Structured Computations on F4 - DLR / EADS

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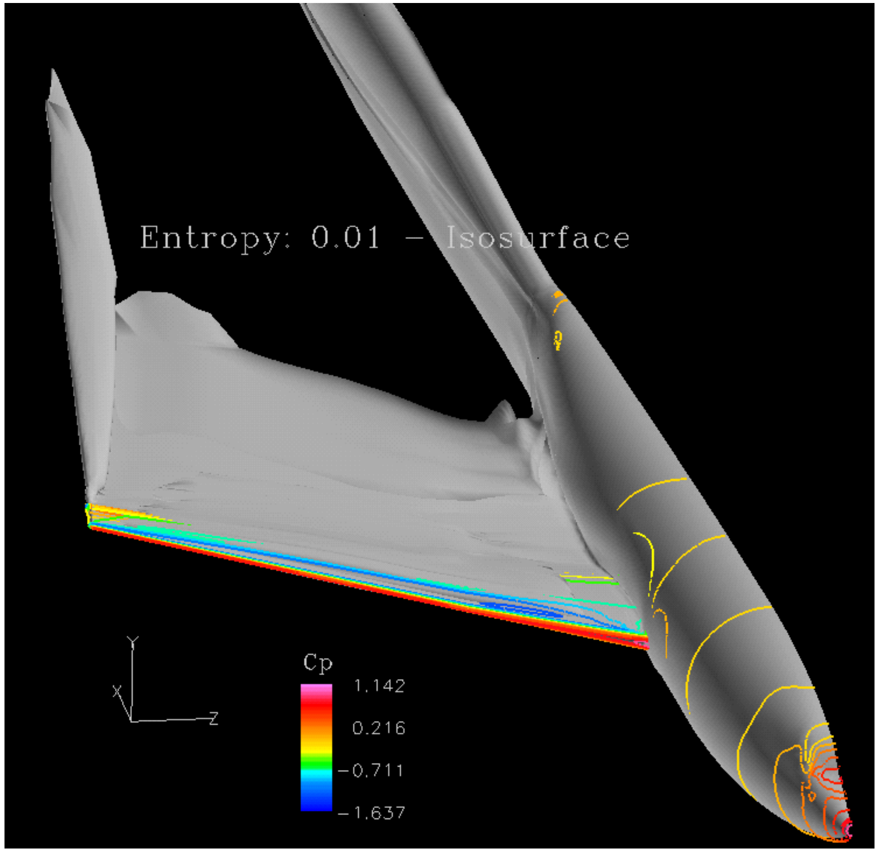

- Introduction
- Grid Generation / Flow Solver
- Results Case 1 - 4
- Additional Work
- Conclusions of Workshop
- Improved Results

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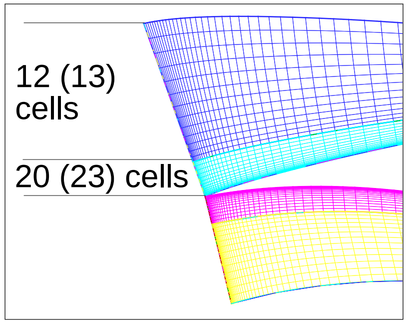
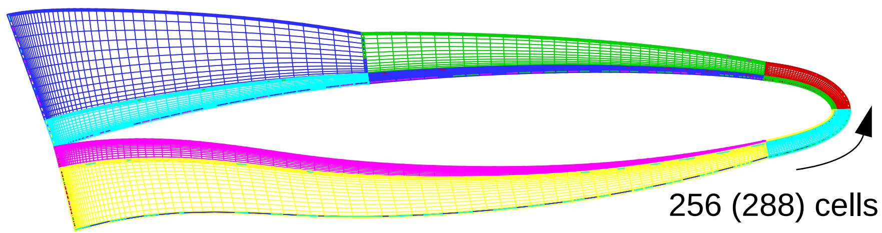
Grid Generation with MegaCads

Parametric generation of 2 grids: 3.5e6 cells and 5e6 cells with COH-topology, elliptic smoothing

Boundary layer adaption (AIAA-87-1302) -> inner BL-block inside BL for polar

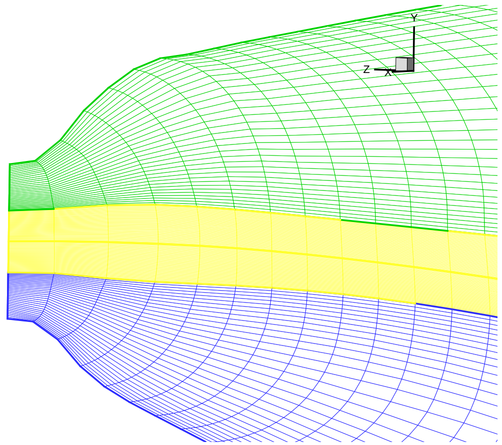


Trailing edge closed with Bézier-splines (AIAA-95-0089), camberline retained



Modification fuselage end -> C-Block around wing

32 (36) cells in fuselage BL-block (turb. flat plate $\delta *$ factor)



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Remarks slide 2:

- The boundary-layer blocks on the wing are divided in an inner and outer part. The inner part is adapted according to a computation of the boundary-layer thickness (AIAA-87-1302) to be in the boundary-layer for the whole polar.
- The thickness of the fuselage boundary-layer blocks is estimated by the turbulent flat plate formula times a factor.
- The wing trailing edge is closed according to AIAA-95-0089. That report shows that blunt trailing edges have to be resolved by 64 cells for 2D transonic flows. In 3D this would lead to an H-block behind the TE with a huge number of high-aspect ratio cells. Closing the TE from 90% of the chord with Bezier-splines and retaining the camber is demonstrated to be a good engineering approximation for transonic airfoil sections.
- The fuselage end is modified with a smooth transition to the symmetry-plane due to the C-block around the wing. The blunt geometry of the fuselage end is retained as much as possible.

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Flow Solver FLOWer

- 3D compressible RANS - eqn. in integral form
- Wilcox kϖ turbulence model
- LEA-kϖ turb. model, mod. for transonic flows (TU Berlin)
- Cell - centered FV - formulation
- Explicit dissipative operator 2nd and 4th differences scaled by the largest eigenvalue (Jameson, Schmidt, Turkel and Martinelli)
  - $\kappa^{(2)}$: 1/2, $\kappa^{(4)}$: 1/64, ζ: 0.67 (scaling due to cell aspect ratio)
- Time integration: explicit hybrid multistage Runge-Kutta scheme
- Acceleration: multigrid, local time stepping, implicit residual averaging
- 2 dummy layers at block intersections, 2nd order accurate in space on smooth meshes

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Remarks slide 3:

- due to stability problems with the cell-vertex mode on the mandatory workshop grid in the beginning of this study, ζ was set too high. This caused an unneccessary high level of drag for ‘Results Case 1 - 4’.
- In chap. ‘Additional Work’ and ‘Improved Computation’ (performed after the workshop), ζ was corrected to 0.2, which caused a decrease in drag.
- The influence of the scaling of artificial dissipation due to cell aspect ratio is demonstrated on slides 9 and10.

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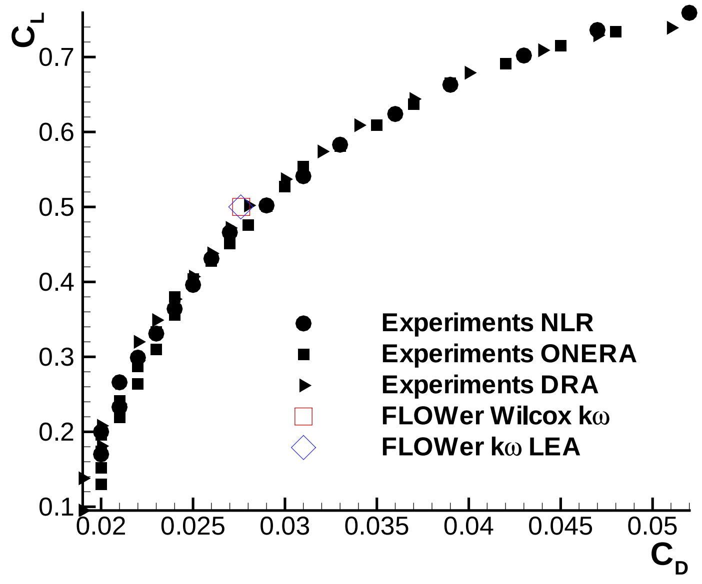
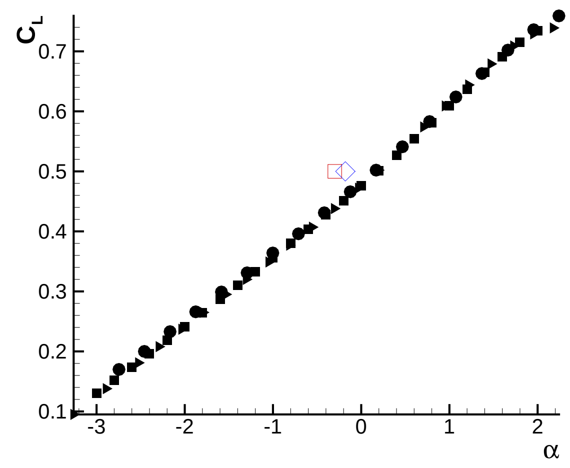
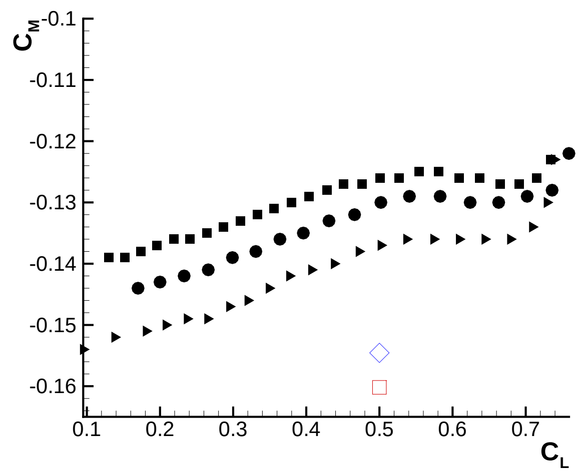
Case 1 (Ma: 0.75, CL: 0.5, Re: 3e6)



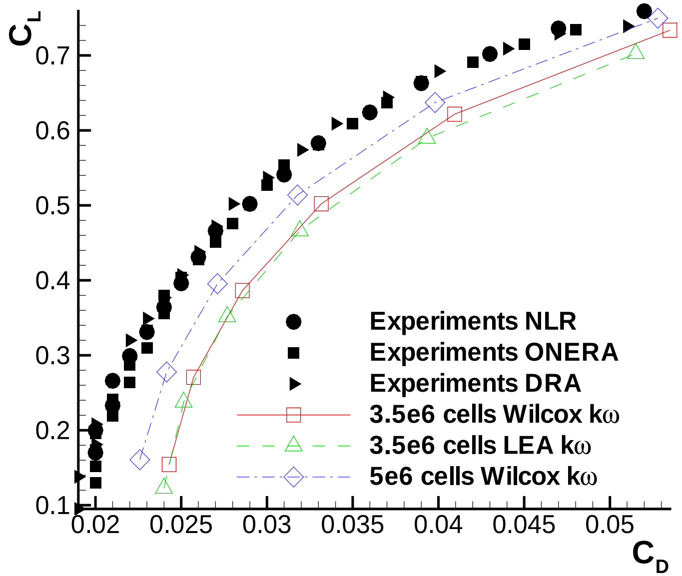


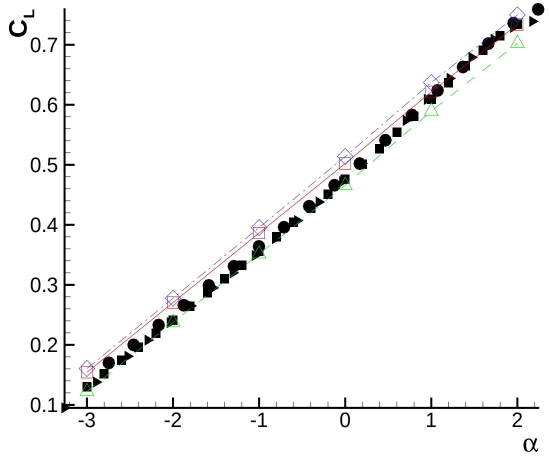


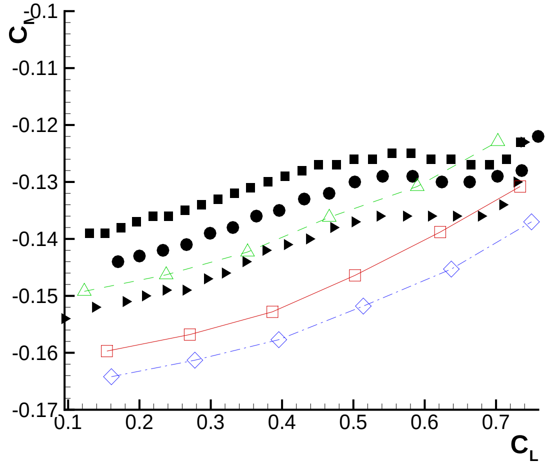
Remarks slide 4:

- Influence of turbulence model on the mandatory grid computations.
- Almost no difference in drag, slight improvement in $C_L(\alpha)$ and $C_M(C_L)$ for the LEA-kω model compared to Wilcox kω.

Case 2 (Ma: 0.75, Re: 3e6, DLR grids)







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Remarks slide 5:

- Influence of mesh size and turbulence model on DLR grid computations.
- The drag polar on the 3.5e6 cells grid shows only minor differences for the two turbulence models. The 5e6 cells grid has a reduced drag level compared to the coarser grid.
- $C_L(\alpha)$ and $C_M(C_L)$ for the LEA-kω model are much better compared to Wilcox kω on the 3.5e6 cells grid.

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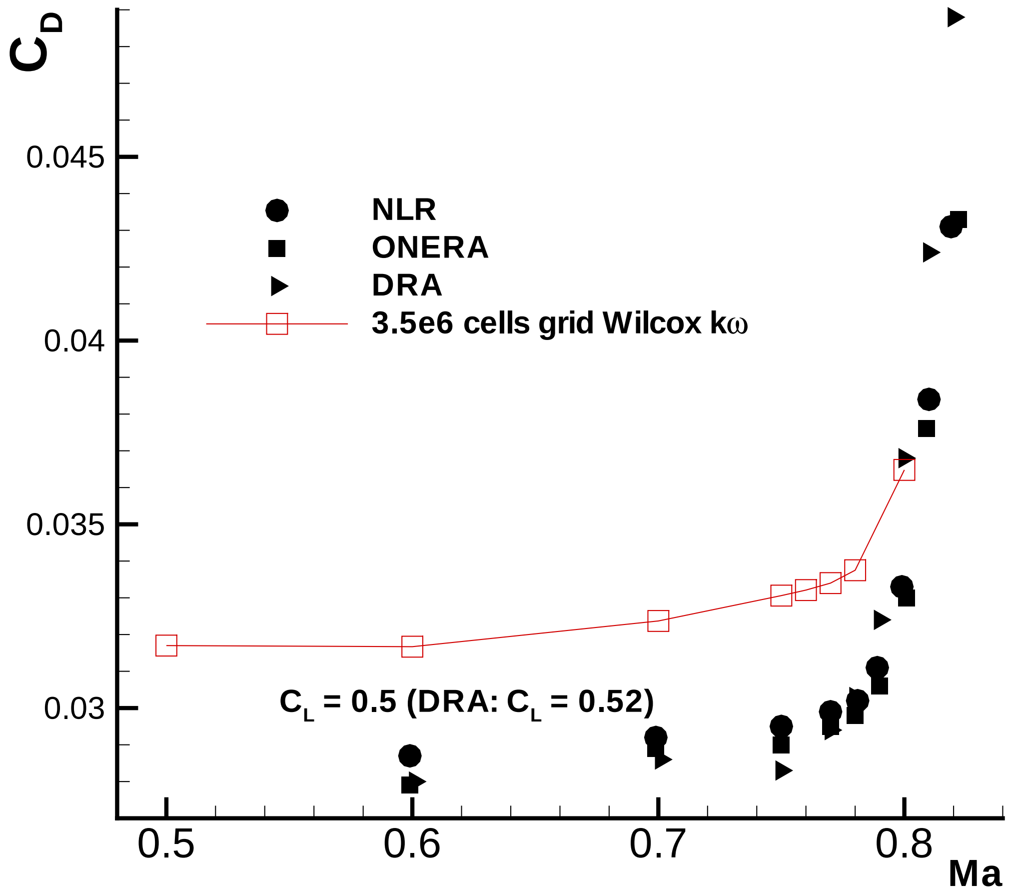
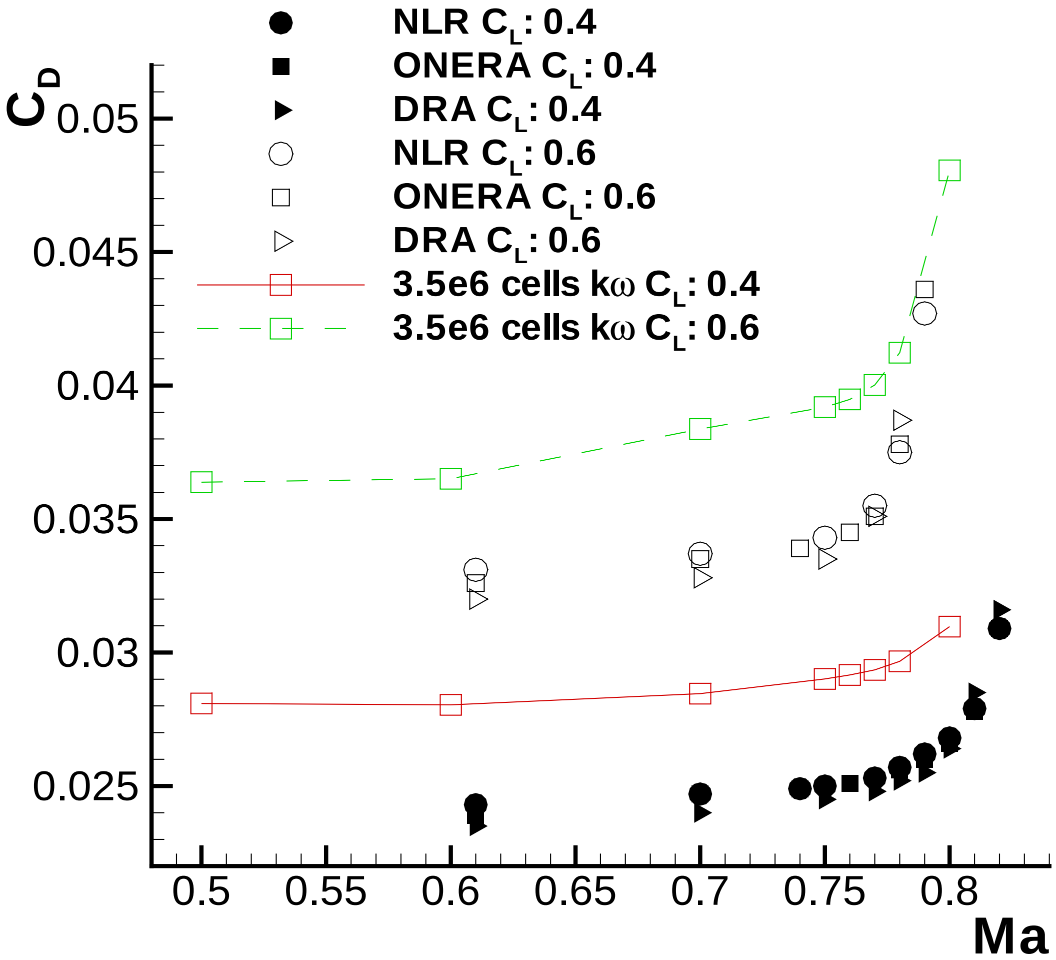
Case 3 (CL: 0.5, Re: 3e6, DLR 3.5e6 cells grid)



Case 4 (C_L:0.4/0.6, Re: 3e6, DLR 3.5e6 cells grid)



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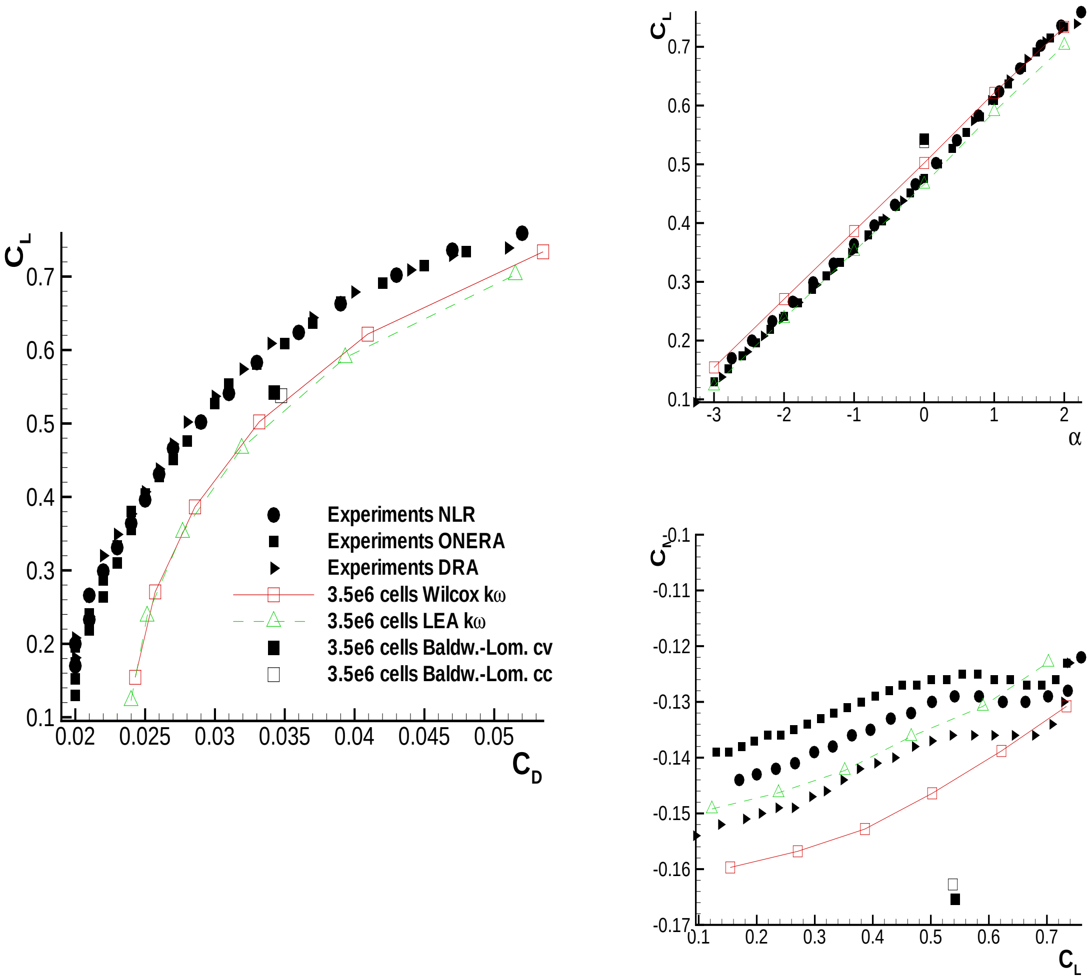
Remarks to slide 6 and 7:

- The level of drag for the drag rise curves is too high due to the aforementioned (remarks slide 3) high level of numerical dissipation.
- The shape of the experimental curves is captured quite well.

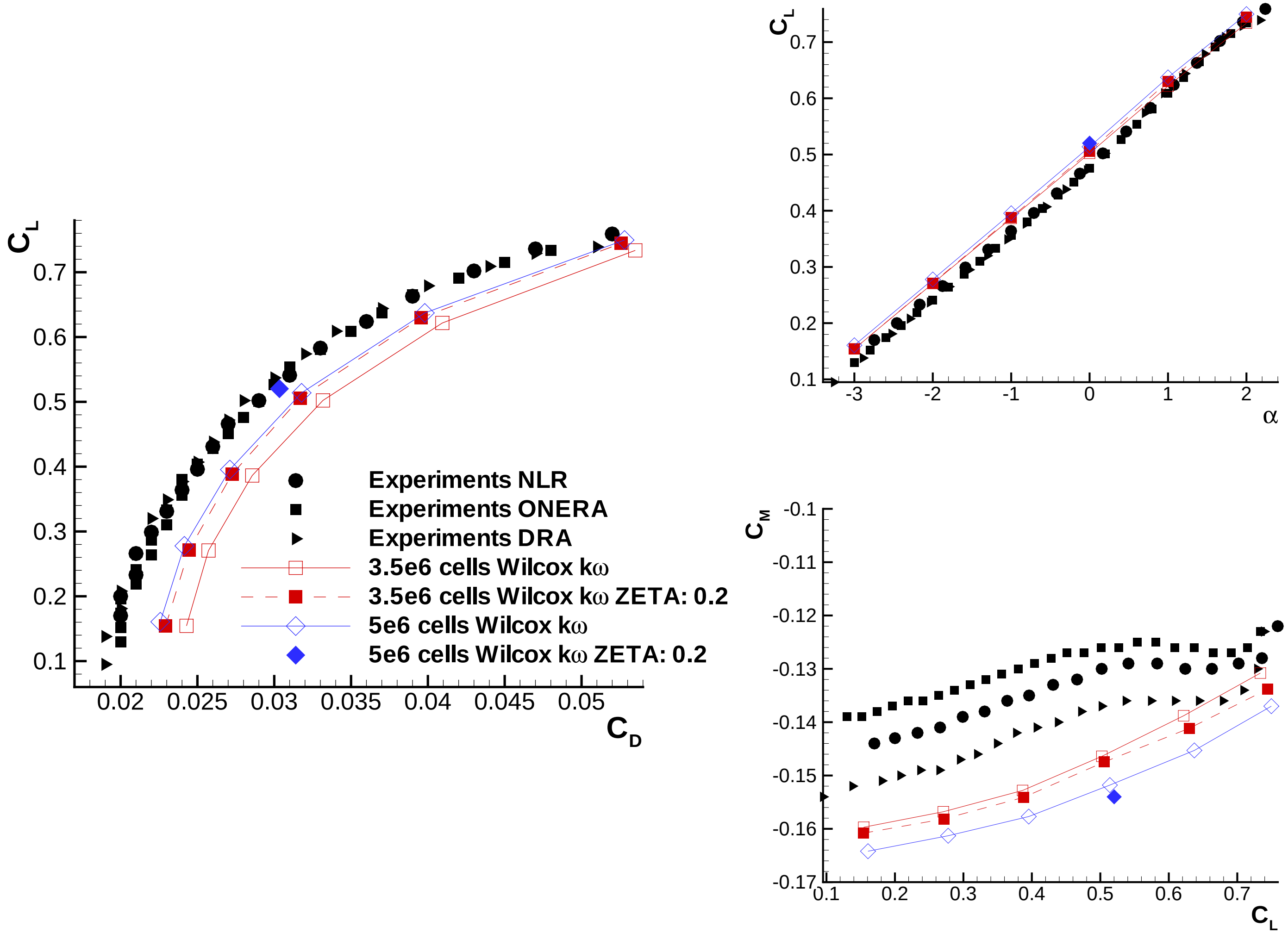
Influence Turbulence Modelling (Ma: 0.75, Re: 3e6, DLR 3.5e6 cells grid)



Remarks slide 8:

- The LEA-kω model shows an improved behaviour concerning $C_L(\alpha)$ and $C_M(C_L)$ compared to the Wilcox-kω model.
- Here it can be seen that the offset in drag is not caused by the turbulence models (check with Baldwin-Lomax).
- The turbulence model has a noticeable influence on $C_L(\alpha)$ and a very significant influence on $C_M(C_L)$ (check LEA-, Wilcox-kω and Baldwin-Lomax results)

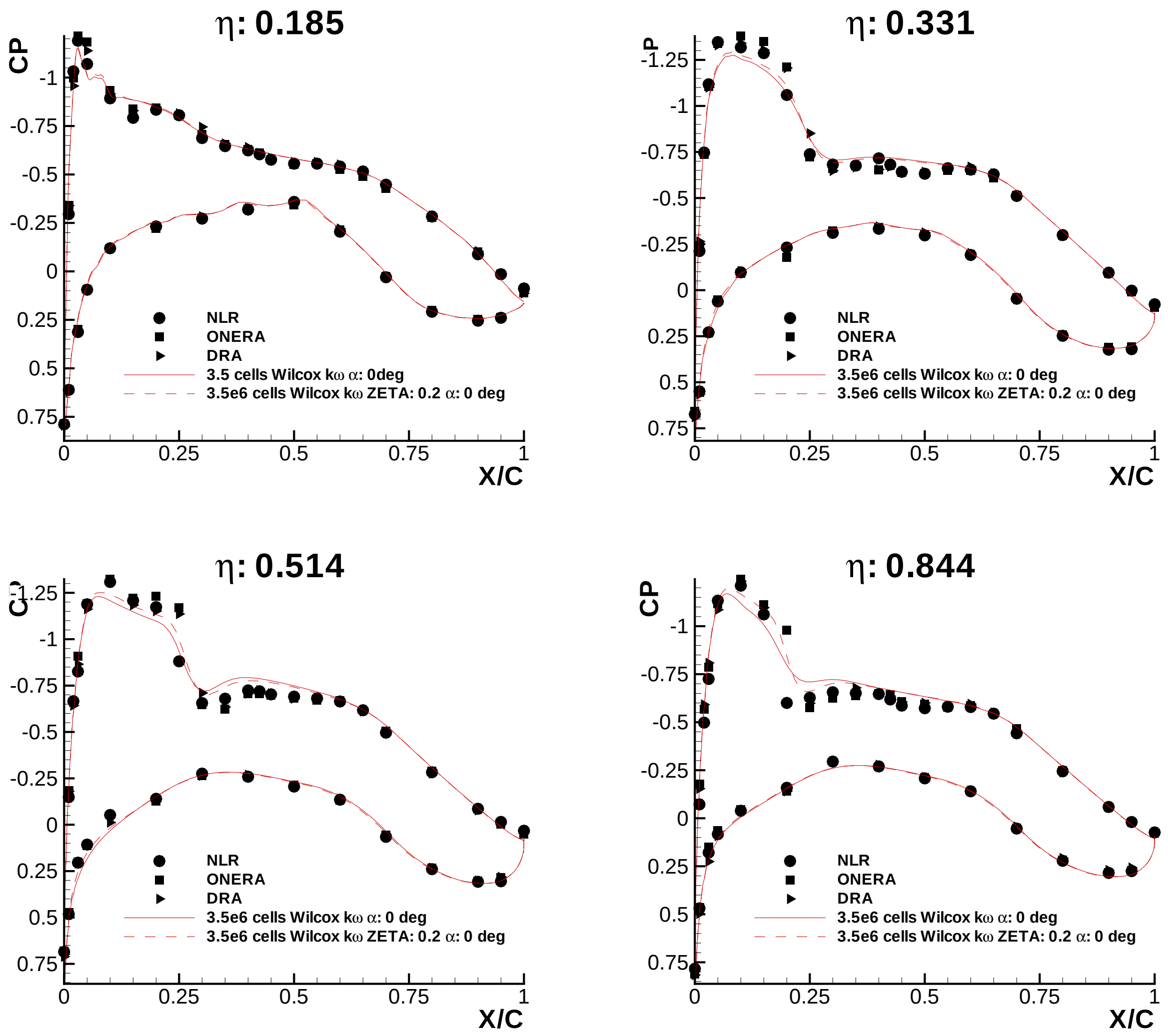
Influence Num. Dissipation (Ma: 0.75, Re: 3e6, DLR grids)



Remarks slide 9:

- Here the influence of the scaling parameter ζ (ZETA) on drag is demonstrated for ζ: 0.67 (higher drag) and ζ: 0.2 for the two DLR grids. The lower ζ moves the polar to a lower drag level.
- $C_L(\alpha)$ and $C_M(C_L)$ change only slightly due to ζ.

Influence Num. Dissip. (Ma: 0.75, Re: 3e6, α: 0 deg, ZETA: 0.2/0.67, DLR grid)



Remarks slide 10:

- From η: 0.331 the rooftop moves up and the shock steepens due to the lower artificial viscosity.

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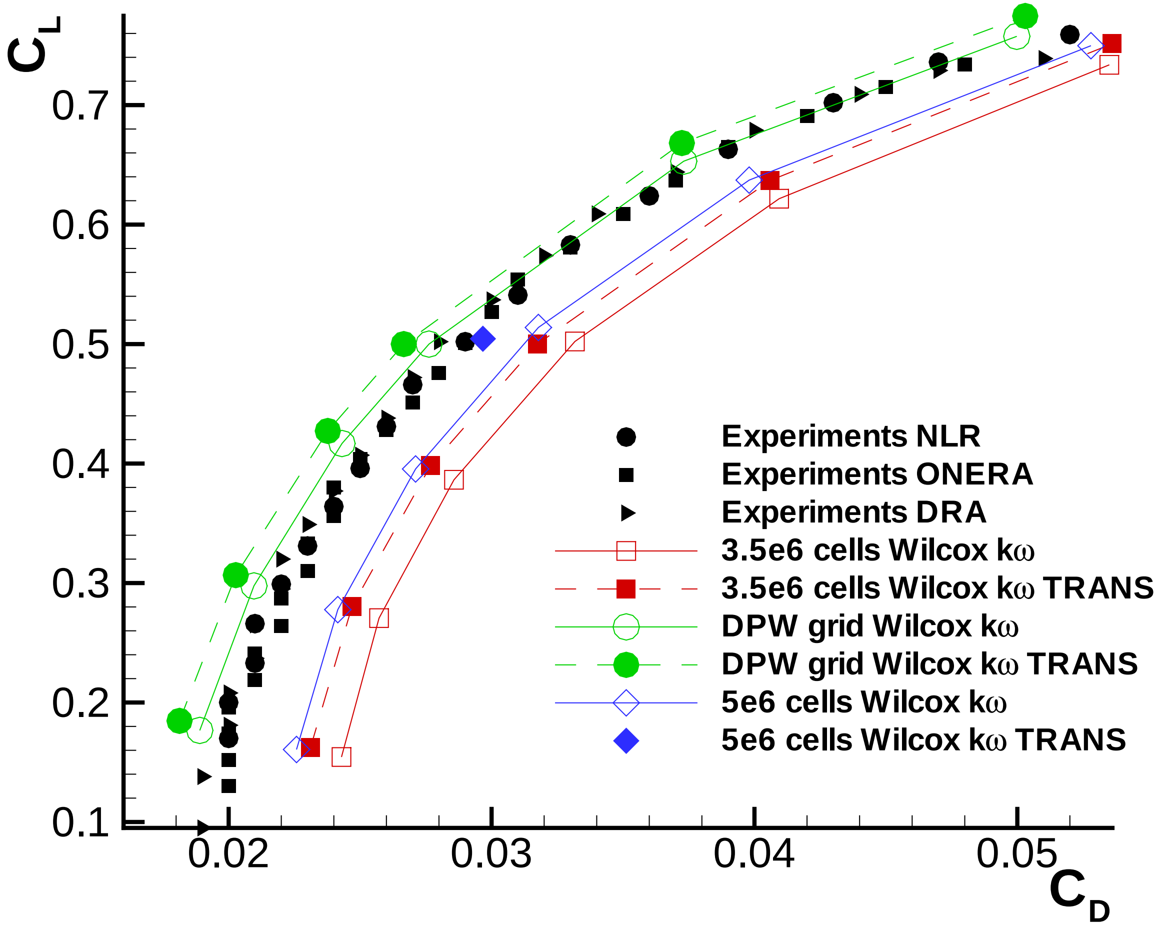
Influence Transition and Mesh (Ma: 0.75, Re: 3e6, DPW and DLR grids)



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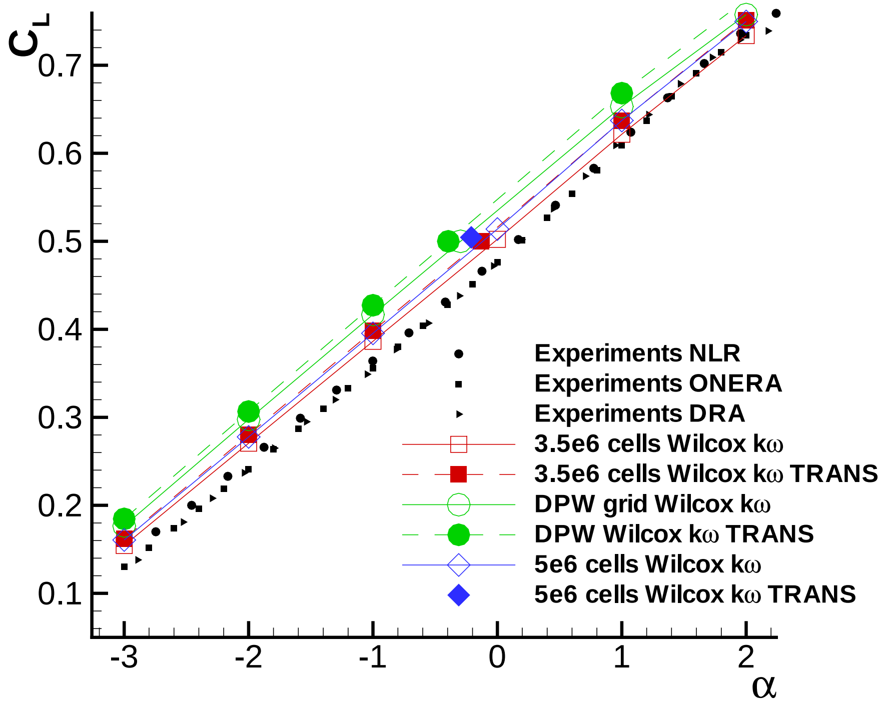
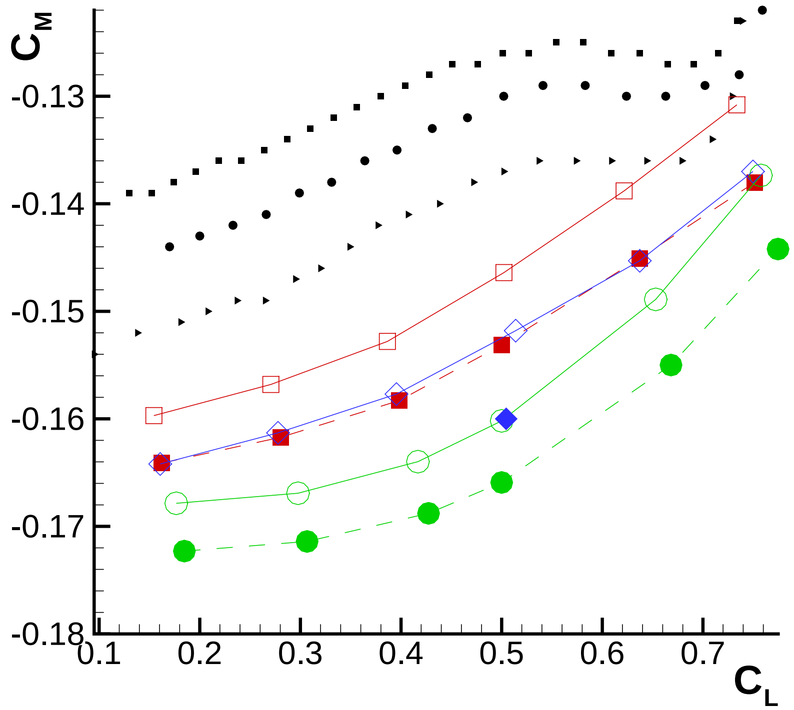
Remarks slide 11:

- Computations with transition (all computations here with transition use the experimental transition strip locations) have about 5% less drag than fully turbulent calculations.
- The DPW grid computation without transition compares well with experiment (which uses transition strips) and gets worse when using the experimental transition locations.
- The two DLR grid computations improve when using transition compared to the experimental polars. The fine grid solution (blue diamond) is very close to the polar.

Influence Transition and Mesh (Ma: 0.75, Re: 3e6, DPW and DLR grid)

C_L - α and C_M - C_L

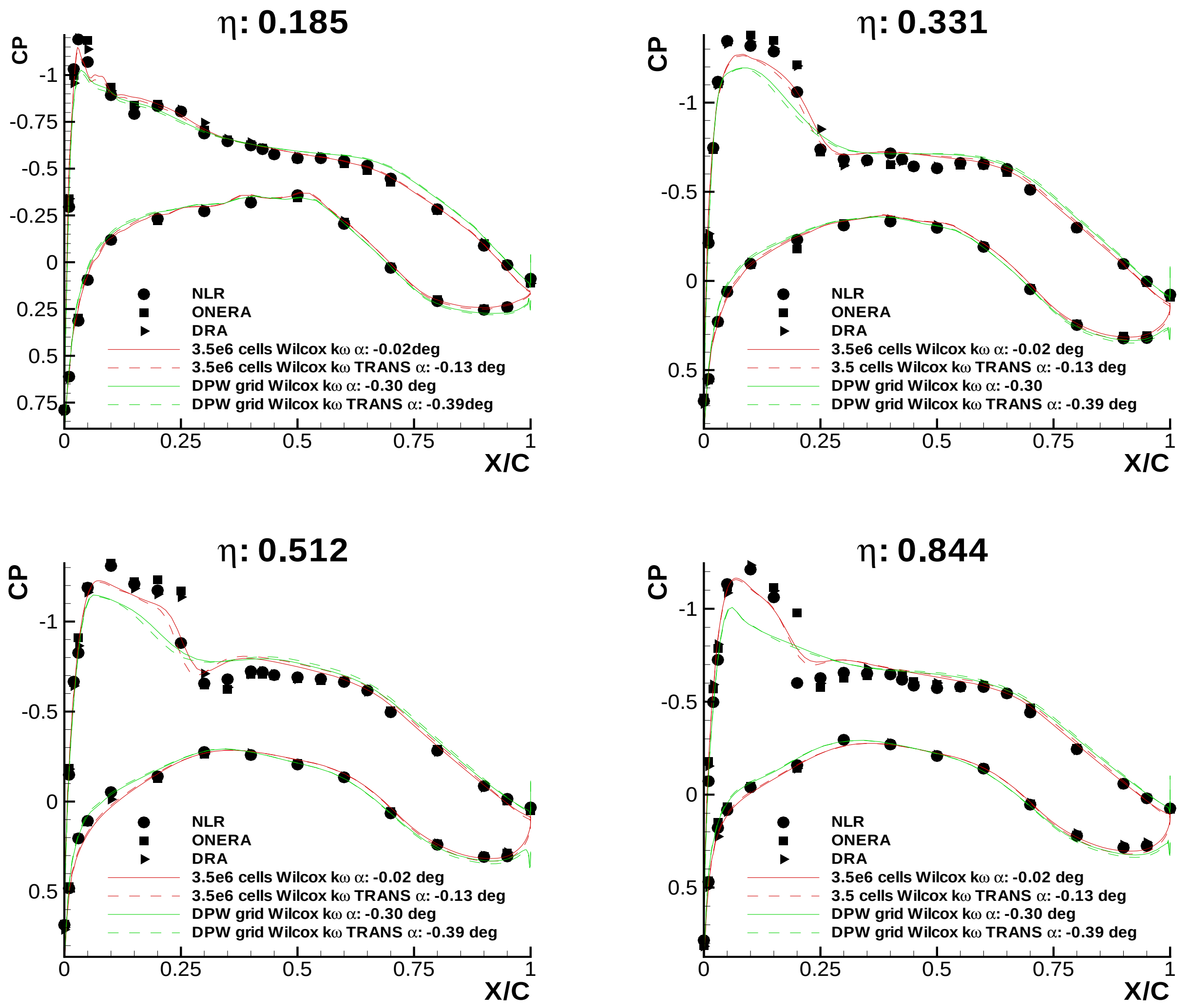




Remarks slide 12:

- For $C_L(\alpha)$ and $C_M(C_L)$ the comparison to experiment deteriorates for all three grids when using transition.

Influence Trans. and Mesh (Ma: 0.75, Re: 3e6, C_L: 0.5, DPW and DLR grid)



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Remarks slide 13:

- For C_L= 0.5 the influence of transition on the wing pressure distributions is small, because of an adjustion of the angle of attack.
- The grid quality (3.5e6 cells grid DLR compared to 3.2e6 cells DPW grid) is dominant.

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Conclusions

Drag influencing factors:

- Turbulence model: slight influence on drag, main influence on $C_L(\alpha)$ and $C_M(C_L)$. LEA-kω better on $C_L(\alpha)$ and $C_M(C_L)$ compared to Wilcox kω.
- Transition: ~ 5% reduction of drag
- Numerical dissipation: ~ 2-5% reduction of C_D by proper scaling
- Computational grid:
  - ~ 5% reduction of C_D by grid refinement (3.5e6 cells with r: 1.125 -> 5e6 cells)
  - ~ 20 % variation of drag between meshes of similar size (DPW grid: 3.2e6 cells)!

-> Grid quality is dominant

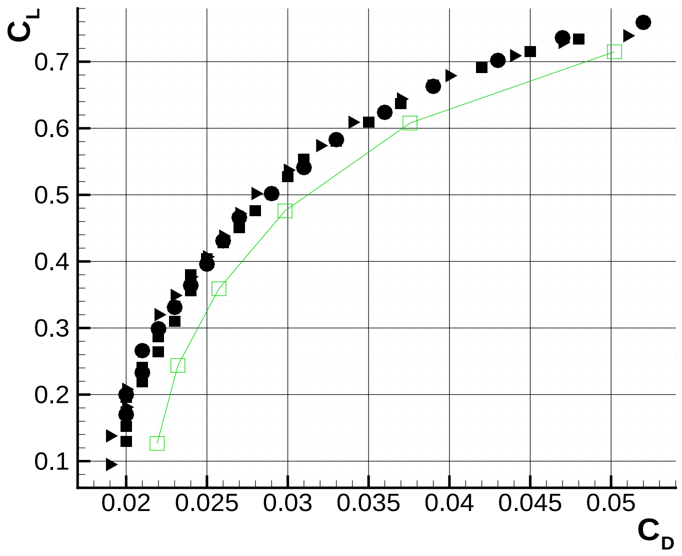
Ongoing research: Grid extrapolations

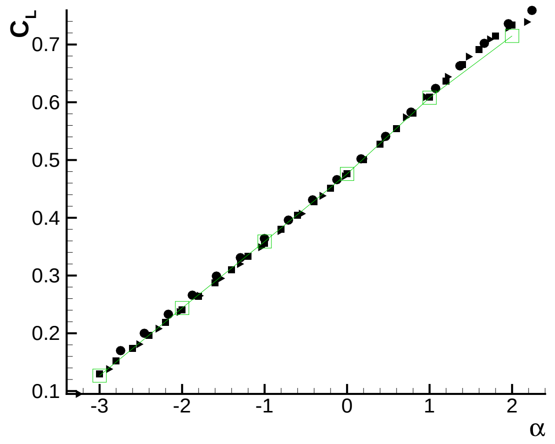
Improved Computation (Ma: 0.75, Re: 3e6, DLR 3.5e6 cells grid)

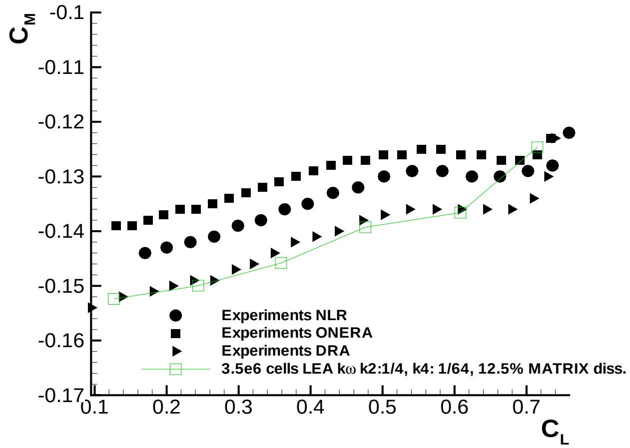
Turbulence model: LEA kω

87.5% scalar dissipation / 12.5% Matrix dissipation
k2: 1/4 k4: 1/64

ζ: 0.2 (scaling due to cell aspect ratio)







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Remarks slide 15:

- As a result of the DPW experience, the computations are carried on with an improved (i.e. low) setting of artificial viscosity and using the LEA-kω turbulence model on the DLR grids.
- The LEA (Linearized Explicit Algebraic Stress) kω turbulence model has a modified anisotropy-factor compared to the Wilcox kω model. It is not a constant any more, but a function of the variables of the mean flow field. The LEA-model is therefore supposed to be more universally valid, especially for nonplanar shear layers.
- The computed drag polar (fully turbulent) above shows an offset of about 20 dc to the experimental polar (transition strips). The influence of transition is a reduction of about 14 dc.
- The computed $C_L(\alpha)$-curve compares very well to the experimental curve up to α: 1 deg and captures the slightly nonlinear behaviour between 0 and 1 deg. The calulated C_L for α: 2 deg is slightly low.
- One conclusion of the workshop was, that it is very difficult to capture the $C_M(C_L)$-curve. There were few computations which had these curves

somewhere in the area of the experiments, but none of these captured the slope of the experimental moments. The picture above shows an encouraging agreement of the computed moment-curve with the DRA-experiment up to α: 1 deg. Another computation for α: 1.5 deg is necessary to show if the simulation is able to capture the change in slope there.

- **Conclusion:** It is possible to achieve high quality CFD results even for the moment-curve by using careful parameter settings for the artificial viscosity, a proper grid and a sophisticated turbulence model. if all these prerequisites are set, global force and moments agree with the experiments as well as detailed pressure distributions (see last slide).

Improved Computation (C_P-distributions on wing)