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

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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 $\bar{\omega} = 1/(\bar{\omega} + \bar{\omega}_0)$ instead of $\bar{\omega}$, to remove singular behaviour of $\bar{\omega}$ at solid walls
  - Production term in k-equation has been limited to prevent unphysical high values of k near stagnation point
NLR results (ENSOLV)

Grid

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

- Coarse: 3.3 M elements
- Medium: 5.5 M elements
- Fine: 10 M elements
- Coarse: 4.5 M elements
- Medium: 8.3 M elements
- Fine: 13.7 M elements
NLR results (ENSOLV)

Solution information

<table>
<thead>
<tr>
<th></th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Const. CL</th>
<th>CPU (h)</th>
<th>Mem (GByte)</th>
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<td>1000 (1 MG)</td>
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- **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)**
**NLR results (ENSOLV)**

**Case 1: Single point grid convergence study**

- **Mach = 0.75**
- **Reynolds Number = 3x10^6**
- **Lift Coefficient = 0.500±0.001**
- **“Fully turbulent” solution**

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<table>
<thead>
<tr>
<th>Grid Type</th>
<th>CD</th>
<th>C_D Installation</th>
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<tbody>
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<td>Coarse</td>
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<tr>
<td>Medium</td>
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<td>Fine</td>
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<tr>
<td>Experiment</td>
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</tbody>
</table>
NLR results (ENSOLV)

Case 1: Single point grid convergence study (wb)

\( y^+ \)

\( C_p \)

Coarse: 3.3 M elements

Medium: 5.5 M elements

Fine: 10 M elements

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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
Alpha=0.490 CL=0.4984

y/b=0.514

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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 $h=0.844$
  - 5% chord at tip

NLR results (ENSOLV) Trip location

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NLR results (ENSOLV)
Case 2: Drag Polar

- Mach = 0.75
- Reynolds Number = 3x10^6
- 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)

**Experiment**

- \( y/b = 0.331 \)
- Alpha = 0.490
- CL = 0.4984

- \( y/b = 0.514 \)

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**NLR results (ENSOLV)**

**Case 3: Effect of transition**

- **Mach = 0.75**
- **Reynolds Number = 3x10^6**
- **Lift Coefficient = 0.500 ± 0.001**
- “Fully turbulent” vs. “Tripped” solution

<table>
<thead>
<tr>
<th>CD Installation</th>
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</thead>
<tbody>
<tr>
<td>Turbulent: 0.0054</td>
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<tr>
<td>Tripped: 0.0054</td>
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<tr>
<td>Experiment: 0.0043</td>
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</tbody>
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NLR results (ENSOLV)
Case 3: Effect of transition

Experiment
Alpha=0.490 CL=0.4984

y/b=0.331
y/b=0.514

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