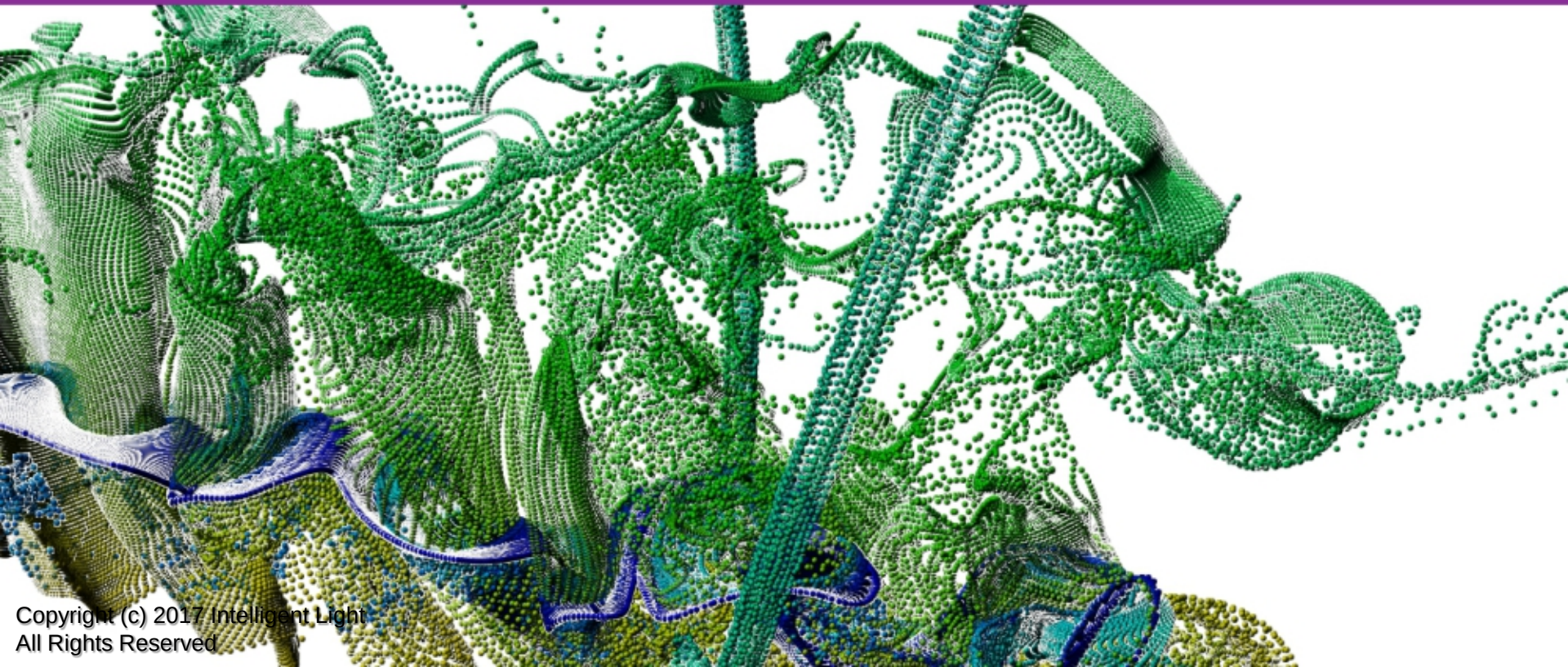
Applied Research Group

Seeking Answers, Deploying Solutions

Intelligent Light



Contribution to HiLiftPW-3

Earl P.N. Duque
Intelligent Light

#040

3rd High Lift Prediction Workshop
Denver, CO June 3-4, 2017

Outline

- Purpose
  - IL's contribution to the knowledge base
  - Exercise UQ methods
- Demonstrate Large scale big data workflow processes with Dakota + FieldView
- Predictive blind study with UQ

AIAA High Lift Prediction Workshop 3

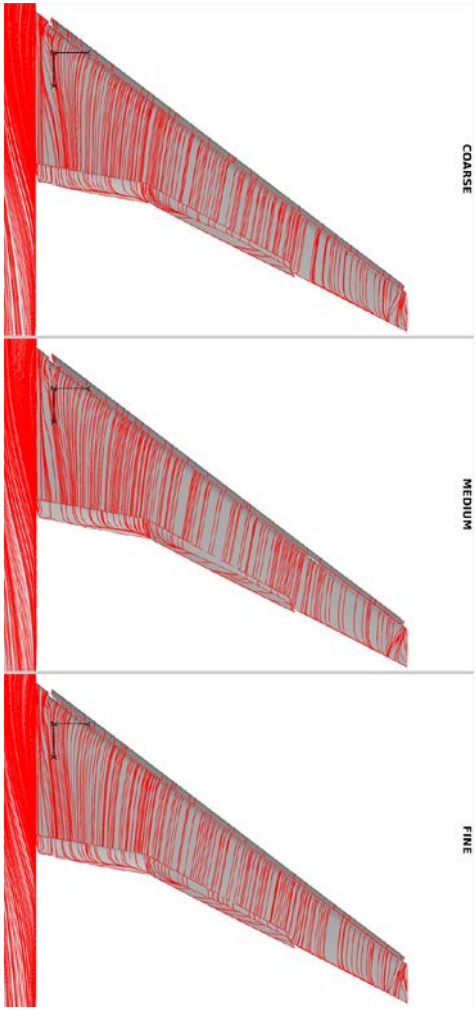
- Case 1a – High Lift CRM Model
  - OVERFLOW2.2l solver
  - Overset Structure #2, Coarse, medium, fine and extra fine grid
  - SA-noft2 Turbulence model
  - Alpha – 8, 16
  - Steady
  - Blind Run up to 50,000 time steps
- Tools Used
  - FieldView – Data extracts for local Diss error
  - VisIt – mesh extracts for local Diss error
  - Dakota – Model input sampling
  - Octave – Global & local UQ calcs, 2-D plots
- Perform UQ
  - Both Global and Local
  - Discretization Uncertainty
  - Model Input Uncertainty Mix Uncertainty
    - Latin Hypercube Sampling
    - Model Input Uncertainty
    - Medium Grid
    - Blind Run 20,000 time steps

Case	Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Other
1a (full gap)	yes	yes	OVERFLOW2.2l C,M,F,EF SA-noft2
1b (full gap w adaption)	no	no	
1c (partial seal)	no	no	
1d (partial seal w adaption)	no	no	
Other			

Grid System	Case(s)	If committee grid, report any problems/issues If user grid, reason for generating grid system
Overset Structure #2	1a	Worked very well, no issues
User (Grid type/description)	1a, 2a, 2c…	Generated grid system because…
Other		

OVERFLOW, FieldView, Visit Workflows

- Solver - OVERFLOW-2.2l
  - Cray XE-40
    - Dual socket Broadwell
  - 176-1408 cores Methodologies
    - RHS - Central
    - LHS – Scalar Penta
    - Multi-Grid – 2 levels (FMG = .F.)
    - SA-noft2 Fully Turbulent
- FieldView 16.1
  - Cray XE-40 – 44 cores
  - Automated Batch Post-Processing
  - XDB workflow for surface data extraction and velocity plots
- VisIt 2.12.1
  - Local laptop
  - XDB Data extracts for grid volume and skewness



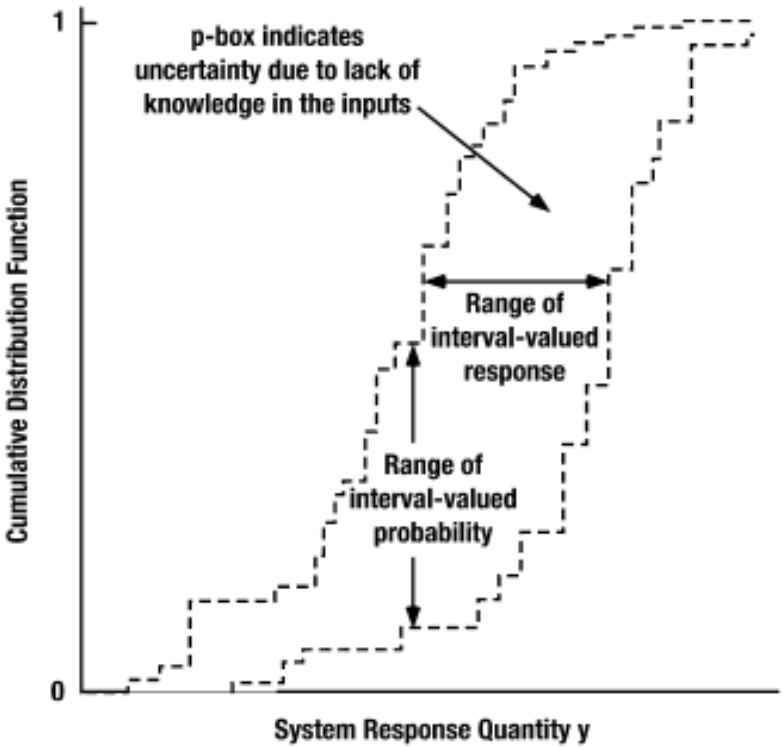
DAKOTA

Explore and predict with confidence.

- Dakota from Sandia National Lab has been in existence for two decades.
- Extensive capabilities to perform optimization and UQ studies.
- Well thought out, easy to use, python interface to manage and launch solvers.
- It has considerable capability for sampling, an automated system for launching simulations and various analysis methods.

UQ methodology by Oberkampf and Roy (2010)

- Identify all sources of uncertainty
- Characterize uncertainties
- Propagate input uncertainties through the model
  - Aleatory uncertainty
  - Epistemic uncertainty
  - Combined aleatory and epistemic uncertainty
- Determine total uncertainty in the SRQ
  - $\boldsymbol{U_{total}} = \boldsymbol{U_{diss}} + U_{iter} + \boldsymbol{U_{Model\ Input}} + U_{Model\ Form} + U_{exp}$
  - Results in a P-Box Plot
    - CDF, but with a finite width that denotes the epistemic (lack of knowledge) uncertainty



P-Box plot example

Discretization Error

Celik, et.al. (JFM 2008) & ASME VV20

- Define Representative Grid Size
  - Global – $h_i = N^{2/3}$ (Where i=1- Extrafine, 2-Fine, 3-Medium)
  - Line Plots – $h_i(x, y, z) = V_i(x, y, z)^{1/3}$
  - Refinement ratio - $r_{ij} = {}^{h_i}/_{h_j}$
- Observed Order – P

$$P = \frac{1}{\ln(r_{21})}\left|ln\left|\frac{\varepsilon_{32}}{\varepsilon_{21}}\right| + q(p)\right|$$

$$q(p) = ln\left(\frac{r_{21}^{p} - s}{r_{32}^{p} - s}\right) ; s = sig(\varepsilon_{32}/\varepsilon_{21})$$

Discretization Error

- Calculate Extrapolated Value (Celik, 2008)

$$\phi_{ext}^{21} = \left(r_{21}^{p}\,\phi_1 - \phi_2\right)/\left(r_{21}^{p} - 1\right)$$
$$\phi_{ext}^{32} = \left(r_{32}^{p}\,\phi_2 - \phi_3\right)/\left(r_{32}^{p} - 1\right)$$

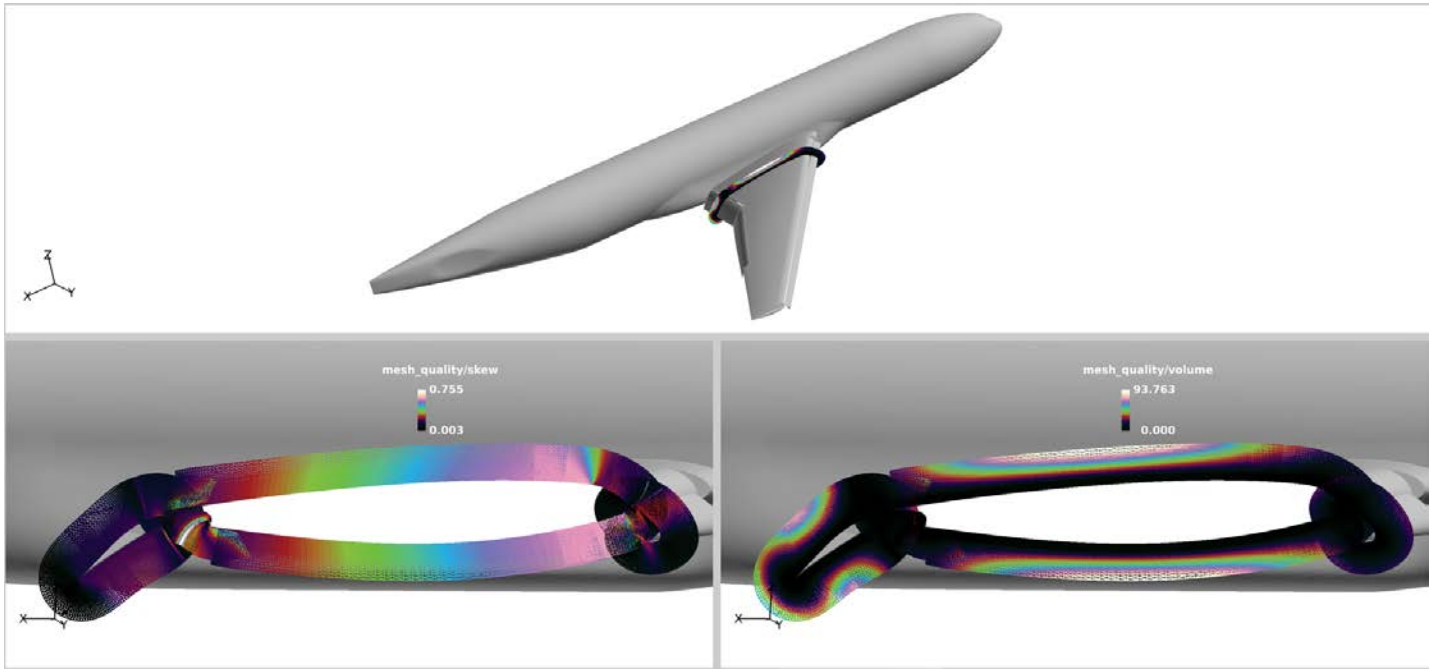
- Discretization Error

$$U_{num} = \left|\frac{1.25(\phi_1 - \phi_2)}{r_{21}^{p} - 1}\right|;\ p > 1 \text{ (Roache, 1998)}$$
$$U_{num} = \left|3(\phi_3 - \phi_1)\right|;\ p < 1 \text{ (Eca, 2009)}$$

- Assume $p = p_{average}$ for local line plots (Celik, 2008)

Line plots require Mesh Quality Metrics

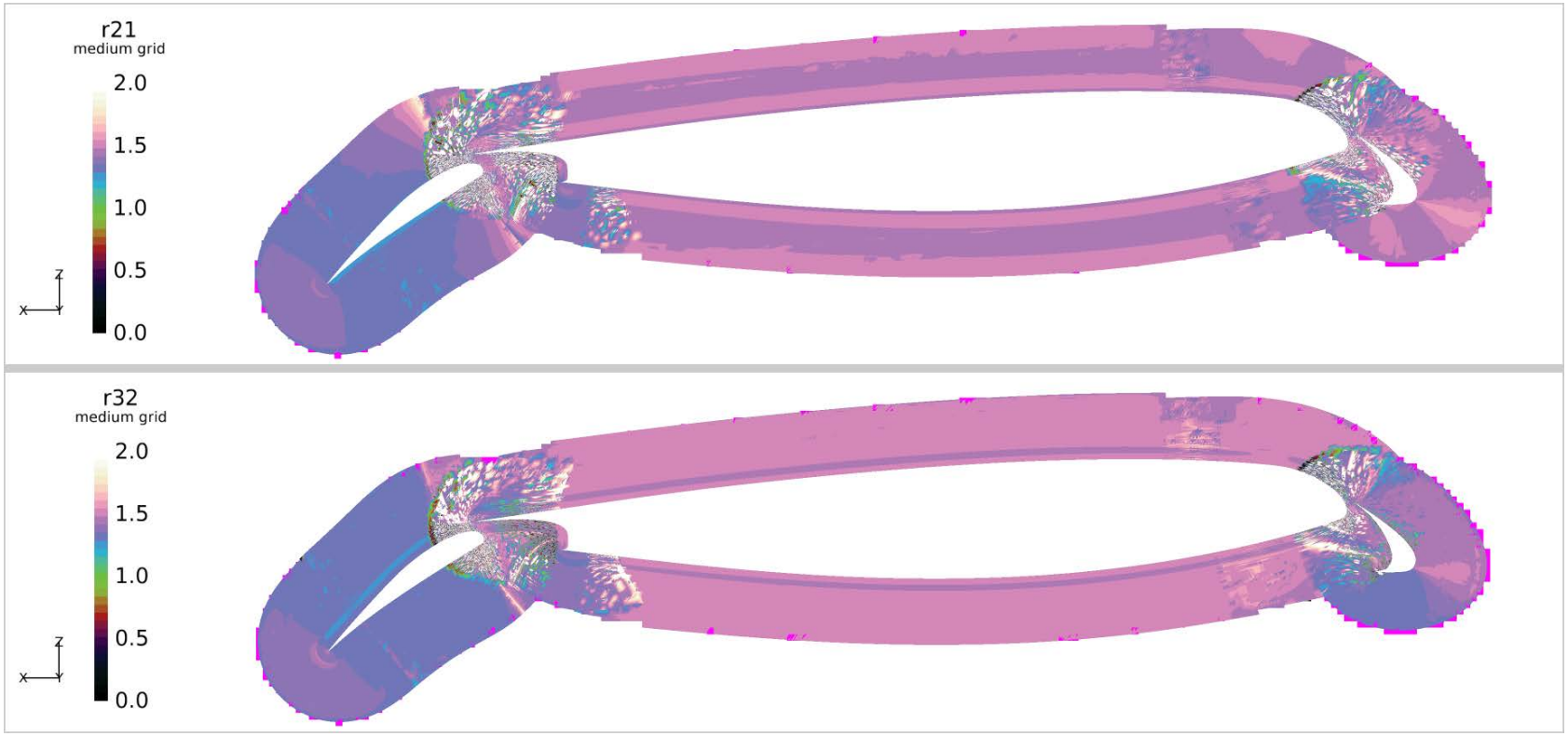
- Grid skewness and volume (V) from VisIt to XDB
- XDB used in FieldView to compute the local mesh size and grid refinement levels
- Used medium, fine, extrafine interpolated to medium



Refinement comparisons

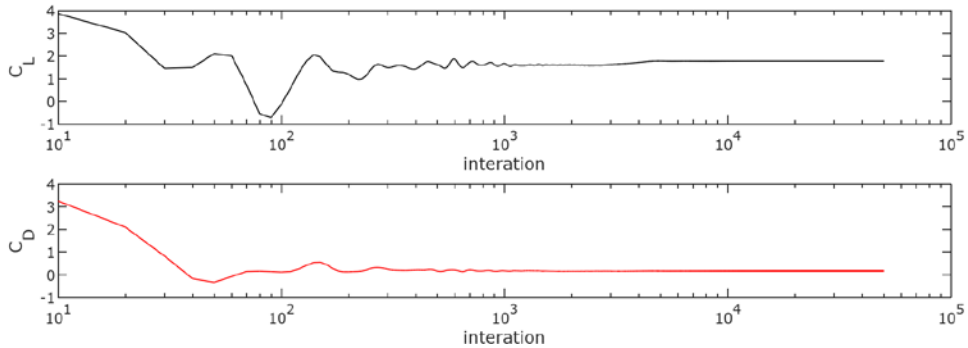
- $h_i(x,y,z) = V_i(x,y,z)^{1/3}$
- 2D cut from the 3D mesh

- $r_{21} = \frac{h_{fine}}{h_{extrafine}}$; $r_{32} = \frac{h_{medium}}{h_{fine}}$
- Mesh is not uniformly refined

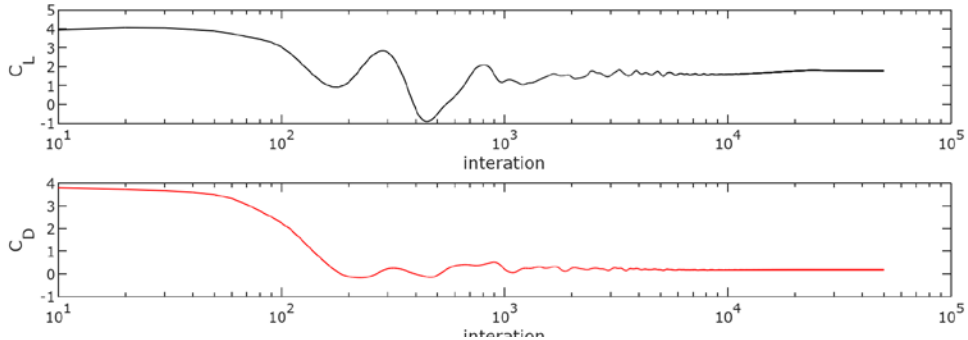


Iteration History – 8 deg

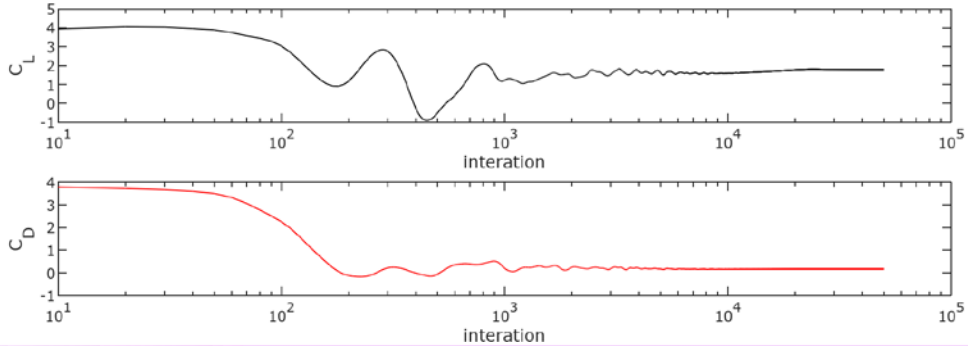
Extrafine



Fine



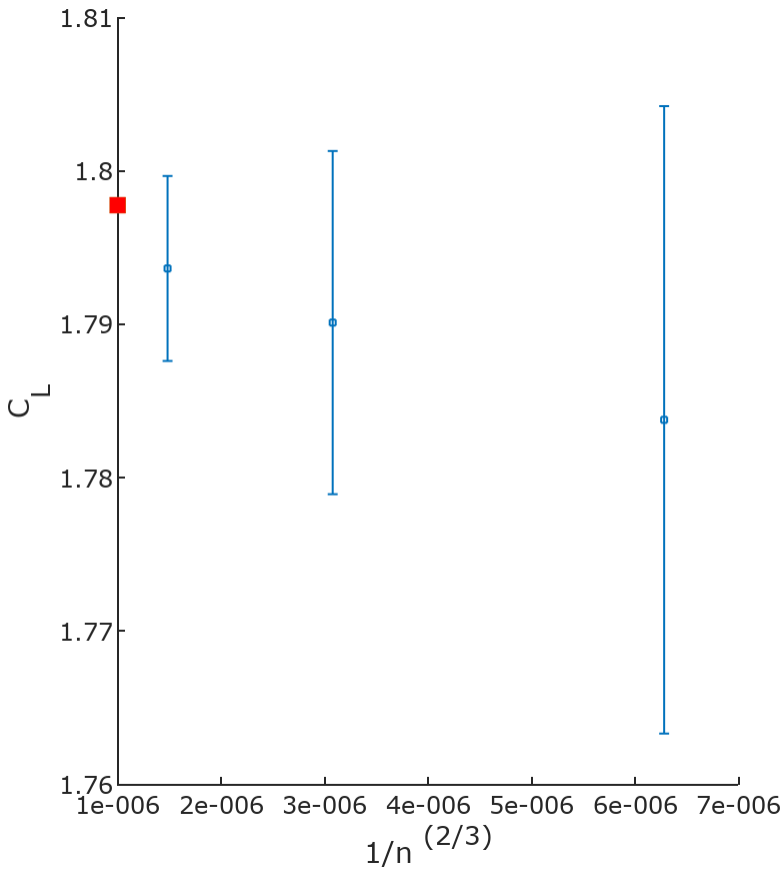
Medium

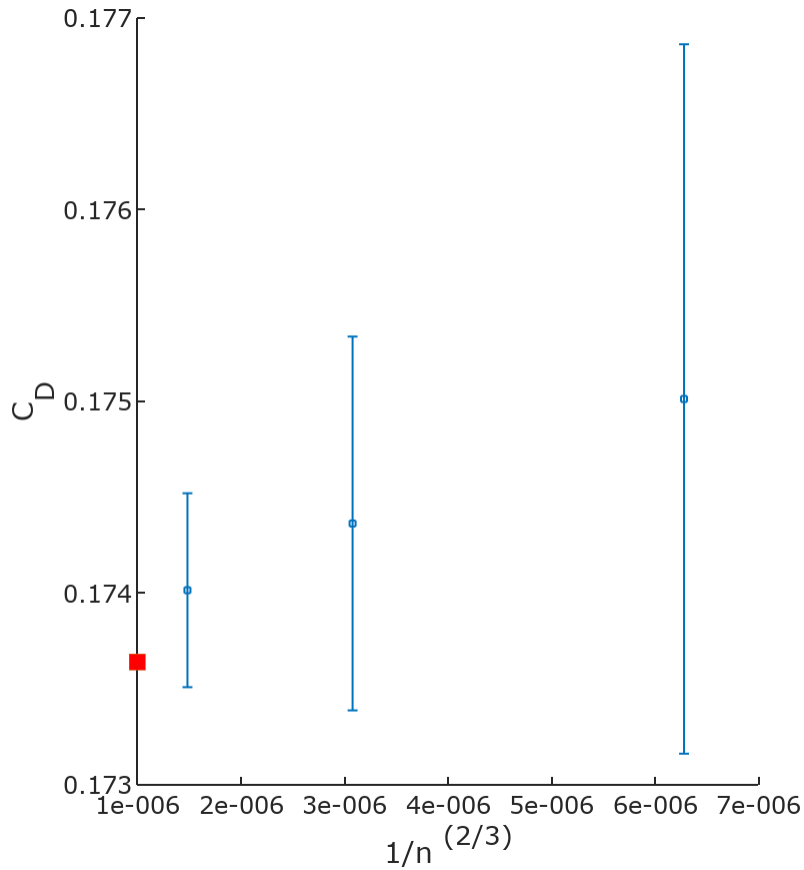


Discretization Error (DE) – 8 deg

- P=1.69225
- GCI=0.00287513
- CI_{exp} = 1.7978

- P=1.79687
- GCI = 0.00269556
- CD_{exp}=0.17364



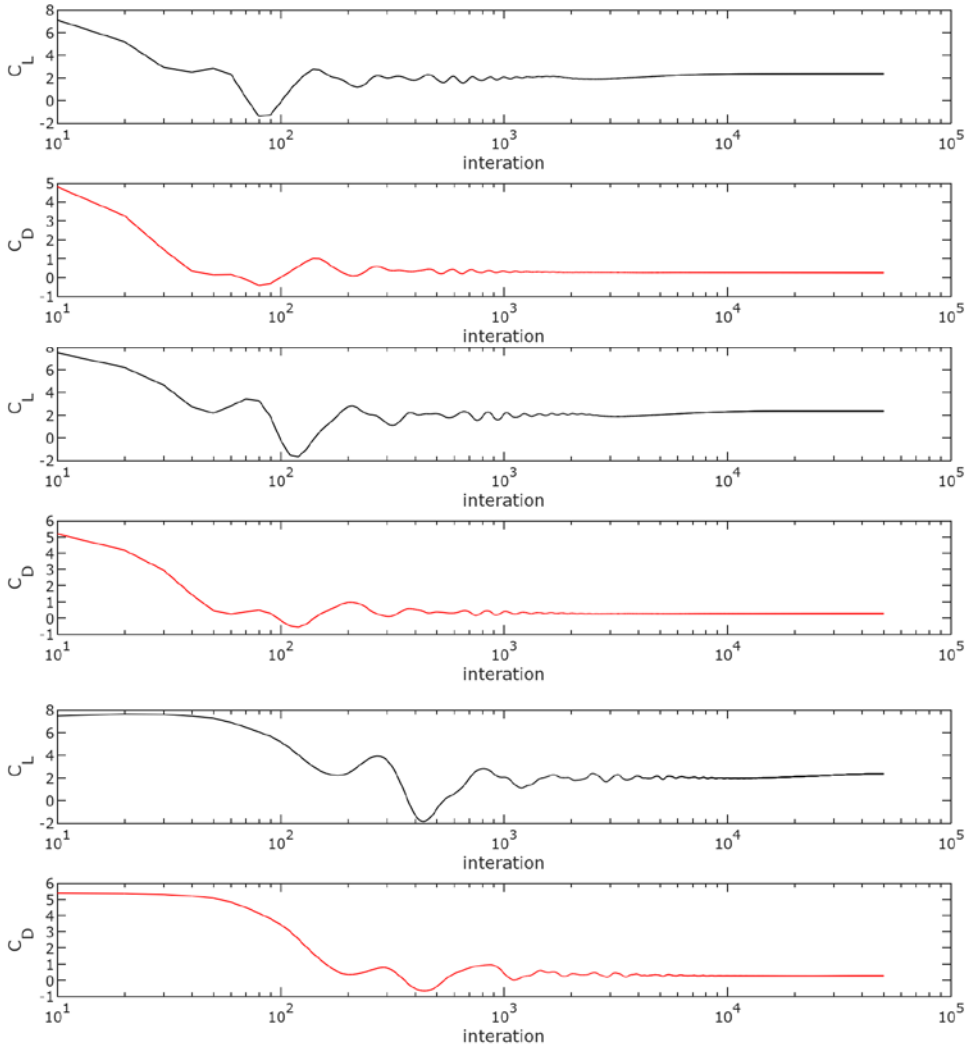


Iteration History – 16 deg

Extrafine

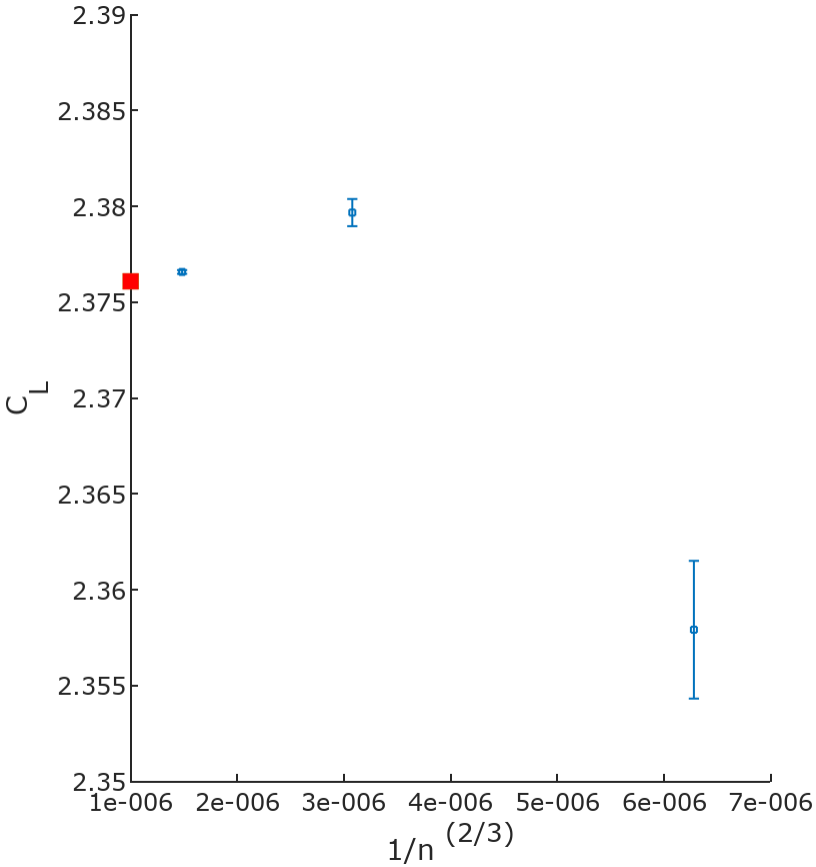
Fine

Medium

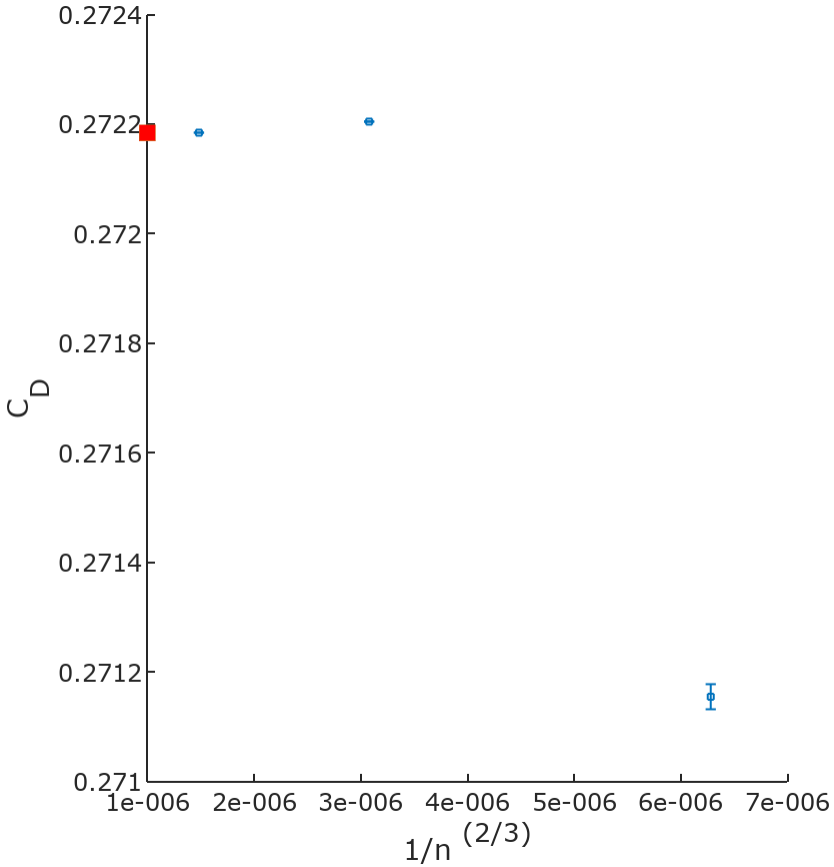


Discretization Error (DE) – 16 deg

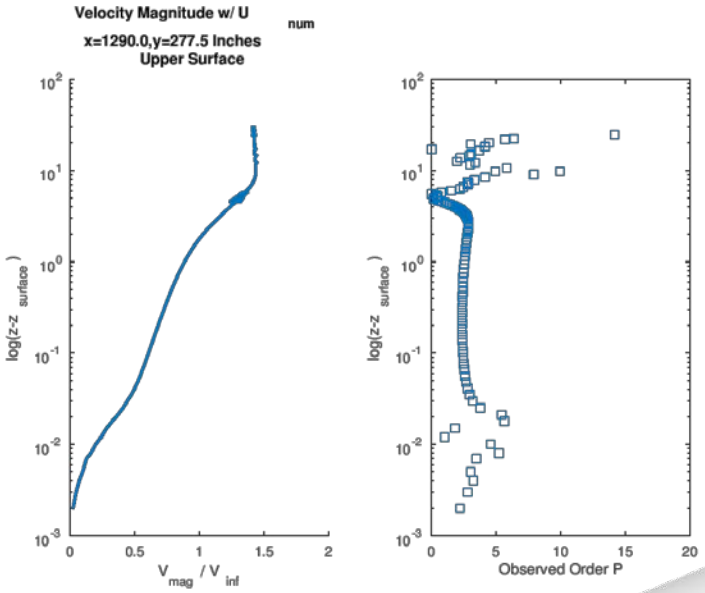
- P = 5.45217
- GCI = 0.000257509
- CL_{ext}=2.376

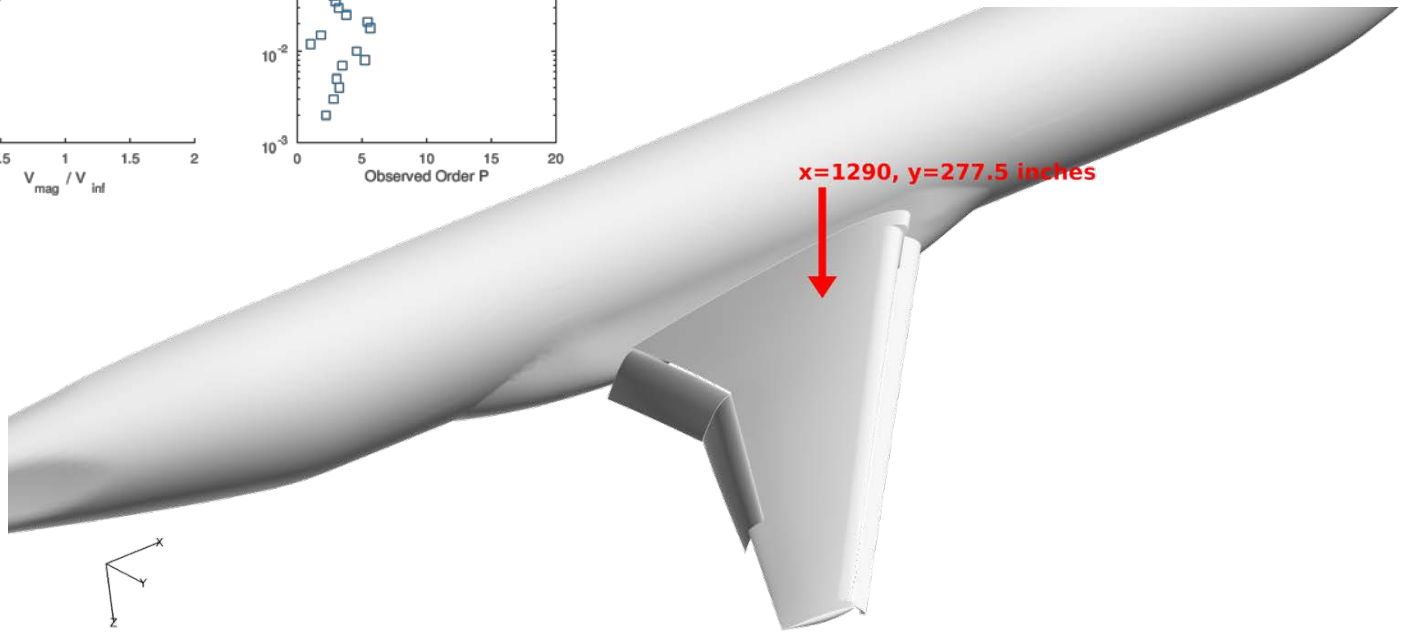


- P=11.08
- GCI = 1.64845e-006
- CD_{ext} = .272

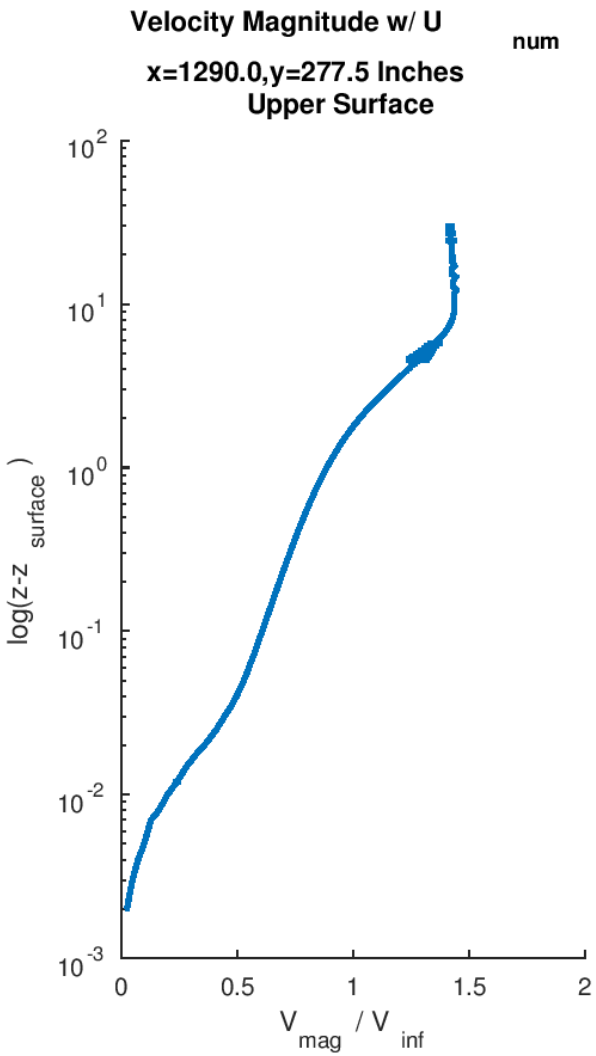


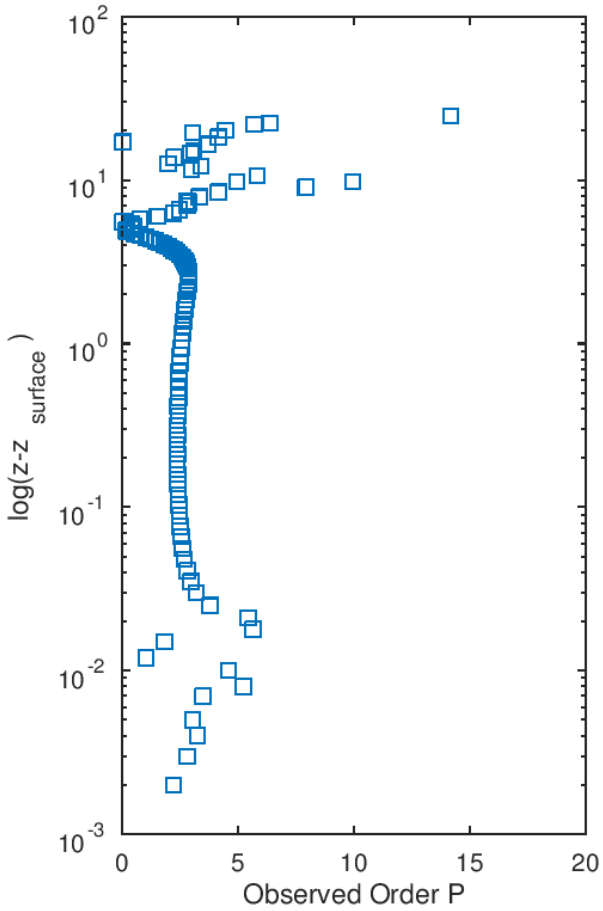
Velocity Plots



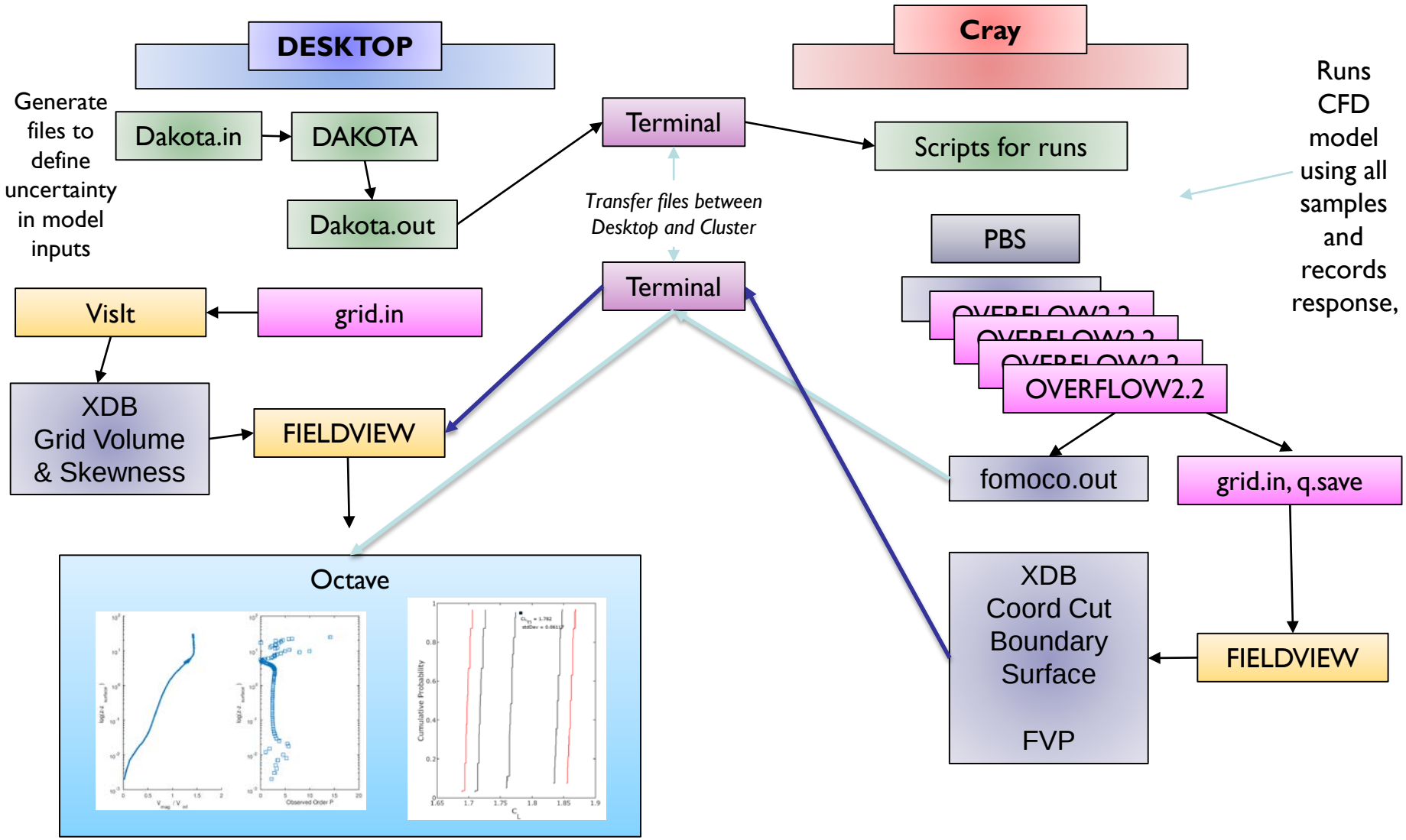


Numerical Uncertainty – 16 Deg

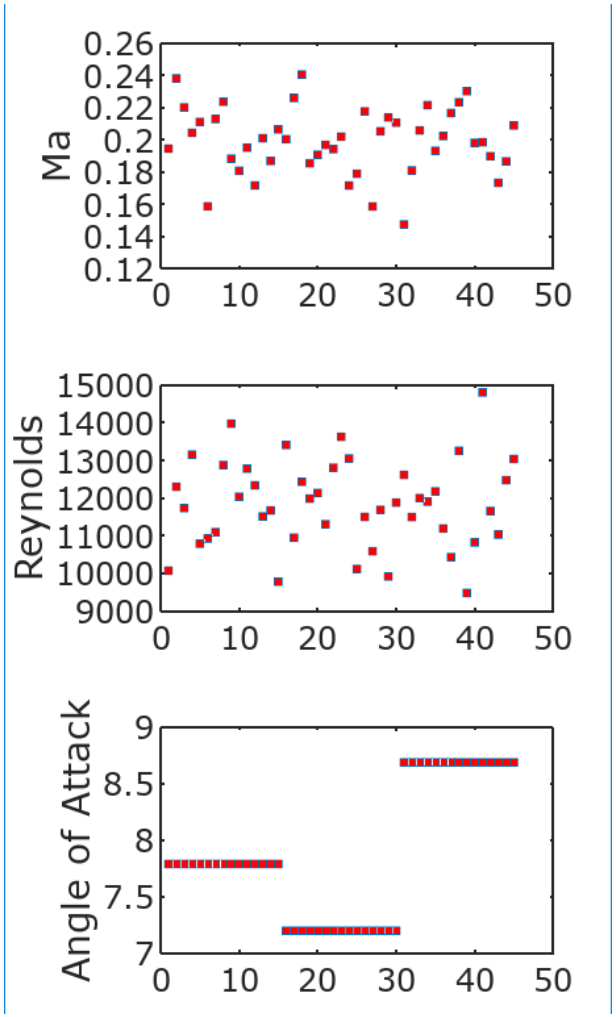




Uncertainty in model inputs



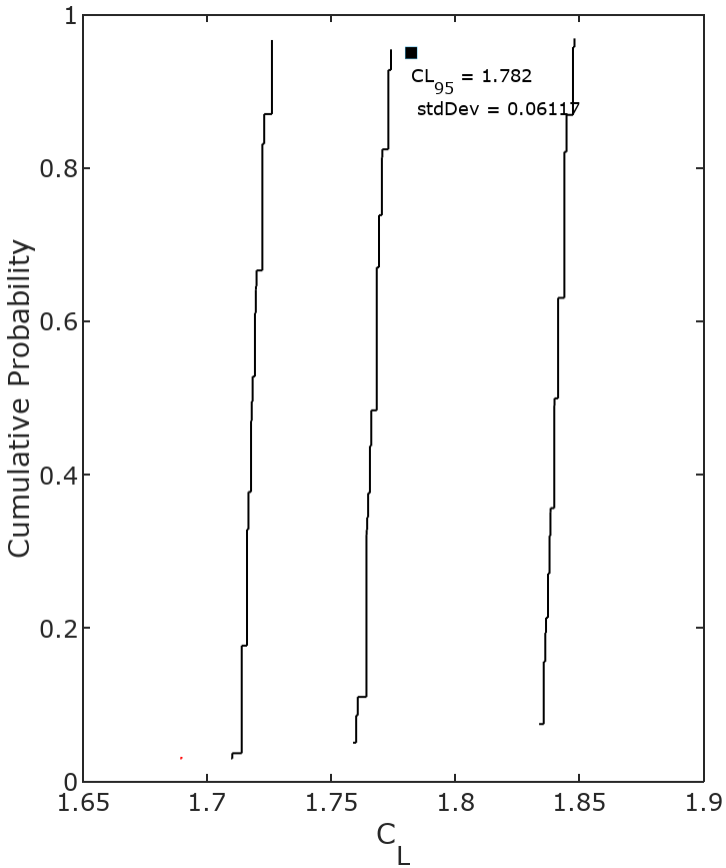
Model Input Uncertainty



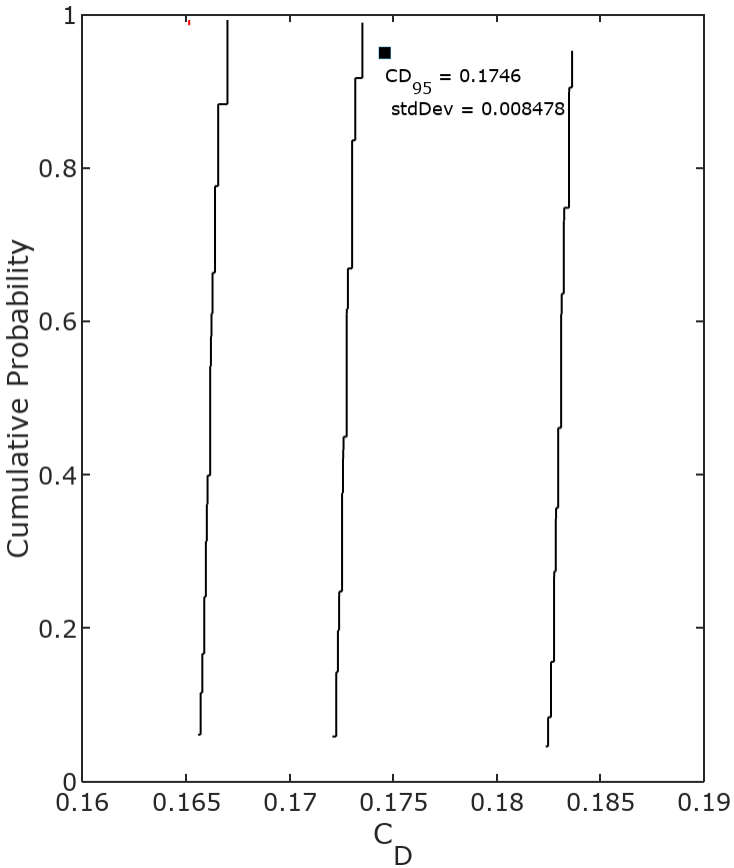
- Aleatory - Gaussian
  - Mach
    - Mean = 0.2
    - Standard Dev = 0.02
  - Reynolds Number
    - 3.26 Million (MAC)/11,820 per inch
    - Standard Dev = 10%
- Epistemic - Interval
  - Angle of Attack – 8 & 16
  - +-1.0 Degrees
- Latin Hypercube Sampling

P-Box 8 Deg – Medium Grid

CL_{95}=1.782

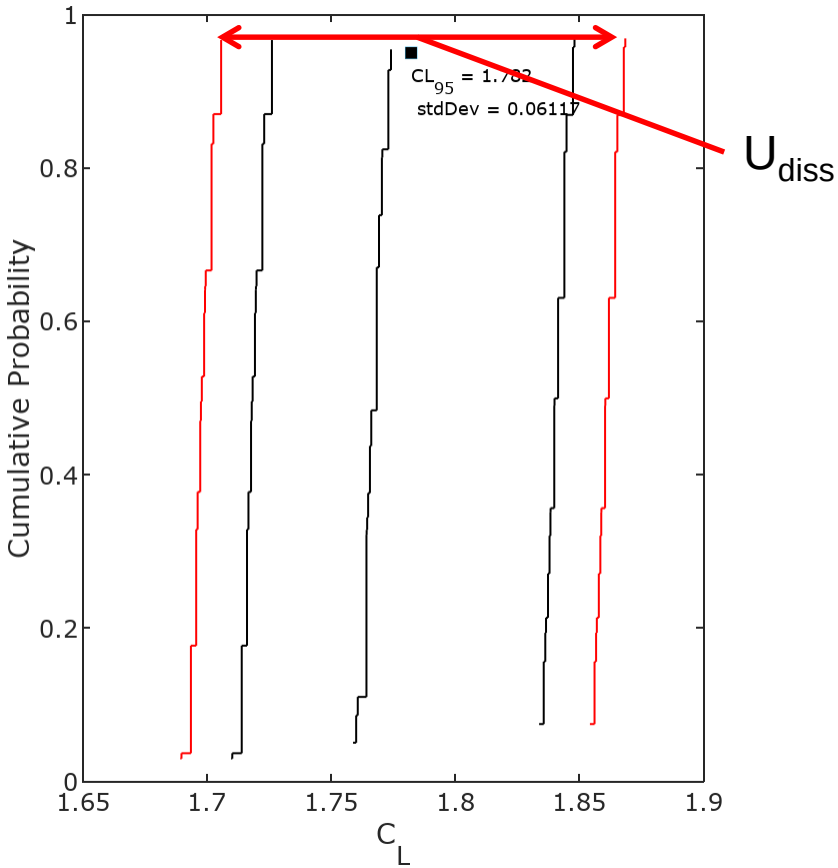


CD_{95}=0.1746

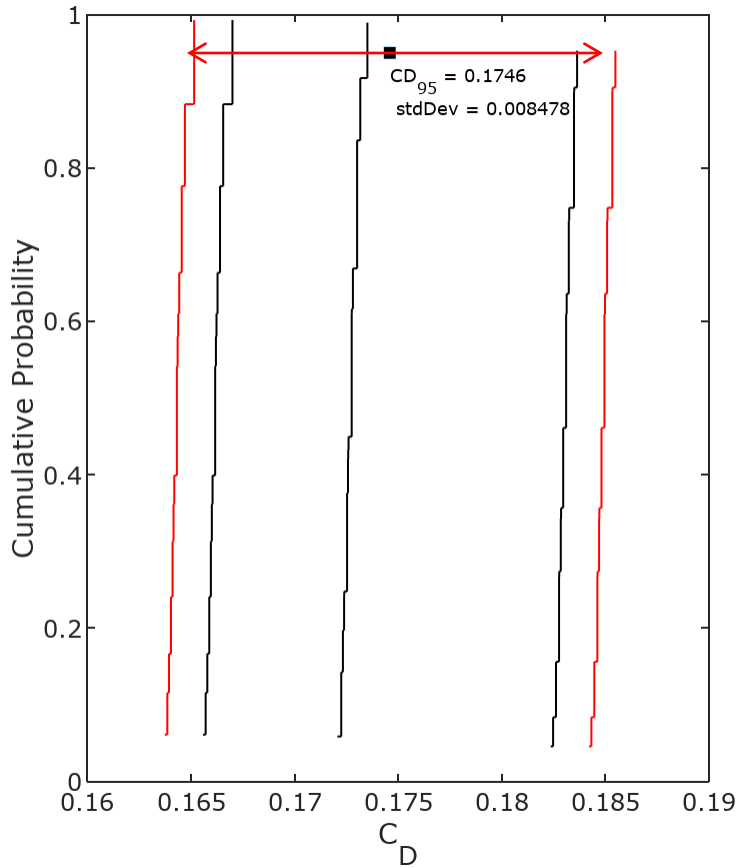


P-Box 8 Deg – Medium Grid

CL_{95}=1.782

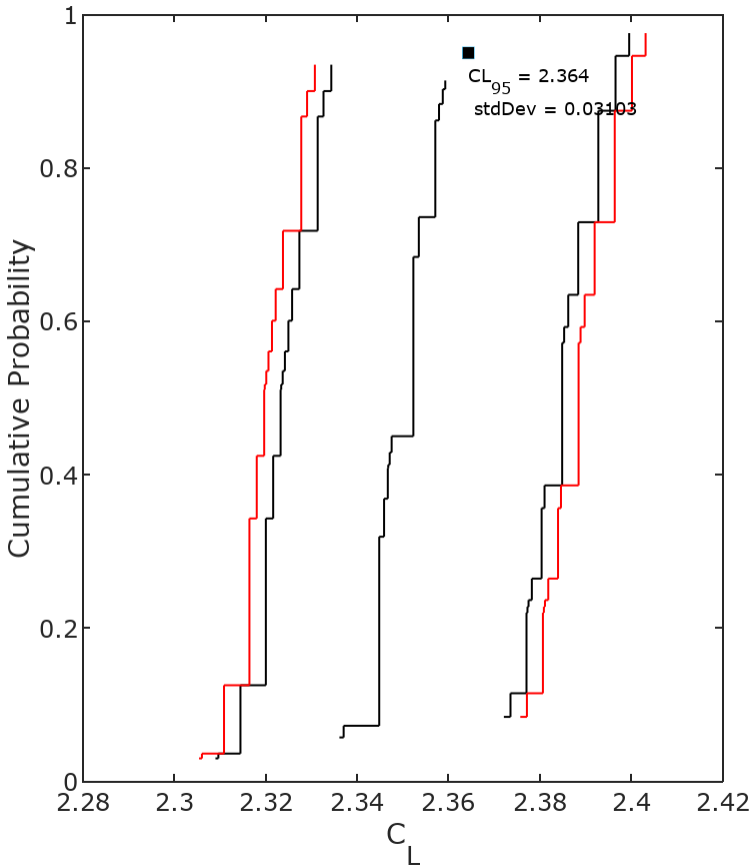


CD_{95}=0.1746

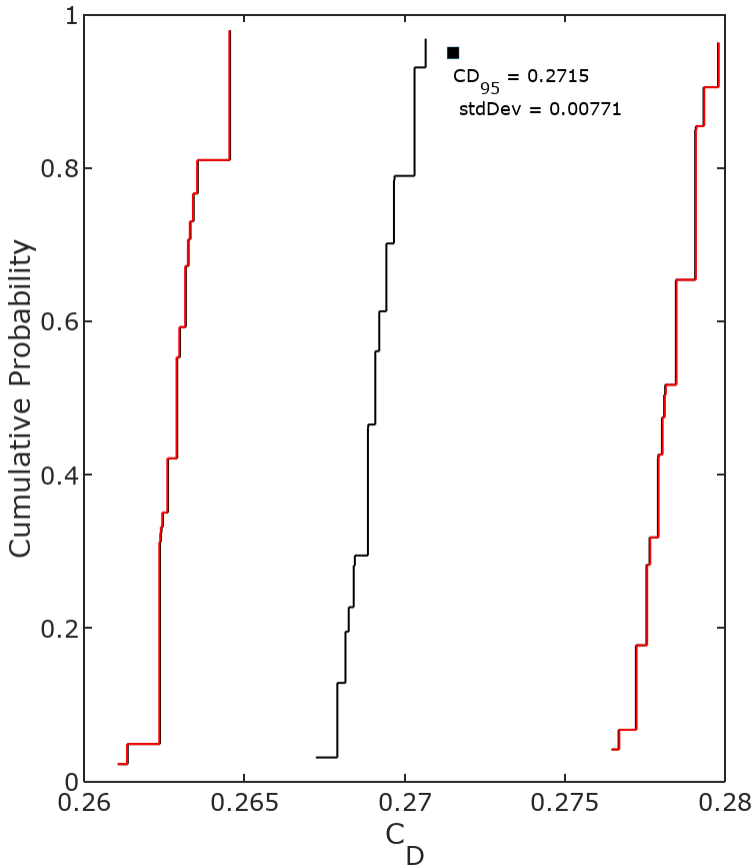


P-Box 16 Deg – Medium Grid

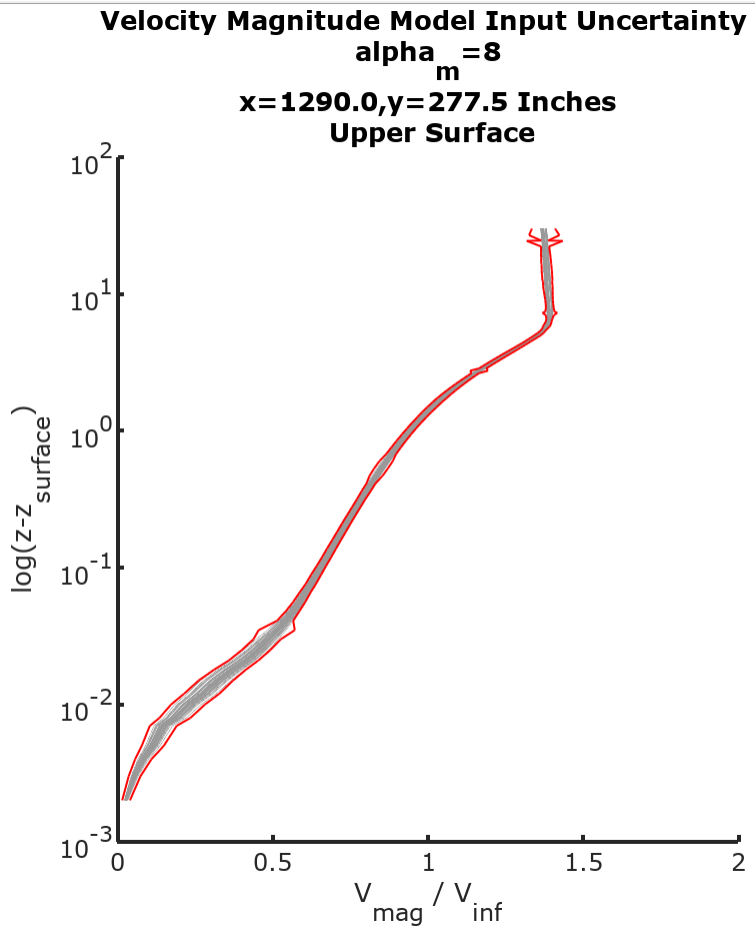
CL_{95}=2.364

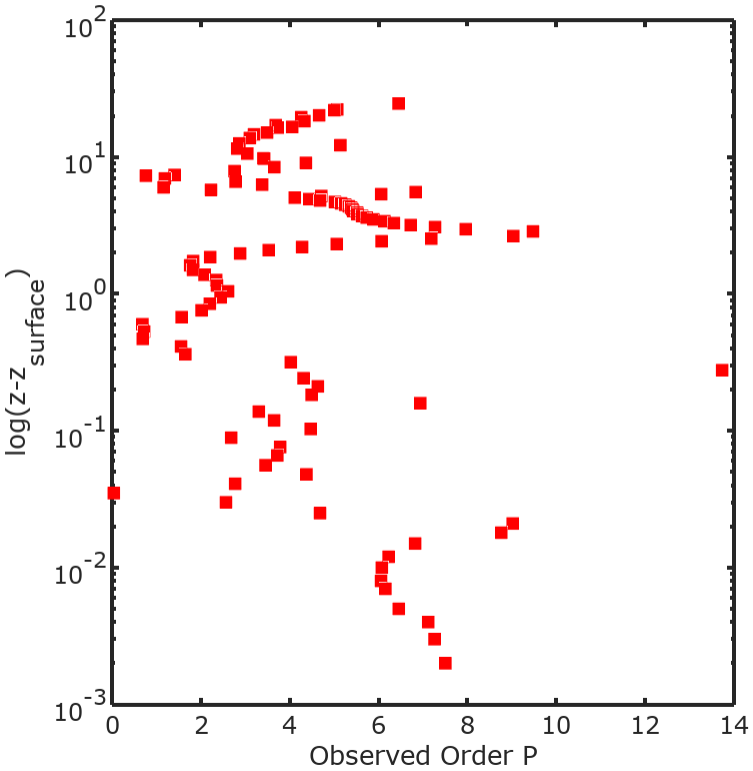


CD_{95}=0.2715

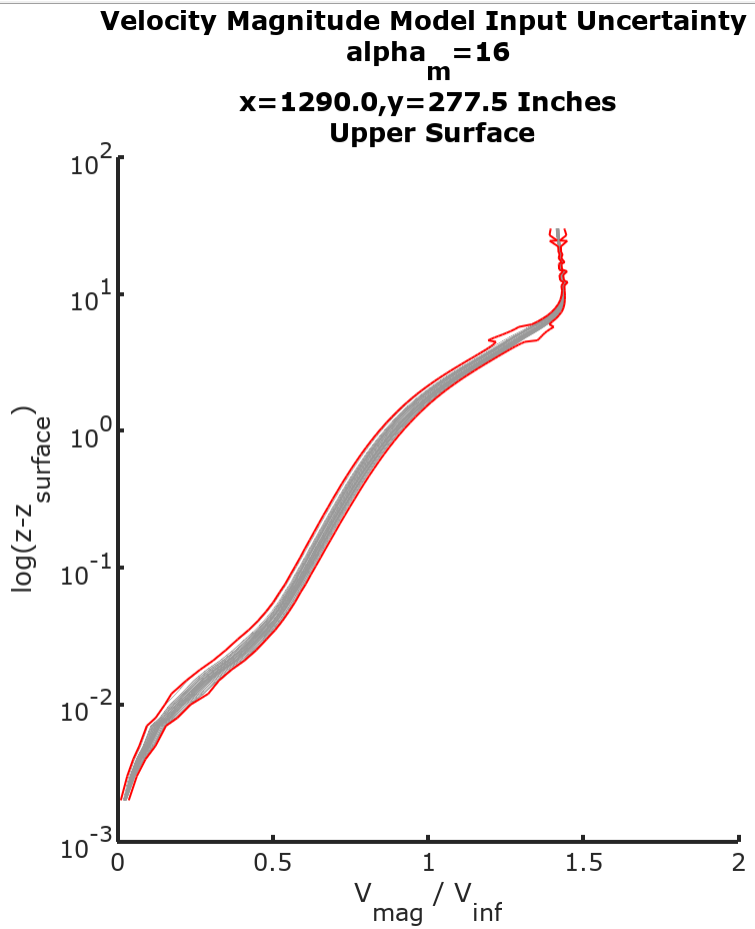


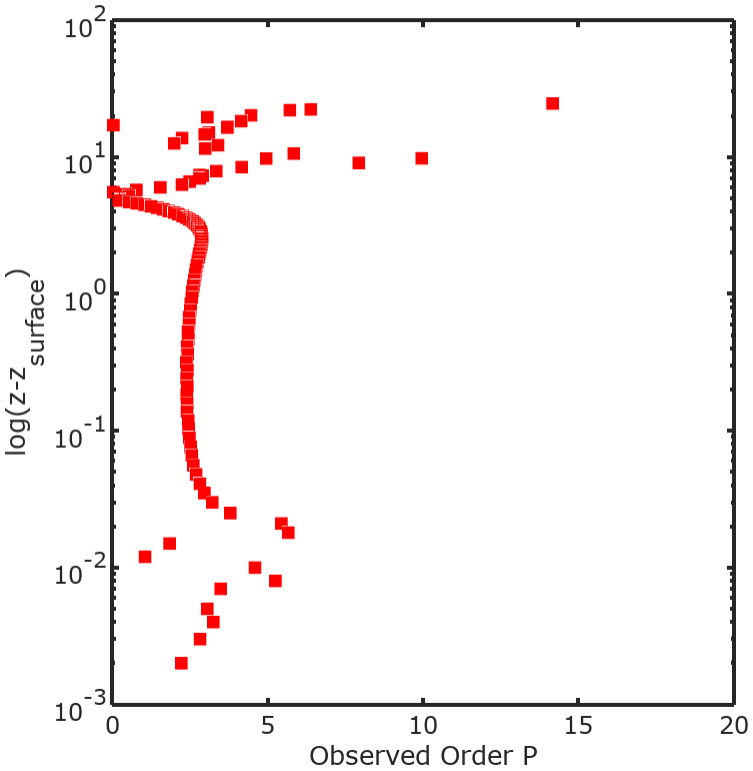
Velocity Plots – $\alpha_m = 8$





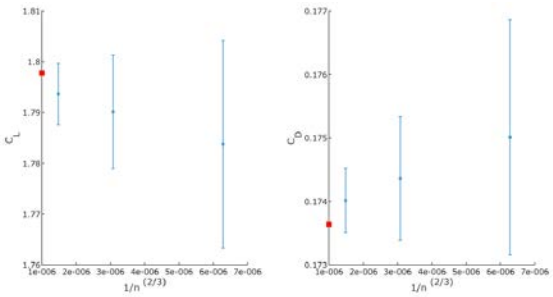
Velocity Plots – $\alpha_m = 16$

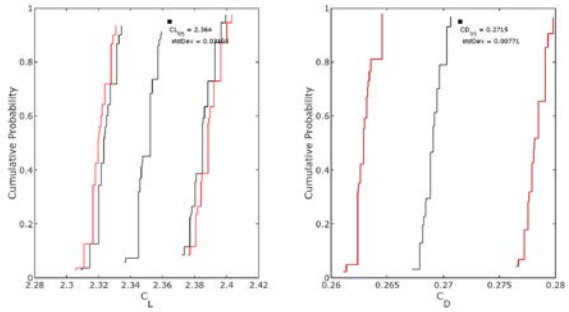


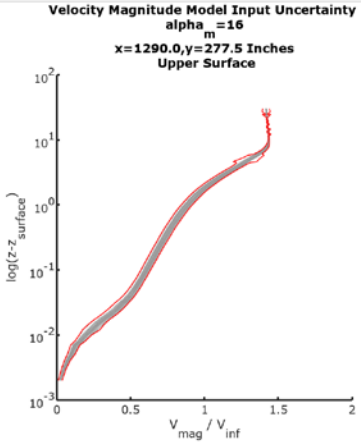


Summary

- UQ study of Case1a
  - U_{diss} & $U_{model\ Input}$
  - Global Uncertainty (CL,CD)
  - Local/Piecewise (Velocity Magnitude)
- Grid Convergence depends upon the flow condition
  - 8 deg converged monotonically
  - 16 deg oscillatory convergence
- Model Input
  - Mainly sensitive to angle of attack
  - 16 Deg more sensitive to Mach number than 8 deg
- Non-uniform refinement may be an issue for the UQ methods used
- Need to explore all the velocity profiles and Cp







Acknowledgements

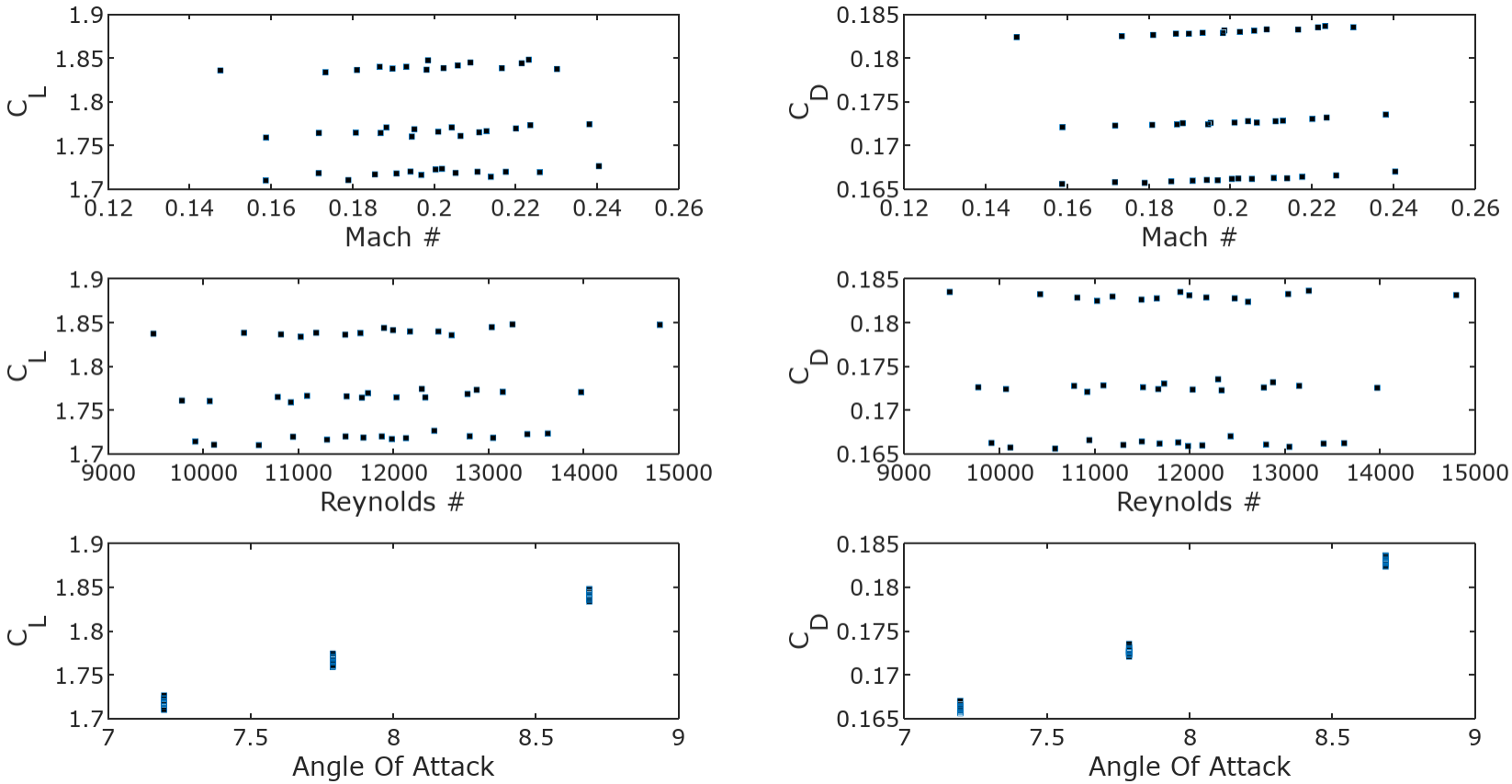
- The author would like to thank Cray Inc. for provided access to their corporate Cray XE40 computer
  - Geert Wenes and Greg Clifford of Cray Inc. for helping to acquire access.
  - David Whitaker from Cray Inc. for assistance in porting of OVERFLOW2 to the XE40 and for streamlining the use of FieldView on their system.
- This work could not have been accomplished without good overset grid systems. Thanks to the workshop team members for providing the grid and input files for OVERFLOW.
- Finally, much gratitude to Steve M. Legensky, General Manager and Founder at Intelligent Light, for his support of this work

References

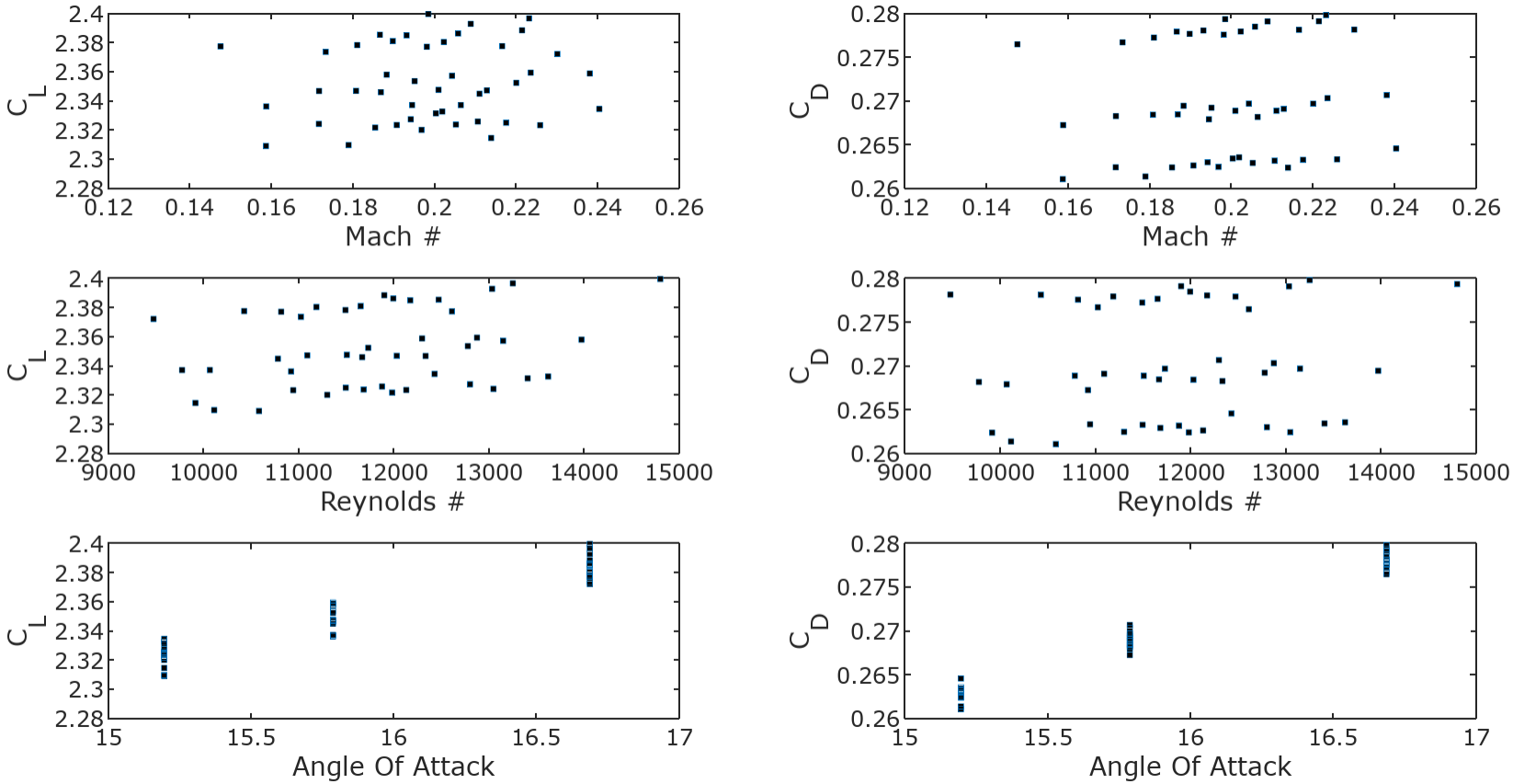
- P. J. Roache, Verification and Validation in Computational Science and Engineering. Albuquerque: Hermosa Publishers, 1998
- L. Eca and M. Hoekstra, “Evaluation of numerical error estimation based on grid refinement studies with the method of the manufactured solutions,” Comput. Fluids, vol. 38, no. 8, pp. 1580–1591, 2009.
- P.E. Raad I.B. Celik, U. Ghia, P.J. Roache, C.J. Freitas, H. Coleman, Procedure for Estimation and Reporting of Uncertainty Due to Discretization in CFD Applications, Journal of Fluids Engineering, Volume 130, Issue 7
- Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer, ASME 2009, **ISBN**: 9780791832097
- William L. Oberkampf, Christopher J. Roy, *Verification and Validation in Scientific Computing*, Cambridge University Press, Oct 14, 2010

Additional Slides

Sensitivity – 8 degs



Sensitivity – 16 degs



Visualizations