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2nd AIAA CFD Drag Prediction Workshop

NLR results obtained using the multiblock structured flow solver ENSOLV

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NLR results (ENSOLV)
CFD Method

- **ENSOLV (part of NLR's flow simulation system ENFLOW)**
  - Time-dependent Reynolds-averaged Navier-Stokes equations
  - Cell-centred, central difference, finite volume scheme
  - (Pseudo) time integration by explicit Runge-Kutta scheme to obtain steady-state solution
  - Artificial dissipation (scalar and matrix) to prevent odd-even decoupling
  - Local time stepping, multi-grid and residual averaging to accelerate convergence

NLR results (ENSOLV)
CFD Method

- **ENSOLV (part of NLR's flow simulation system ENFLOW)**
  - Original k-ω turbulence model as proposed by Wilcox
  - Slight modification by introduction of 'cross diffusion' term to eliminate free-stream dependency of ω
  - Solve $\omega = 1/(\omega + \omega_0)$ instead of ω, to remove singular behaviour of ω at solid walls
  - Production term in k-equation has been limited to prevent unphysical high values of k near stagnation point

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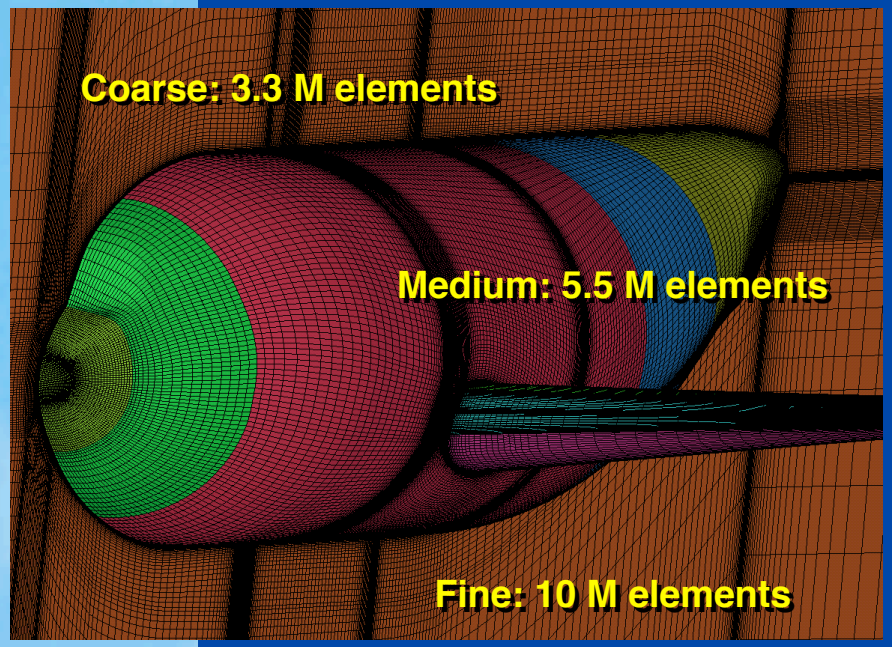
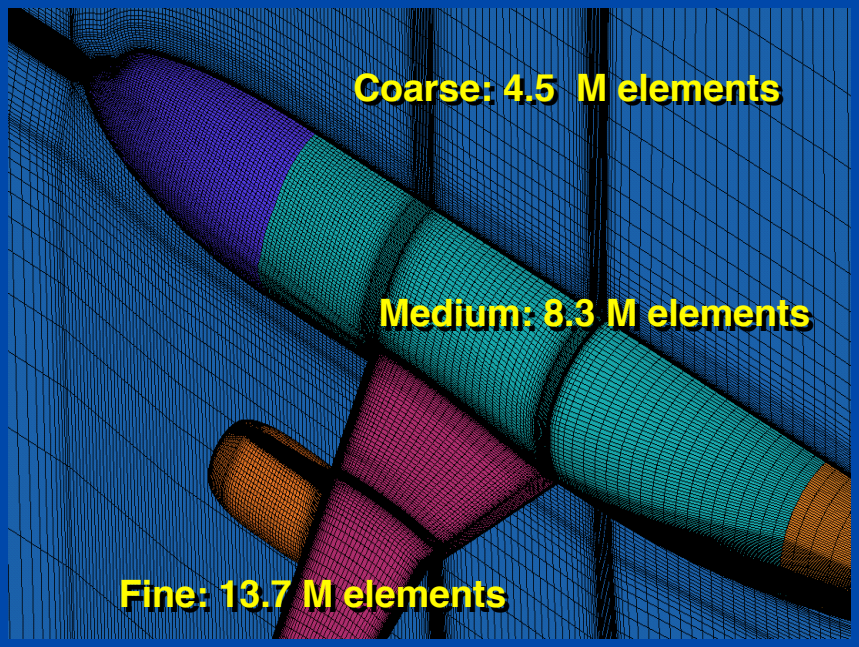
NLR results (ENSOLV)
Grid





- ICEM CFD multi-block C-topology grids for wing/body and wing/body/pylon/nacelle

NLR results (ENSOLV)
Solution information

		Level 1	Level 2	Level 3	Const. CL	CPU (h)	Mem (GByte)
wb	coarse	1500	1500 (1 MG)	1000 (1 MG)	1250 (1MG)	13.5	2.5
	medium	1500	1500 (1MG)	1000 (1 MG)	1250 (1MG)	22.9	4.1
	fine	1500	1500	750	1000	18.5	7.5
wbnp	coarse	1500	1000		1250	27.8	3.3
	medium	1500	1500	1000	1250	47.1	5.4
	fine	1500	1500	1000	1250	66.4	8.4

- **Computer platform: NLR's NEC SX-5/8B parallel vector super computer**
  - Operating system: SUPER-UX sx5 11.1 E SX-5/8B
  - Compiler: FORTRAN90/SX Version 2.45 for SX-5
- **Number of processors used (1-6) was such that complete simulation could be carried out within one night (12 h)**

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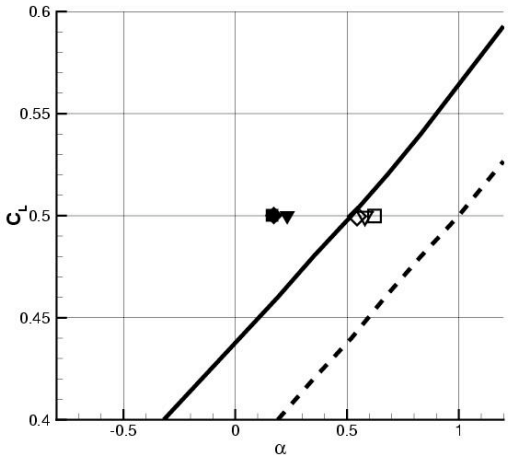
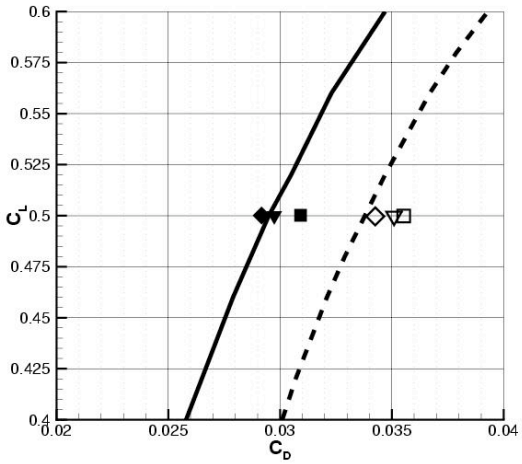
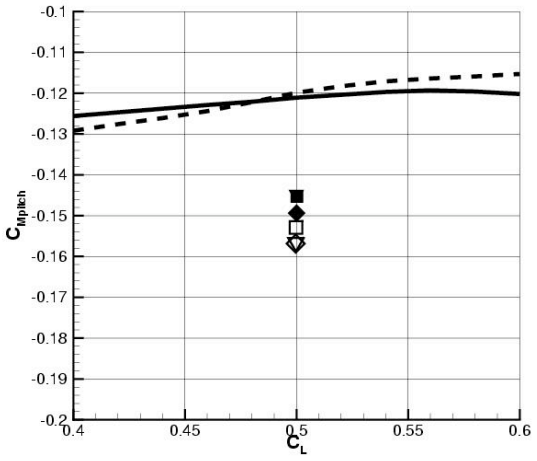
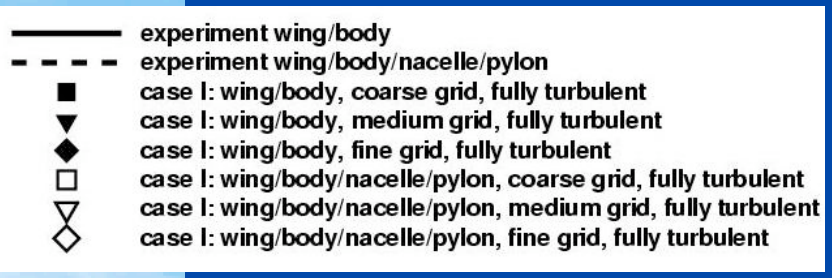
NLR results (ENSOLV)
Case 1: Single point grid convergence study









- Mach = 0.75
- Reynolds Number = 3×10^6
- Lift Coefficient = 0.500±0.001
- "Fully turbulent" solution

C_D installation

Coarse:	0.0046
Medium:	0.0054
Fine:	0.0051
Experiment:	0.0043

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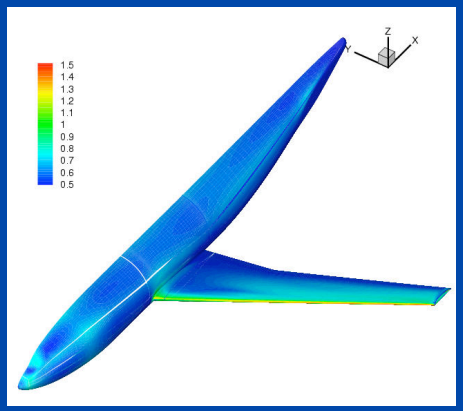
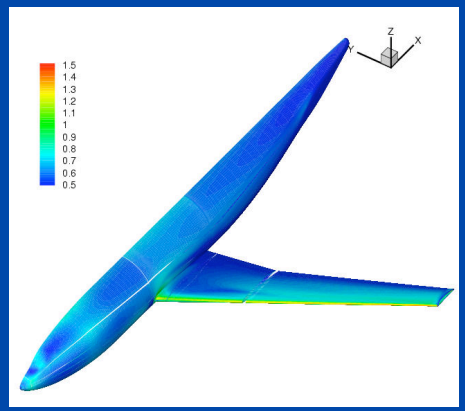
NLR results (ENSOLV)
Case 1: Single point grid convergence study (wb)

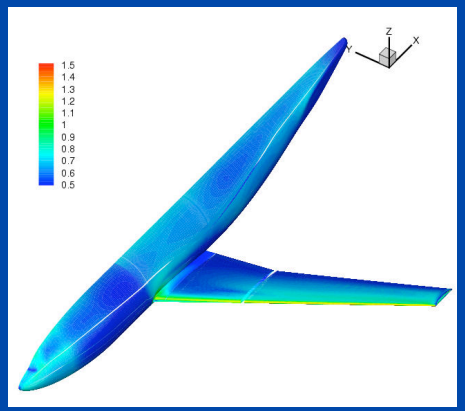
y^+



Coarse: 3.3 M elements

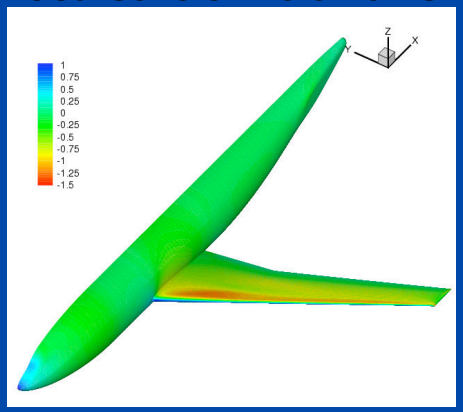


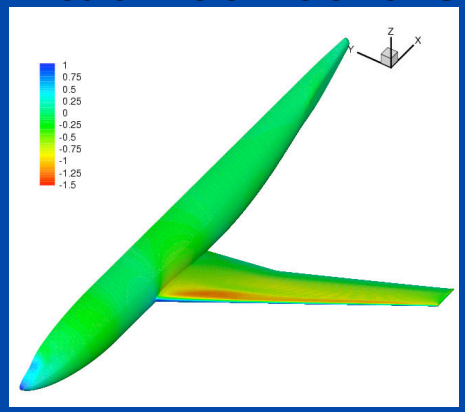
Medium: 5.5 M elements

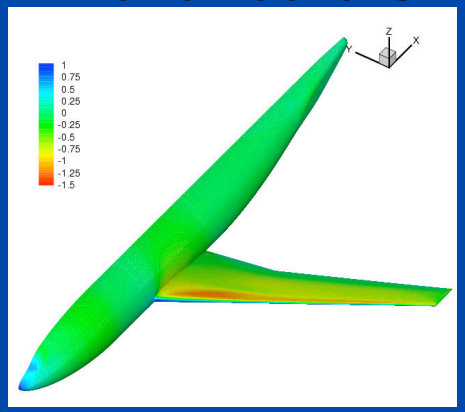


Fine: 10 M elements

C_p







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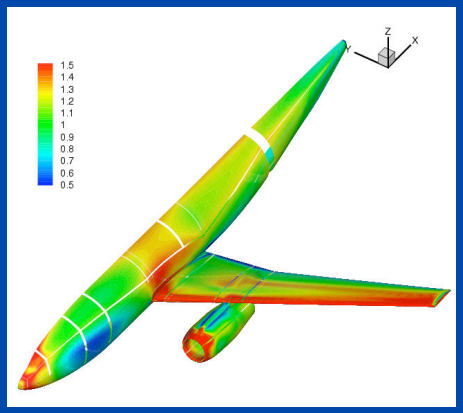
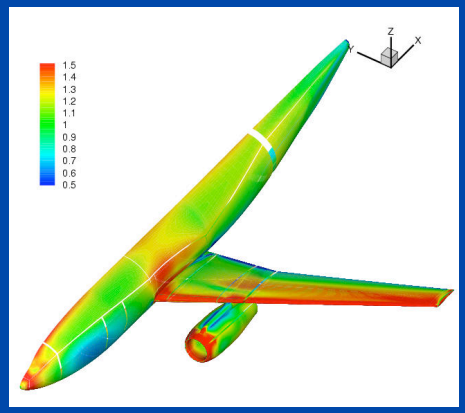
NLR results (ENSOLV)
Case 1: Single point grid convergence study (wbnp)

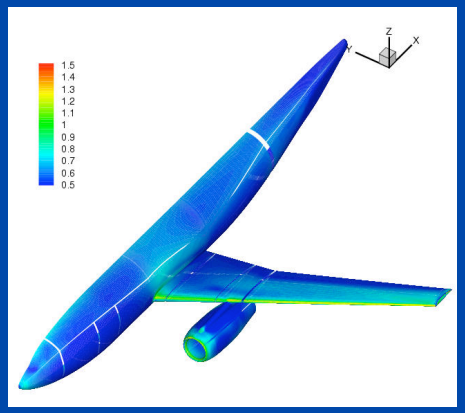
y^+



Coarse: 4.5 M elements

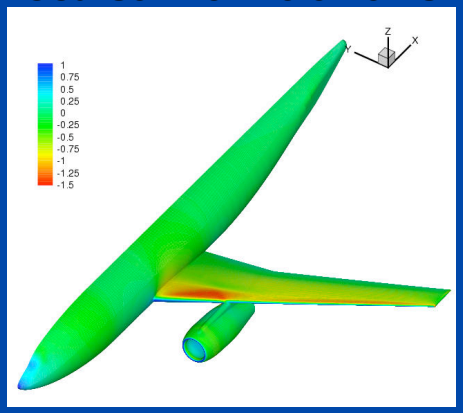


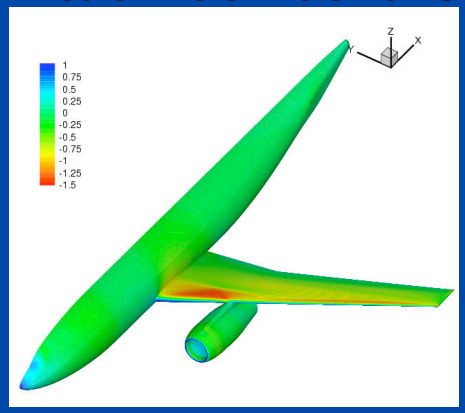
Medium: 8.3 M elements

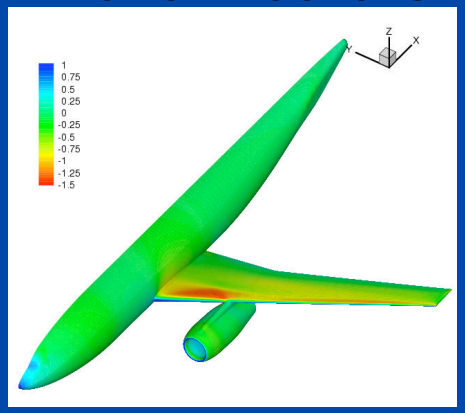


Fine: 13.7 M elements

C_p







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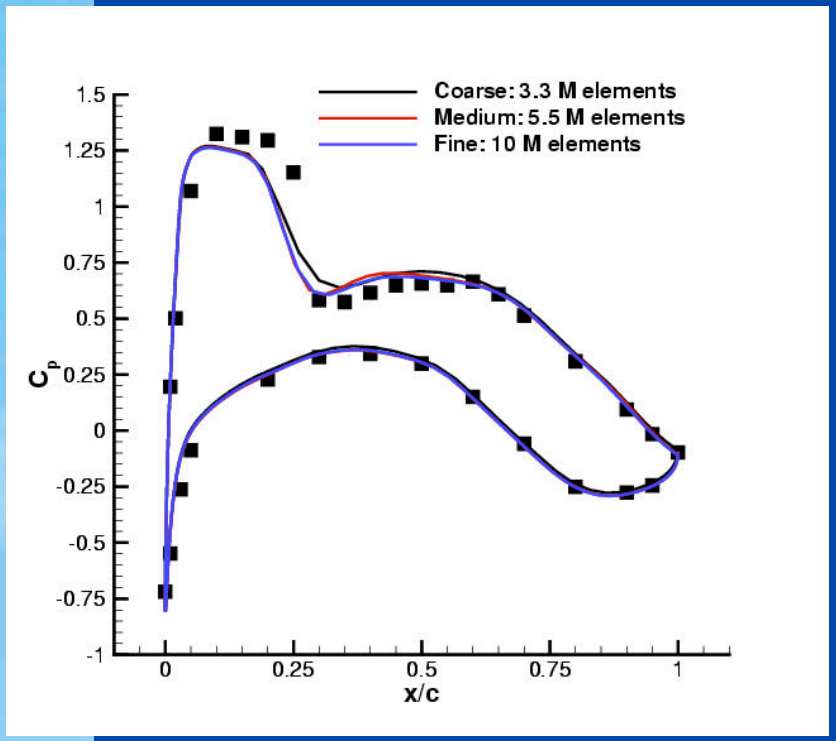
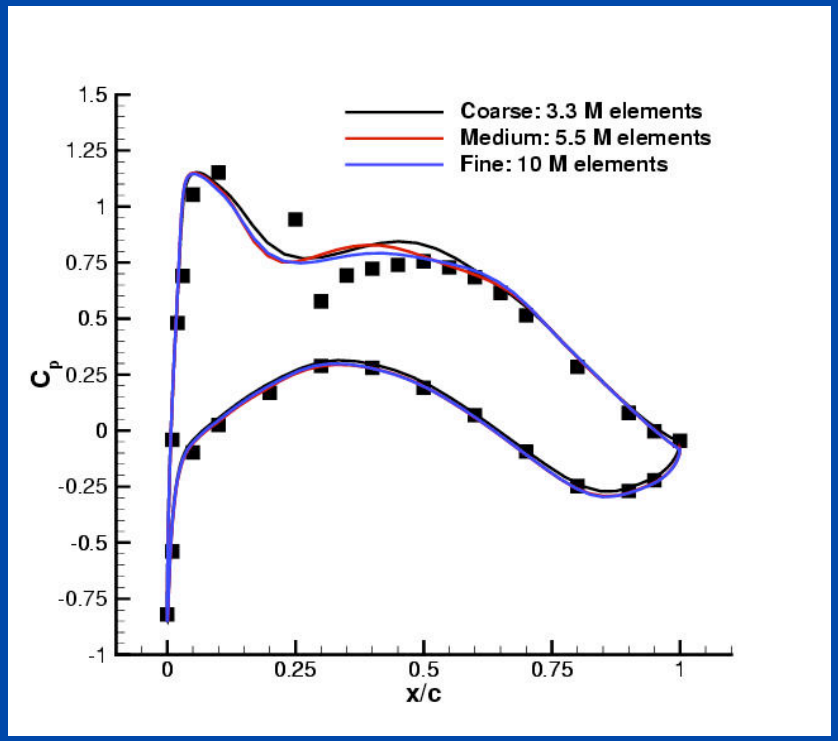
NLR results (ENSOLV)
Case 1: Single point grid convergence study (wb)





y/b=0.331 **Experiment** **y/b=0.514**

Alpha=0.490 CL=0.4984

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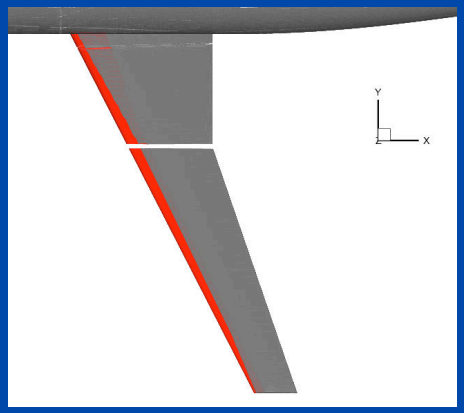
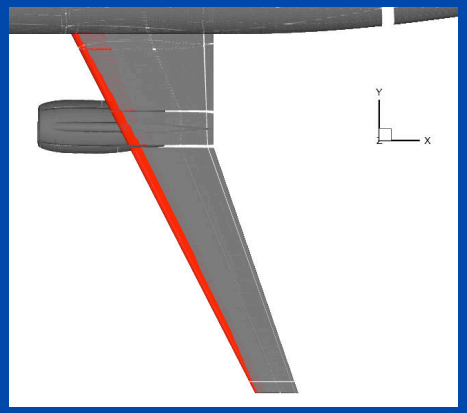
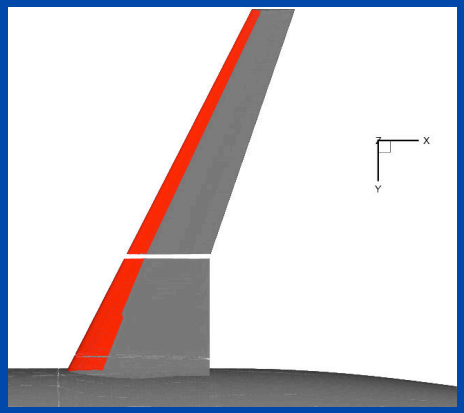
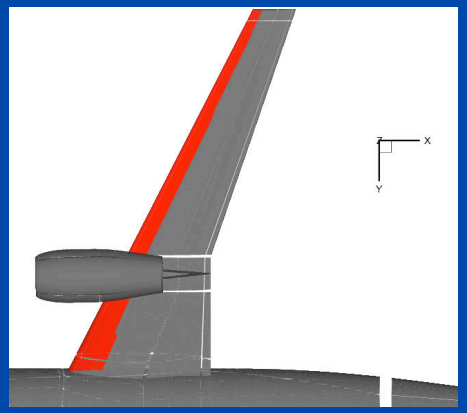
NLR results (ENSOLV)
Trip location





- **Lower surface**
  - 25 % chord





- **Upper surface**
  - 5 % chord at root
  - 15 % chord at kink
  - 15 % chord at η=0.844
  - 5% chord at tip

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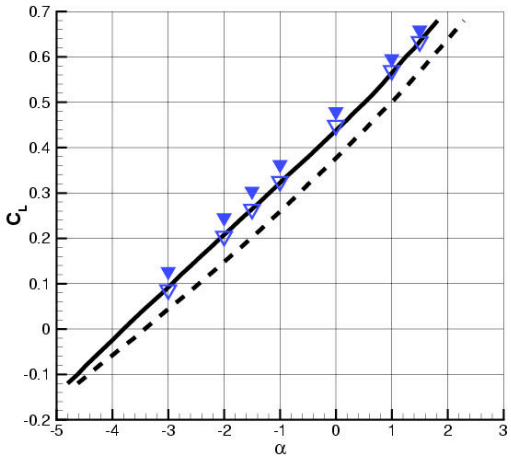
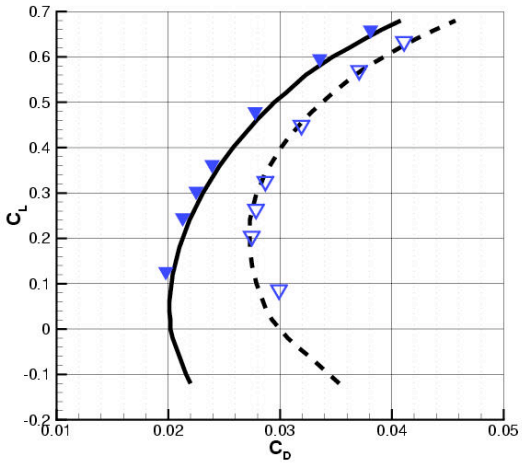
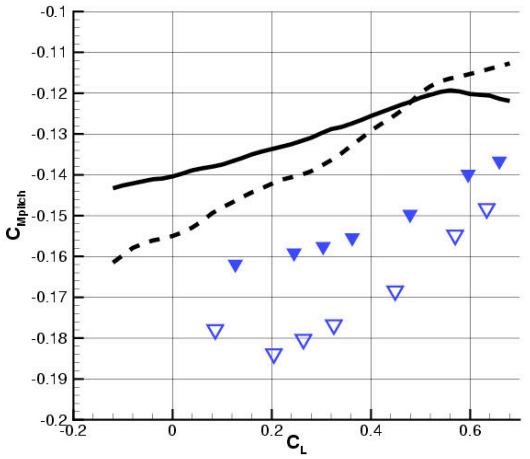
NLR results (ENSOLV)
Case 2: Drag Polar







experiment wing/body
experiment wing/body/nacelle/pylon
case II: wing/body, medium grid, tripped
case II: wing/body/nacelle/pylon, medium grid, tripped

- Mach = 0.75
- Reynolds Number = 3×10^6
- Angle of Attack = -3, -2, -1.5, -1, 0, 1, 1.5°
- "Tripped" solution

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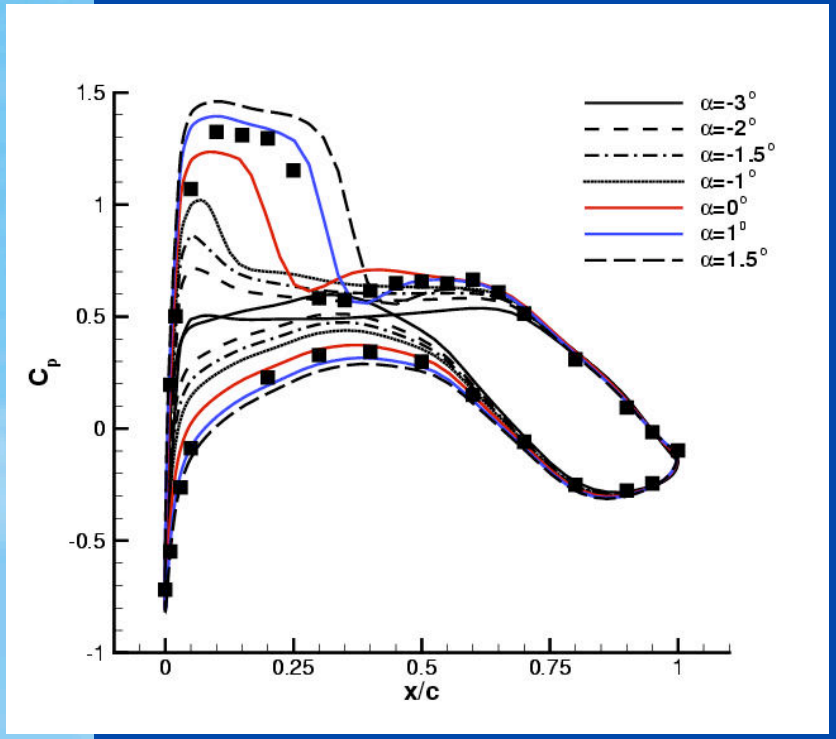
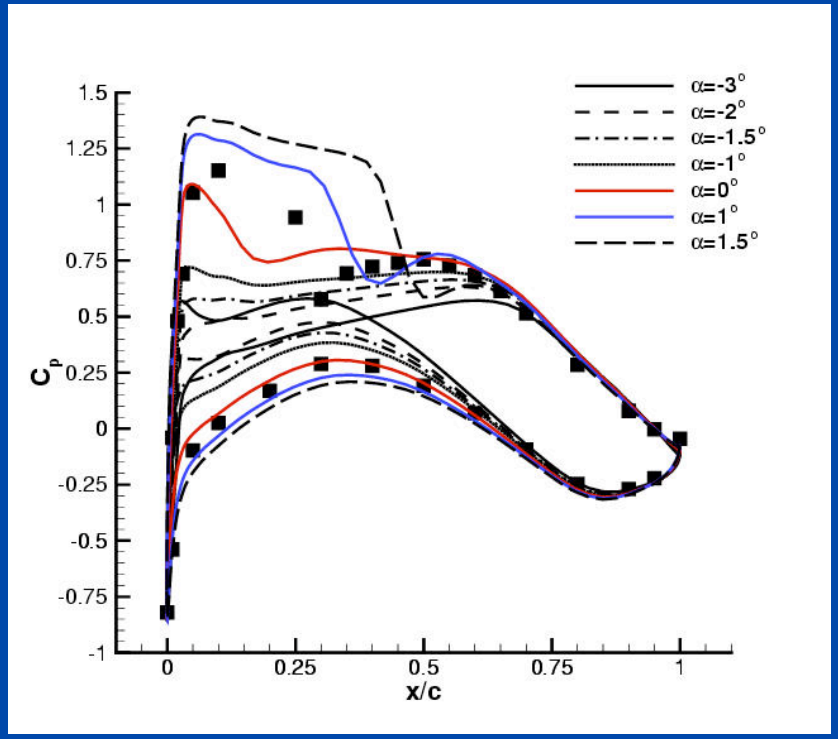
NLR results (ENSOLV)
Case 2: Drag Polar (wb)



y/b=0.331



y/b=0.514

Experiment
Alpha=0.490 CL=0.4984

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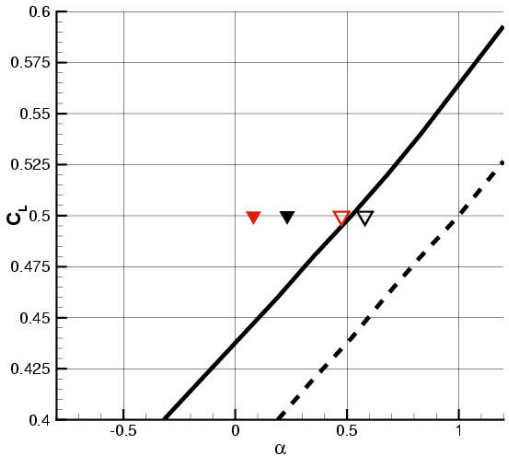
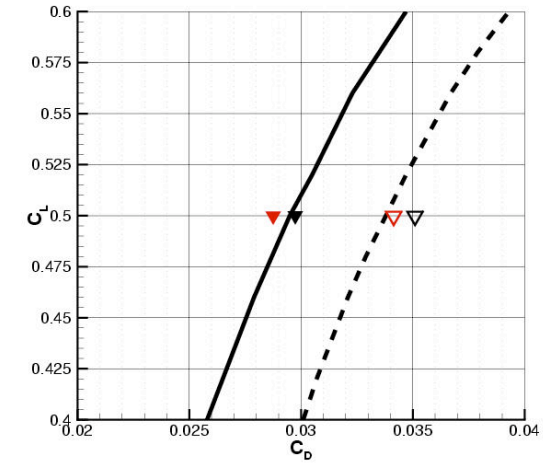
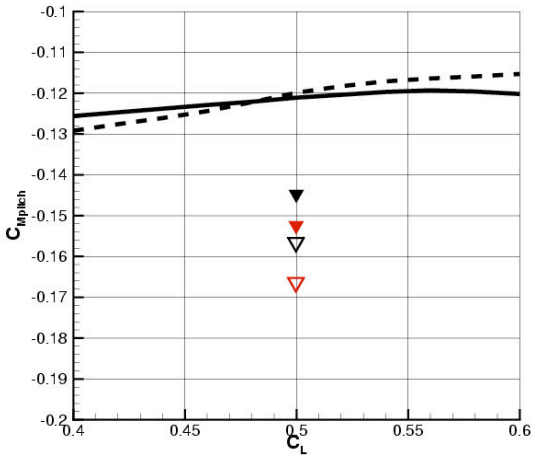
NLR results (ENSOLV)
Case 3: Effect of transition







experiment wing/body
experiment wing/body/nacelle/pylon
case I: wing/body, medium grid, fully turbulent
case I: wing/body/nacelle/pylon, medium grid, fully turbulent
case III: wing/body, medium grid, tripped
case III: wing/body/nacelle/pylon, medium grid, tripped

- Mach = 0.75
- Reynolds Number = 3×10^6
- Lift Coefficient = 0.500±0.001
- "Fully turbulent" vs. "Tripped" solution

C_D installation

Turbulent:	0.0054
Tripped:	0.0054

Experiment: 0.0043

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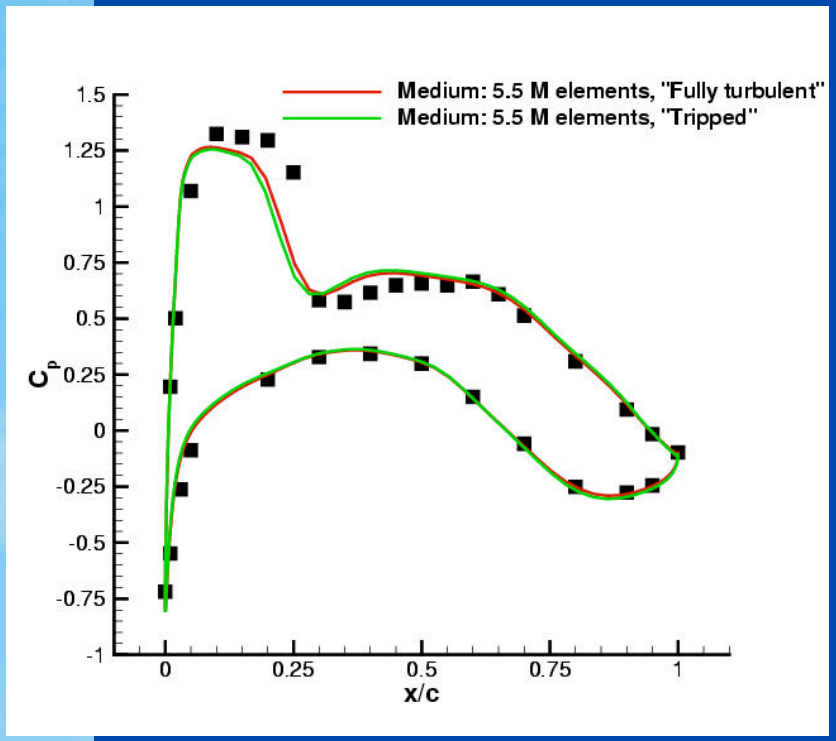
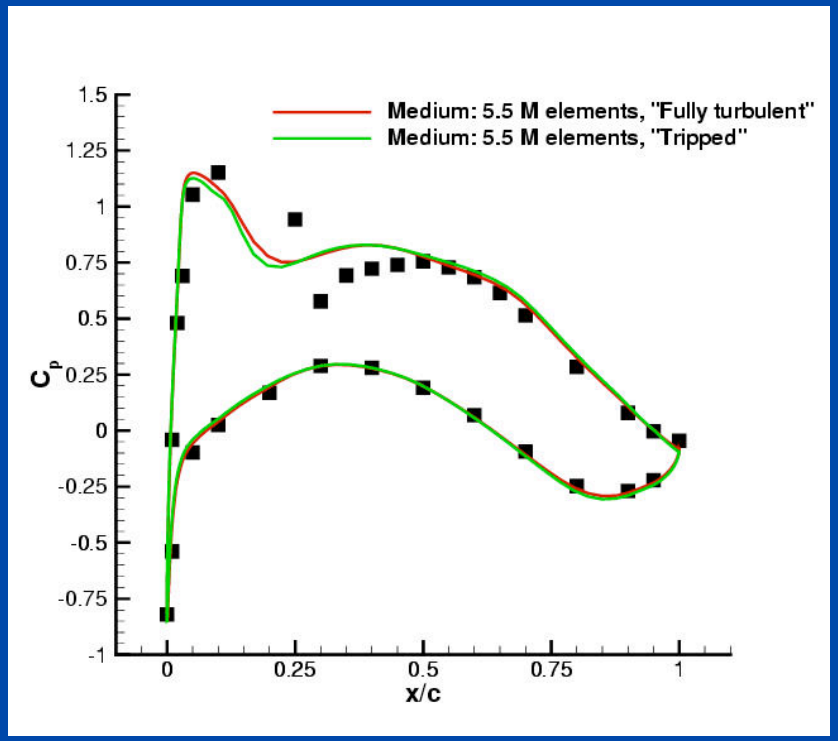
NLR results (ENSOLV)
Case 3: Effect of transition





y/b=0.331 **Experiment** **y/b=0.514**
Alpha=0.490 CL=0.4984