Drag Prediction for the CRM model using the Edge solver

by

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Overview

- Calculations with Edge solver
  - Hybrid unstructured grids
- Two families of grids computed
  - Provided by DLR, results delivered to DPW
  - In-house grids generated, not delivered yet
    - Grid generation delayed, results only just finalized
- Mandatory Case1
  - Grid convergence study
  - Downwash study

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Selected grids

- Two families of unstructured grids used, from DLR and FOI
- DLR grids generated with SOLAR grid generator

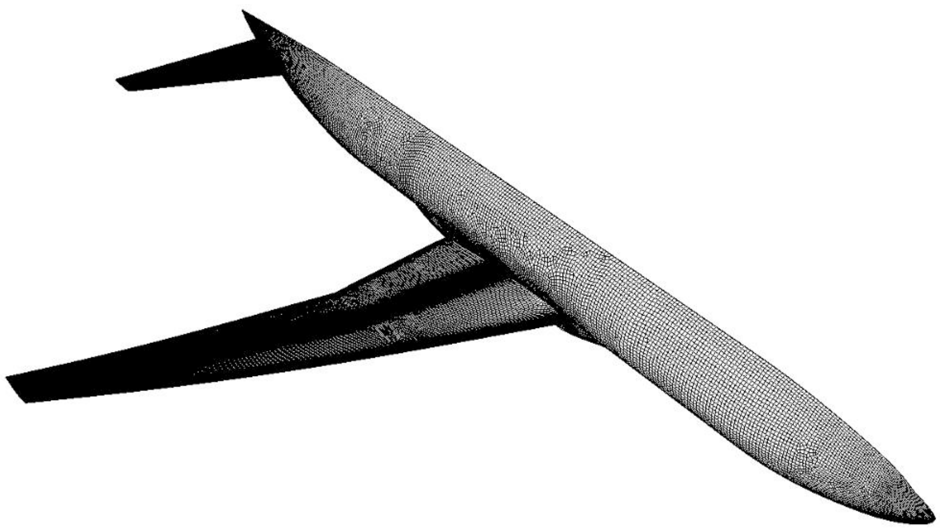
DLR grids, tail 0	Coarse	Medium	Fine
# nodes	4.1×10^6	11.7×10^6	34.1×10^6
# boundary nodes	108×10^3	226×10^3	470×10^3
# hexahedral elements	3.1×10^6	9.2×10^6	72.7×10^6
# prisms	1.8×10^3	3.4×10^3	3.4×10^3
# tetrahedral elements	5.3×10^6	14.3×10^6	38.6×10^6

- FOI grid generated with in-house grid generator Tritet

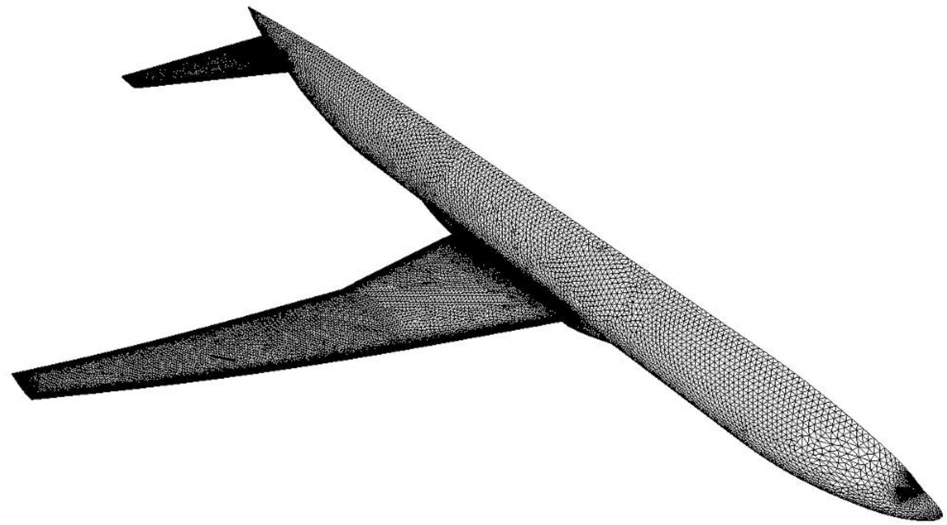
FOI grids, tail 0	Coarse	Medium	Fine
# nodes	3.2×10^6	10.1×10^6	32.1×10^6
# boundary nodes	153×10^3	336×10^3	734×10^3
# hexahedral elements	0	0	0
# prisms	5.5×10^6	18.3×10^6	59.1×10^6
# tetrahedral elements	1.7×10^6	4.1×10^6	10.9×10^6

Grid pictures

DLR medium grid, tail 0

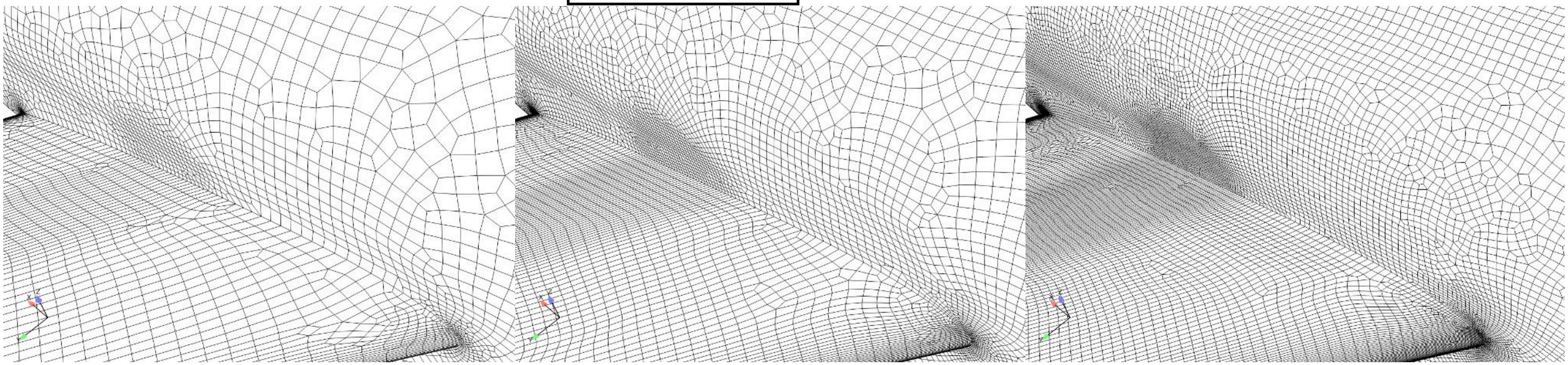


FOI medium grid, tail 0

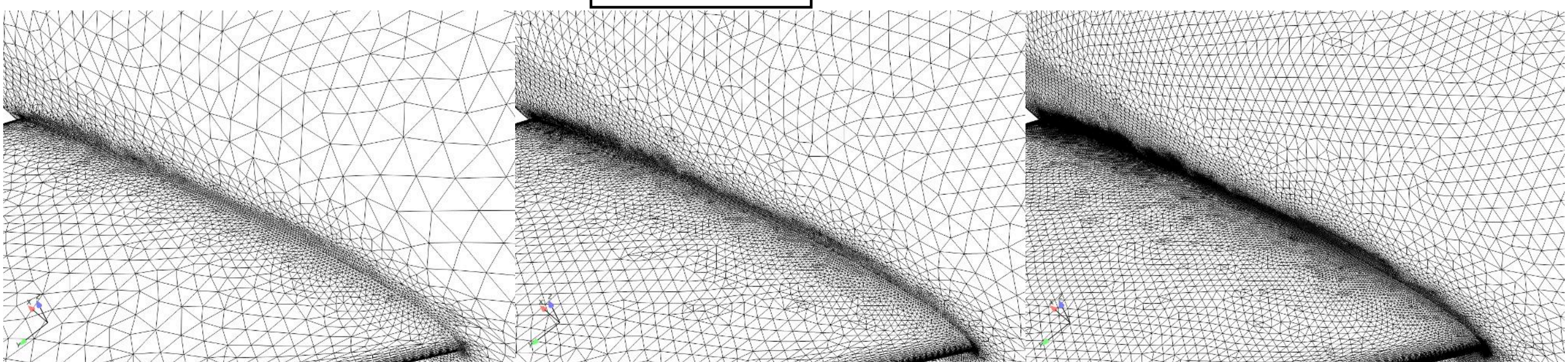


Grid pictures, WB junction

DLR grids, tail 0

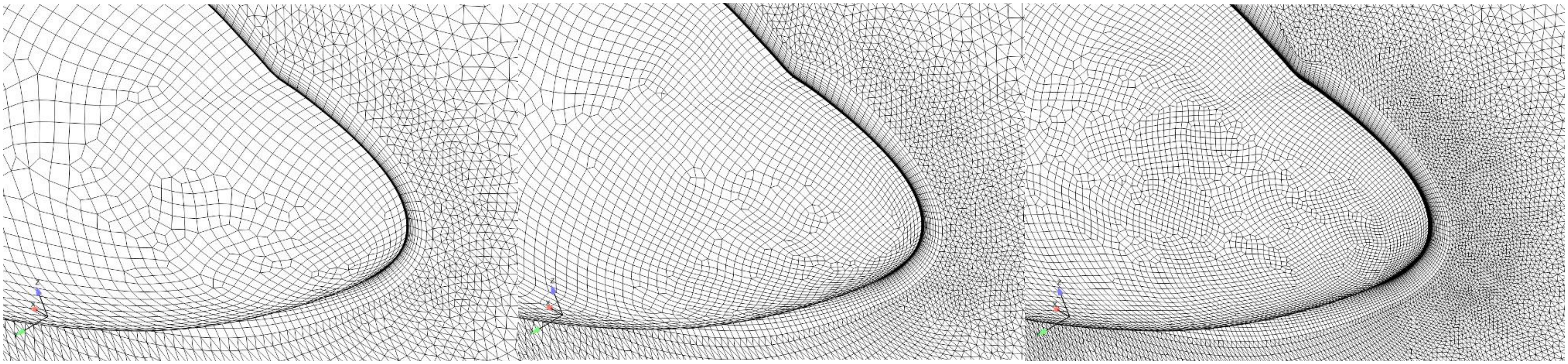


FOI grids, tail 0

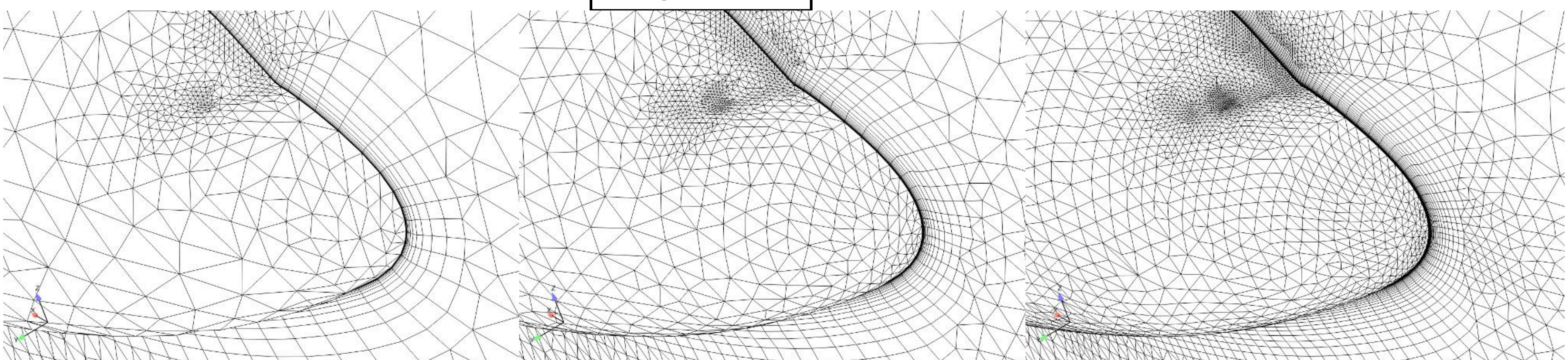


Grid pictures, nose

DLR grids, tail 0

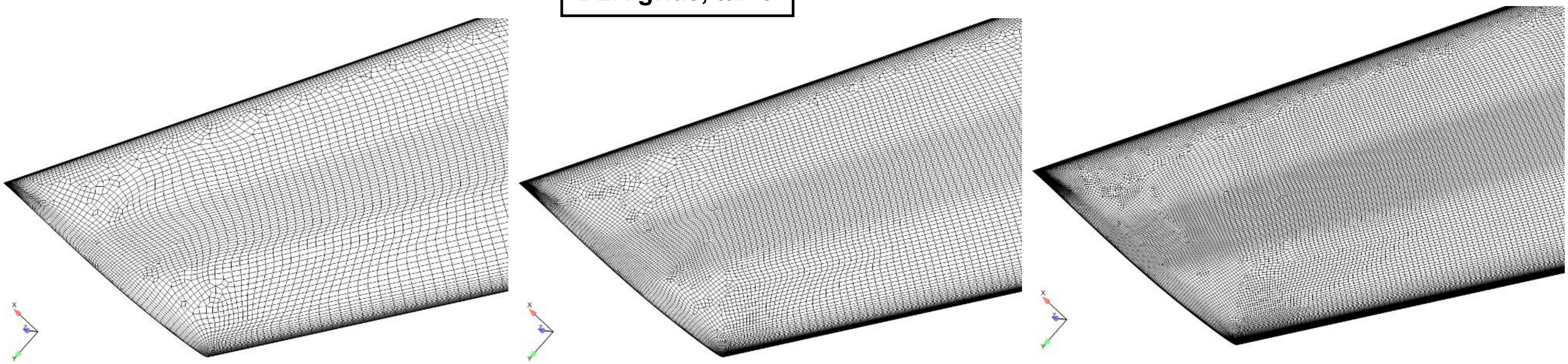


FOI grids, tail 0

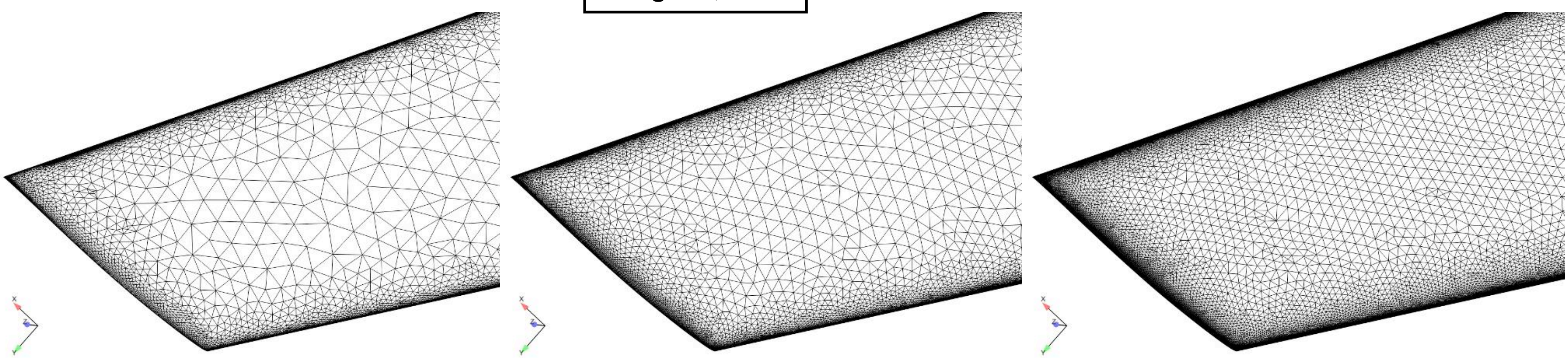


Grid pictures, wing tip

DLR grids, tail 0



FOI grids, tail 0



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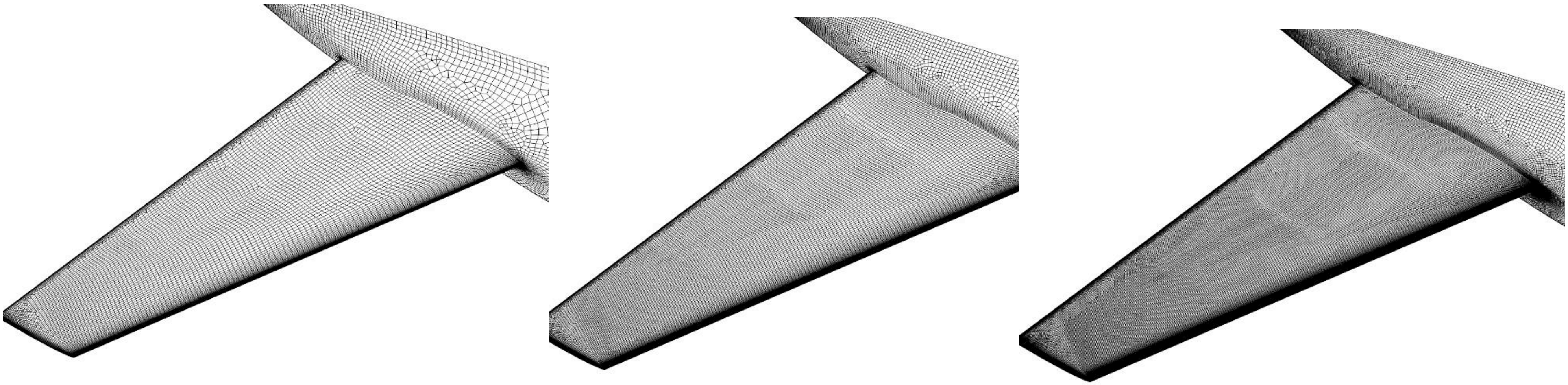
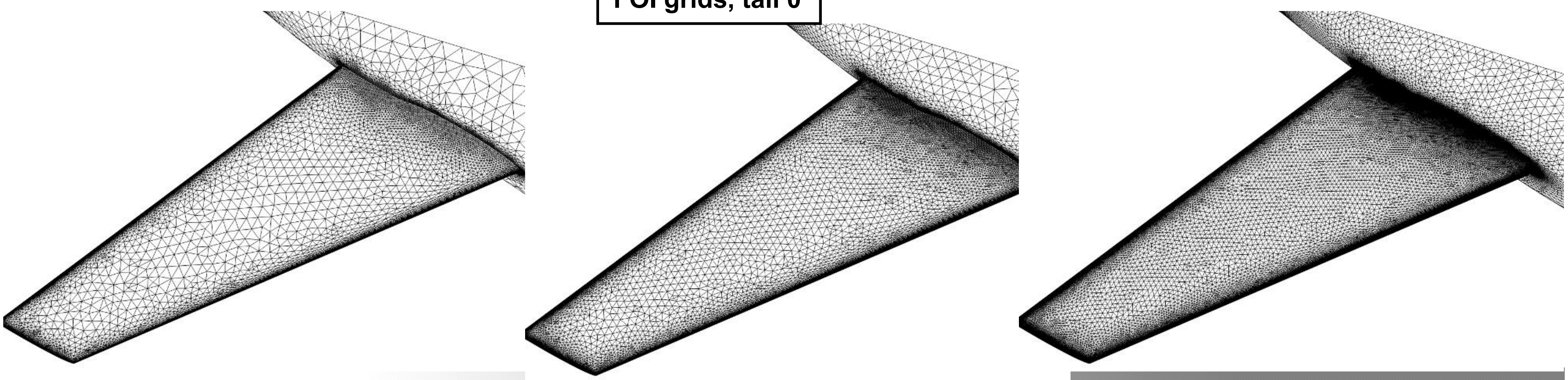
Grid pictures, tail

DLR grids, tail 0



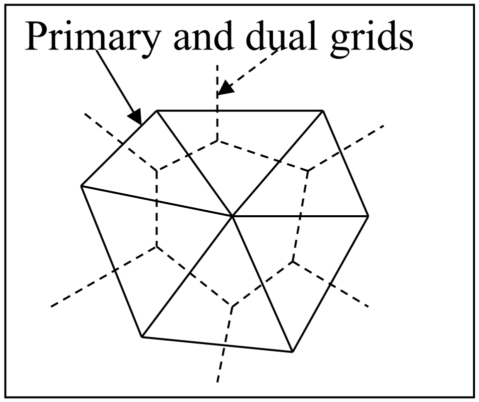
FOI grids, tail 0

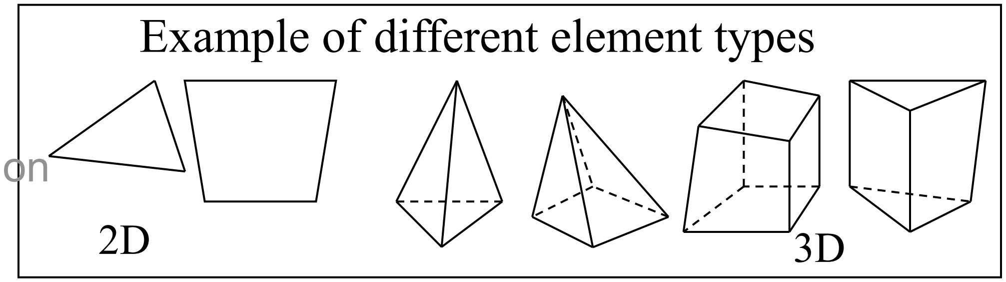


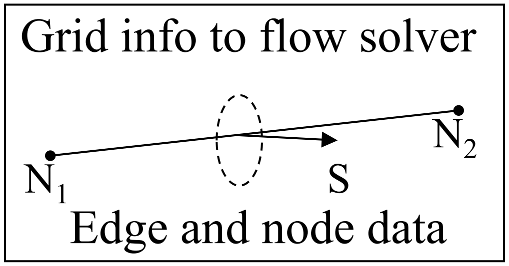
Edge solver

Edge – a Navier-Stokes solver for unstructured grids

- Solves the compressible NS equations
- RANS/RANS-LES/LES solver
- Node-centered/ finite-volume formulation
- Edge based formulation with median dual grids
- Runge-Kutta time integration
- Agglomeration multigrid
- Parallel with MPI
- Dual time stepping for unsteady extension
- High temperature extension
- Low speed preconditioning
- Aeroelastic capability
- Grid adaptation
- Adjoint solver for shape optimization







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Computational information

Computational settings

- Hellsten k-ω EARSM for the turbulence (AIAA Journal, Vol. 43, 2005)
  - Grid convergence calculations with k-ω SST
- 3-4 level W-cycles, full multigrid
  - Semi coarsening, 1:4
- 3-stage Runge-Kutta scheme, CFL=1.25
- Central scheme with artificial dissipation for mean flow and turbulence
- Full NS, compact discretization of normal derivatives
- Linux cluster used, up to 64 processors
  - Computing time ~ (64*) 6 hours for finest grids (~33 M nodes)

New since previous workshop

- Line-implicit time integration
- Weak boundary conditions on all variables including no-slip velocity
  - AIAA 2009-3551, presented on Monday June 22, 9.30
- Central discretization of turbulent equations

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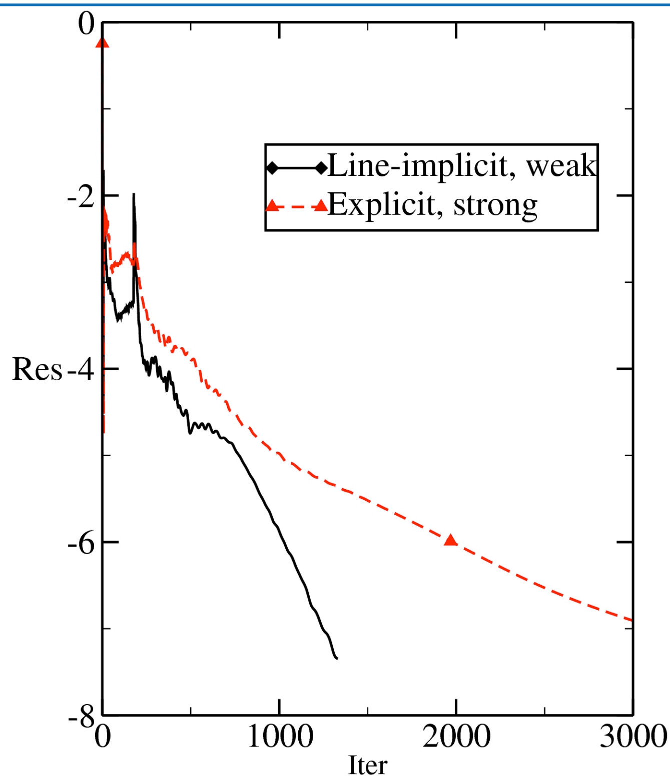
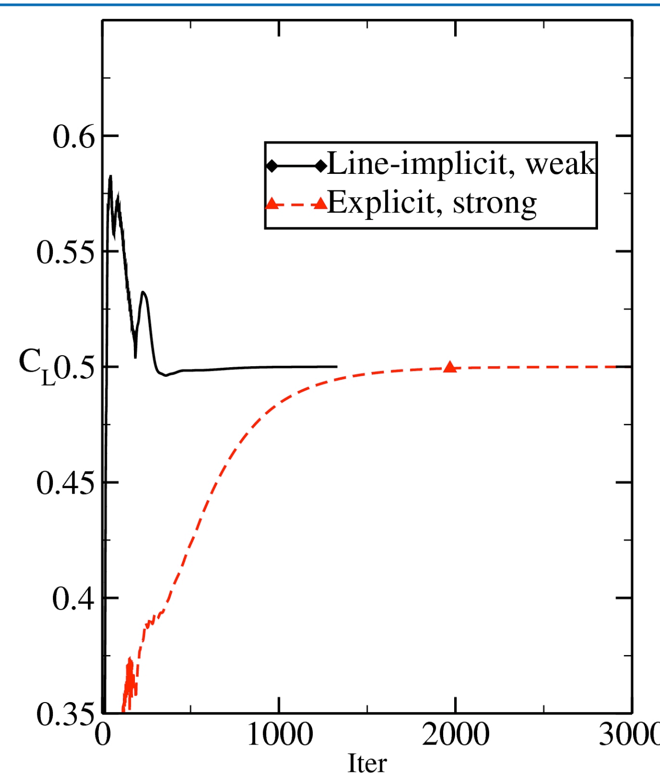
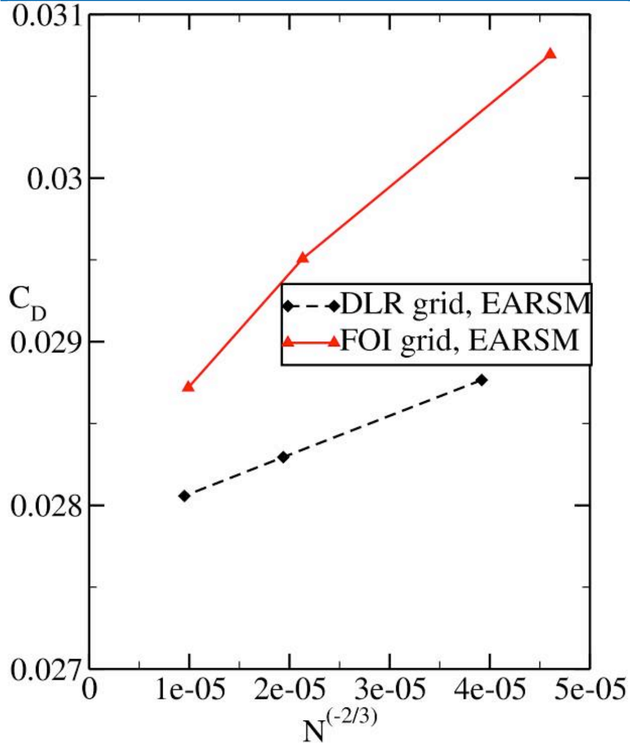
Steady state convergence

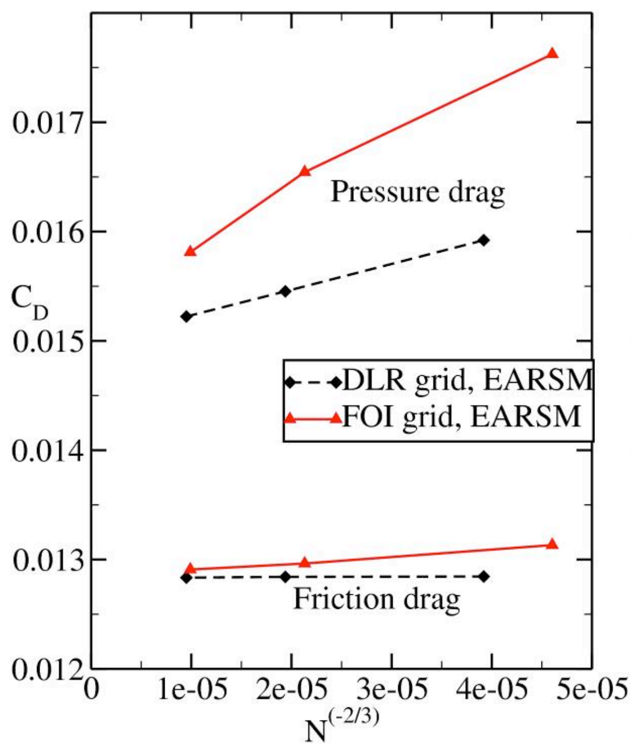


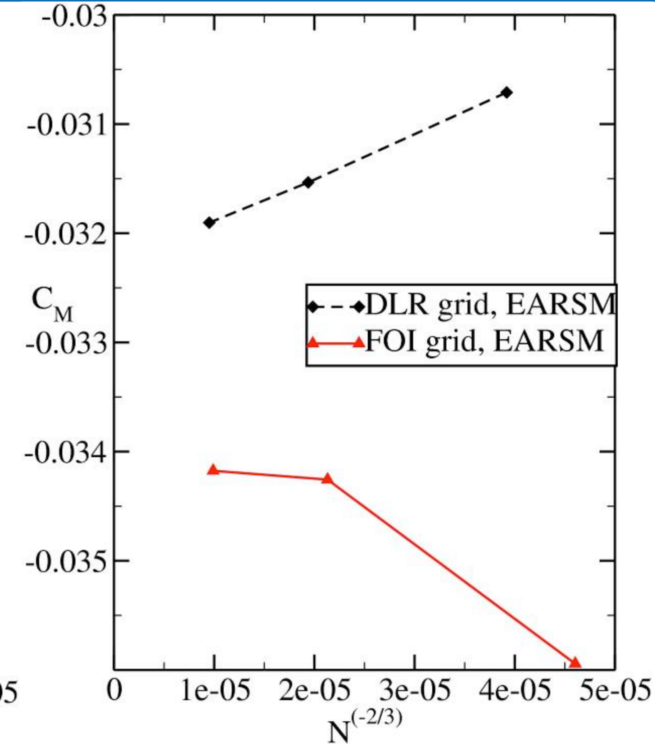


- Convergence (density res. and lift) on DLR medium grid, tail 0, C_L=0.5
- 3 levels full multigrid W cycles
- Convergence $|\Delta C_L<0.1\%|$ requires:
  - ≤ 600 fine grid iterations line implicit
  - ≤ 2000 fine grid iterations explicit
  - Specified C_L requires some extra iterations

Grid convergence, C_L=0.5

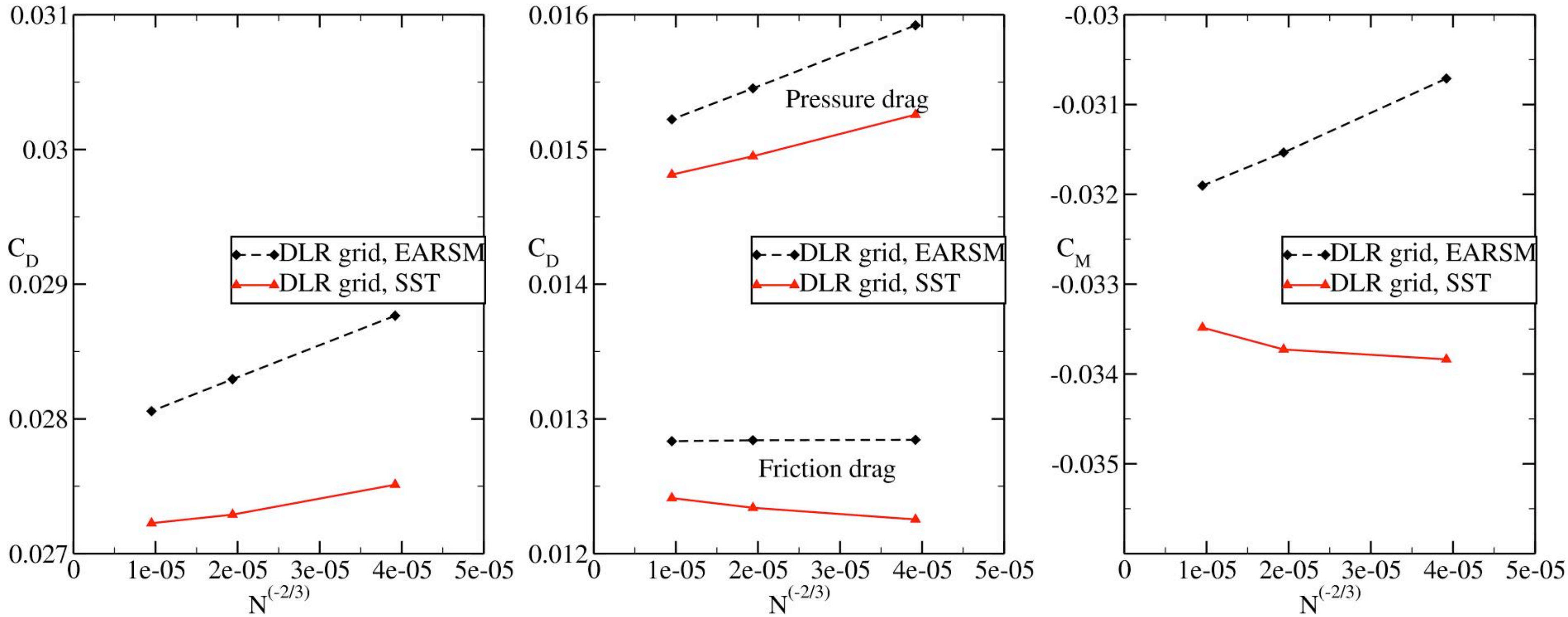






- Comparison between DLR and FOI grids
- Excellent grid convergence with DLR grids
  - Acceptable with FOI grids
- Grid converged drag: DLR grids C_D=278.3, FOI grids C_D=280.3

Grid convergence, C_L=0.5



- Comparison between EARSM and k-ω SST, DLR grids
- Good grid convergence, slightly worse grid convergence with SST
- Converged drag: EARSM C_D=278.3, SST C_D=271.6

Grid convergence, $C_L=0.5$

	EARSM	k-ω SST
DLR grids	0.18×10^{-4}	0.93×10^{-4}
FOI grids	5.0×10^{-4}	-

- Measure of Merit, as defined in DPW3
  - Measures the linearity of the slope of drag grid convergence
  - Based on Richardson extrapolation from coarse-medium and medium-fine grids
  - Low value = good value

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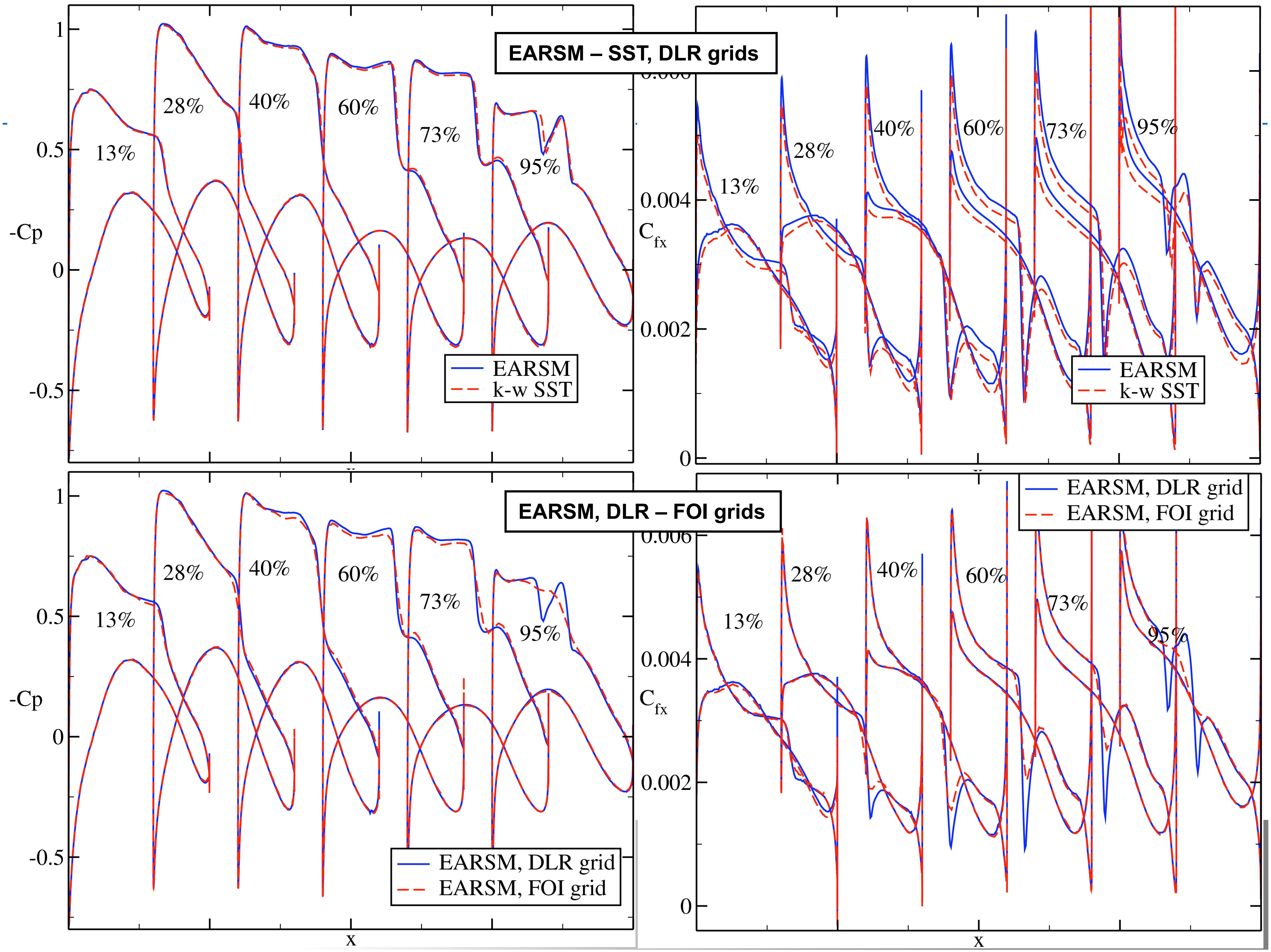
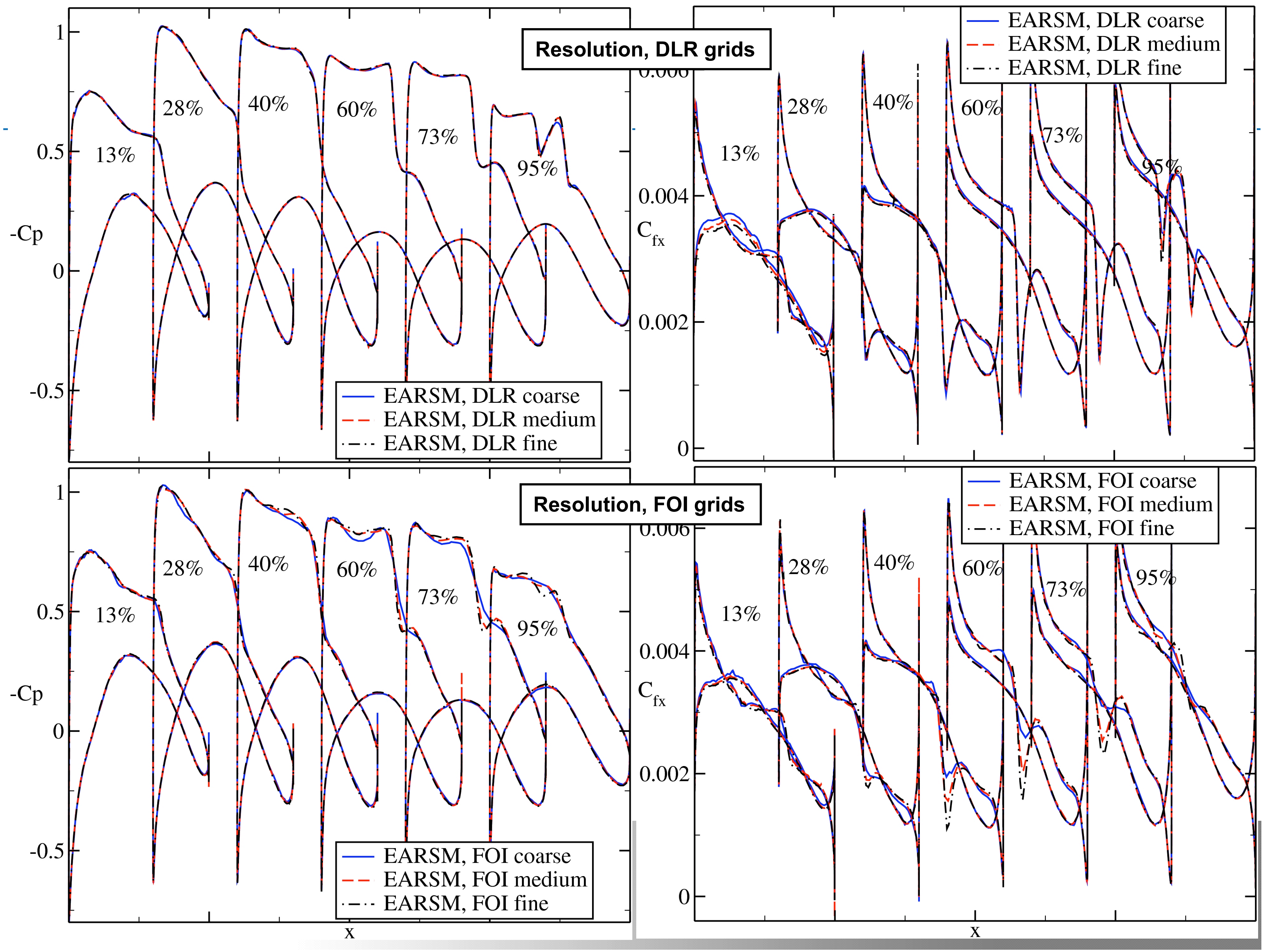
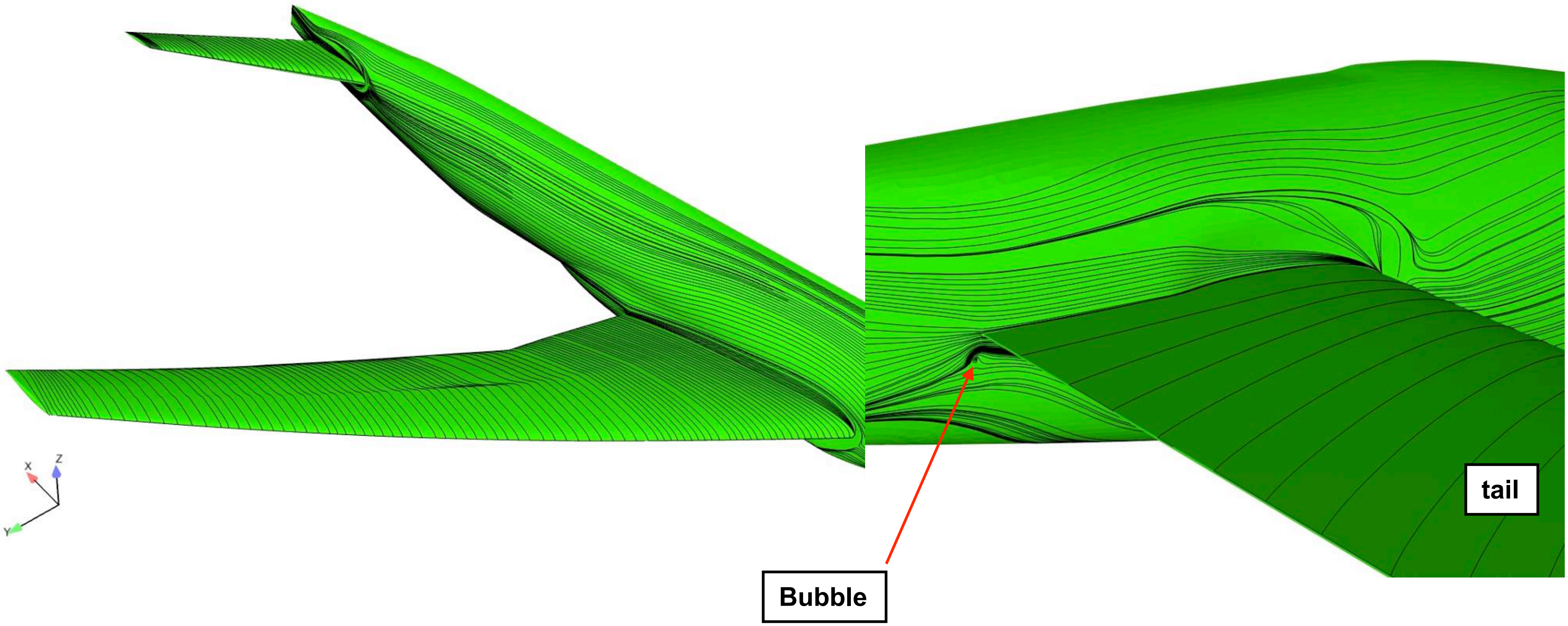

EARSM – SST, DLR grids
EARSM, DLR – FOI grids
-Cp
C_{fx}
x
13%
28%
40%
60%
73%
95%
EARSM
k-w SST
EARSM, DLR grid
EARSM, FOI grid
1
0.5
0
-0.5
0.006
0.004
0.002
0



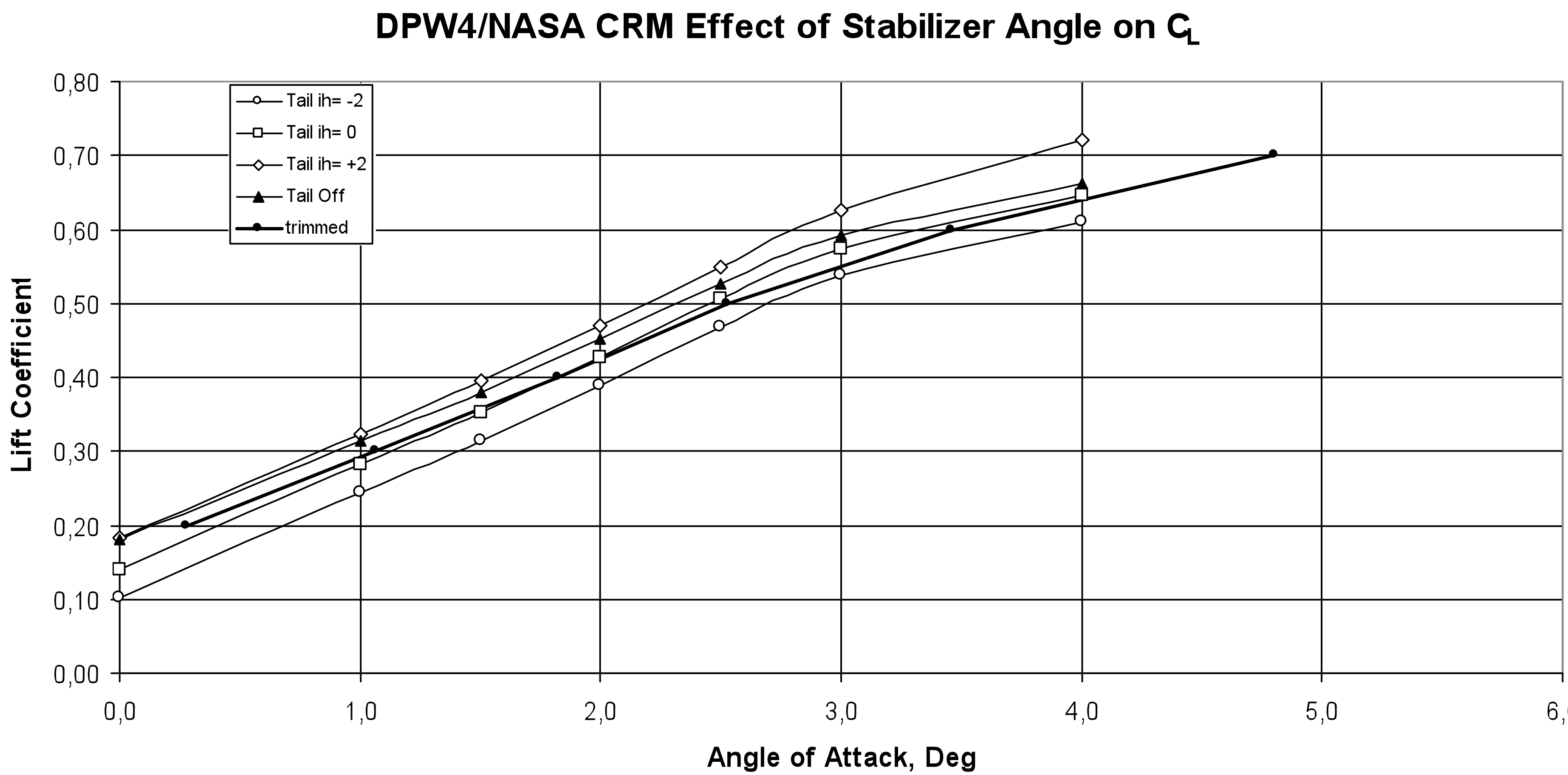
Resolution, DLR grids
Resolution, FOI grids
-Cp
C_{fx}
x
13%
28%
40%
60%
73%
95%
EARSM, DLR coarse
EARSM, DLR medium
EARSM, DLR fine
EARSM, FOI coarse
EARSM, FOI medium
EARSM, FOI fine
1
0.5
0
-0.5
0.006
0.004
0.002
0

Skin friction, tail 0°, C_L=0.5



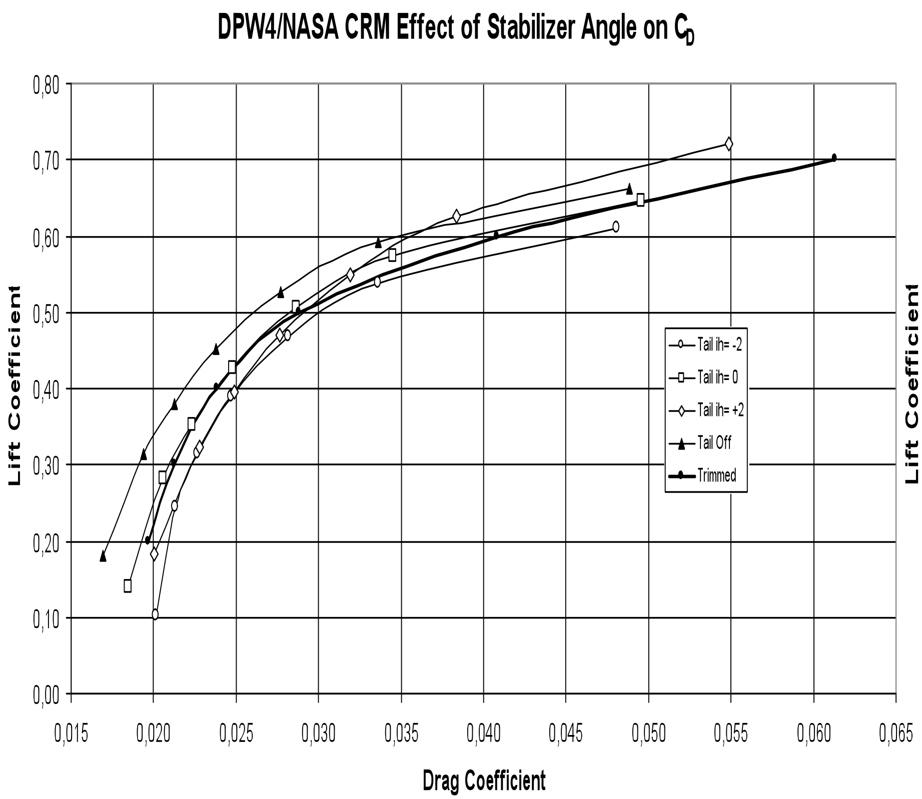
- DLR grid, EARSM
- Attached flow on wing and tail
- Separation on fuselage behind and below tail

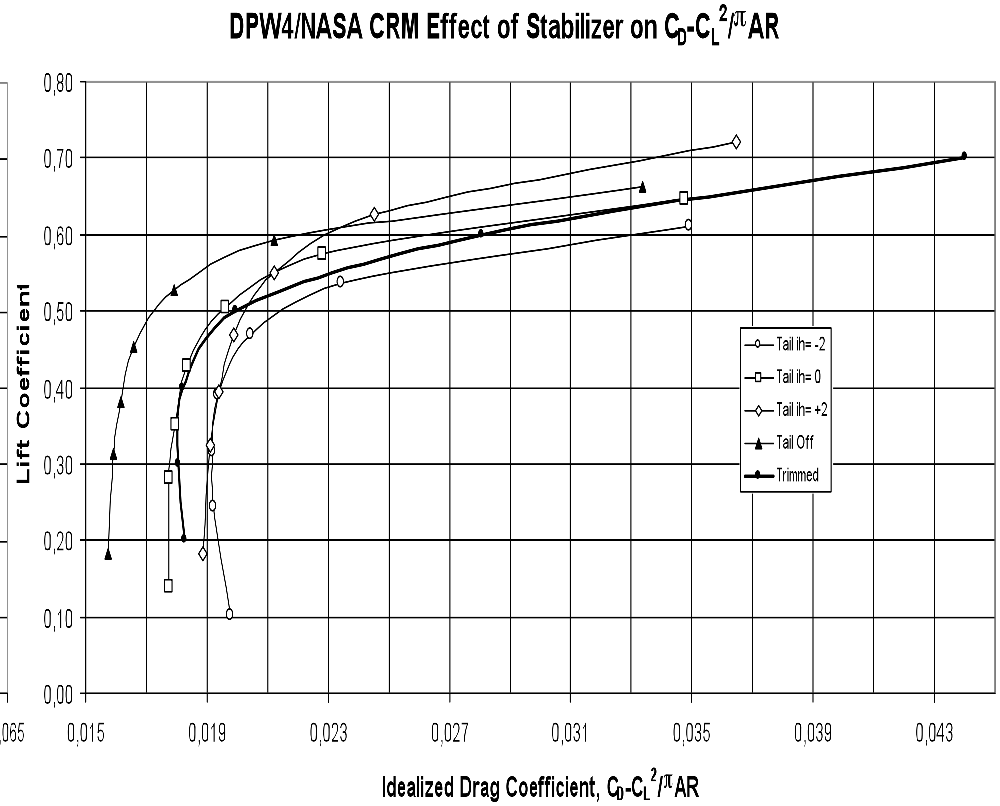
Polars, C_L



- DLR grids, EARSM

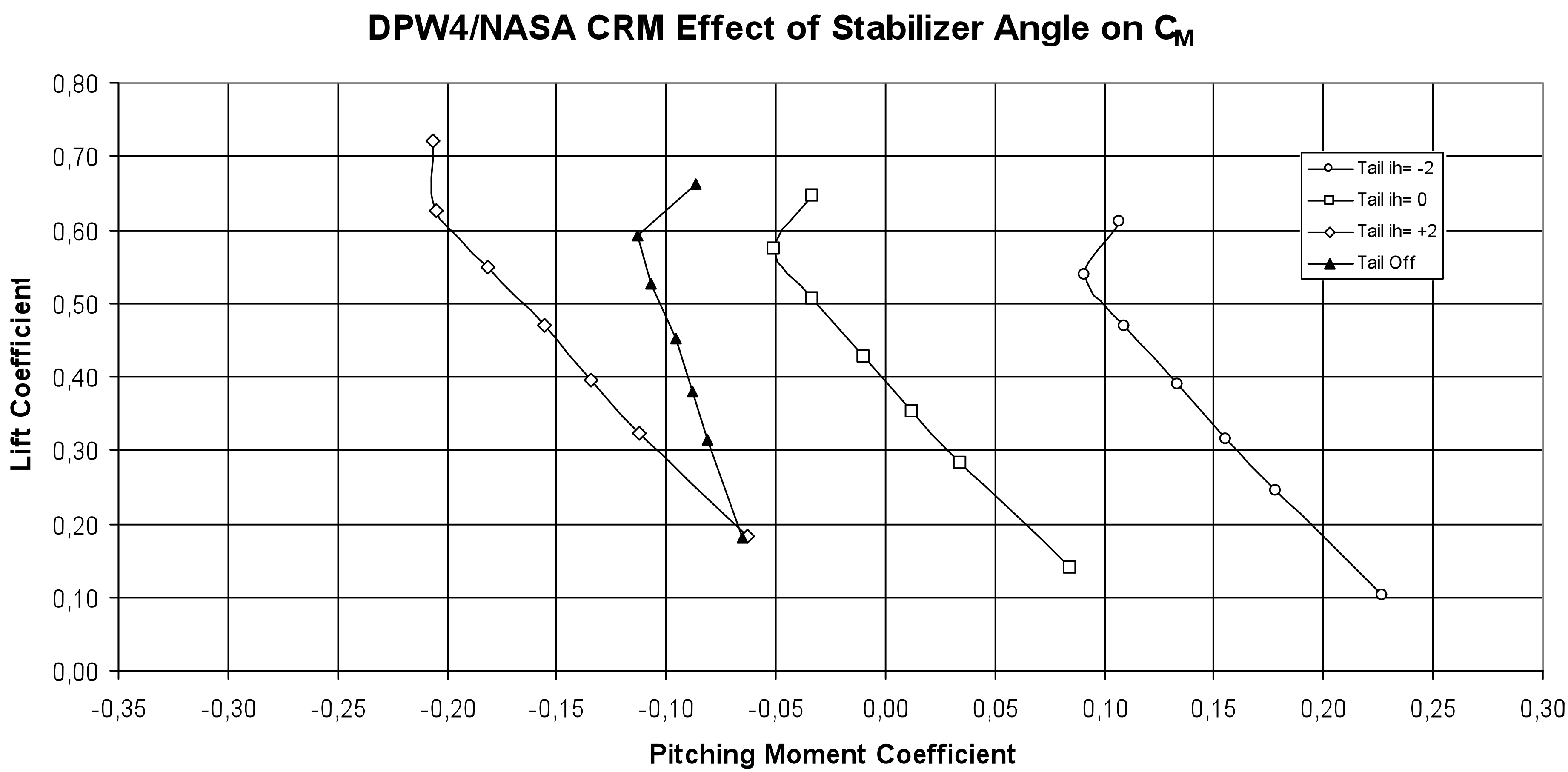
Polars, C_D





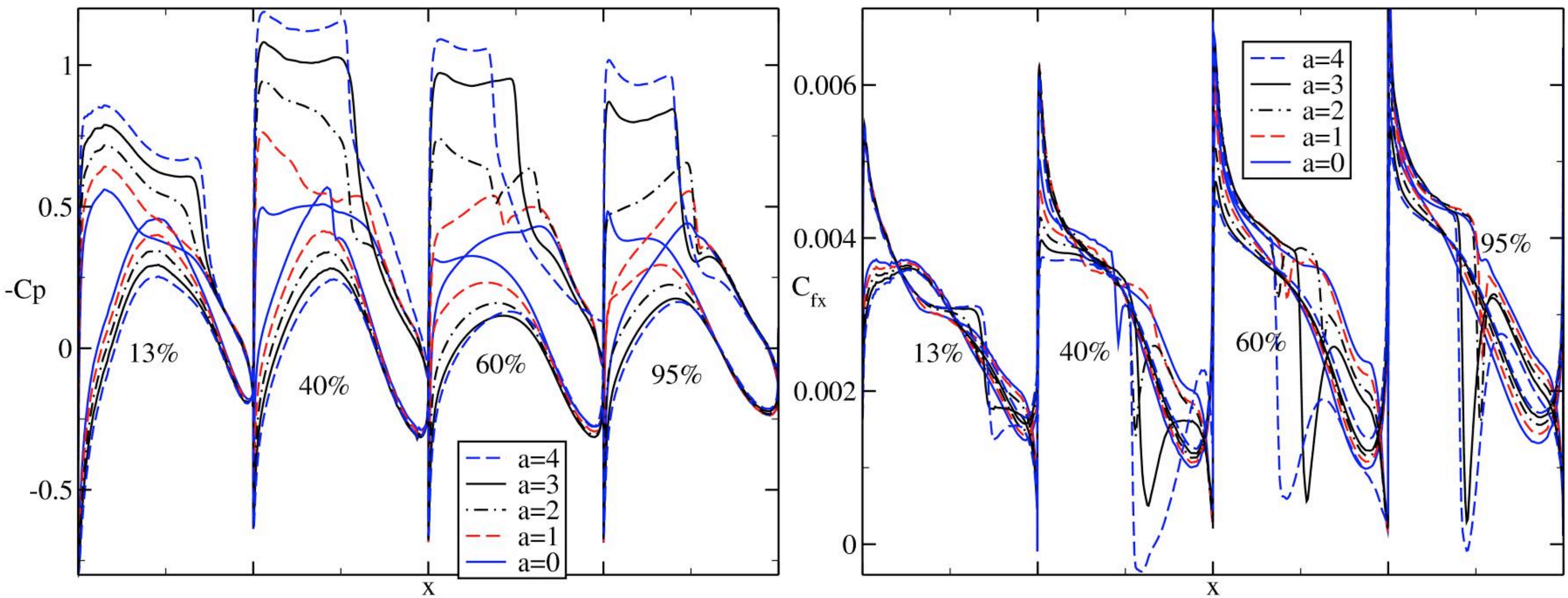
- DLR grids, EARSM
- ΔC_D = 26 cts at C_L=0.5 (trimmed vs. tail off)

Polars, C_M



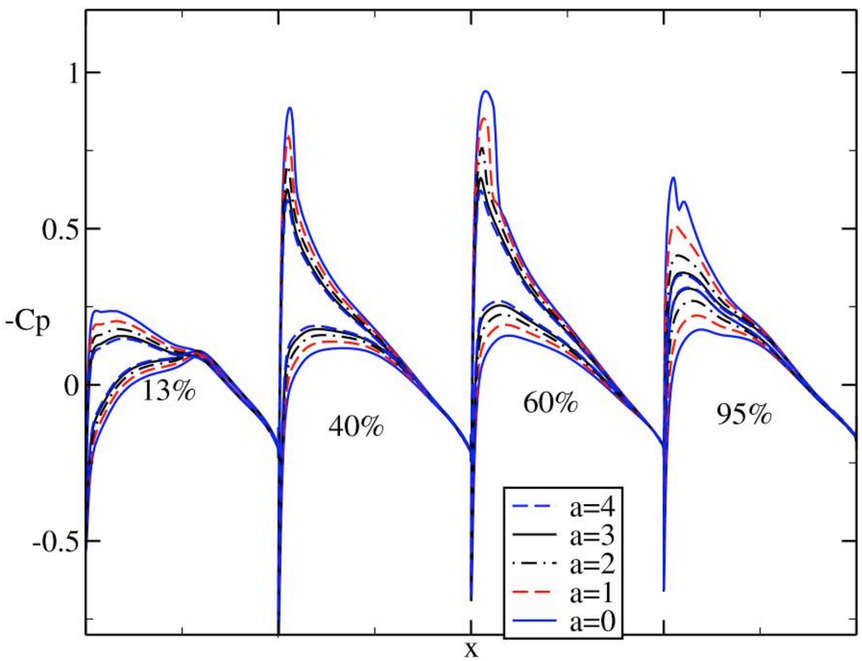
- DLR grids, EARSM

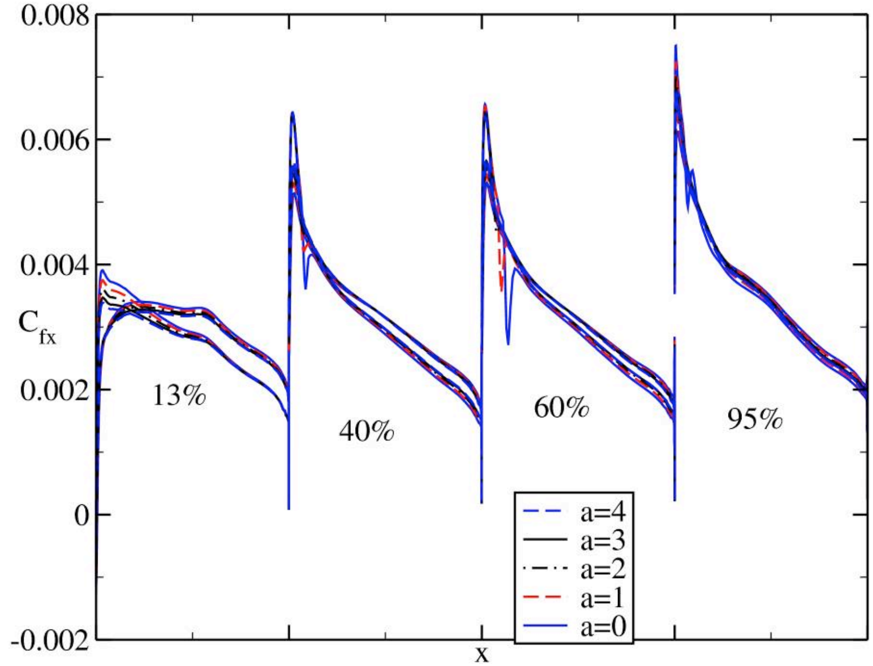
C_P on wing, tail 0°



- 4 span wise cuts
- DLR grids, EARSM, 5 angles of attack
- Attached flow although small area with C_{fx}<0 at about 40% span

C_P on tail, tail 0°





- 4 span wise cuts
- DLR grids, EARSM, 5 angles of attack
- Attached flow

Summary

- Grid convergence
  - Very good results with DLR grids
  - Acceptable with FOI grid, 2 cts difference
  - k-ω SST gives slightly lower drag than EARSM , 7 cts difference
  - $\Delta C_M = 1.9 \times 10^{-3}$ DLR-FOI grids, $\Delta C_M = 1.0 \times 10^{-3}$ EARSM - SST
  - Attached flow on wing and tail, fuselage separation behind/below tail
- Downwash study
  - Linear lift increase up to about $\alpha = 3°$
  - Tendency to separate at highest $\alpha = 4°$