k−ω Model Computations with Variable C_μ

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Overall Objective of NRA

- To develop physics based improvements to RANS and multi-resolution PANS models for highly separated aerodynamic flows
  - Start from fundamental first principles
  - Develop all models from a single unified framework

Background and Motivation

- PANS proven in bluff body flows (FLUENT, FIRE, etc)
- Near-wall low Re PANS yet to be developed
  - Requires development physics based on low Re RANS models
- Many low Re RANS models are ad hoc and can not be directly applied to PANS
- Similar effort underway in Sweden (Peng et. al.)

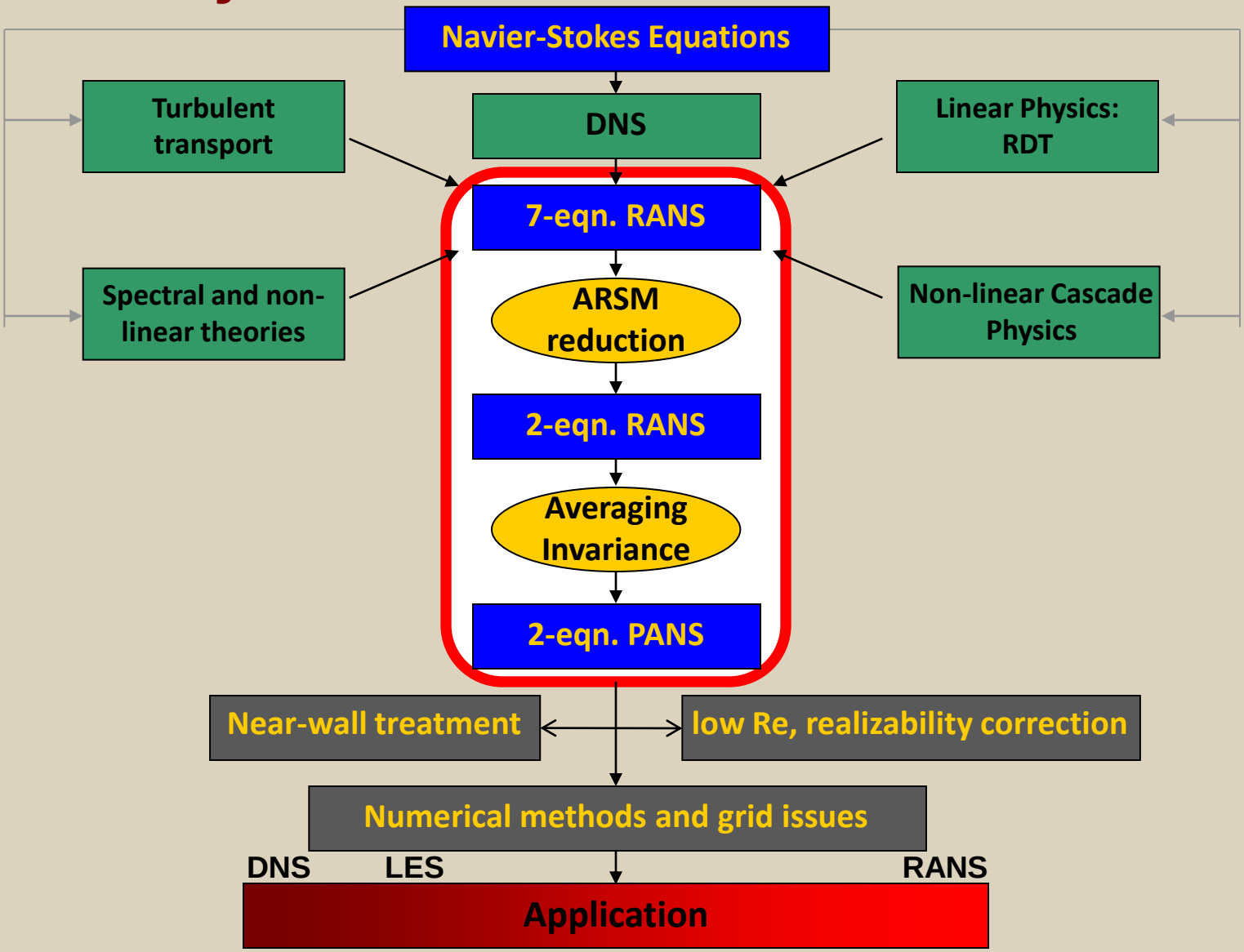
Current Work

- Develop physics based low Re RANS models
  - Low Re flows do not have full spectrum
  - Can be approximated as rapidly distorted flows
  - *Rapid Distortion Theory can be used for deriving low Re Corrections*
  - In RDT limit turbulence behaves as elastic rather than viscous medium

Outline

- Unified Development Methodology
- Proof of Concept
- Workshop Test Cases
- Results
- Conclusions

Unified Physics-Based Multi-Resolution Modeling



Standard Approach: Constant C_μ

- Constant C_μ valid when
  - Strain rate dominates
  - $Sk/\varepsilon = (3,5)$

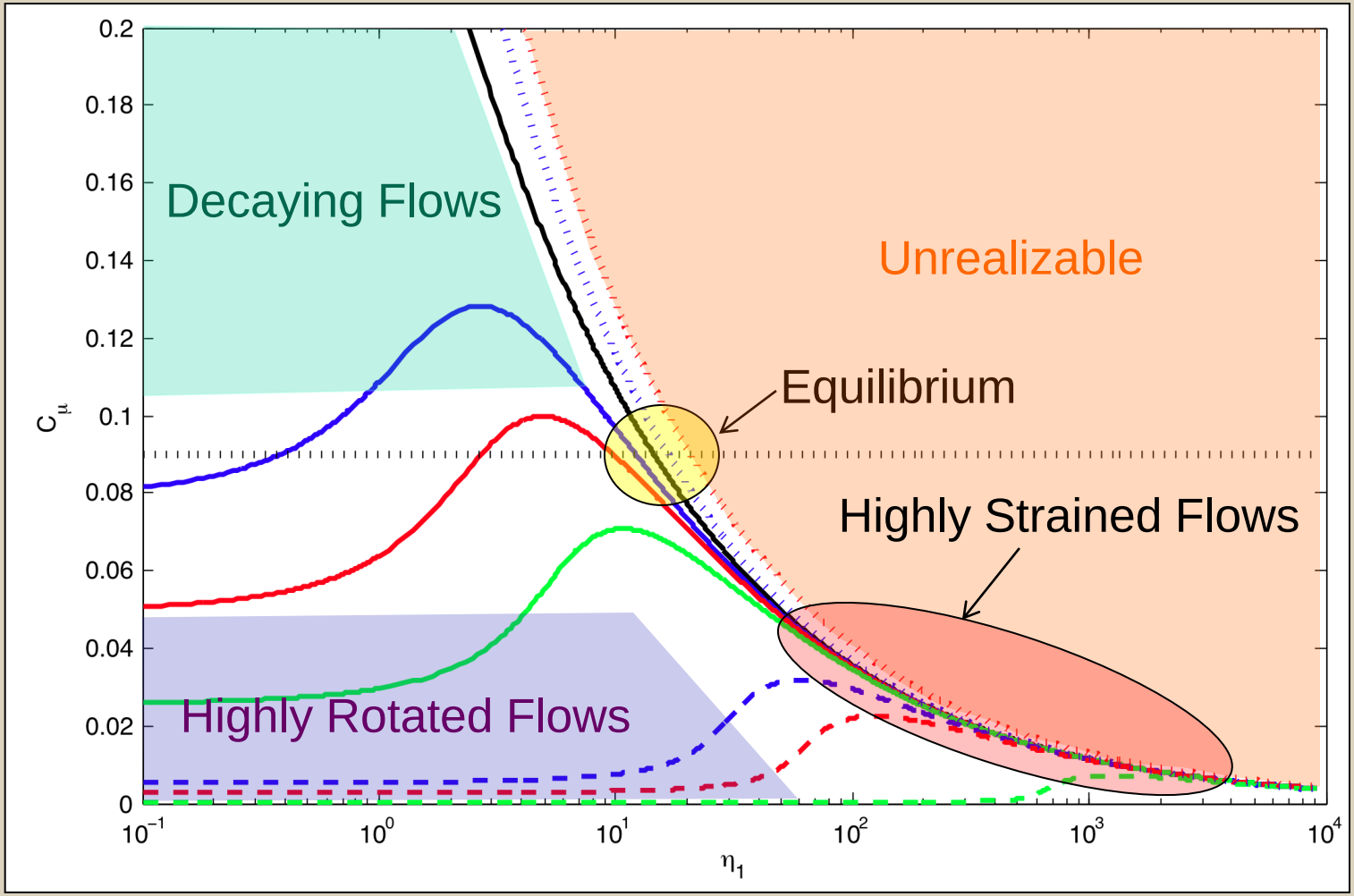
Current Approach: Variable C_μ Modifications

- M1: Valid for all strain rates
  - $Sk/\varepsilon < 5$ ➔ $C_\mu=0.09$
  - $Sk/\varepsilon > 5$ ➔ RDT Values

$$\beta^* = min\left[0.3668\left(\frac{0.09\omega}{S}\right), 0.09\right]$$

- M2: Valid for all strain rates and rotation rates
  - Linear coefficient from ARSM, $C_\mu=C_\mu(\Omega_{ij},S_{ij})$

Variable C_μ RDT Physics



$$\eta_1 = \frac{k^2}{\varepsilon^2} S_{ij} S_{ij}$$

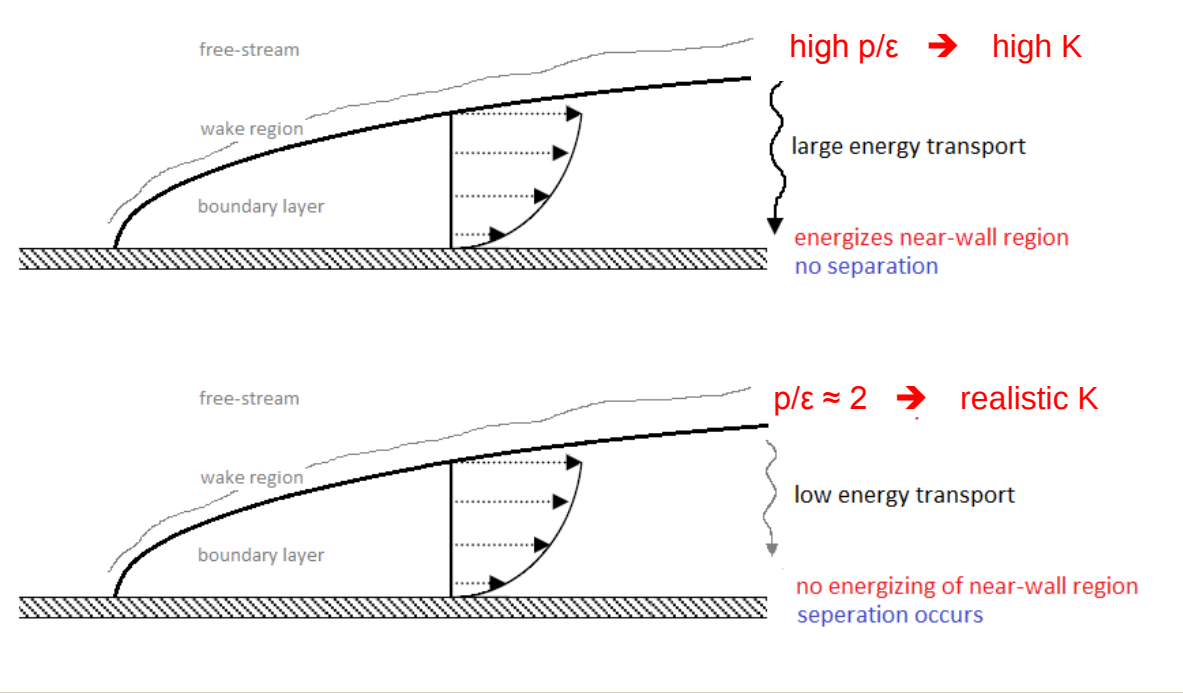
$$\eta_2 = \frac{k^2}{\varepsilon^2} \Omega_{ij} \Omega_{ij}$$

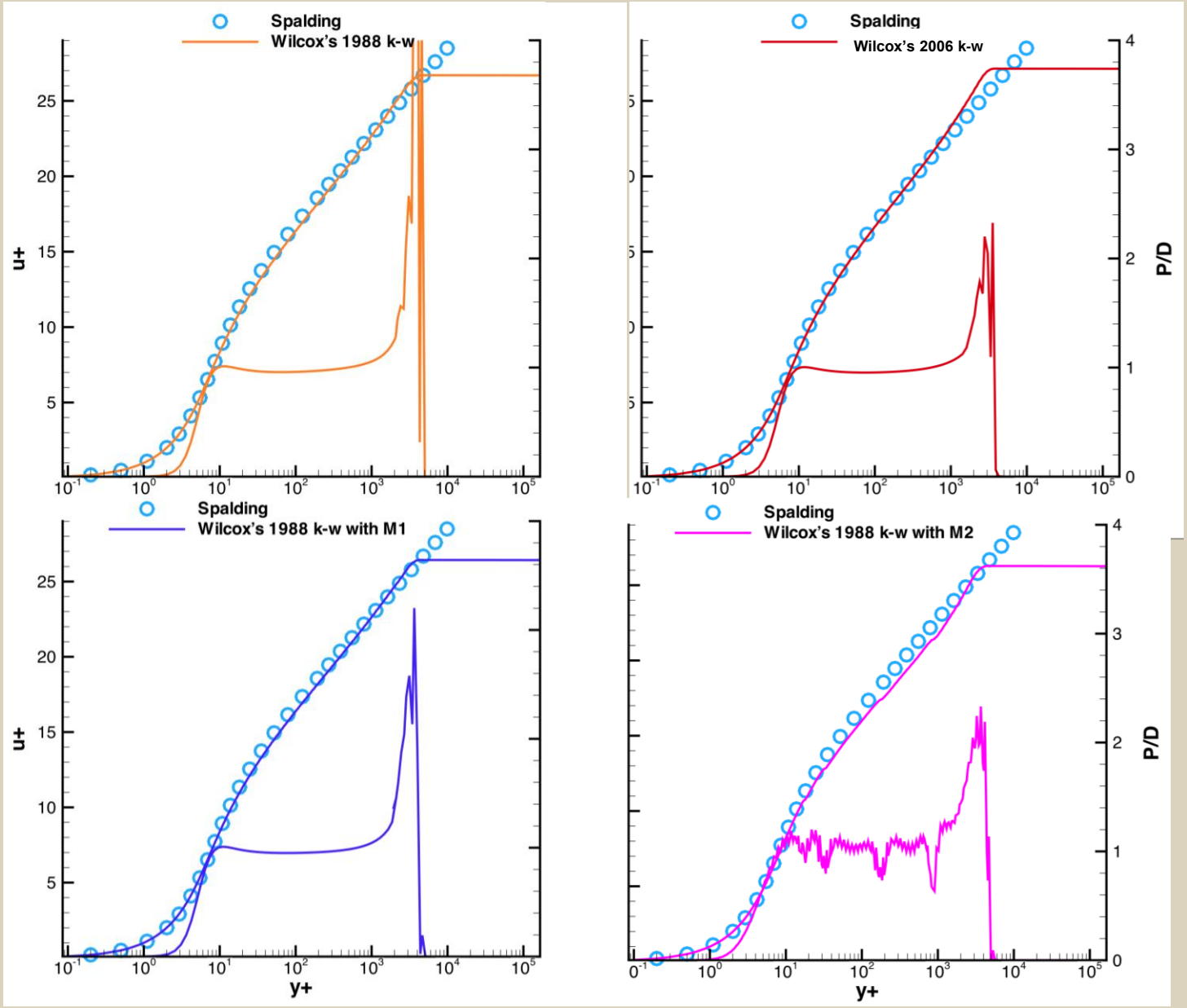
Previous Work
Qualitative Observations about Separation

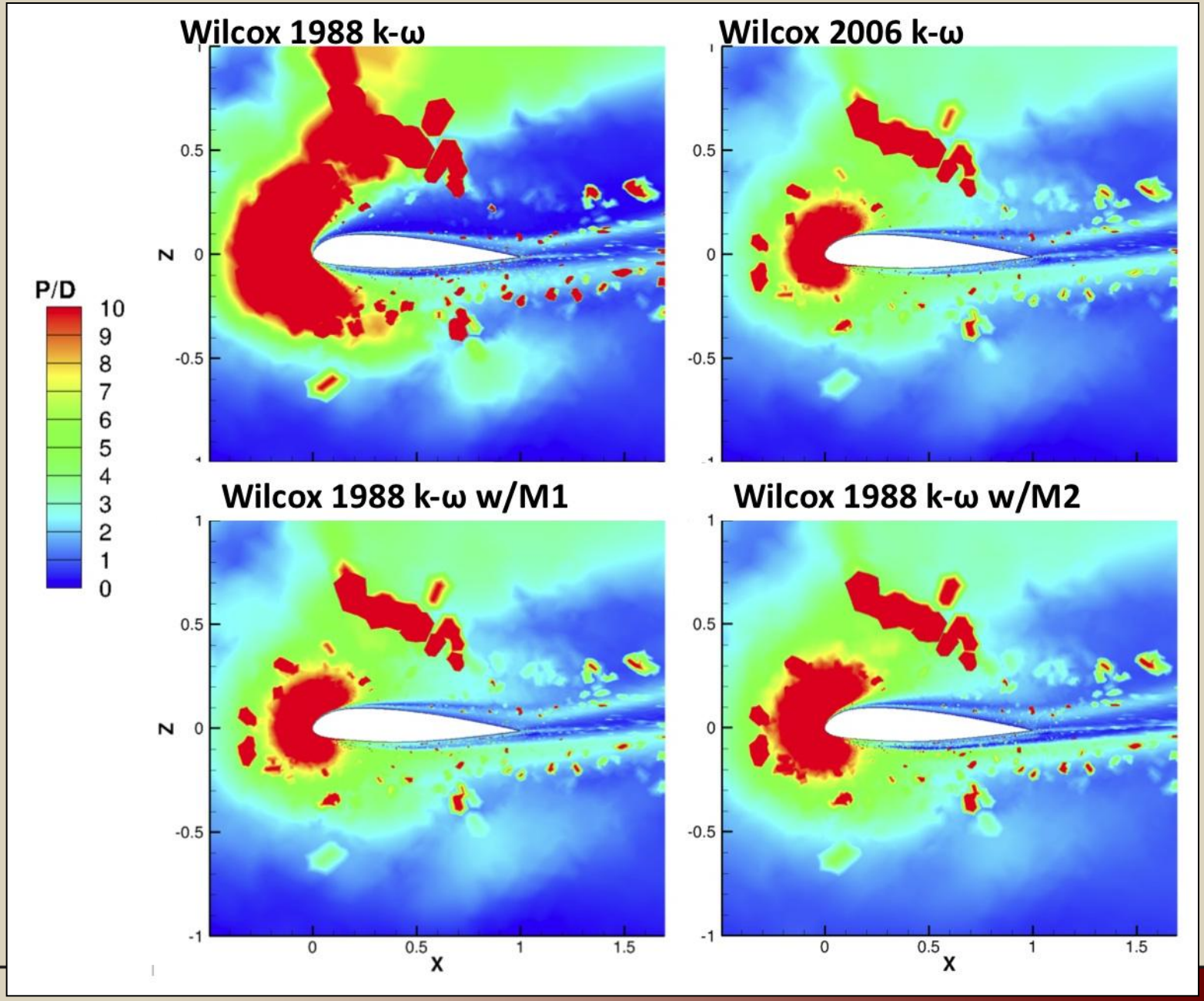
Flat Plate and Aerospatiale Airfoil

Desired wake behavior from model

- Separation behavior dictated by what happens in the wake
- Overly energetic wake/freestream → no separation
- Reasonable wake energy → separation occurs
- **Correct P/ε needed in near wall region**




Spalding
Wilcox's 1988 k-w
u+
Spalding
Wilcox's 2006 k-w
P/D
Spalding
Wilcox's 1988 k-w with M1
u+
y+
Spalding
Wilcox's 1988 k-w with M2
P/D
y+


Wilcox 1988 k-ω
Wilcox 2006 k-ω
Wilcox 1988 k-ω w/M1
Wilcox 1988 k-ω w/M2
P/D
10
9
8
7
6
5
4
3
2
1
0
Z
X
0.5
0
-0.5
-1
1
1.5

Workshop Results

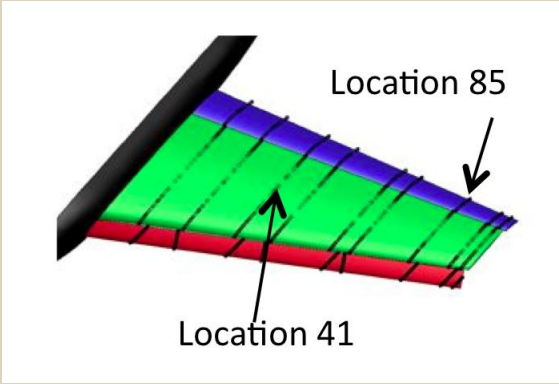
- USM3D
  - tetrahedral time accurate solver
  - all simulations are steady state
- Grids
  - Coarse Grid: 7,237,190
  - Medium Grid: 21,743,354
  - Fine Grid: 62,644,381
- Models
  - Wicox's 1988 k-ω
  - Wilcox's 1988 k-ω with M1 modification

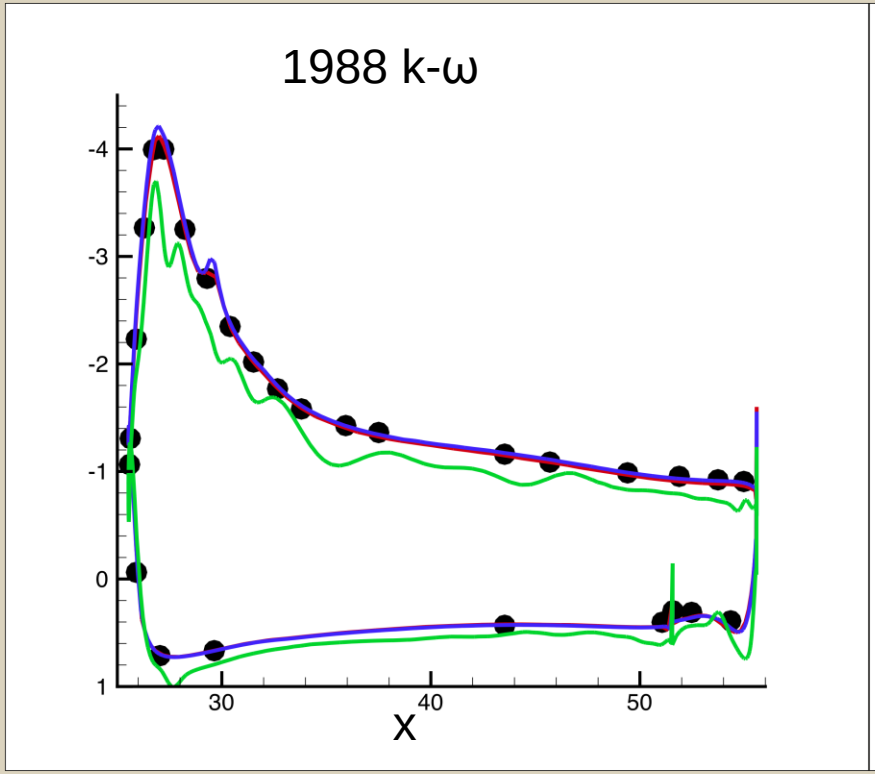
Grid Convergence Studies

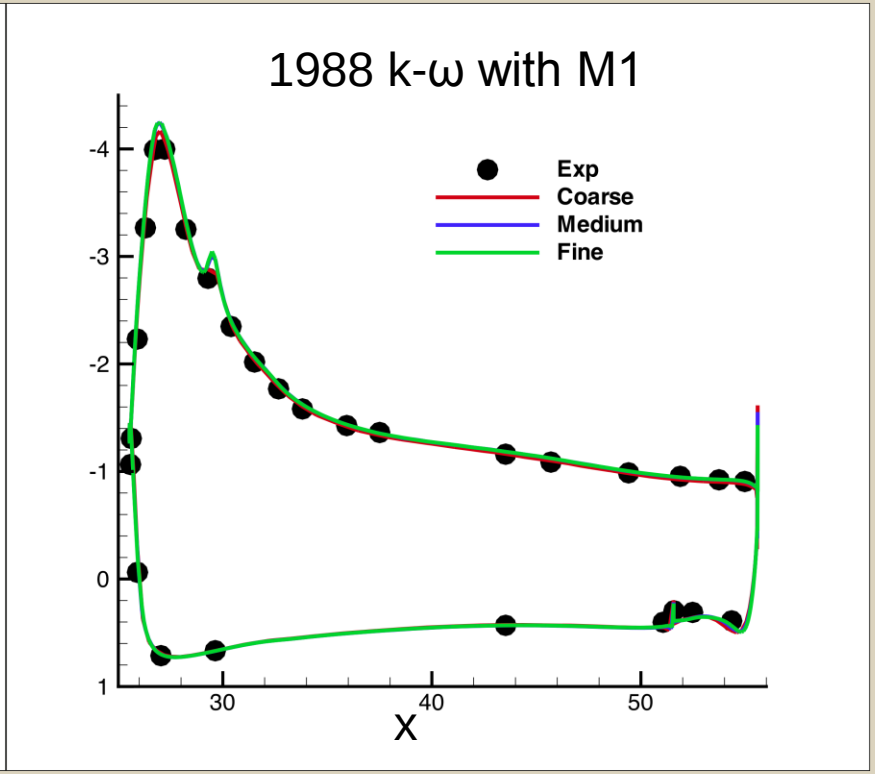
C_p Distribution at AOA 13
Configuration 1

Main 41

AOA 13

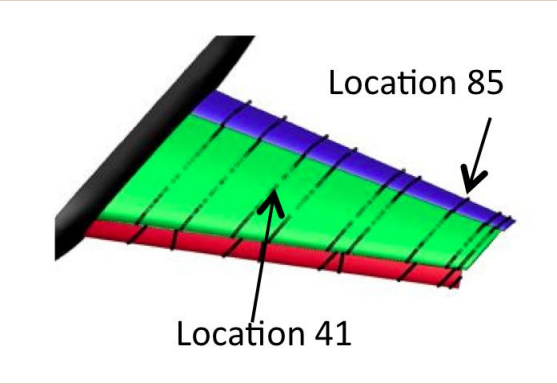


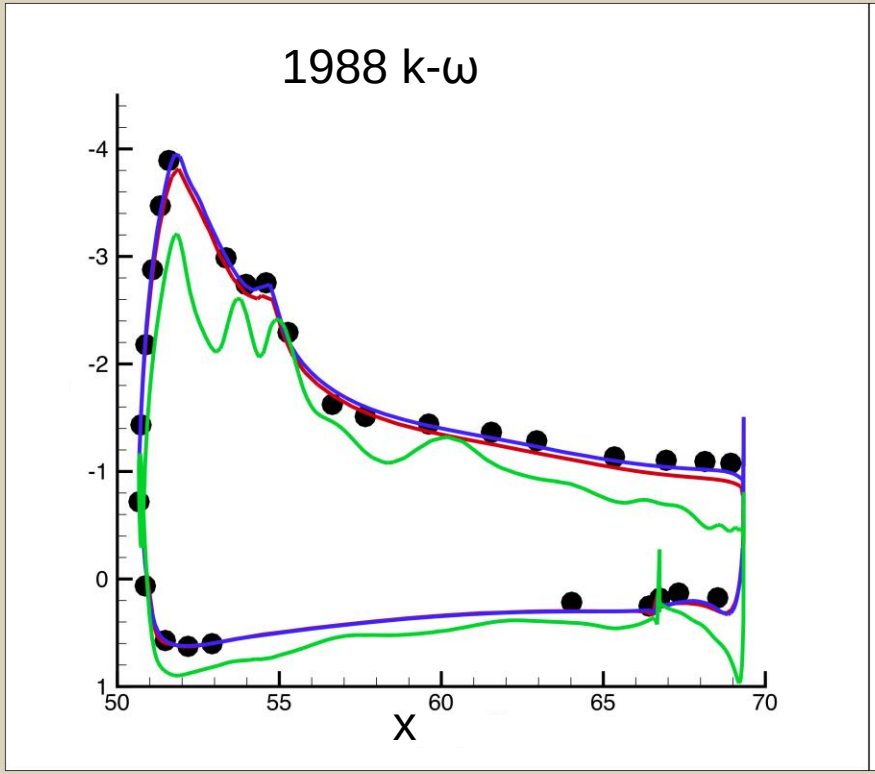


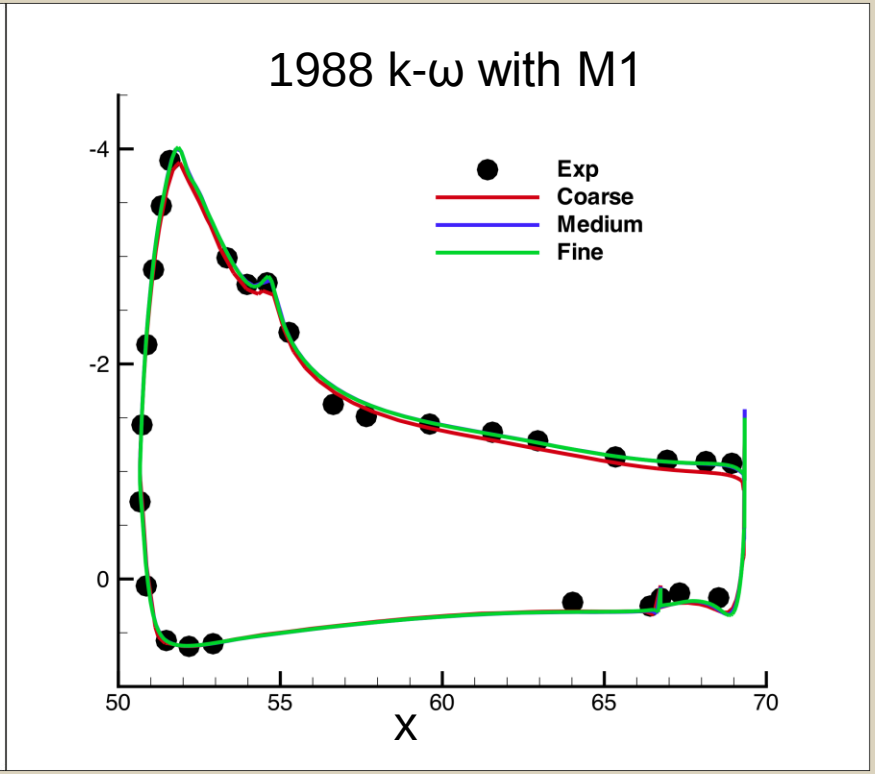


Main 85

AOA 13

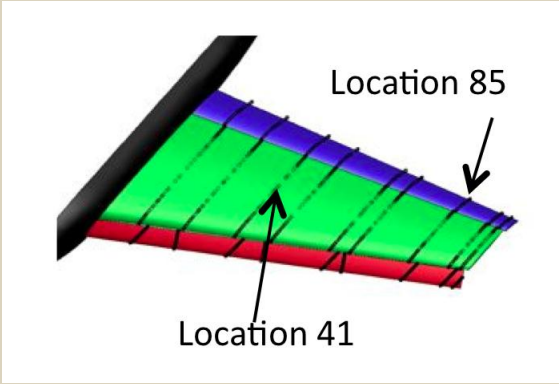


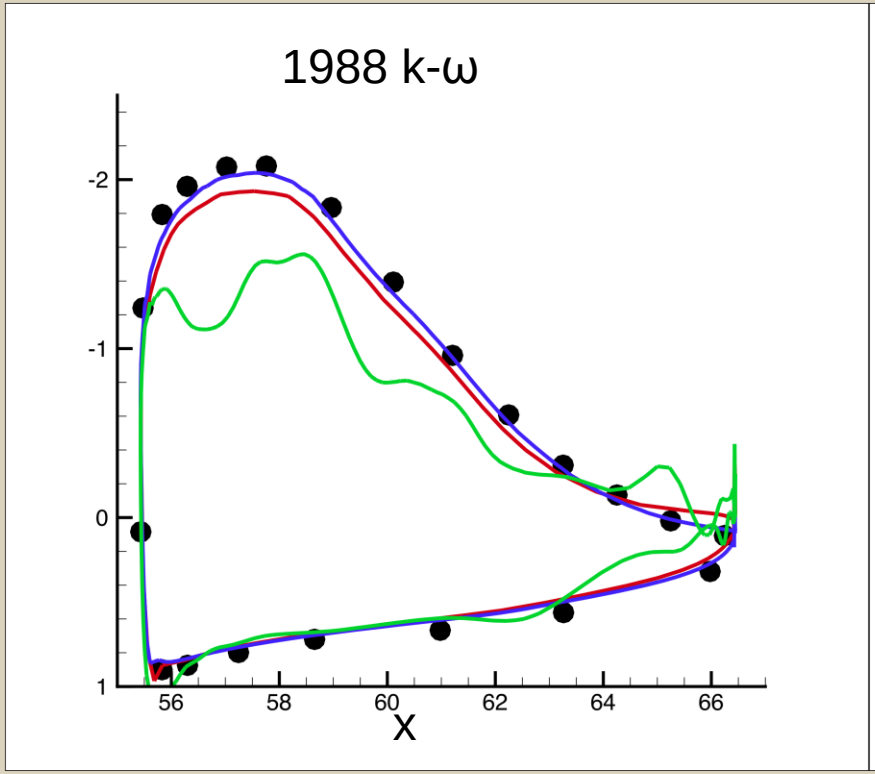


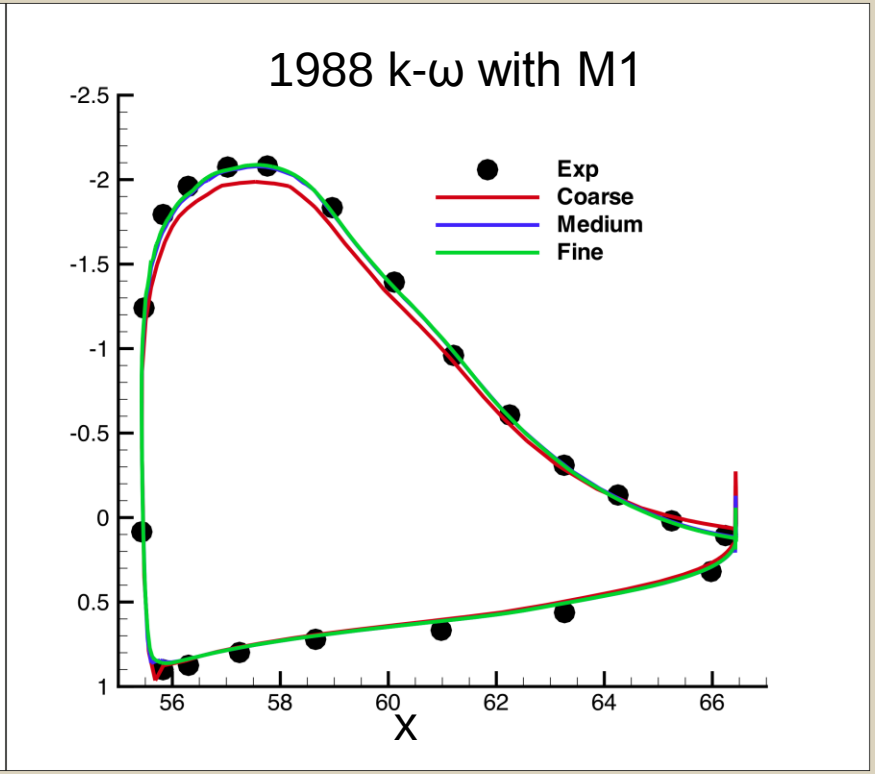


Flap 41

AOA 13

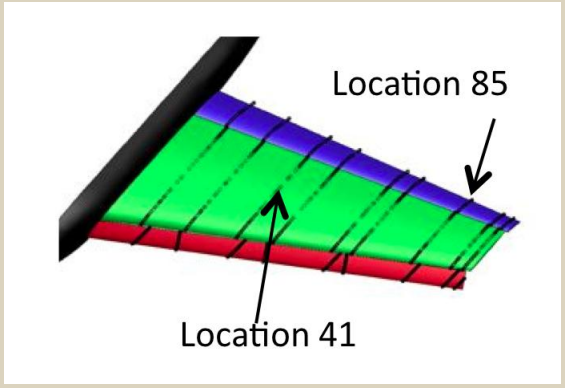


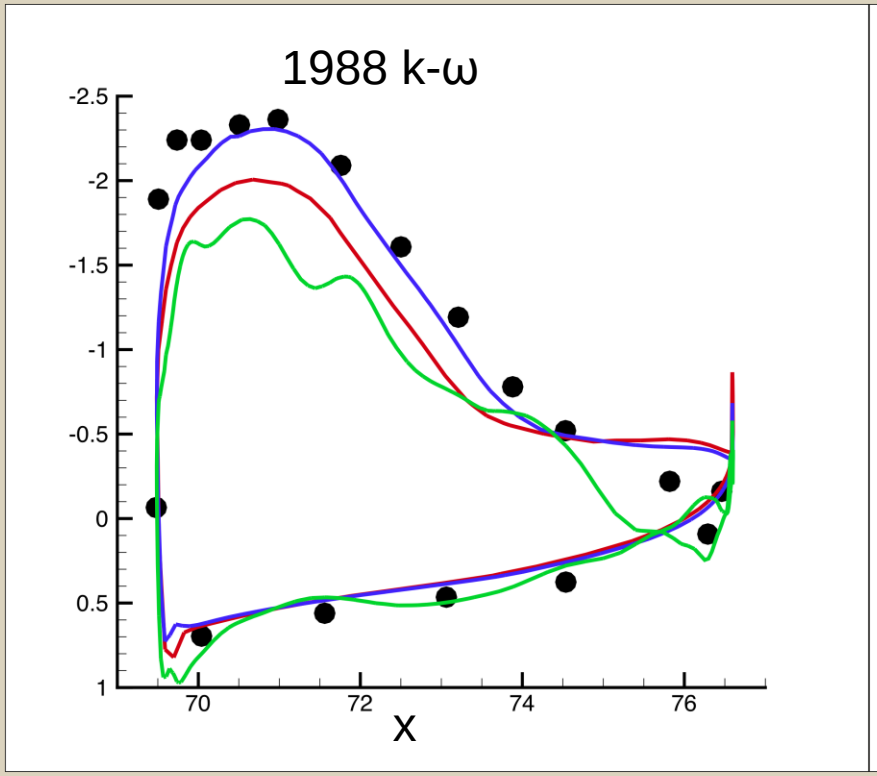


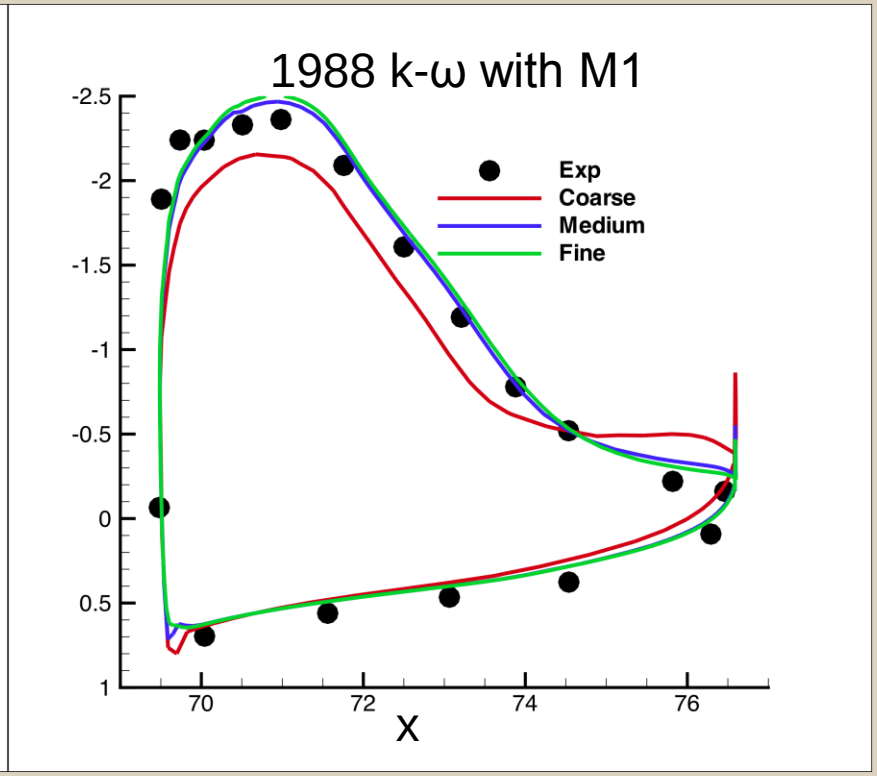


Flap 85

AOA 13





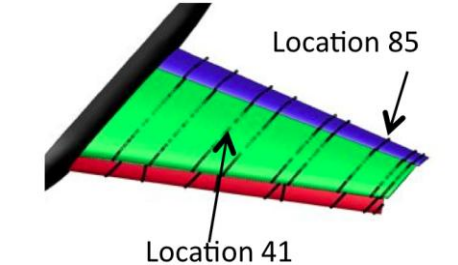


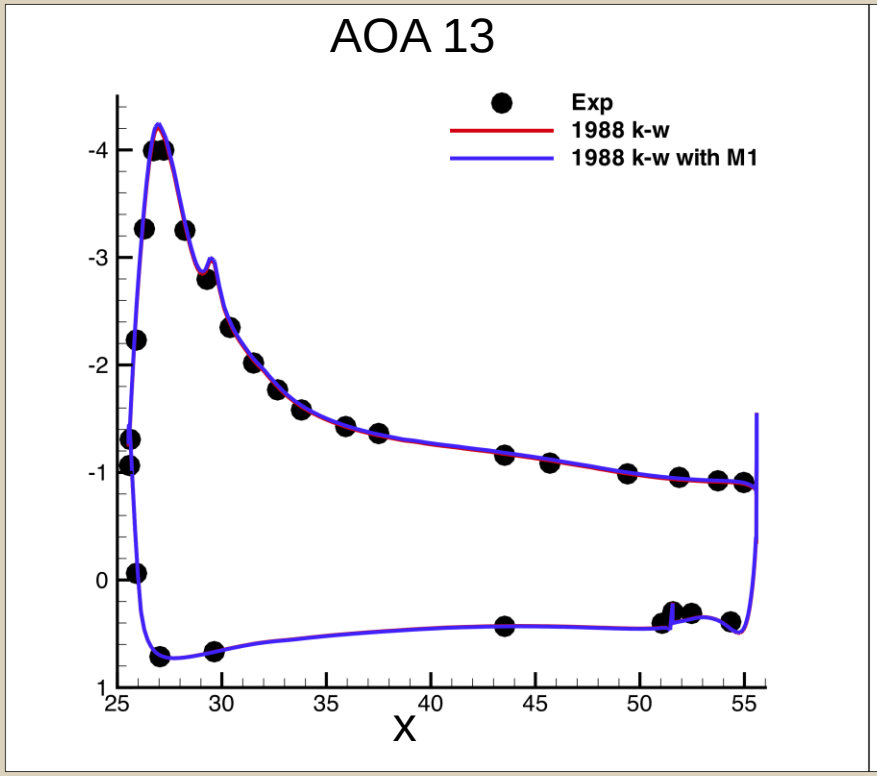
Model Comparisons

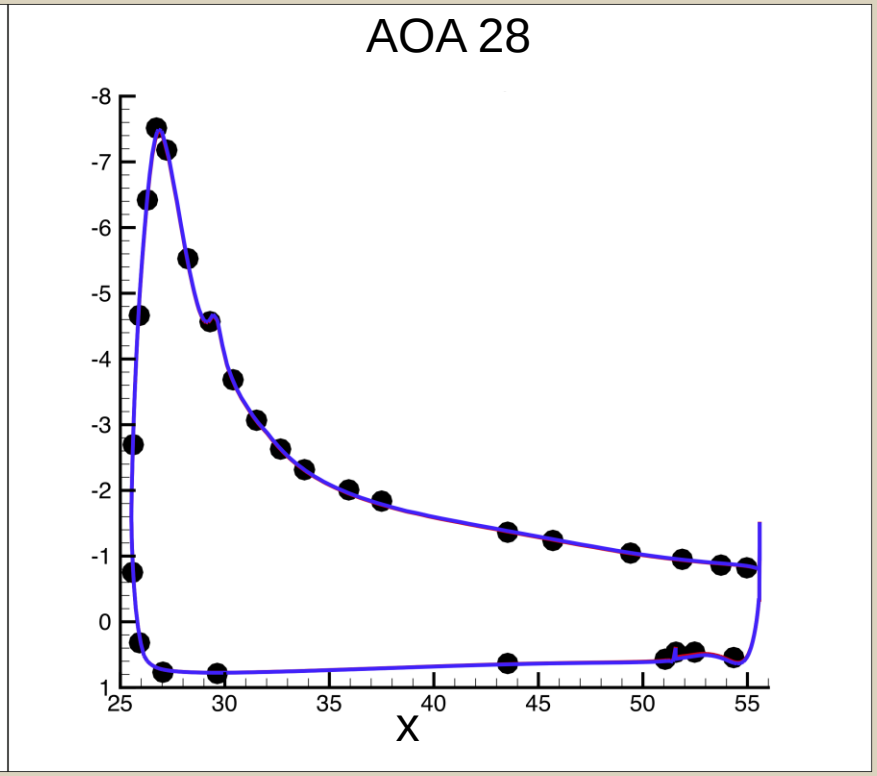
C_p Distribution at AOA 13 & 28

Configuration 1

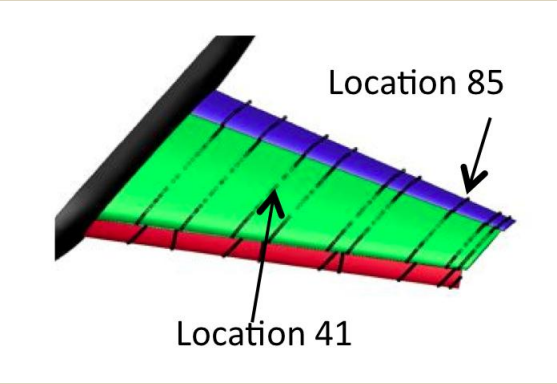
Main 41

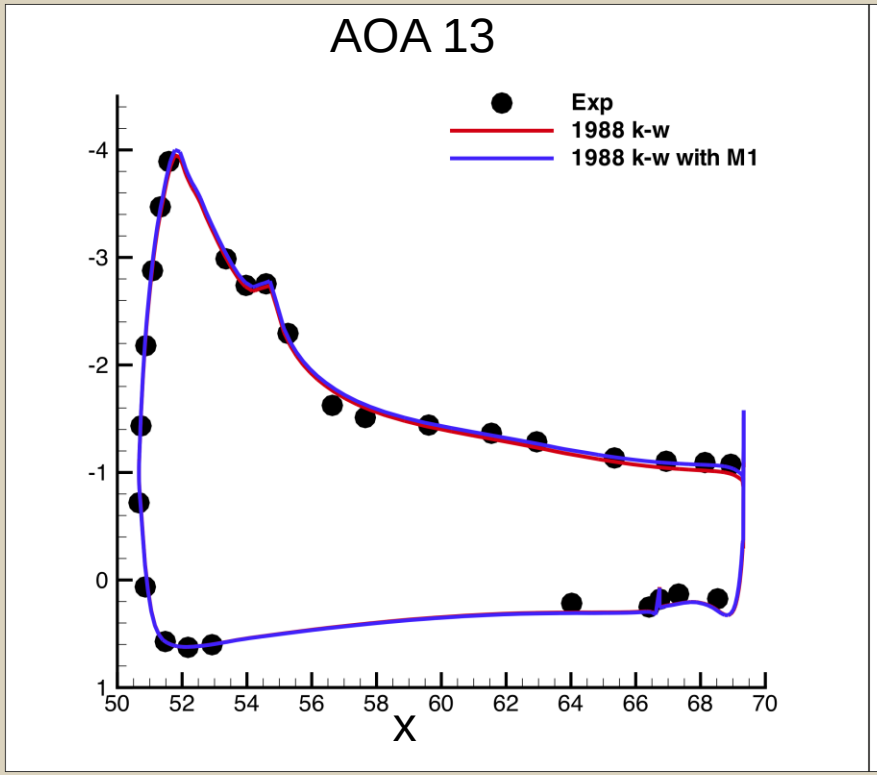

Location 85
Location 41

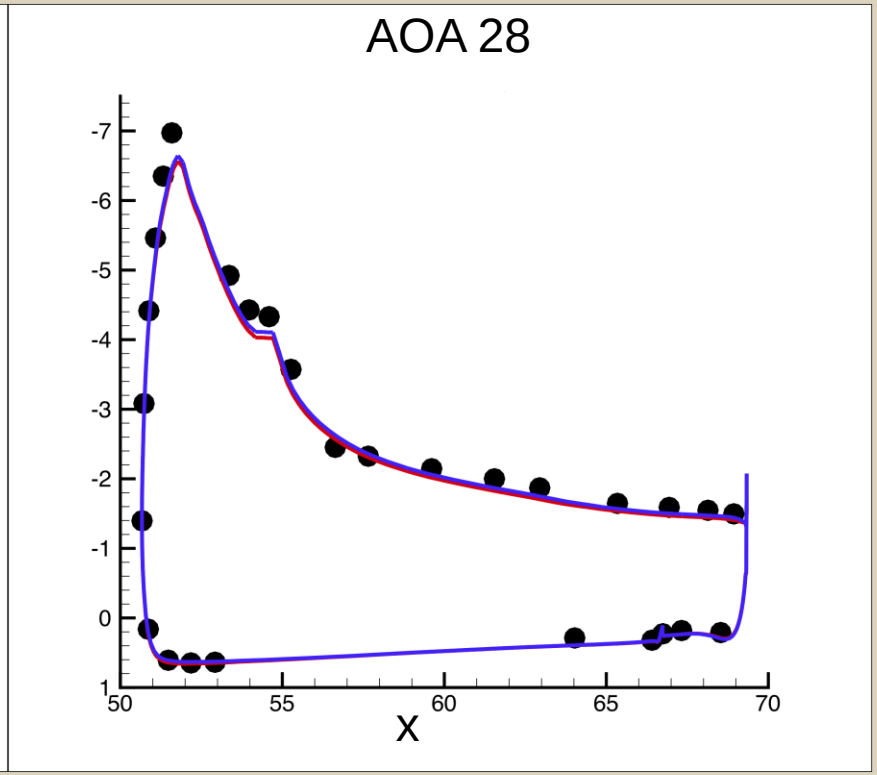

AOA 13
Exp
1988 k-w
1988 k-w with M1
-4
-3
-2
-1
0
1
25
30
35
40
45
50
55
X


AOA 28
-8
-7
-6
-5
-4
-3
-2
-1
0
1
25
30
35
40
45
50
55
X

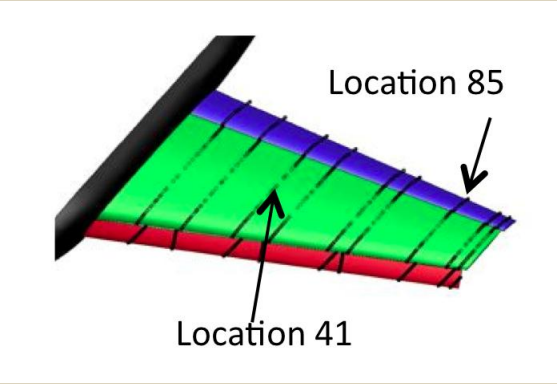
Main 85


Location 85
Location 41


AOA 13
Exp
1988 k-w
1988 k-w with M1
-4
-3
-2
-1
0
1
50
52
54
56
58
60
62
64
66
68
70
X


AOA 28
-7
-6
-5
-4
-3
-2
-1
0
1
50
55
60
65
70
X

Flap 41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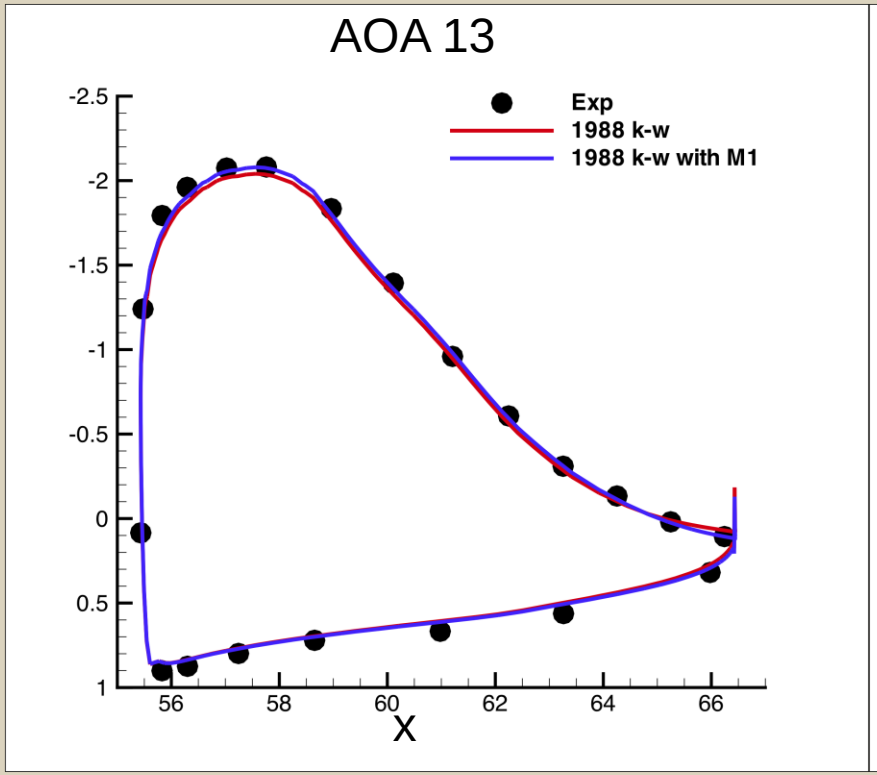
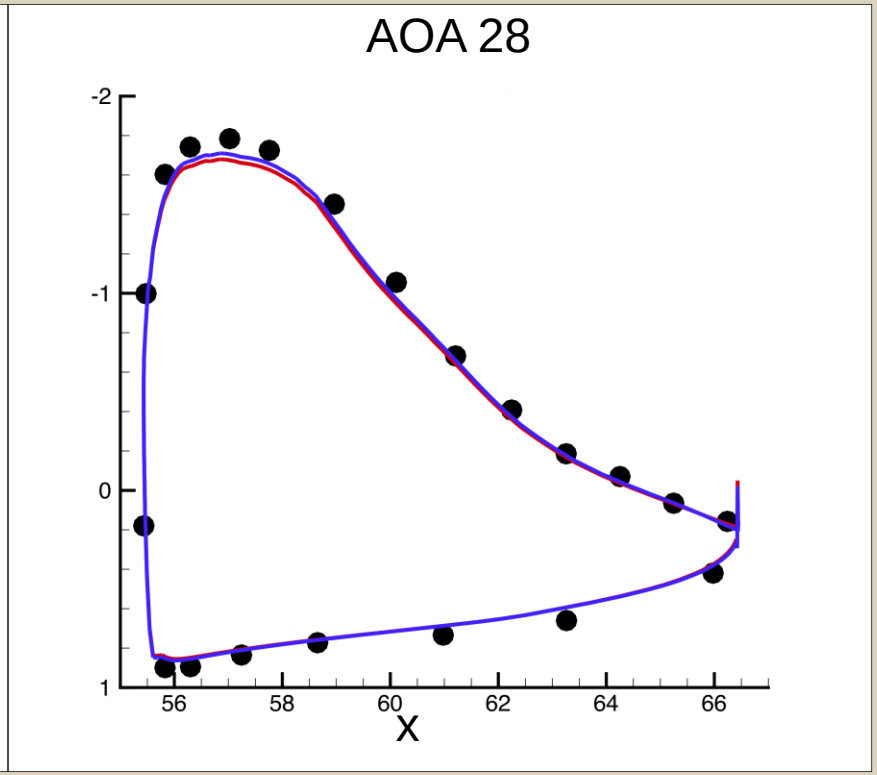
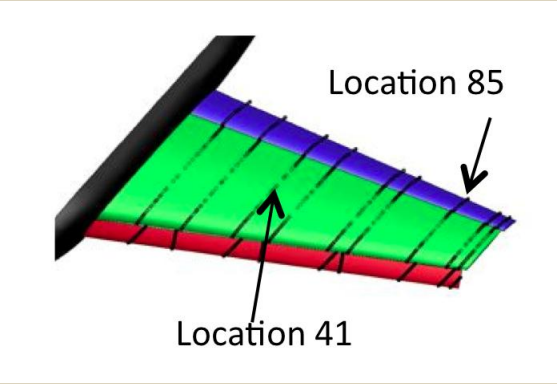
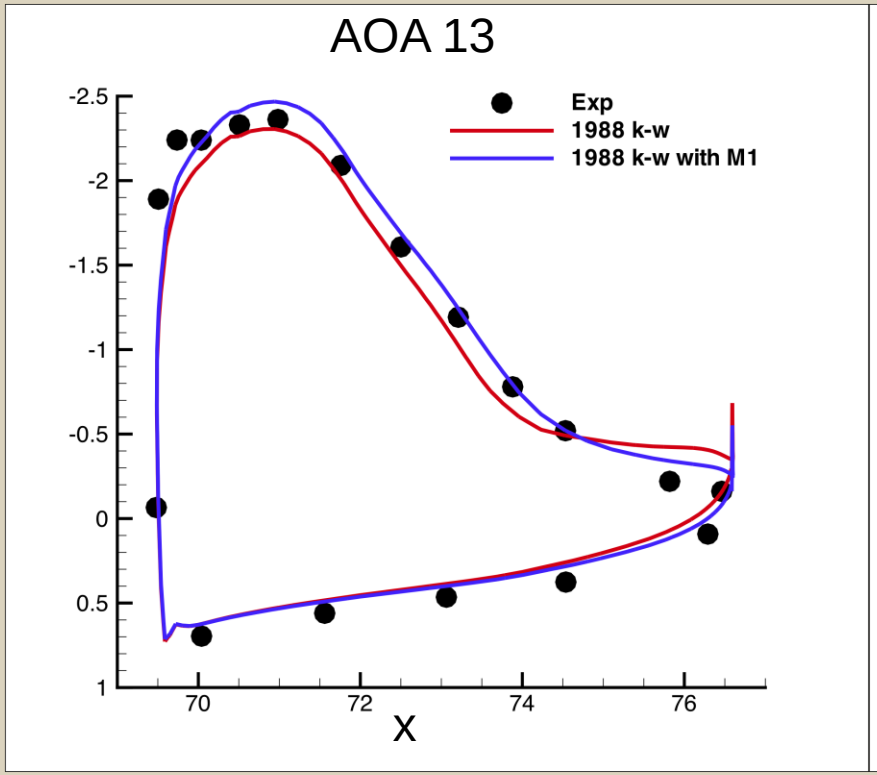
Location 41

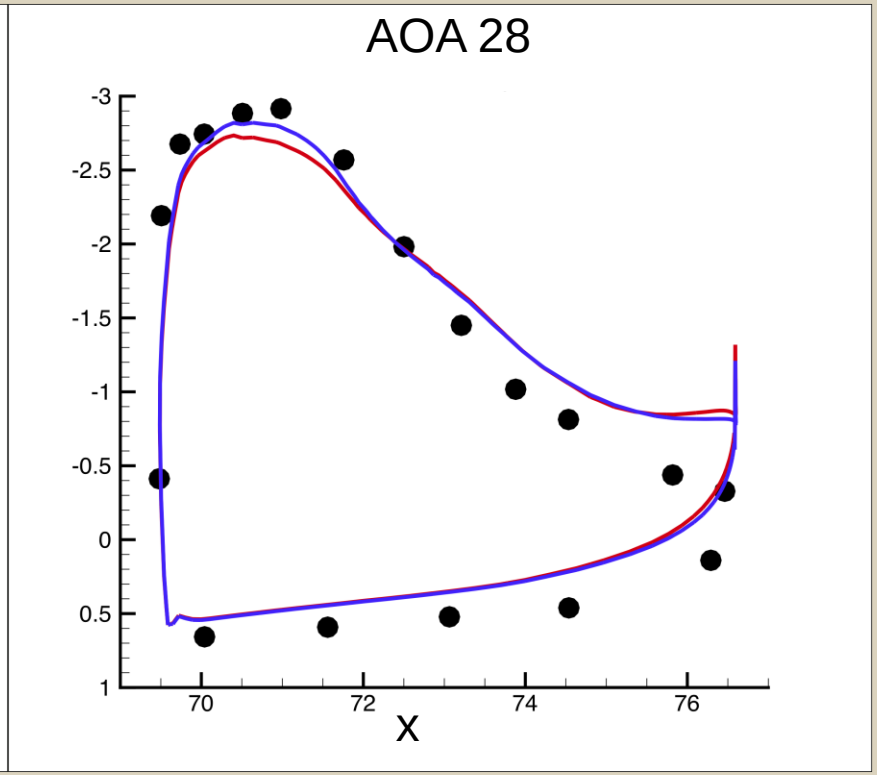

AOA 13
Exp
1988 k-w
1988 k-w with M1
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
56
58
60
62
64
66
X


AOA 28
-2
-1
0
1
56
58
60
62
64
66
X

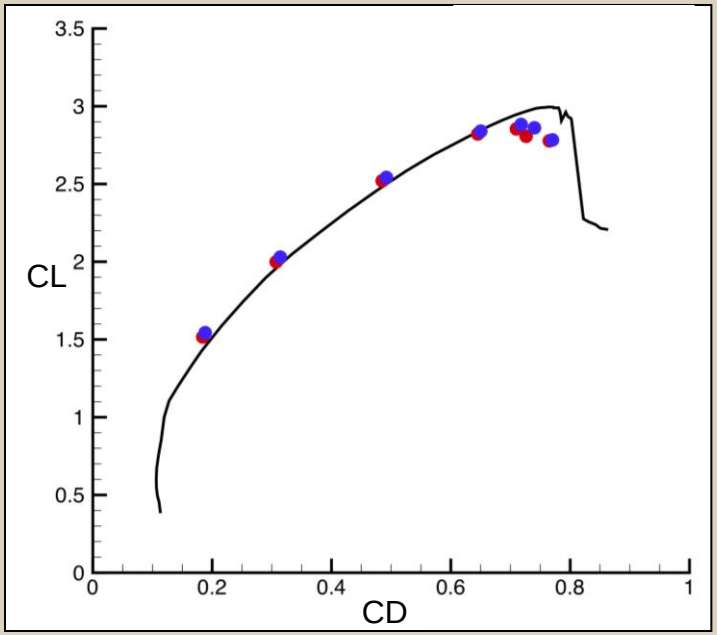
Flap 85

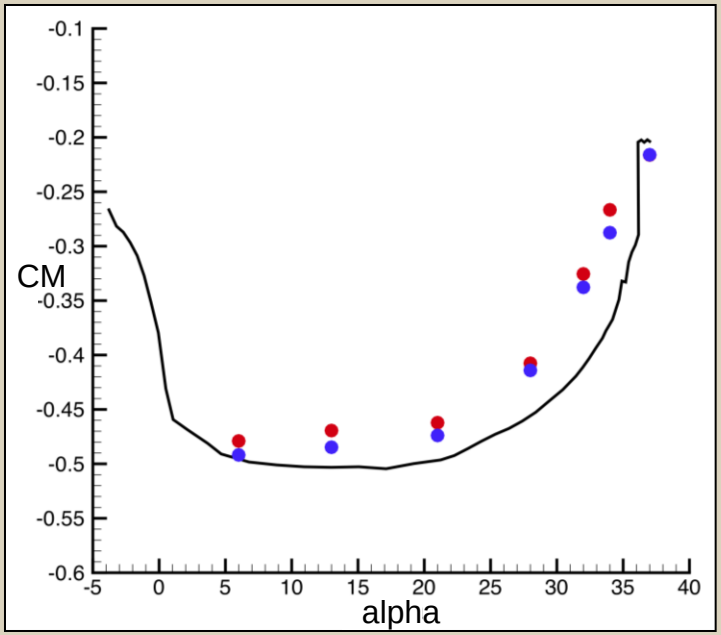

Location 85
Location 41

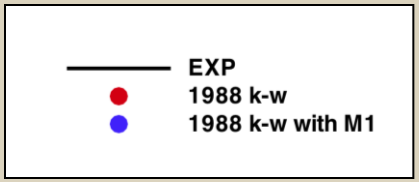

AOA 13
Exp
1988 k-w
1988 k-w with M1
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
70
72
74
76
X

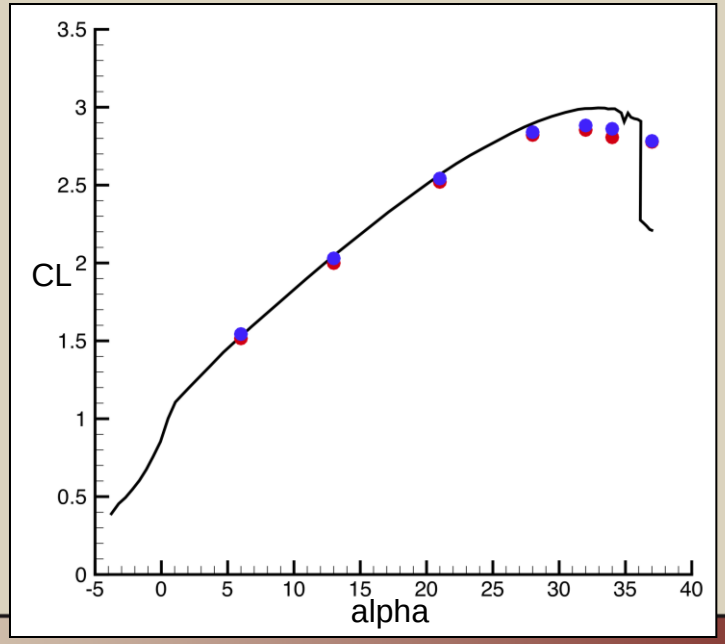

AOA 28
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
70
72
74
76
X

Force and Moment


CL
CD
3.5
3
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1


CM
alpha
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
-0.5
-0.55
-0.6
-5
0
5
10
15
20
25
30
35
40


EXP
1988 k-w
1988 k-w with M1


CL
alpha
3.5
3
2.5
2
1.5
1
0.5
0
-5
0
5
10
15
20
25
30
35
40

Conclusions and Future Plans

- Physics based low Re C_μ correction developed (PhD Dissertation--Sunil Lakshimpathy)
- Correction improves performance in Aerospatiale airfoil – benchmark test case
- For workshop cases standard and M1 models produce similar results
  - However standard model does not converge for all grids
- At high AOA both models require further improvement
  - M2 Rotation effects may be important
- *Low Re and vorticity corrections to be implemented into PANS constitutive relation*