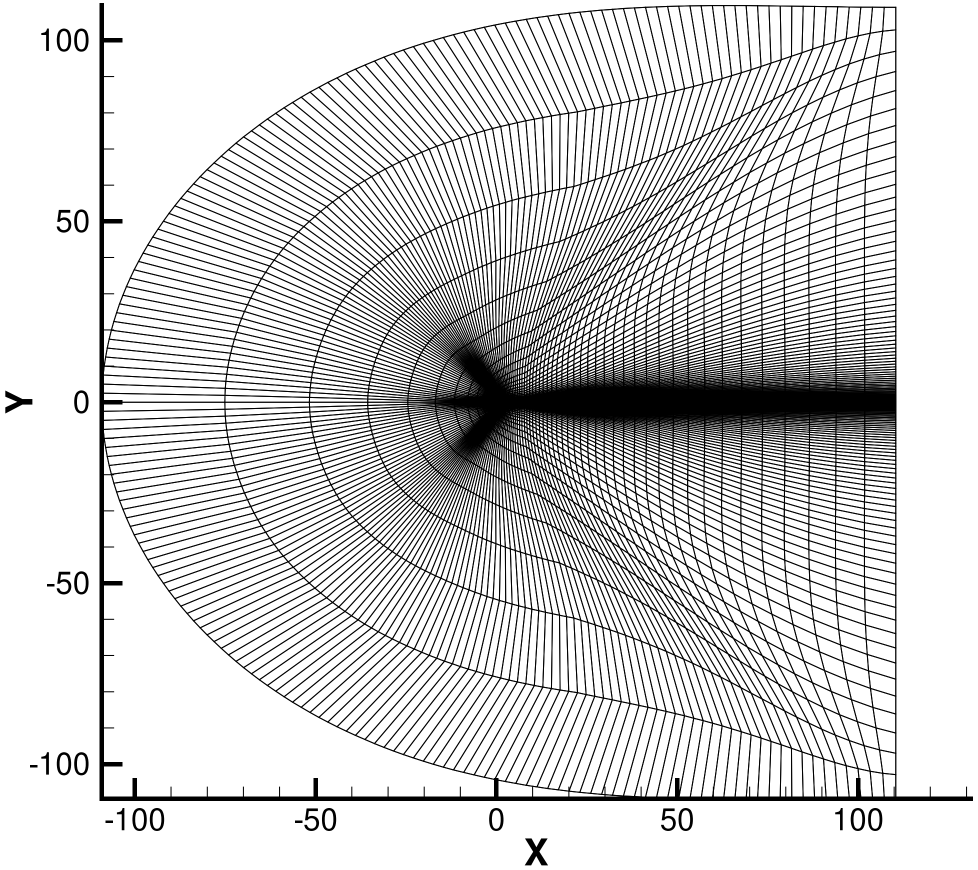
$$T_0 = 491.6°\ R$$

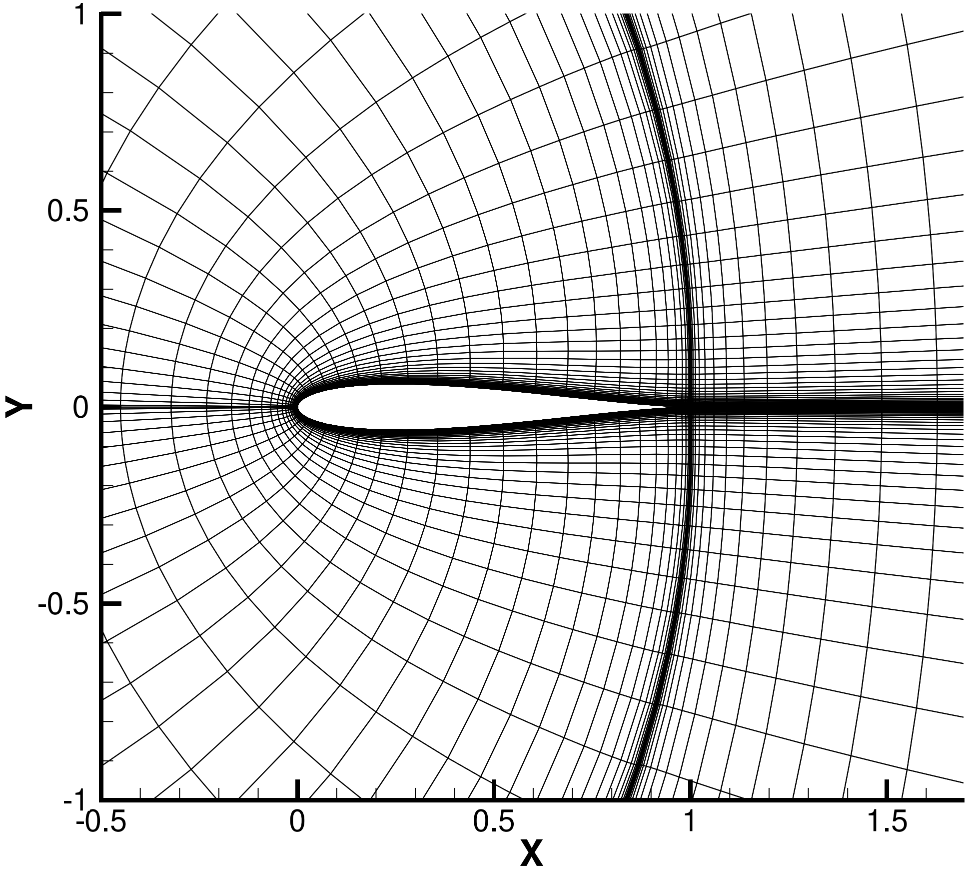
$$S = 198.6°\ R$$

$$\frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{fef}}{T/T_{fef} + S/T_{fef}}\right)$$

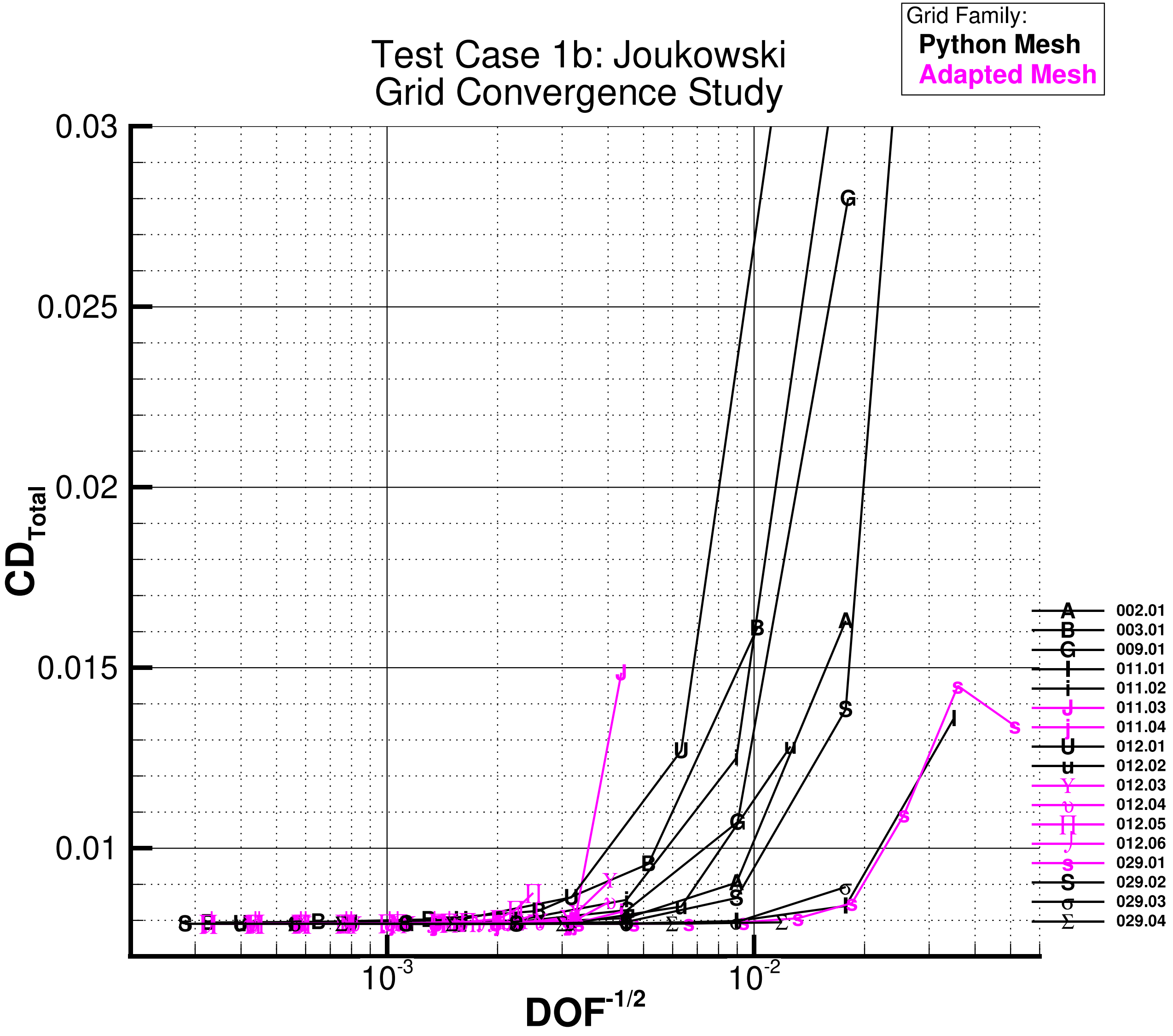
Test Case 1b: Joukowski Airfoil Mesh

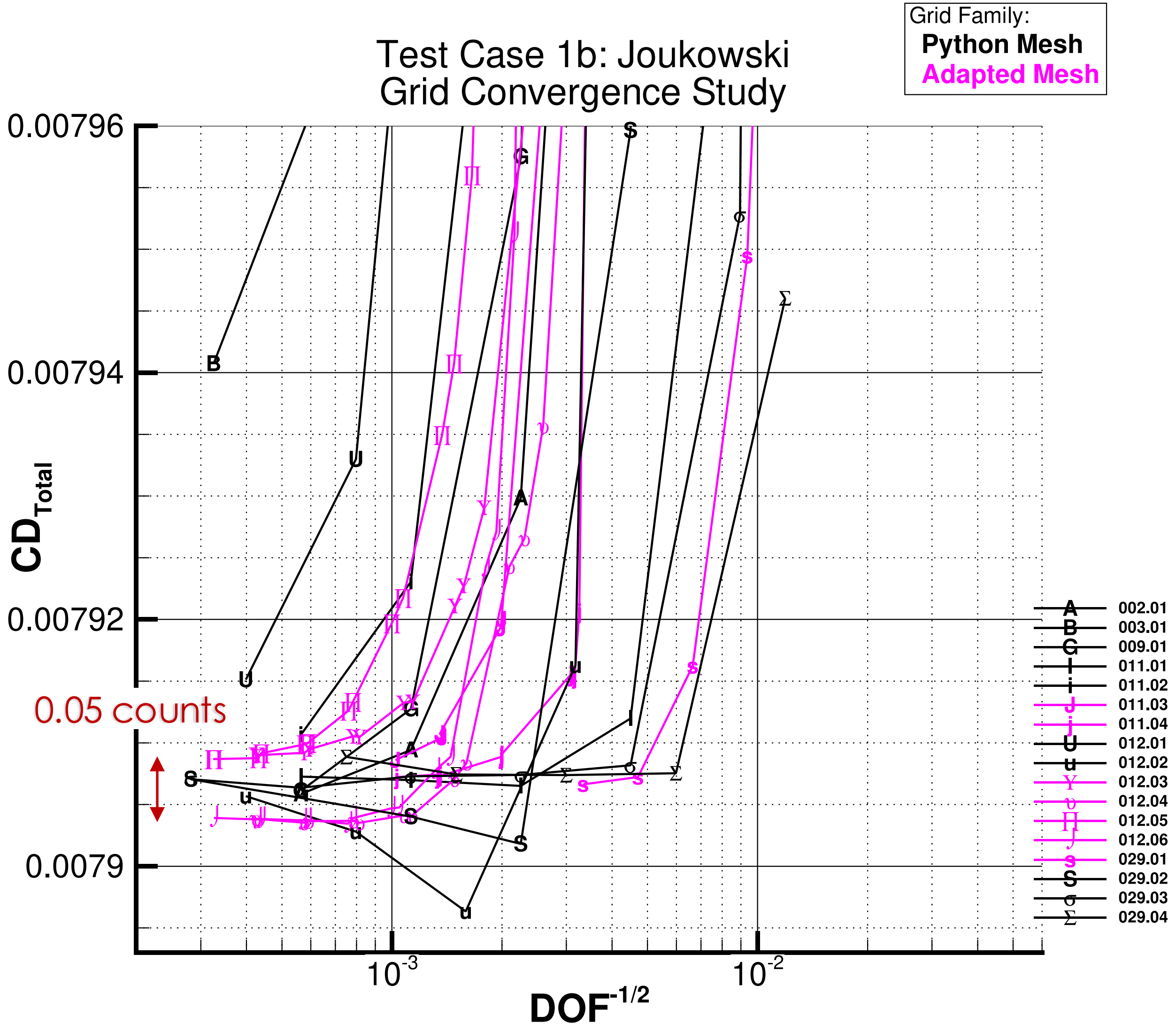
- Cusped trailing edge – remove inviscid singularity
- Zero angle of attack – stagnation point at leading edge
- Custom mesh to observe order of accuracy (Joukowski conformal mapping)



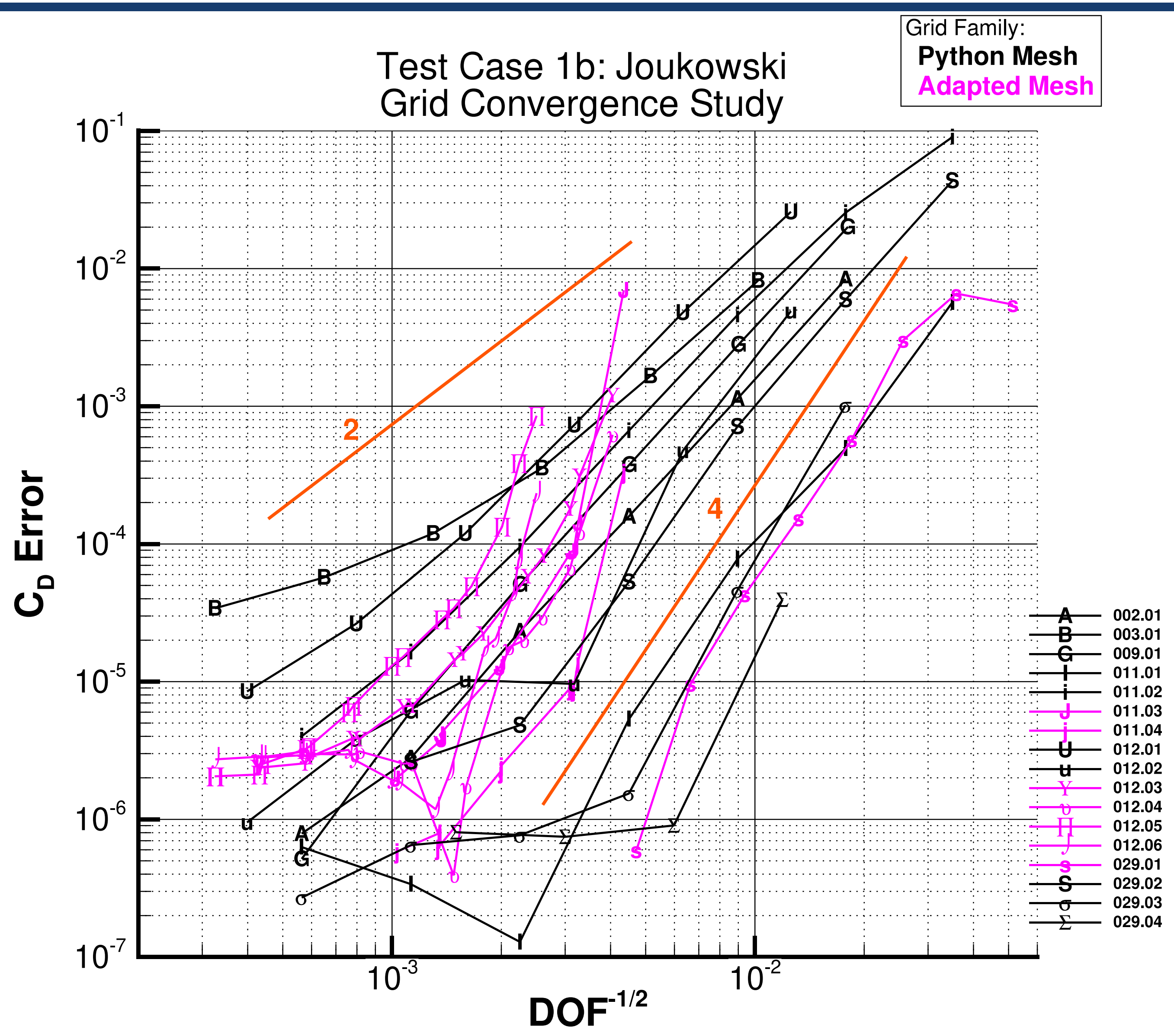


Joukowski C_D Convergence





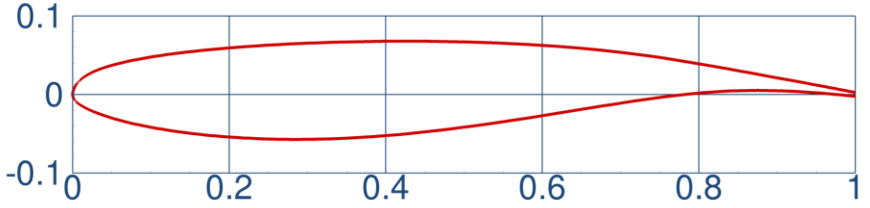
Joukowski Airfoil – Order of Accuracy



Test Case 1c: ONERA OAT15A Airfoil

- **Verification of steady CFD analysis, required**

Jaquin, et al. "Experimental Study of Shock Oscillation over a Transonic Supercritical Profiles." AIAA Journal, Vol. 47, No. 9, 2009. Pages 1985-1994.



ONERA OAT15A Transonic Airfoil

- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg] (All terms!)**
    - Adiabatic Wall (not isothermal)
    - Characteristic Farfield (***1000 chords away***)
    - Use periodic boundary conditions for sidewall boundary conditions
  - Converge residuals to machine precision (~1e-10)
- **Grids**
  - Six-member grid family; four are required, six are desirable
  - Encourage use of committee-supplied grids; user-generated grids are acceptable
    - Cadence Structured/Unstructured, Helden Mesh Unstructured
- **Conditions**

Mach	Re_c	T_{static}	α	γ	Pr	Pr_t	Farfield $\chi = \tilde{\nu}/\nu$
0.73	3×10^6	271 K (487.8 R)	1.5°	1.4	0.72	0.9	3

- **Sutherland's Law**

$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right)$$

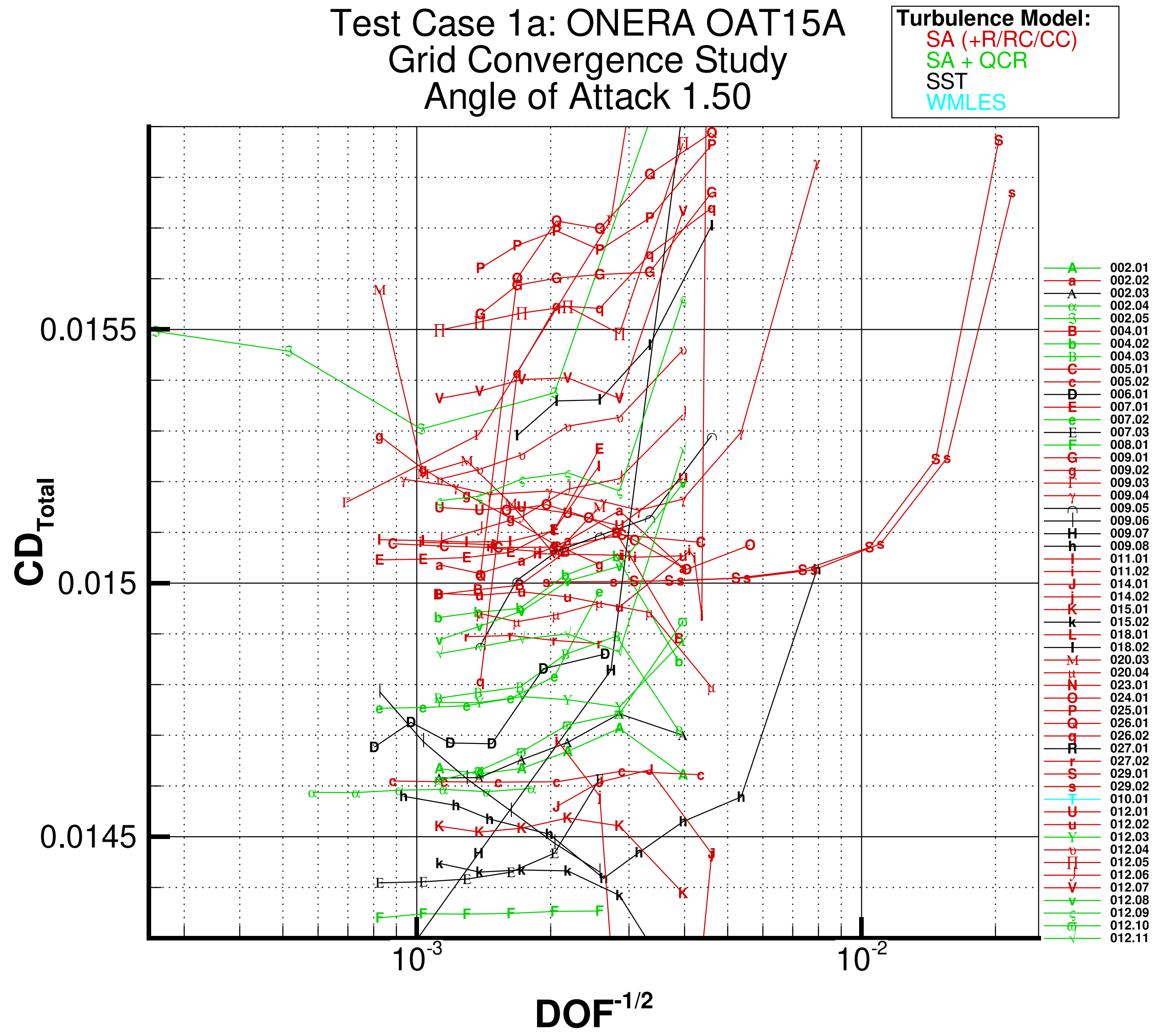
$$\mu_0 = 1.716 \times 10^{-5} \frac{\text{kg}}{m\, s}$$

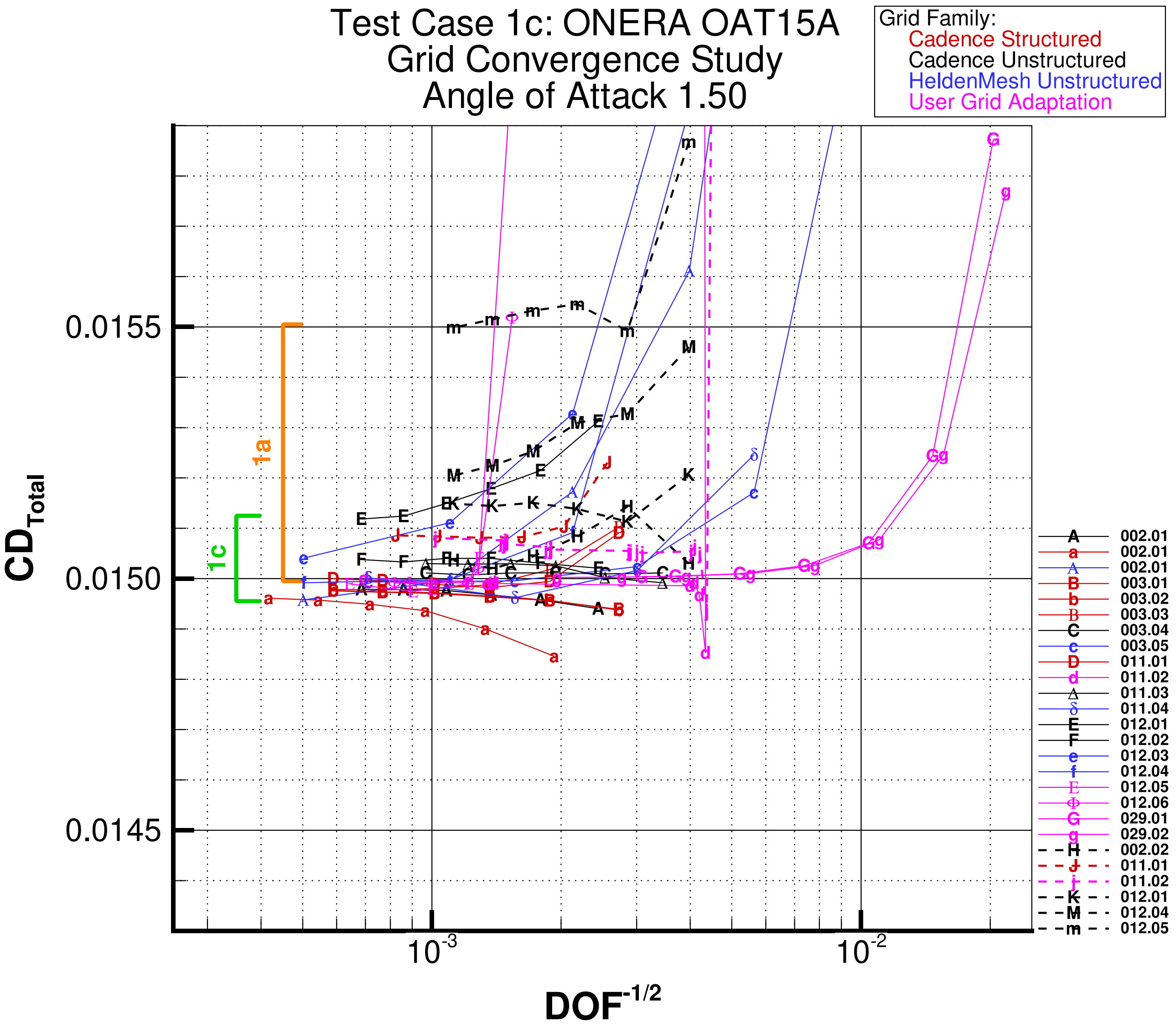
$$T_0 = 491.6^\circ\, R$$

$$S = 198.6^\circ\, R$$

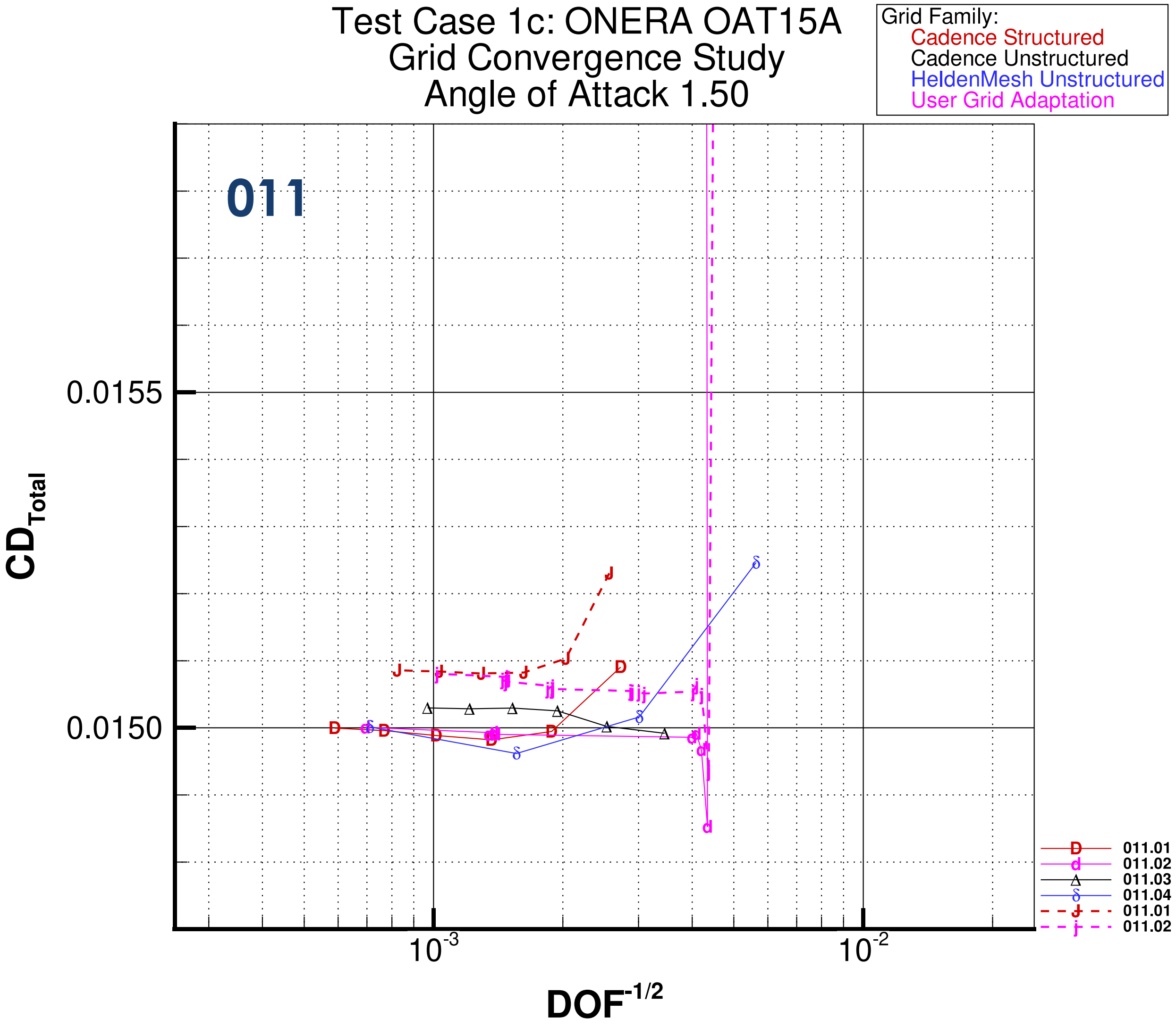
$$\frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{fef}}{T/T_{fef} + S/T_{fef}}\right)$$

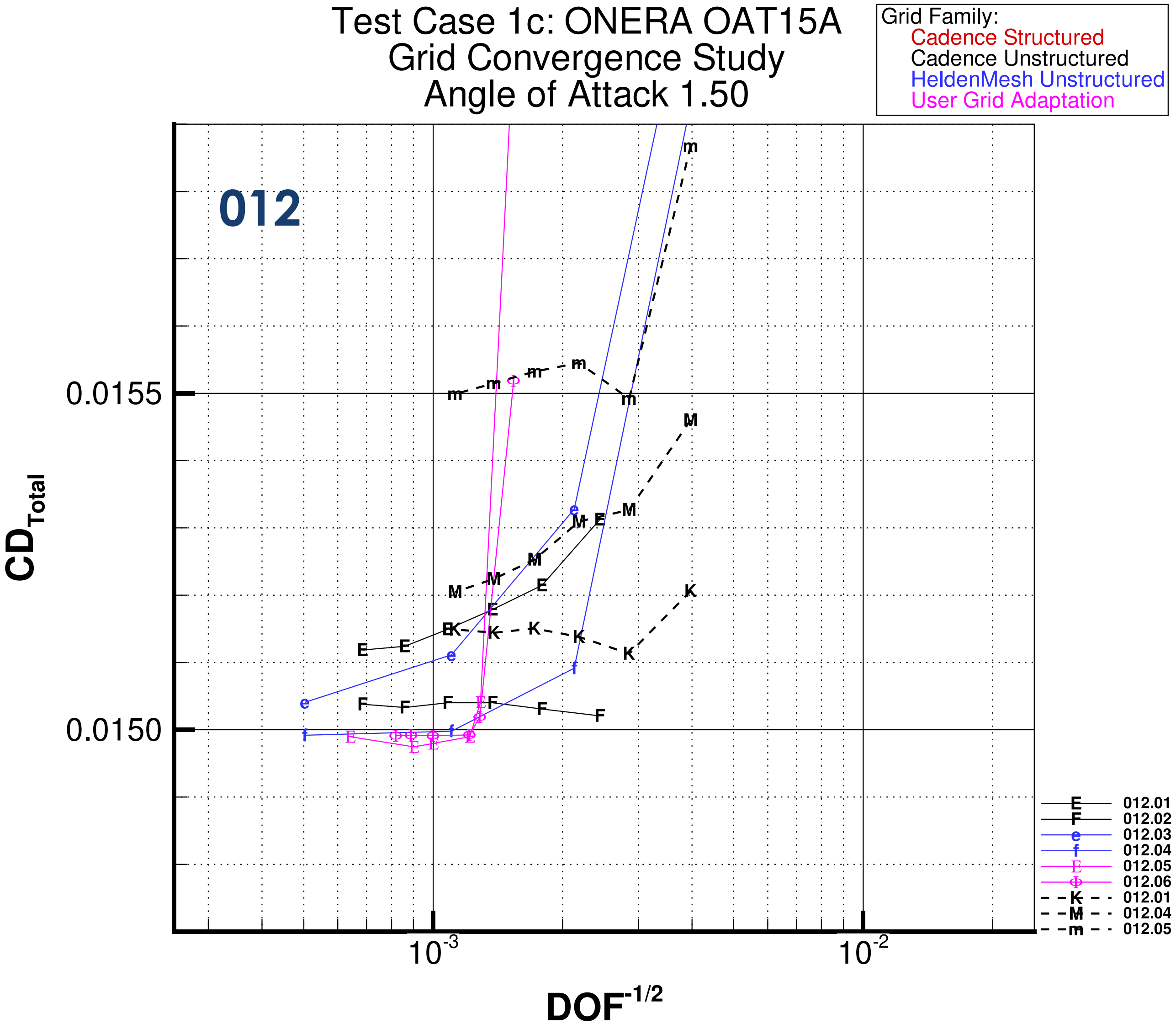
ONERA OAT15A C_D Convergence: $\alpha = 1.5°$



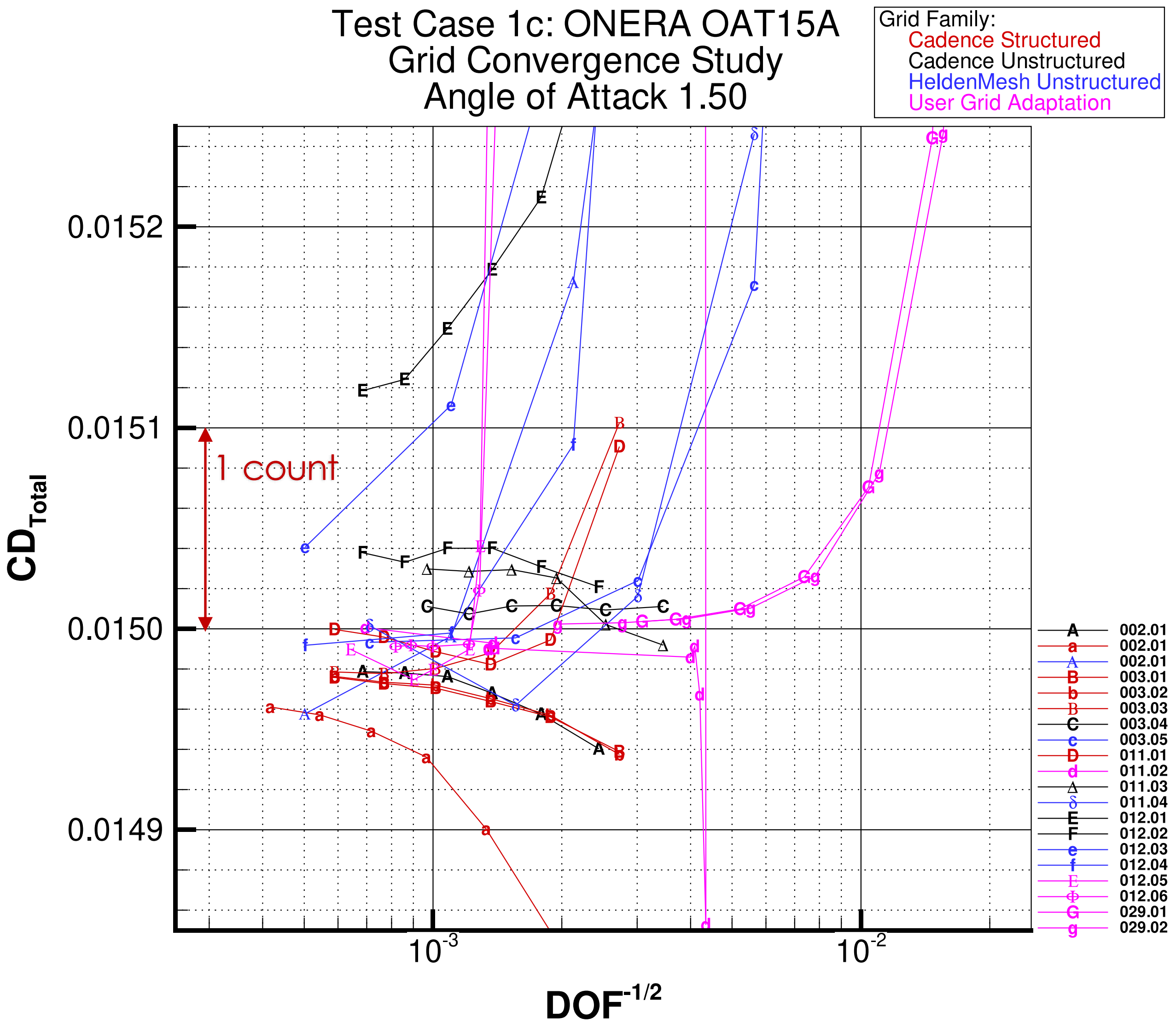


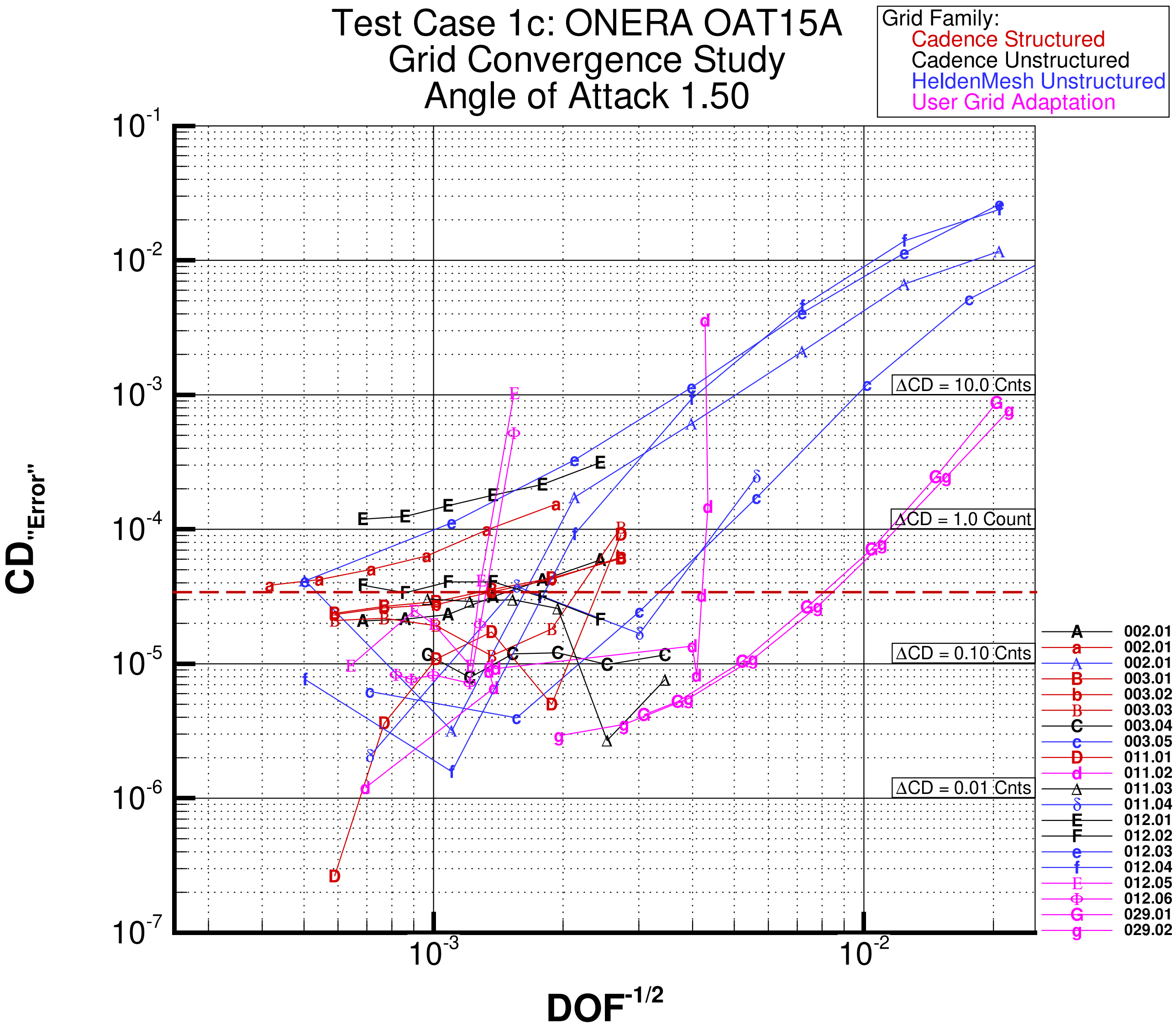
ONERA OAT15A C_D Participant Improvements



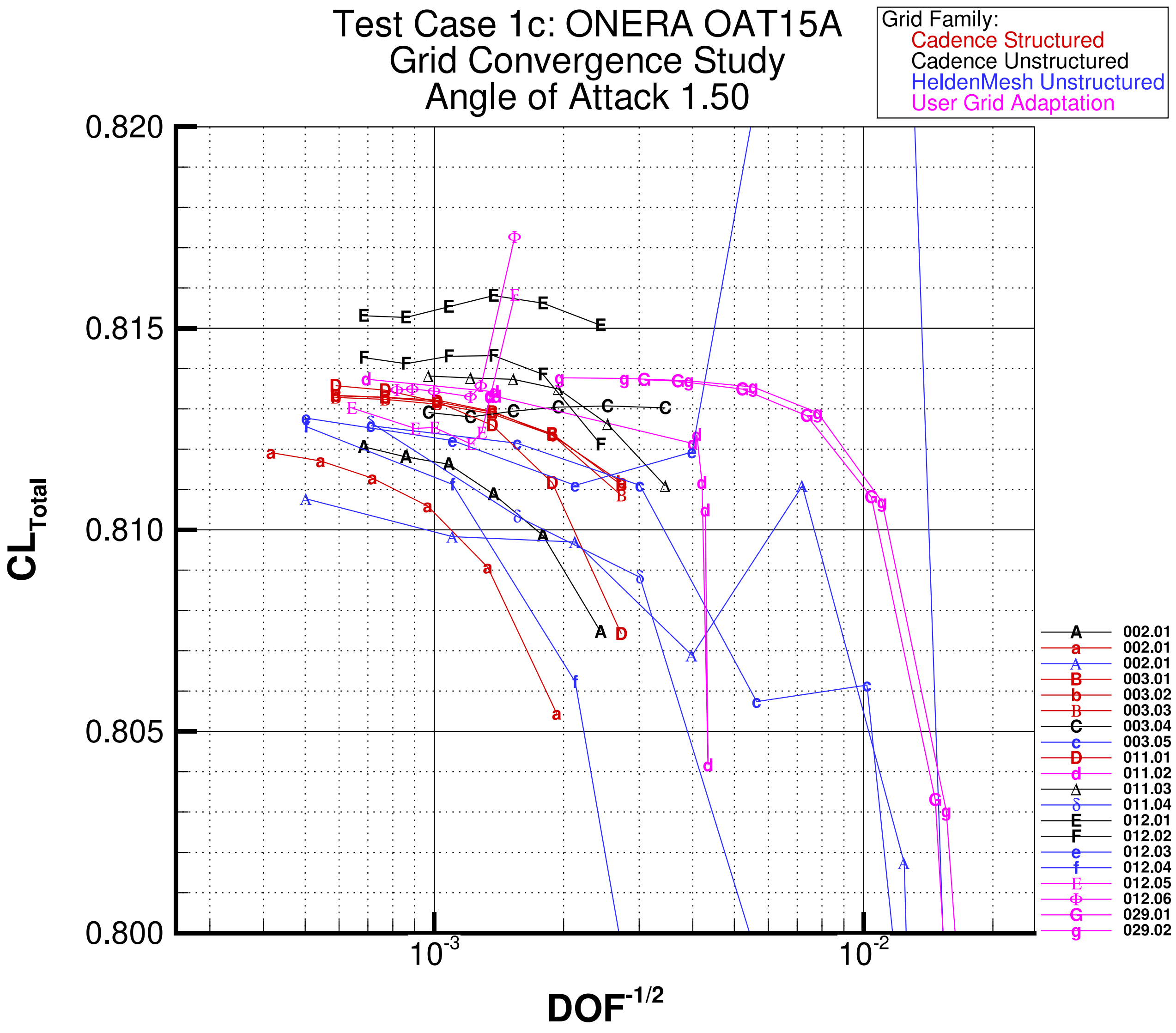


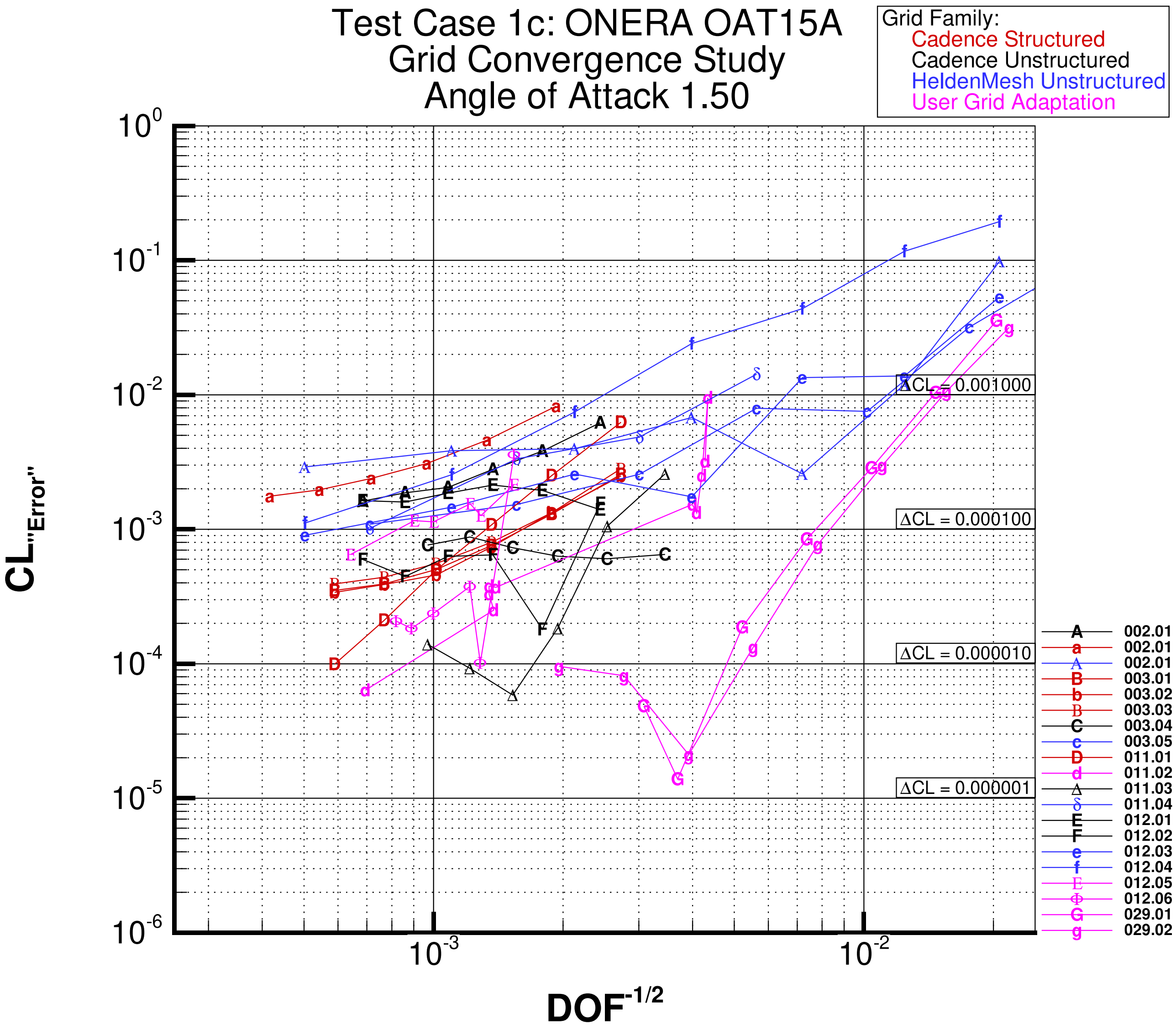
ONERA OAT15A C_D Convergence: $\alpha = 1.5°$



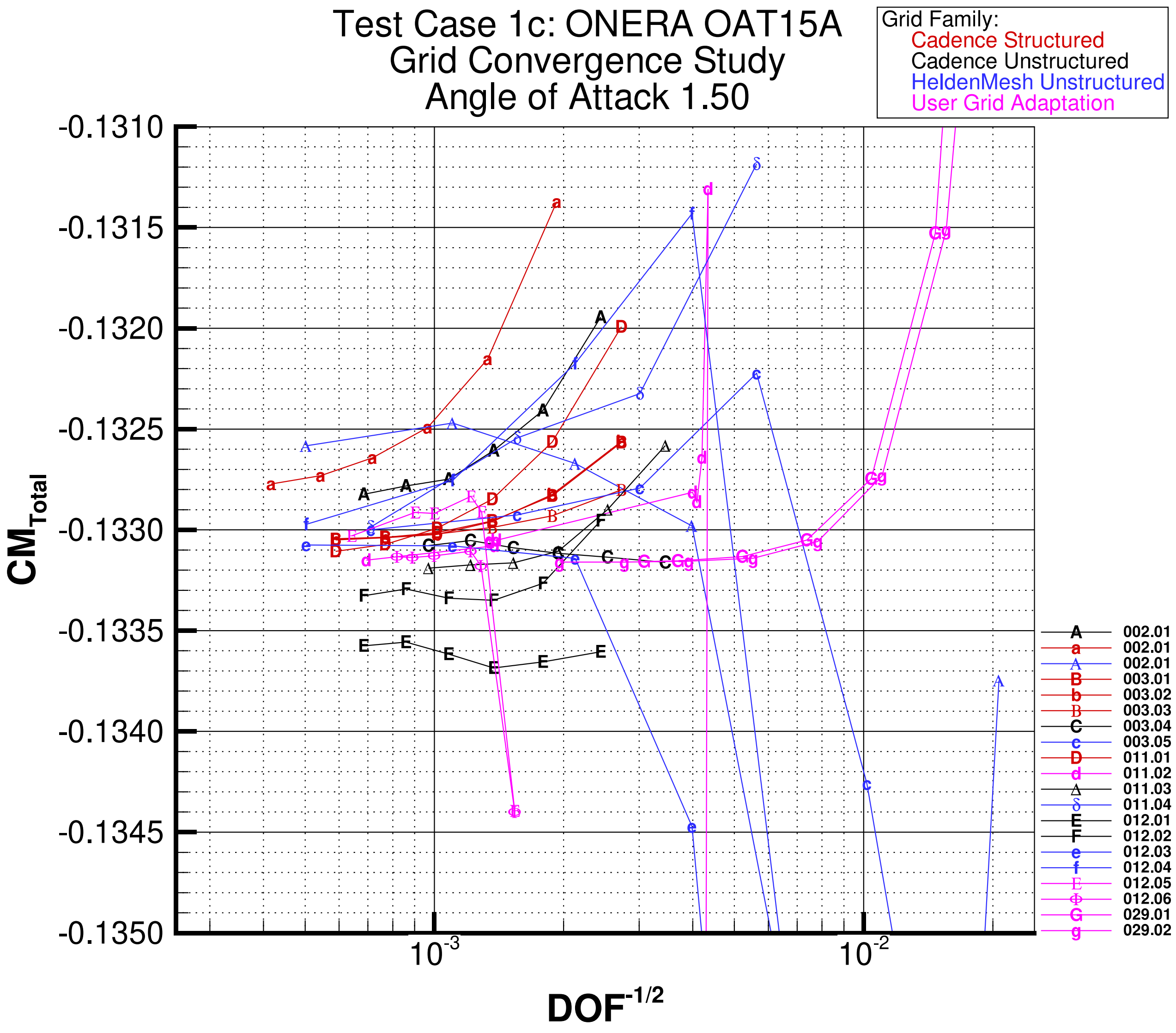


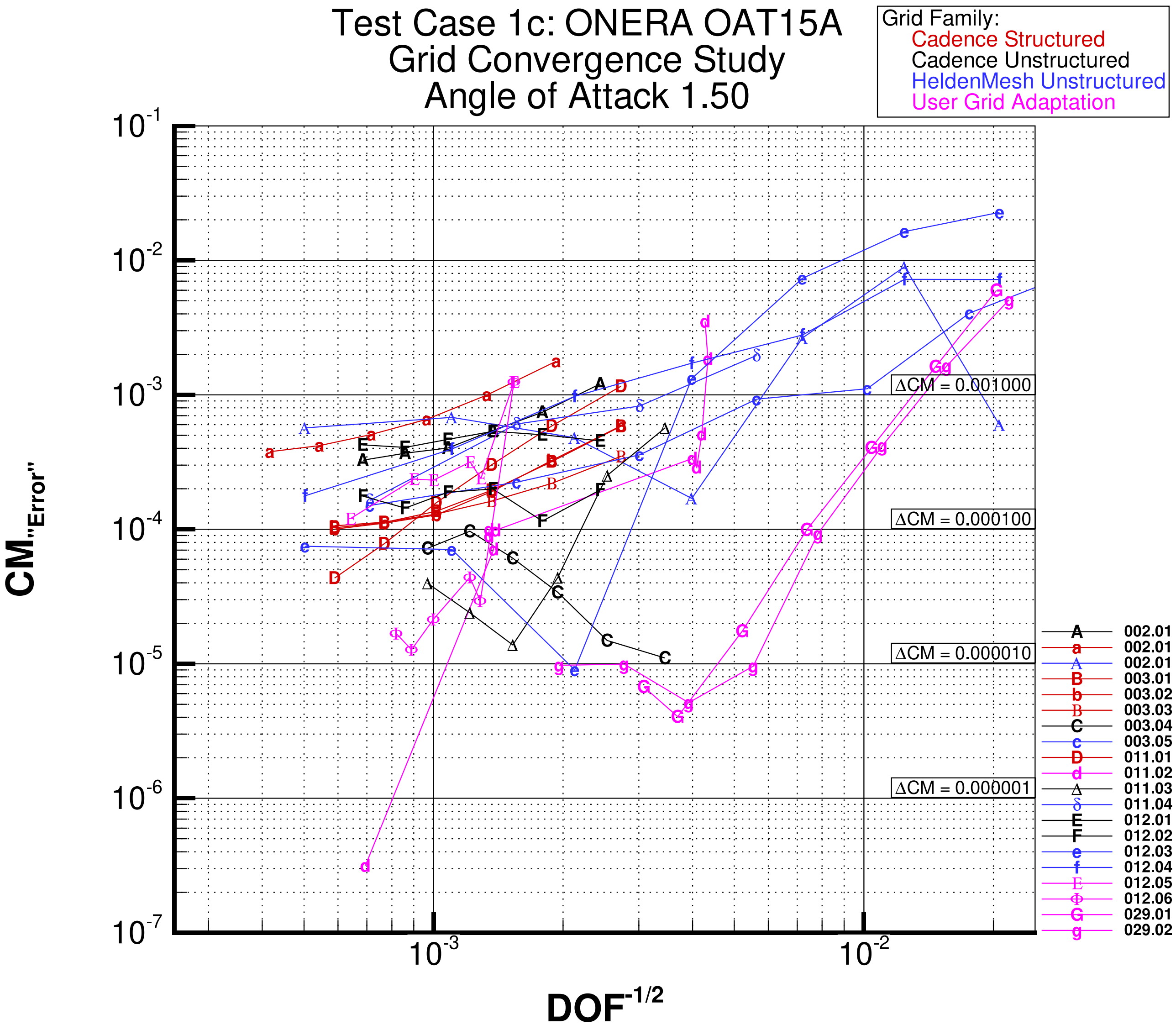
ONERA OAT15A C_L Convergence: $\alpha = 1.5°$



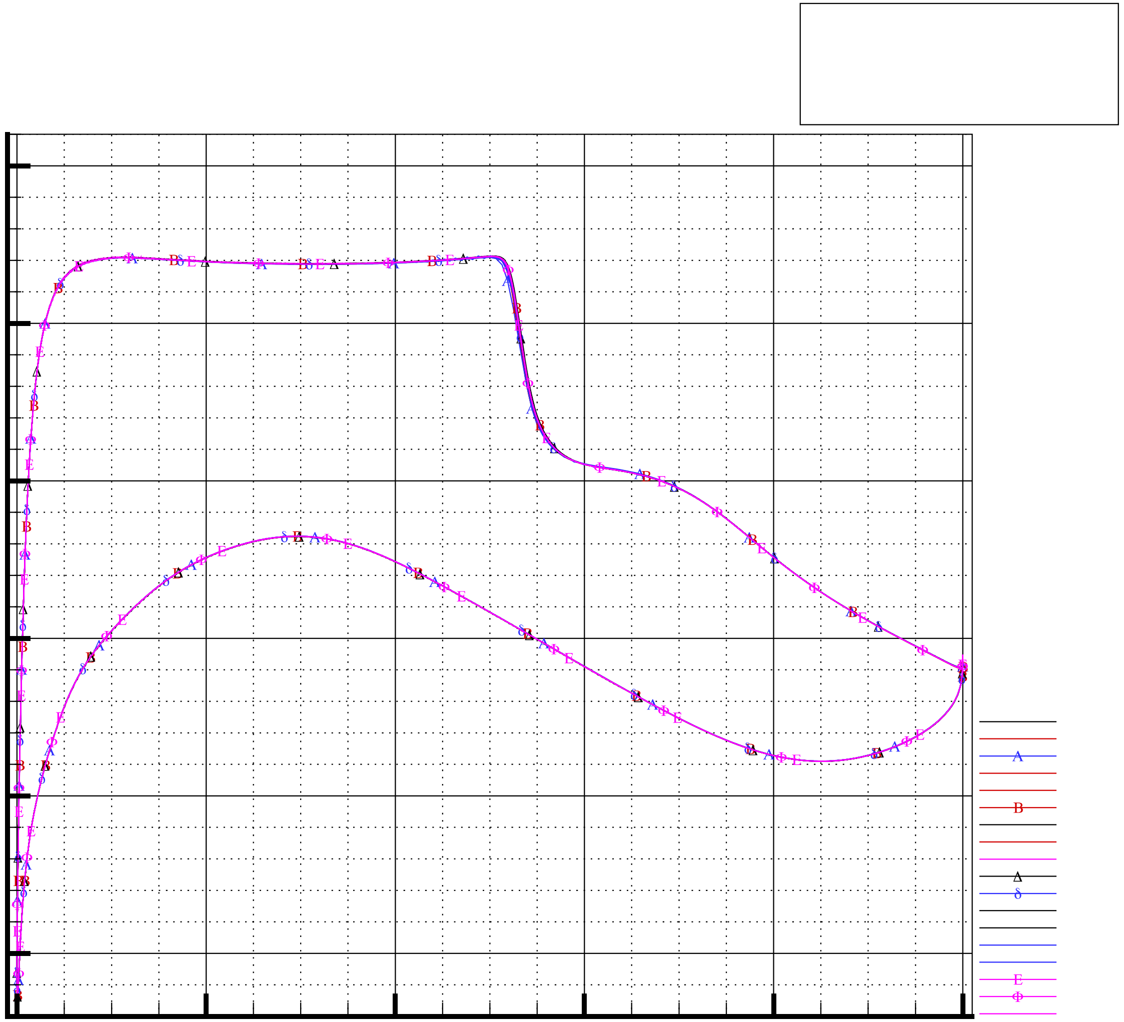


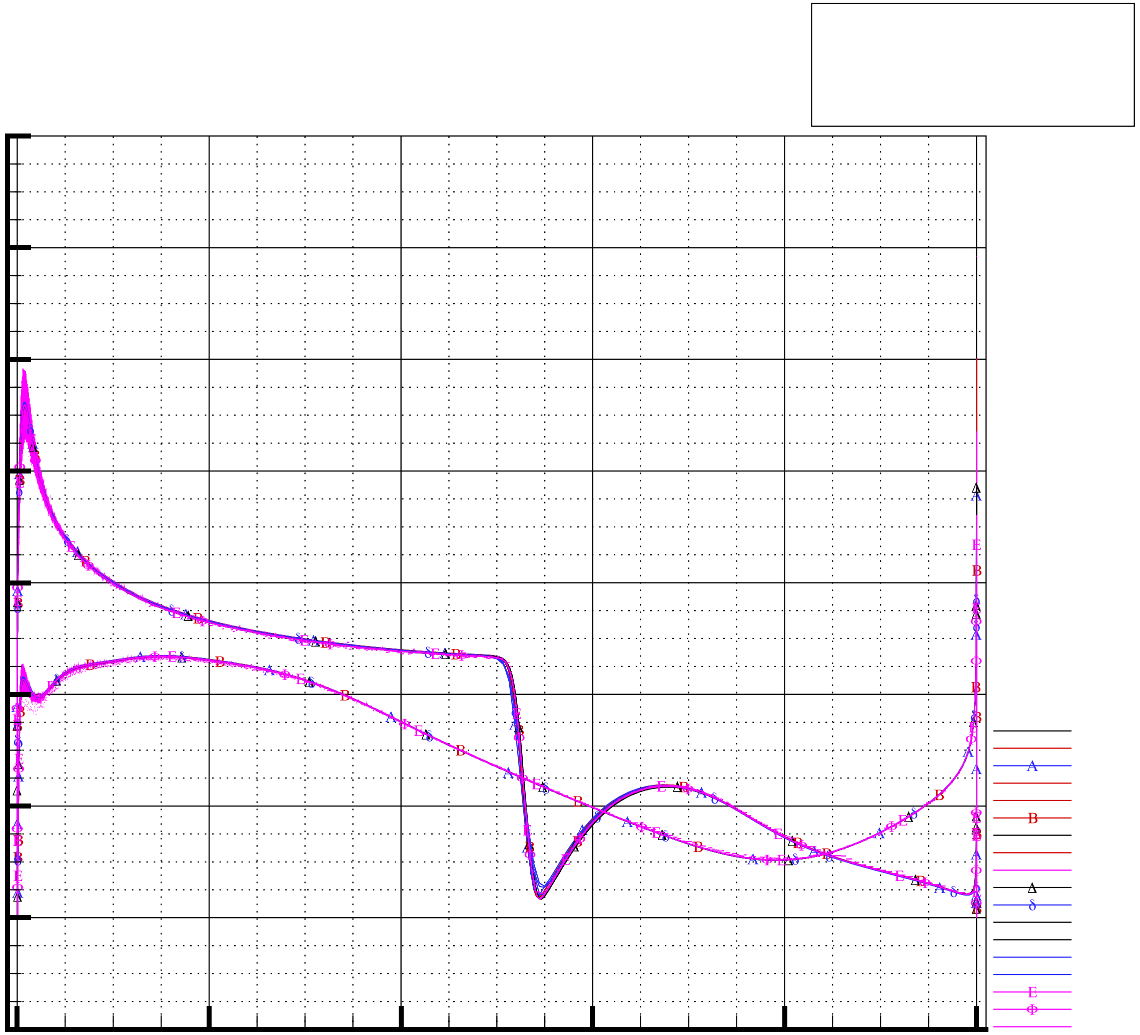
ONERA OAT15A C_M Convergence: $\alpha = 1.5°$



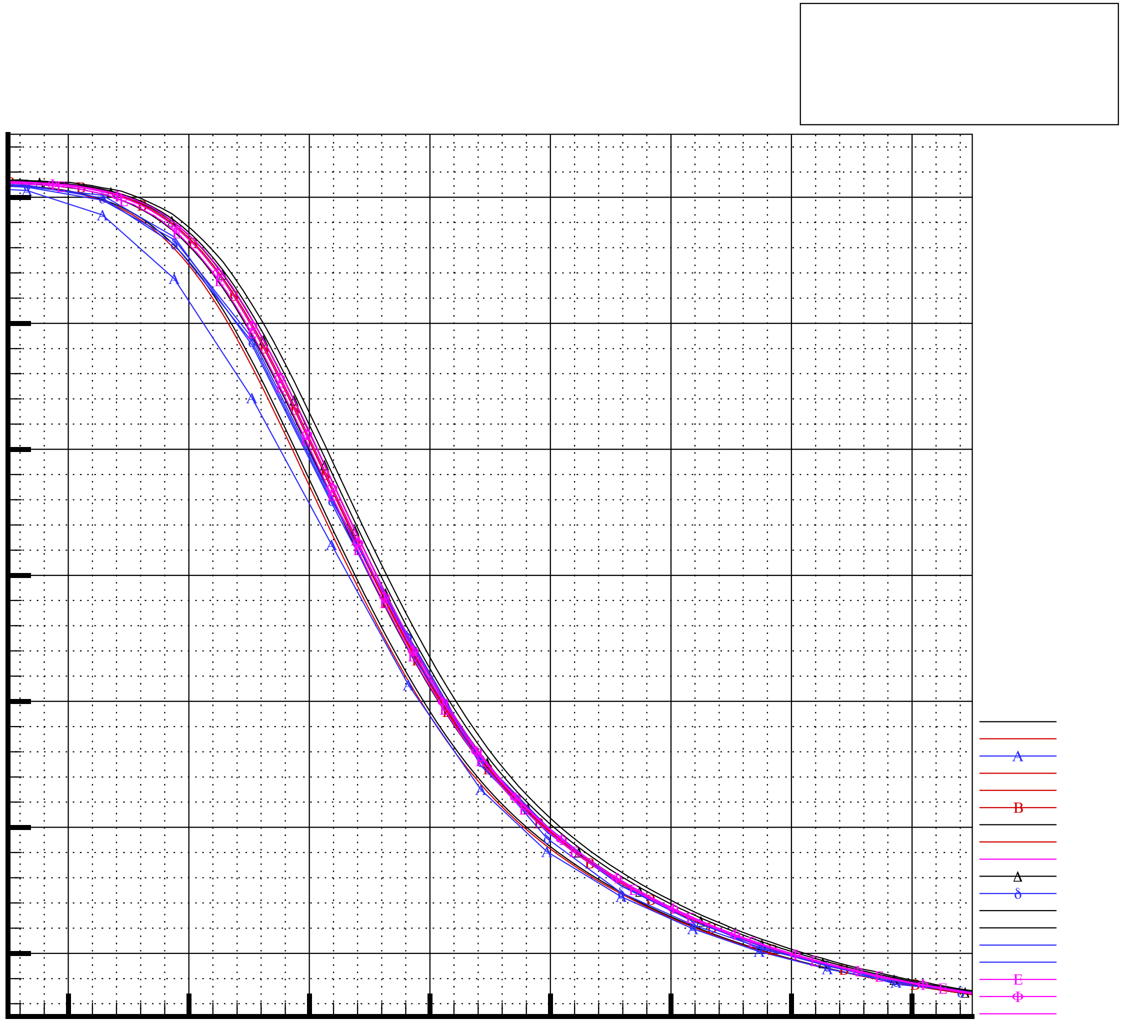


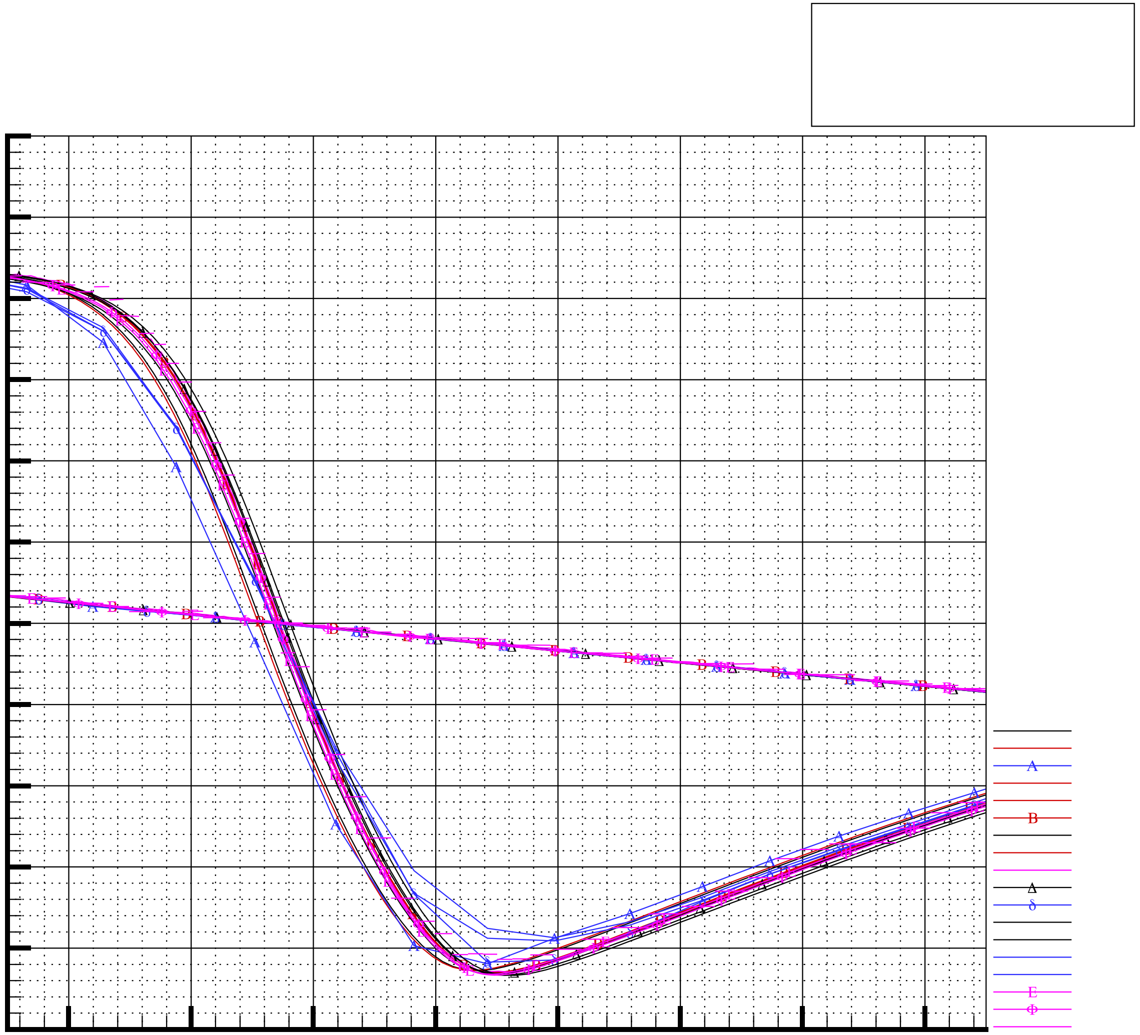
ONERA OAT15A C_p and C_f $\alpha = 1.5^\circ$





ONERA OAT15A C_p and C_f $\alpha = 1.5°$ (Shock)





Test Case 2a: Wing/Body Cruise

- **Verification of steady CFD analysis, required**
- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg] vs QCR2000 (All terms!)**
    - Adiabatic Wall (not isothermal)
  - Converge residuals to machine precision (~1e-10)
- **Grids: https://www.aiaa-dpw.org/DPW8/Scatter/Test_Case_2**
  - NASA CRM geometry including deformed wing matching condition
    - (L1:**T**iny/L2:**C**oarse/L3:**M**edium/L4:**F**ine/L5:e**X**tra-fine/L6:**U**ltra-fine)
    - Six-member grid family; four are required, six are desirable
  - Encourage use of committee-supplied grids; user-generated grids are acceptable
- **Reference Units**

Sref (semi-span grid)	Cref	Semispan	Moment Center
297360.0 sq.in	278.5 in	1156.75 in	(1325.90, 0.00, 177.95)

- **Conditions**

Mach	Re_c	α	T_{static} (120° F)	γ	Pr	Pr_t	Farfield $\chi = \tilde{\nu}/\nu$
0.85	5×10^6	$2.50°$	579.67 R | 322.04 K	1.4	0.72	0.90	3

- **Sutherland's Law**

$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right) \quad \mu_0 = 1.716 \times 10^{-5} \frac{\text{kg}}{m\,s} \quad T_0 = 491.6°\,R \quad S = 198.6°\,R$$

$$\frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{fef}}{T/T_{fef} + S/T_{fef}}\right)$$

Comparison Data

NTF197: r44,r51,r53
NTF215: r43,r103
NTF229: r296,r300,r302
Ames216: r35,r126,r130,r133

Conclusion

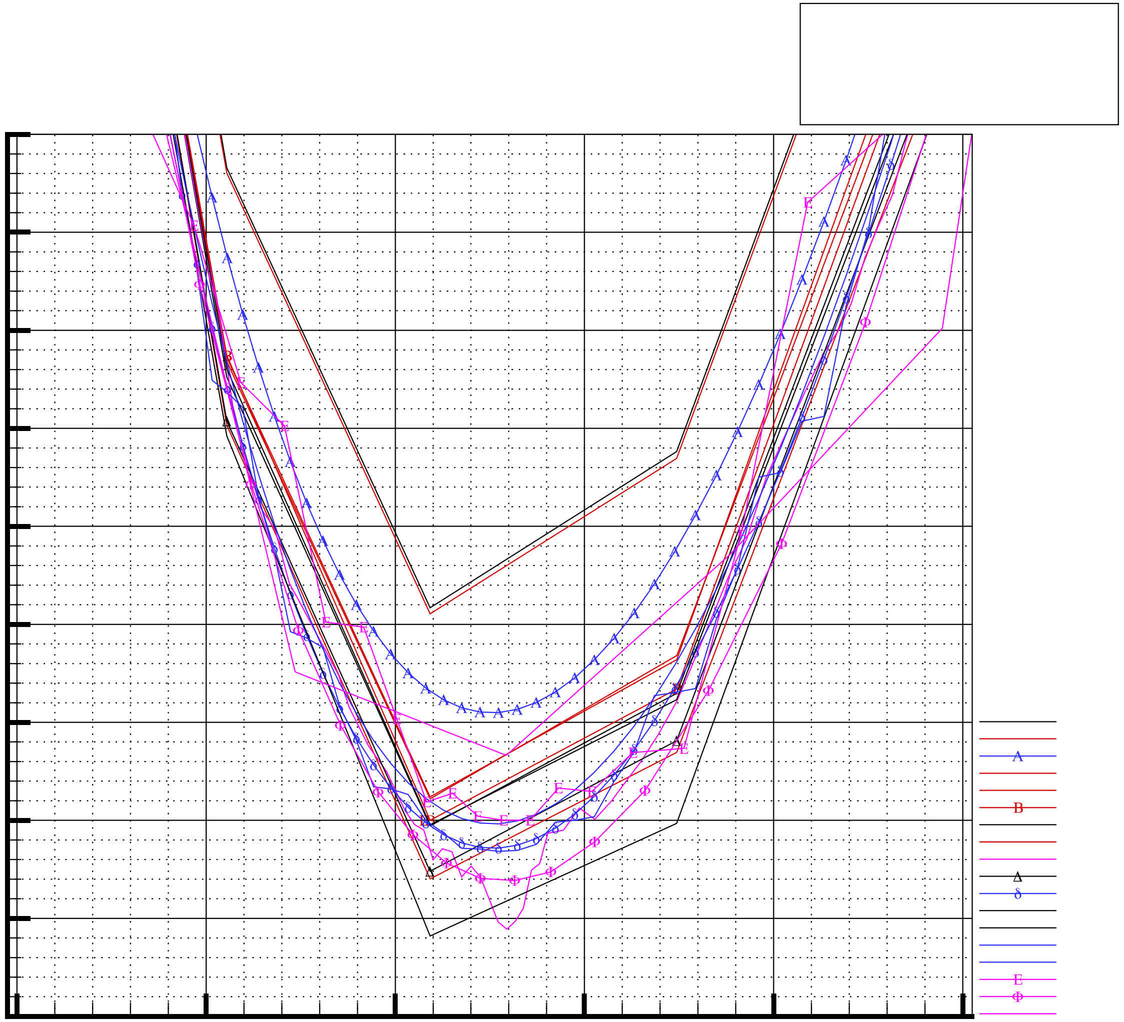
- **Test Case 1a: ONERA OAT15A**
  - Surprisingly large scatter!
- **Test Case 1b: Joukowski**
  - Excellent agreement between participants
  - Clear demonstration of 2nd-order accuracy (and higher!)
- **Test Case 1c: ONERA OAT15A**
  - Reduction in scatter!
    - Consistent Turbulence Model
    - Consistent problem definition (nothing left to participants)
    - Fairfield Distance
    - Residual Convergence
- **Test Case 2a: Wing/Body Cruise**
  - SA-[neg] vs SA-[neg]-QCR2000
- **Want to Participate?**
  - Contact galbramc@mit.edu or Ben.J.Rider2@boeing.com

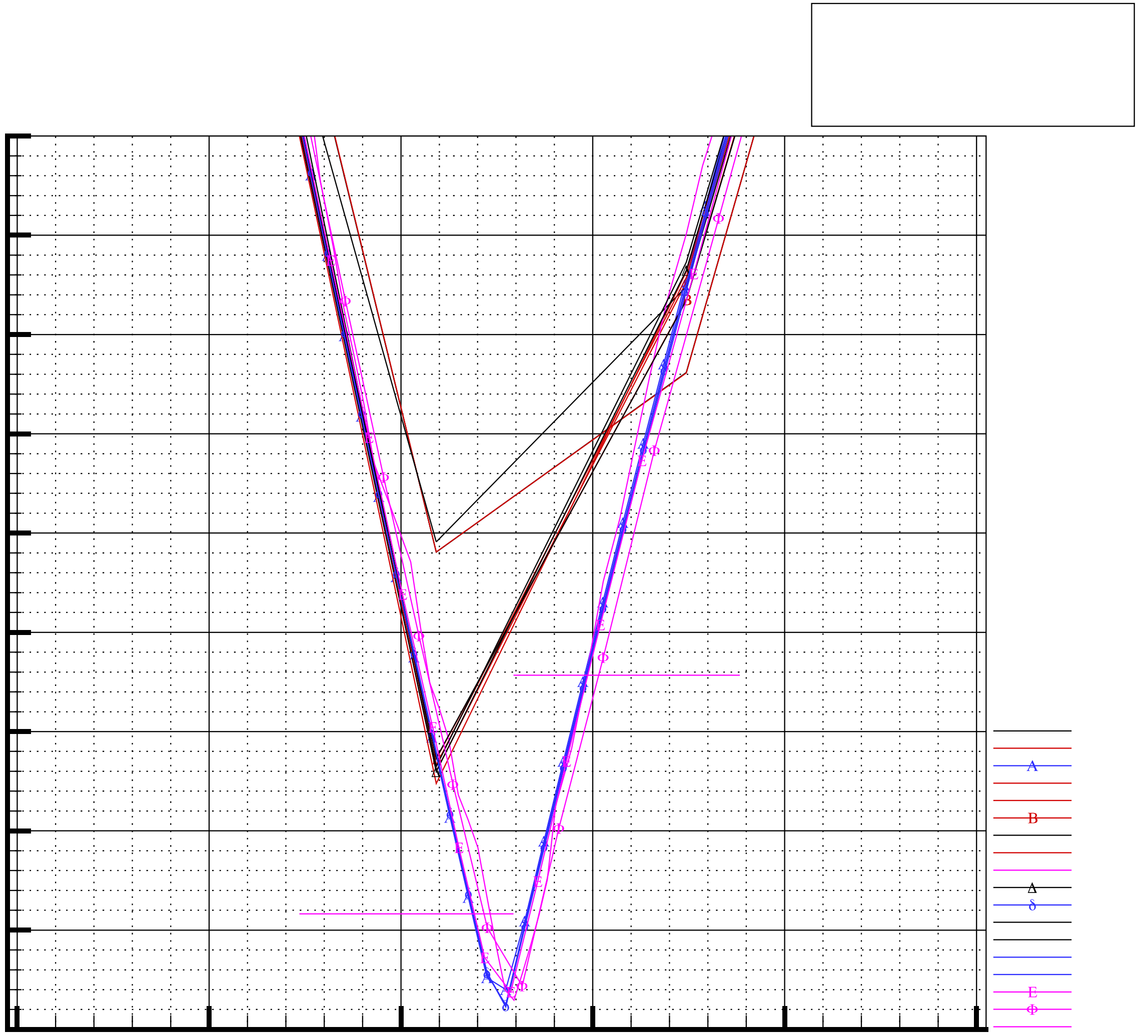
Scatter Reduction Working Group

SHAPING THE FUTURE OF AEROSPACE

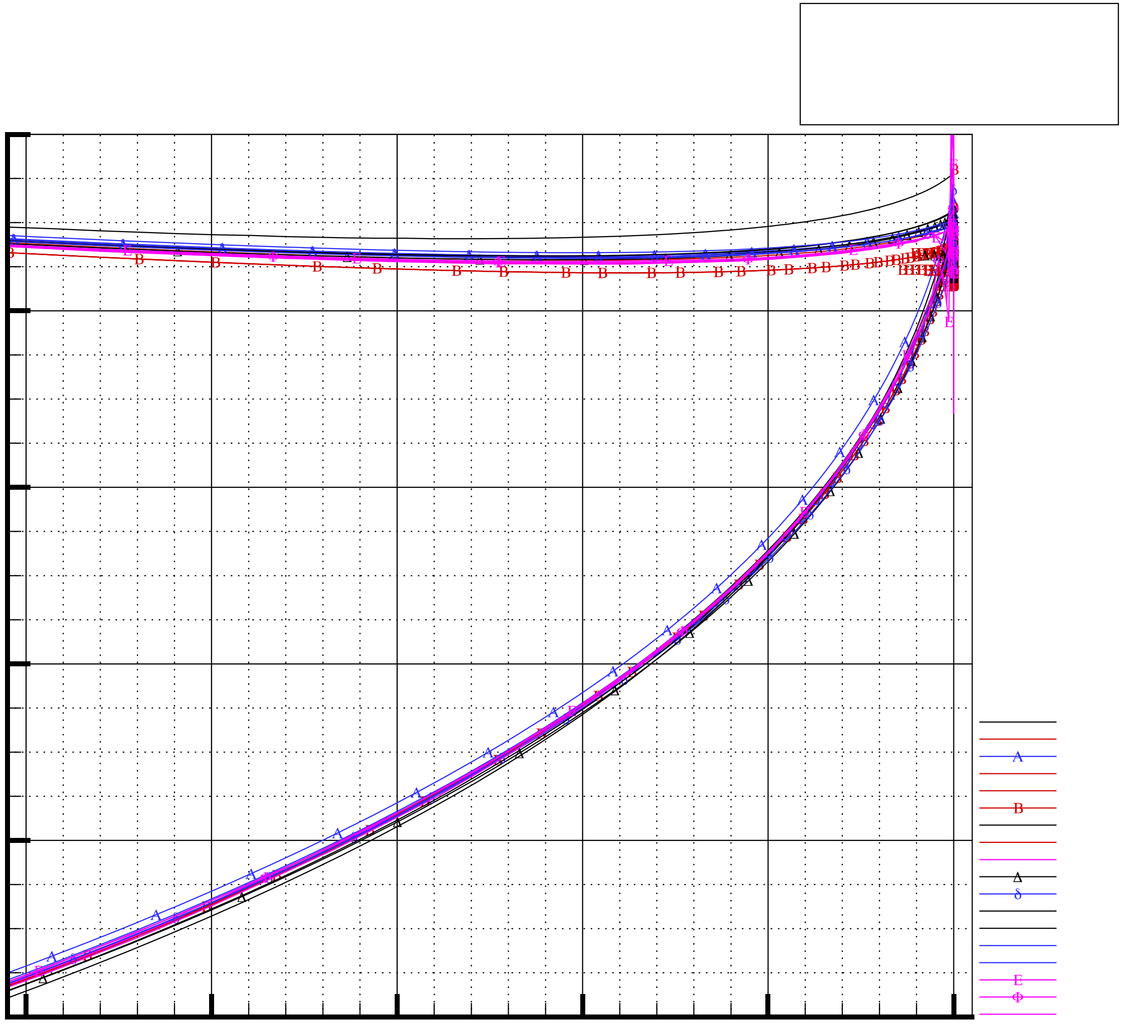
dpwaiaa@gmail.com

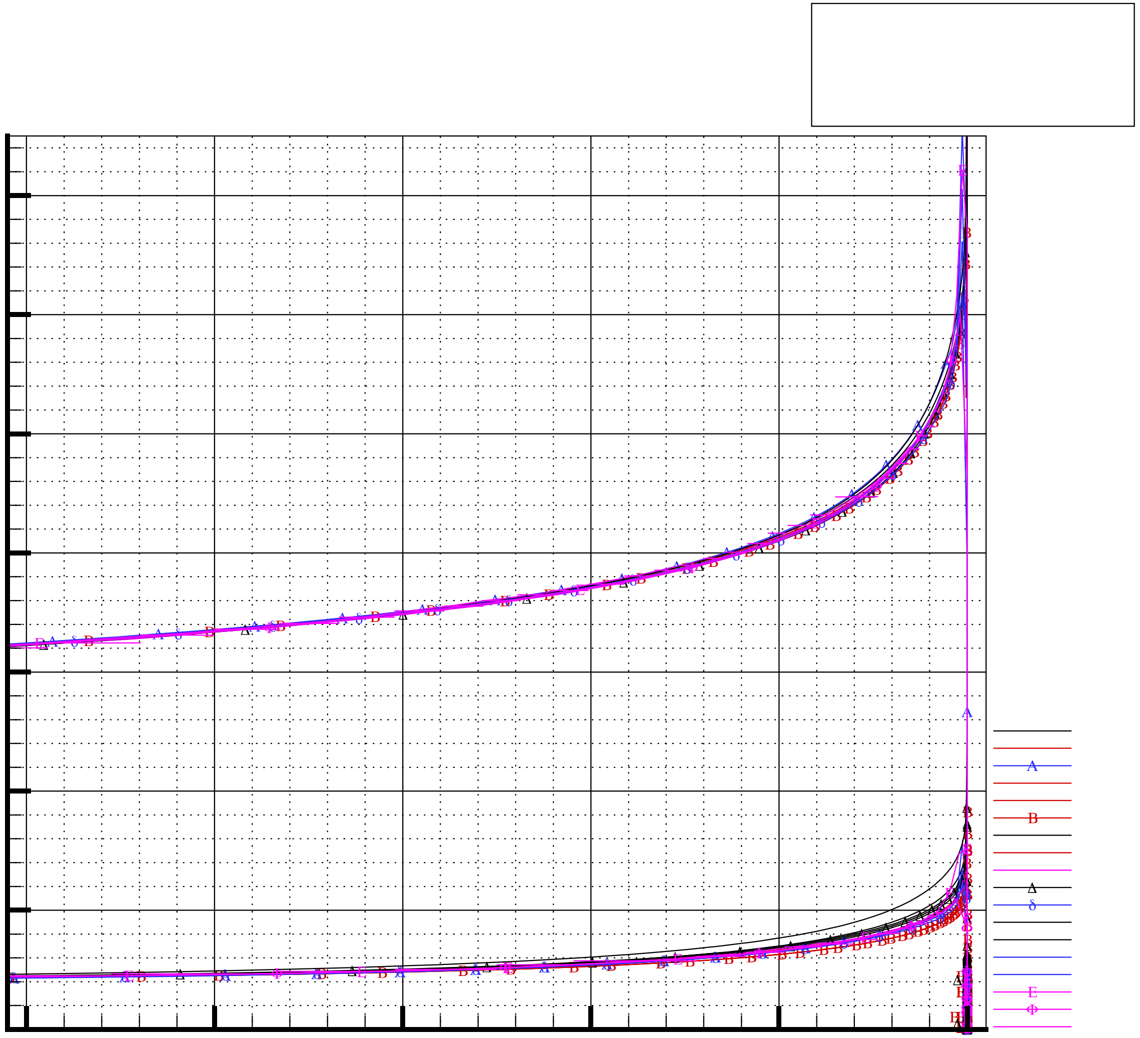
ONERA OAT15A C_p and C_f $\alpha = 1.5°$ (Leading Edge)





ONERA OAT15A C_p and C_f $\alpha = 1.5°$ (Trailing Edge)





Potential Future Test Cases

Test Case 1d: ONERA OAT15A Airfoil

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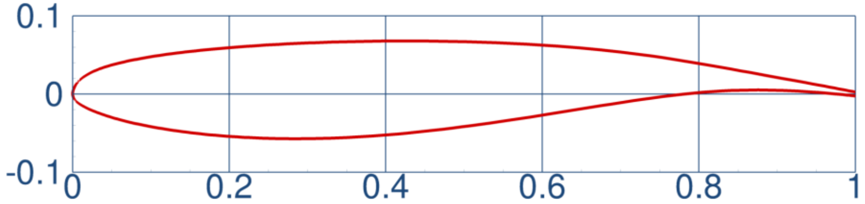

ONERA OAT15A Transonic Airfoil

- **Verification of steady CFD analysis, required**
- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg]** ***+ QCR2000***
    - Adiabatic Wall (not isothermal)
    - Characteristic Farfield (***1000 chords away***)
    - Use periodic boundary conditions for sidewall boundary conditions
  - Converge residuals to machine precision (~1e-10)
- **Grids**
  - Six-member grid family; four are required, six are desirable
  - Encourage use of committee-supplied grids; user-generated grids are acceptable
- **Conditions**

Mach	Re_c	T_{static}	α	γ	Pr	Pr_t	Farfield $\chi = \tilde{\nu}/\nu$
0.73	3×10^6	271 K (487.8 R)	1.5°	1.4	0.72	0.9	3

- **Sutherland's Law**

$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right)$$

$$\mu_0 = 1.716 \times 10^{-5} \frac{\text{kg}}{m\,s}$$

$$T_0 = 491.6^\circ\ R$$

$$S = 198.6^\circ\ R$$

$$\frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{fef}}{T/T_{fef} + S/T_{fef}}\right)$$

Test Case 2b: Wing/Body Cruise

- **Verification of steady CFD analysis, required**
- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg] + *QCR2000* (All terms!)**
    - Adiabatic Wall (not isothermal)
  - Converge residuals to machine precision (~1e-10)
- **Grids: *https://dpw.larc.nasa.gov/DPW8/Scatter/Test_Case_2***
  - NASA CRM geometry including deformed wing matching condition
    - (L1:**T**iny/L2:**C**oarse/L3:**M**edium/L4:**F**ine/L5:e**X**tra-fine/L6:**U**ltra-fine)
    - Six-member grid family; four are required, six are desirable
  - Encourage use of committee-supplied grids; user-generated grids are acceptable
- **Reference Units**

Sref (semi-span grid)	Cref	Semispan	Moment Center
297360.0 sq.in	278.5 in	1156.75 in	(1325.90, 0.00, 177.95)

- **Conditions**

Mach	$\mathrm{Re_c}$	α	T_{static} (120° F)	γ	Pr	$\mathrm{Pr_t}$	Farfield $\chi = \tilde{\nu}/\nu$
0.85	5×10^6	$2.50°$	579.67 R | 322.04 K	1.4	0.72	0.90	3

- **Sutherland's Law**

$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right) \quad \mu_0 = 1.716 \times 10^{-5} \frac{\mathrm{kg}}{m\, s} \quad T_0 = 491.6^\circ\, R \quad S = 198.6^\circ\, R$$

$$\frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{fef}}{T/T_{fef} + S/T_{fef}}\right)$$

Comparison Data

NTF197: r44,r51,r53
NTF215: r43,r103
NTF229: r296,r300,r302
Ames216: r35,r126,r130,r133

Test Case 2c: Wing/Body Cruise

- **Far Field Sensitivity Study: Steady CFD analysis**
- **Settings**
  - Steady CFD RANS **French Vanilla SA-[neg] + *QCR2000* (All terms!)**
    - Adiabatic Wall (not isothermal)
  - Converge residuals to machine precision (~1e-10)
- **Grids: https://dpw.larc.nasa.gov/DPW8/Scatter/Test_Case_2**
  - NASA CRM geometry including deformed wing matching condition
    - (L1:**T**iny/L2:**C**oarse/L3:**M**edium/L4:**F**ine/L5:e**X**tra-fine/L6:**U**ltra-fine)
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- **Sutherland's Law**

$$\mu(T) = \mu_0 \left(\frac{T}{T_0}\right)^{3/2} \left(\frac{T_0 + S}{T + S}\right) \quad \mu_0 = 1.716 \times 10^{-5} \frac{\text{kg}}{m\, s} \quad T_0 = 491.6^\circ\, R \quad S = 198.6^\circ\, R$$

$$\frac{\mu(T)}{\mu_{ref}} = \left(\frac{T}{T_{ref}}\right)^{3/2} \left(\frac{1 + S/T_{fef}}{T/T_{fef} + S/T_{fef}}\right)$$

Comparison Data

NTF197: r44,r51,r53
NTF215: r43,r103
NTF229: r296,r300,r302
Ames216: r35,r126,r130,r133

Test Case 3a: Wing/Body Polar

- **CRM Wing/Body**
  - Reynolds number: 5M (LoQ)
  - Dynamic Pressure: Q_∞ =1384 psf
  - Mach number: 0.85(M_{cruise})
  - Angles of attack: <u>**2.50**</u>, 3.00, <u>**3.25**</u>, 3.50, 4.00, 4.25
  - Temperature: 120.0 F (579.67 R / 322.04 K)
  - Reference Information: https://aiaa-dpw.larc.nasa.gov/Workshop7/DPW7-geom.html

Grid: Level 3
<u>**Grid: Level 1-6**</u>

<u>Comparison Data</u>
NTF197: r44,r51,r53
NTF197: r92,r97,r99 *(WBT0)*
NTF215: r43,r103
NTF229: r296,r300,r302
Ames216: r35,r126,r130,r133

- **Committee-supplied**
  - NASA CRM geometry including deformed wing matching condition
    - Trip location – Wing: 10% chord upper/lower surface
  - Grid Family (L1:<u>**T**</u>iny/L2:<u>**C**</u>oarse/L3:<u>**M**</u>edium/L4:<u>**F**</u>ine/L5:e<u>**X**</u>tra-fine/L6:<u>**U**</u>ltra-fine)

DRAFT

- **Comparison metrics**
  - Forces / Moments
  - Sectional Twist / Deformation
  - Sectional C_P distribution
  - Residuals (Flow & Structural Solver)

Test Case 3b: Wing/Body Polar (R=20M)

- **CRM Wing/Body**
  - Reynolds number: 20M (HiQ)
  - Dynamic Pressure: Q_∞ = ?
  - Mach number: 0.85(M_{cruise})
  - Angles of attack: -1.50, 0.00, 1.50, **2.75**, 3.10, **3.50**, 4.00, 4.50
  - Temperature: ? F (? R / ? K)
  - Reference Information: https://aiaa-dpw.larc.nasa.gov/Workshop7/DPW7-geom.html

Grid: Level 3

Grid: Level 1-6

Comparison Data

NTF197: r?,r?

NTF197: r?,r? *(WBT0)*

NTF215: r?

NTF229: r?

ETW ESWIRP: r?

- **Committee-supplied**
  - NASA CRM geometry including deformed wing matching condition
    - Trip location – Wing: 10% chord upper/lower surface
  - Grid Family (L1:**T**iny/L2:**C**oarse/L3:**M**edium/L4:**F**ine/L5:e**X**tra-fine/L6:**U**ltra-fine)

- **Comparison metrics**
  - Forces / Moments
  - Sectional Twist / Deformation
  - Sectional C_P distribution
  - Residuals (Flow & Structural Solver)

Test Case 3c: Wing/Body Mach Sweep

- **CRM Wing/Body**
  - Reynolds number: 5M (LoQ)
  - Dynamic Pressure: Q_∞ =?,?,?,1384, ? psf
  - Mach numbers: 0.70, 0.80, 0.82, 0.85, 0.87
  - Angle of attack: 2.75
  - Temperature: ?, ?,?,120.0,? F (579.67 R / 322.04 K)
  - Reference Information: https://aiaa-dpw.larc.nasa.gov/Workshop7/DPW7-geom.html

Grid: Level 1-6

Comparison Data
NTF197: r?,r?
NTF197: r?,r? *(WBT0)*
NTF215: r?
NTF229: r?
ETW ESWIRP: r?
Ames216: r?

- **Committee-supplied**
  - NASA CRM geometry including deformed wing matching condition
    - Trip location – Wing: 10% chord upper/lower surface
  - Grid Family (L1:**T**iny/L2:**C**oarse/L3:**M**edium/L4:**F**ine/L5:e**X**tra-fine/L6:**U**ltra-fine)

DRAFT

- **Comparison metrics**
  - Forces / Moments
  - Sectional Twist / Deformation
  - Sectional C_P distribution
  - Residuals (Flow & Structural Solver)

Scatter Reduction Working Group Leadership

- Marshall Galbraith, Massachusetts Institute of Technology
- Kevin Holst, University of Tennessee, Knoxville
- Ben Rider, The Boeing Company

Geometry/Grid Far Field Details

NASA CRM (Full Scale)
MAC = 275.8"
Semispan = 1156.75"

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DPW7: iges files (box)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (inch)	-22440.9,	23838.6	23139.75	~ 84.0	~ 20.0
Y (inch)	0.0	35433.1	35433.1	~ 128.6	~ 30.6
Z (inch)	-23405.5	23838.6	23838.6	~ 86.5	~ 20.6

https://aiaa-dpw.larc.nasa.gov/Workshop7/Geometry/2021-03-02_Version_01/DPW7geometries.zip

DPW8

DPW8: HeldenMesh (box)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (inch)	-55160.0	55160.0	55160.0	200.0	~ 47.7
Y (inch)	0.0	55160.0	55160.0	200.0	~ 47.7
Z (inch)	-55160.0	55160.0	55160.0	200.0	~ 47.7

https://dpw.larc.nasa.gov/DPW8/Scatter/Test_Case_2/Helden_Grids.REV00/

DPW8: Cadence (box)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (inch)	-115582.5	118237.9	116910.2	~ 424.2	~ 101.1
Y (inch)	0.0	116834.7	116834.7	~ 423.9	~ 101.0
Z (inch)	-115584.0	116018.1	115801.1	~ 420.2	~ 100.1

https://dpw.larc.nasa.gov/DPW8/Scatter/Test_Case_2/Cadence_Grids.REV00/

DPW7

DPW7: Vassberg (sphere)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (inch)	-30328.203	32996.560	31662.382	~ 114.8	~ 27.4
Y (inch)	0.0	31664.519	31664.519	~ 114.8	~ 27.4
Z (inch)	-31449.638	31865.992	31657.815	~ 114.8	~ 27.4

https://dpw.larc.nasa.gov/DPW7/Vassberg_Grids.REV00/

DPW7: JAXA (sphere)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (MAC)	-413.890	424.690	419.290	~ 419.3	~ 100
Y (MAC)	0.0	419.349	419.349	~ 419.3	~ 100
Z (MAC)	-418.675	420.005	419.340	~ 419.3	~ 100

https://dpw.larc.nasa.gov/DPW7/JAXA_Grids.REV00/

DPW7: NLR (sphere)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (m)	-2949.98	3050.00	2999.99	~ 428.2	~ 102.1
Y (m)	0.0	3000.00	3000.00	~ 428.2	~ 102.1
Z (m)	-2995.1	3004.99	3000.05	~ 428.2	~ 102.1

https://dpw.larc.nasa.gov/DPW7/NLR_Grids.REV00/DPW7-NLR-grids/

DPW7: DLR (box)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (m)	-570.0	630.0	1200.0	~ 171.3	~ 40.9
Y (m)	0.0	900.0	900.0	~ 128.5	~ 30.6
Z (m)	-594.5	605.5	1200.0	~ 171.3	~ 40.9

https://dpw.larc.nasa.gov/DPW7/DLR_Grids.REV00/

DPW7: GGNS (box)	Min	Max	+/- Range	Range / MAC	Range / Semispan
X (inch)	-22400.0	22400.0	22400.0	~ 81.2	~19.4
Y (inch)	0.0	22400.0	22400.0	~ 81.2	~19.4
Z (inch)	-22400.0	22400.0	22400.0	~ 81.2	~19.4

Adapted grids (not publicly released)