June, 2016

in Washington, Drag Counts

CFD Investigations on the Wing-Body-Nacelle-Pylon DPW-6 Configuration using the elsA Solver and the Far-Field Approach

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ONERA

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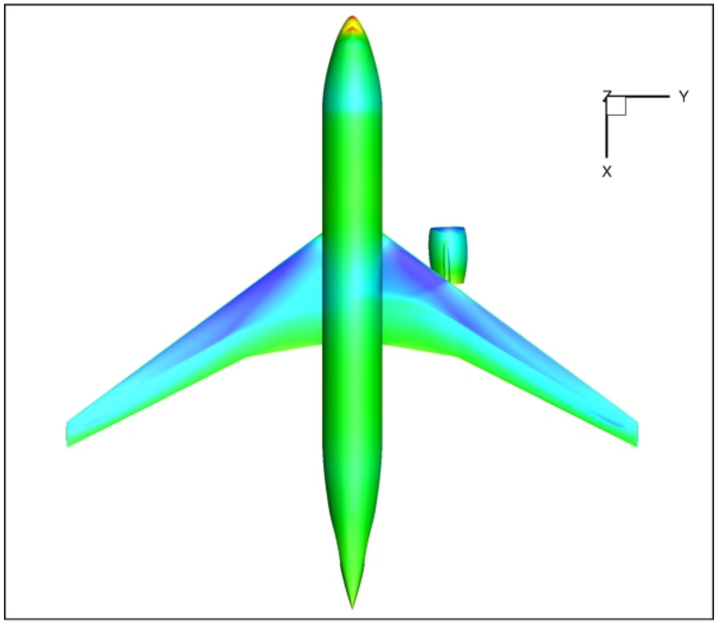
return on innovation

Outline

- Test-Case 1 (NACA0012)
- NASA-CRM WB and WBNP geometries
- Structured Overset Grids (Boeing)
- NS solver (elsA) and Far-Field software (ffd72)
- Test-Case 2 (CRM WB + WBNP)
- Test-Case 3 (CRM WB)
- Conclusions

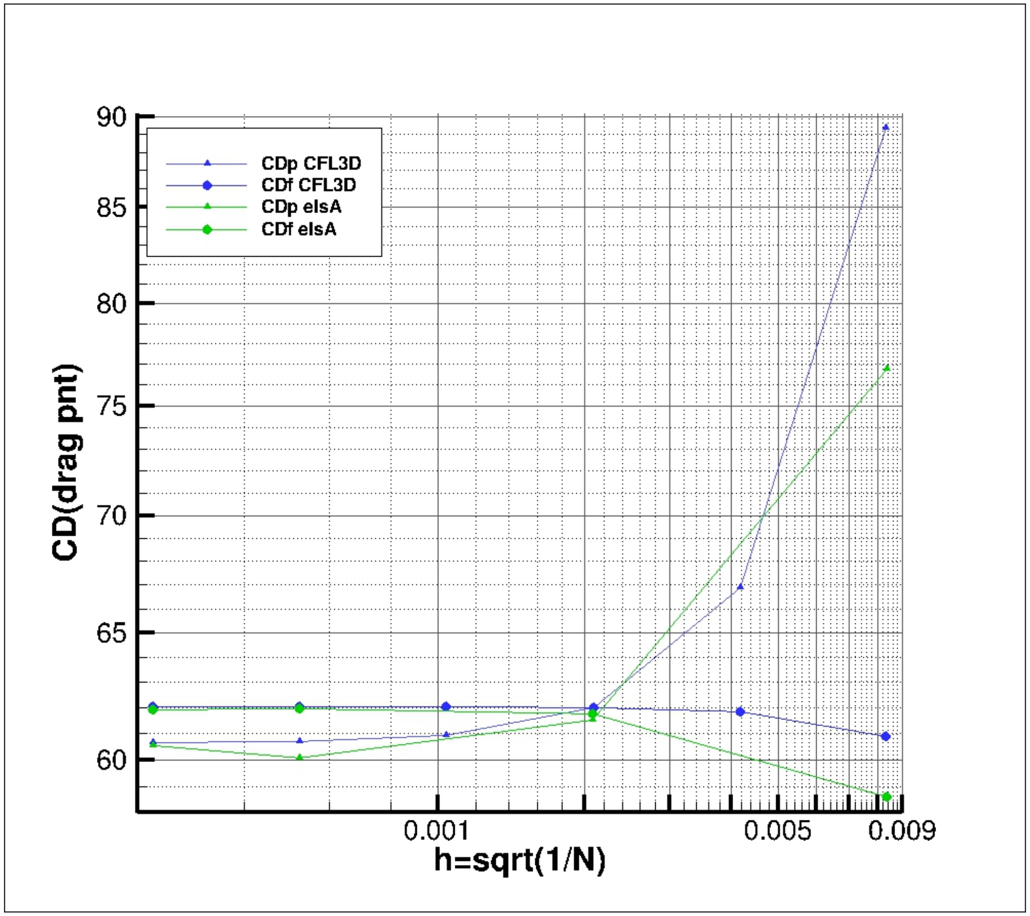


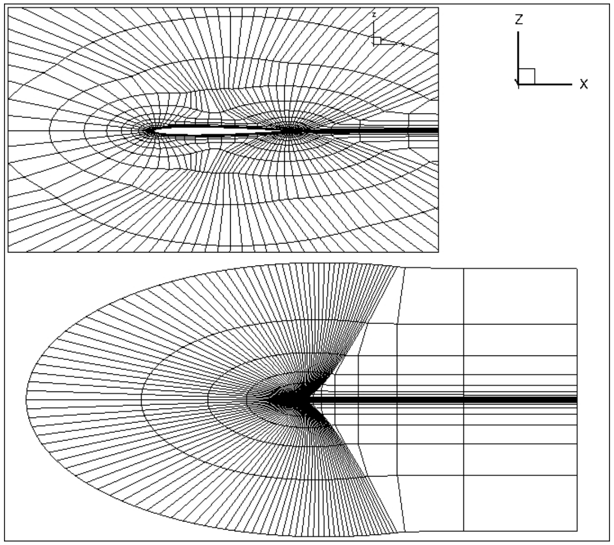
WB versus WBNP in cruise flight (pressure distribution)

Test-Case 1
2D NACA0012 Airfoil

Verification Study

NACA0012 airfoil – Ma = 0.15, AoA = 10°, $Re_{/c}$ = 6.10^6

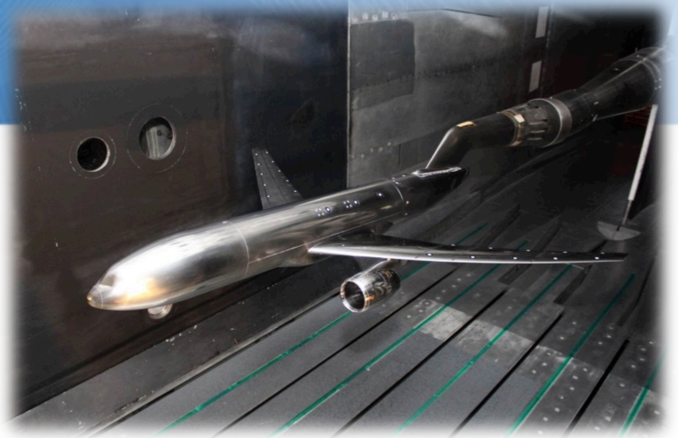




ONERA-elsA solver with SA model without vortex BC Grid Family II (3D)

Very good agreement observed for both pressure and friction components

CFL3D Data and Grids from NASA-TMR website:
http://turbmodels.larc.nasa.gov/naca0012numerics_val_sa_withoutpv.html

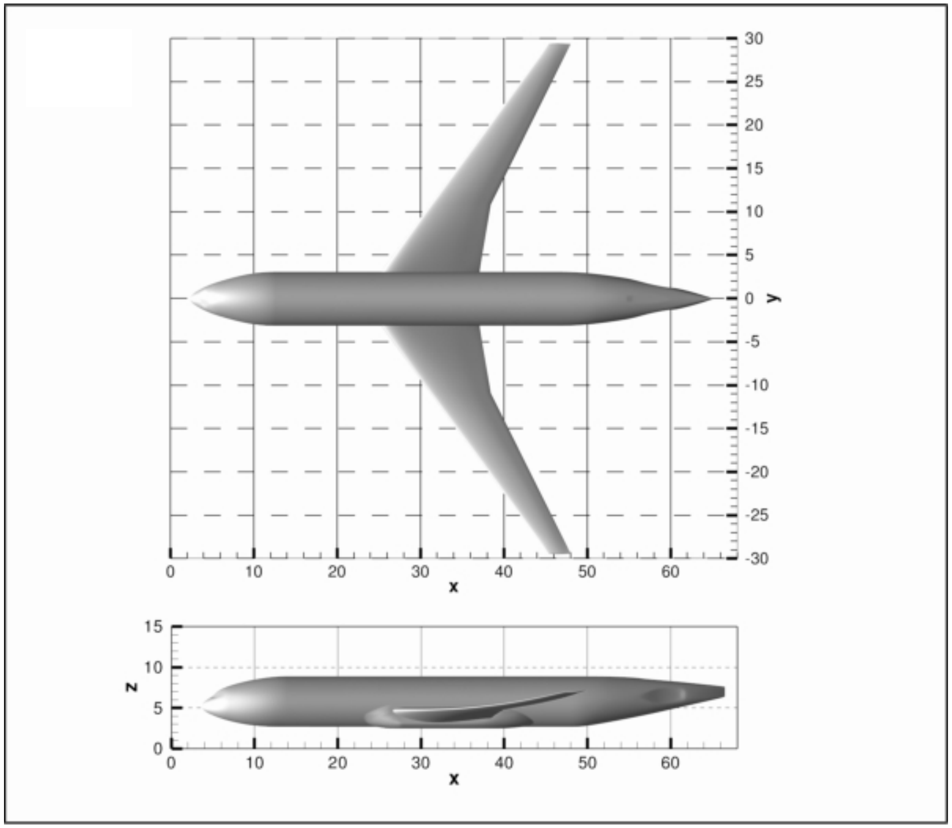


Test-Cases 2 & 3
NASA-CRM WB and WBNP Configurations

NASA-CRM WB and WBNP geometries

The CRM in a few figures:

- Used in DPW 4, 5, and 6
- Design Mach number of 0.85
- Conventional low-wing configuration
- Representative of today's aircraft
- Aerodynamic chord = 7.00532 m
- Reference surface = 383.68956 m^2
- Semispan = 29.38145 m
- Aspect ratio = 9.0
- Moment reference center:
  - Xref = 33.67786 m
  - Yref = 0.0 m
  - Zref = 4.51993 m

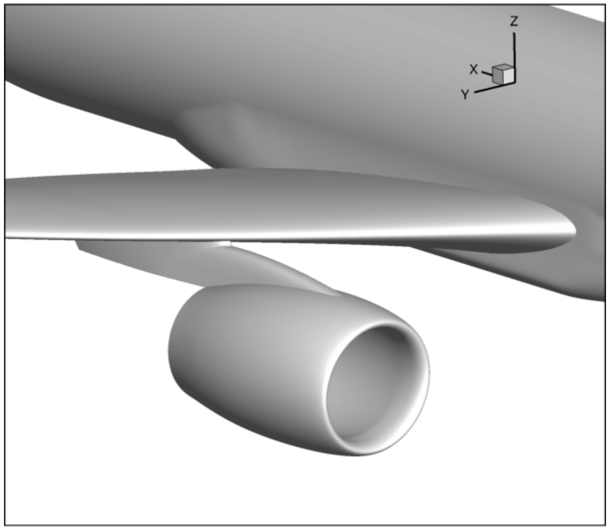


NASA-CRM Wing-Body geometry in meters

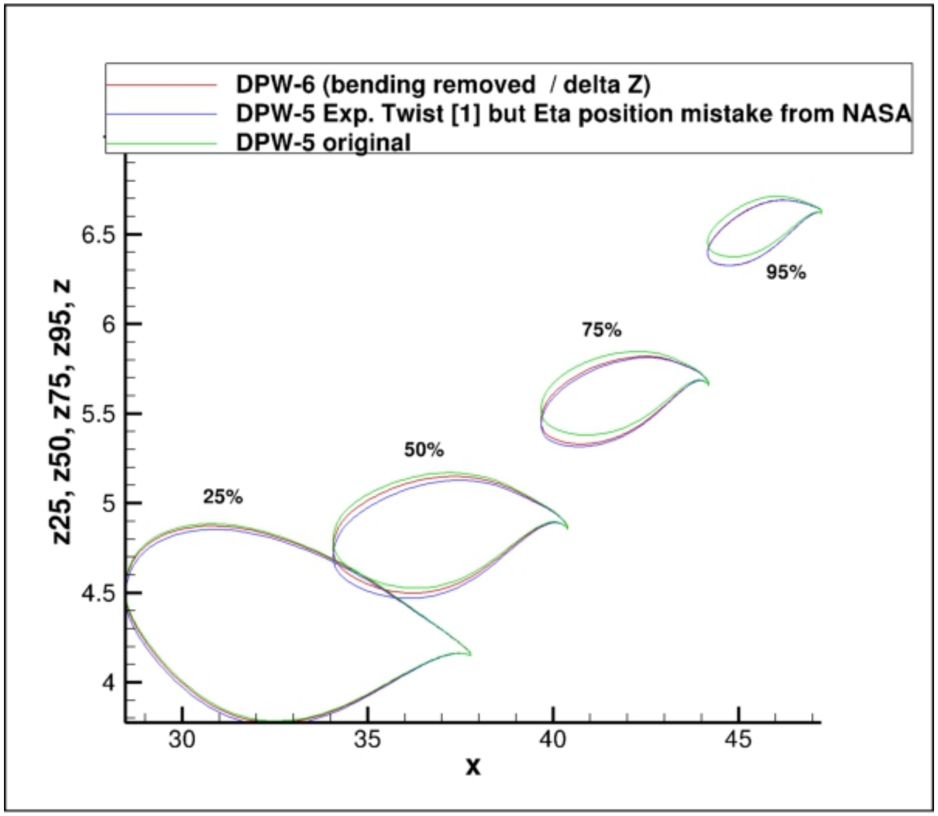
NASA-CRM WB and WBNP geometries

What is specific in DPW-6:

- Original DPW-5 wings have been deformed to better match the experimental twist and bending for each AoA (measurements from NTF, JAXA, ETW)
- The WBNP configuration allows NP drag increment assessment (Through Flow Nacelle)



Nacelle-Pylon Installation



NASA-CRM Wing twist versions (CL= 0,5 – 2p75)

[1] Hue, D., "Fifth Drag Prediction Workshop: ONERA Investigations with Experimental Wing Twist and Laminarity," Journal of Aircraft, vol.51(4), pp. 1311-1322, 2014

Structured Overset Grids

- **Overset Grids Boeing Serrano REV00:**
  - Overset grids for WB and WBNP configurations
  - 8 Overset bases for the WB ('body','wbcol','boxin'…) and 25 for the WBNP
  - 6 grid levels for each configuration + 6 WB grids at different AoA from 2,50 to 4,00°
  - WB and WBNP grid families exhibit similar grid-size-ratios of about 11 (versus 216 in DPW-5 when coarsest grids were really much coarser…)
  - Plot3d files converted into CGNS format with in-house tools
  - The Overset data iblank from Boeing was not used and the blanking and overlapping processes have been carried out with the ONERA software Cassiopee [2]: Pretty challenging for the WBNP configuration

N°	Level	TotPts WB / WBNP (in millions)	Wing deformation
1	Tiny	7.4 / 11.9	2p75
2	Coarse	14.4 / 23.0	2p75
3	Medium	24.7 / 39.5	2p75
4	Fine	39.1 / 62.6	2p75
5	XFine	58.2 / 93.2	2p75
6	UFine	82.8 / 132.4	2p75

WB and WBNP Overset Grid families for Test-Case 2

Level	Wing deformation
Medium	2p50
Medium	3p00
Medium	3p25
Medium	3p50
Medium	3p75
Medium	4p00

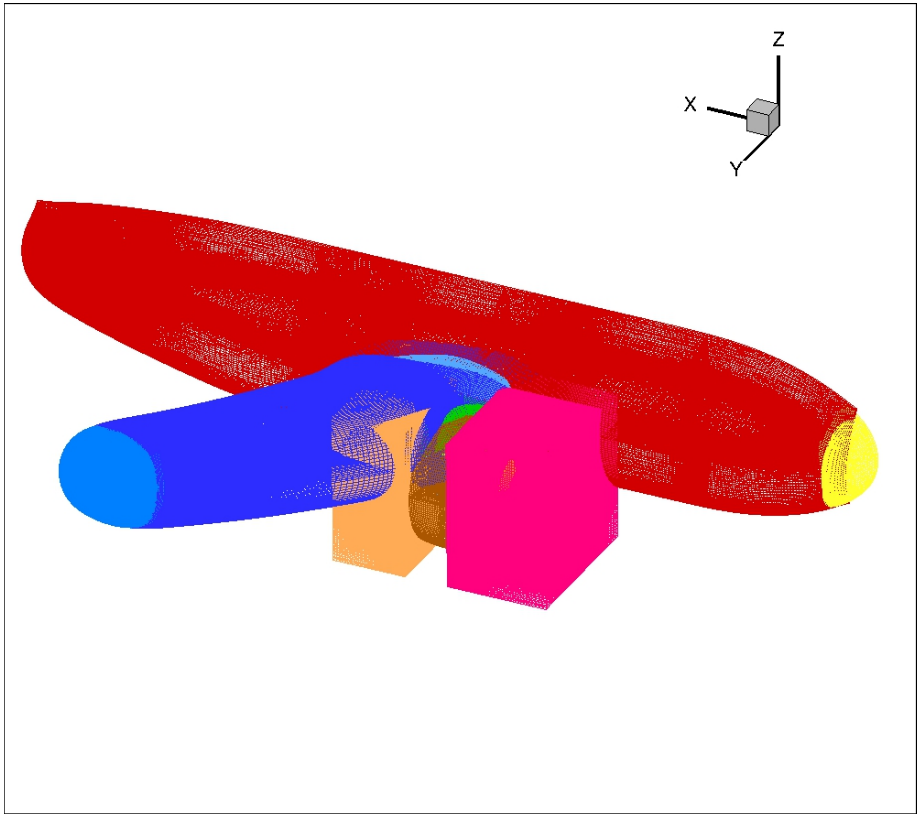
WB Overset Grids for Test-Case 3

Grids not used for convergence or ressources issues

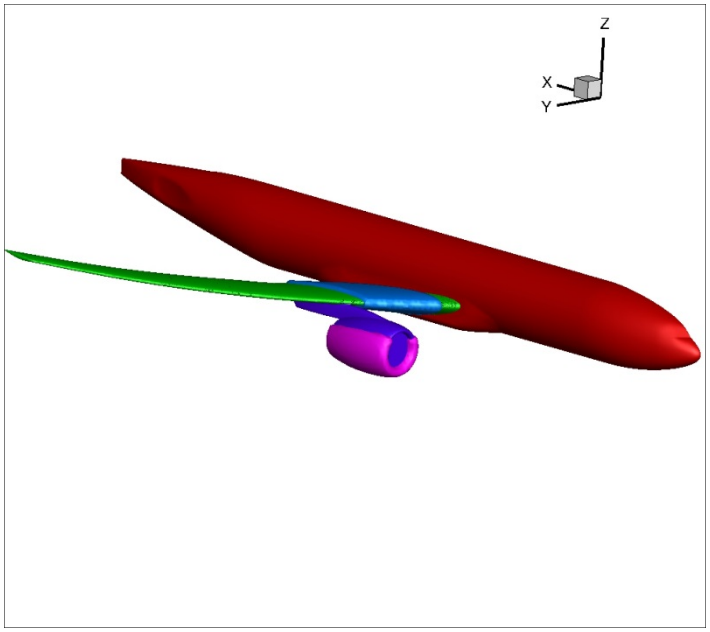
[2] Péron, S., Benoit, C., Landier, S., and Raud, P., "Cassiopée: CFD Advanced Set of Services In an Open Python EnvironmEnt," 12th Symposium on Overset Grid and Solution Technology, Atlanta, 2014

Structured Overset Grids

- **Illustration of the blanking and overlapping processes:**



25 Overset Bases for the WBNP Boeing Grids



ONERA blanking bodies (offsets from walls)

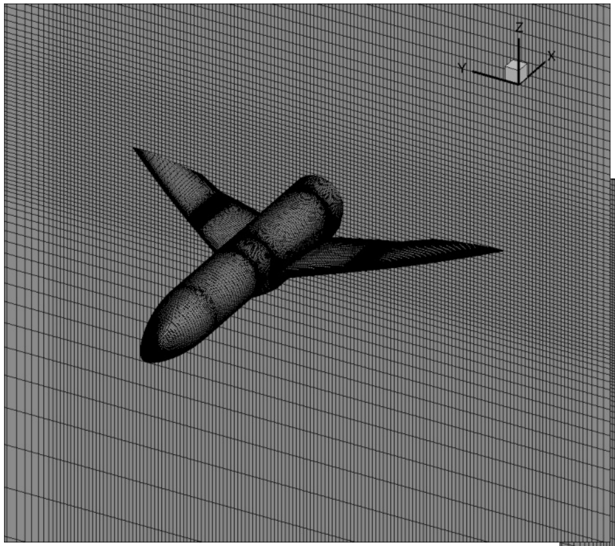
ONERA Overset techniques described in [3]

25 bases from Boeing reduced to 10
6 blanking bodies (to avoid grid cells inside physical bodies)

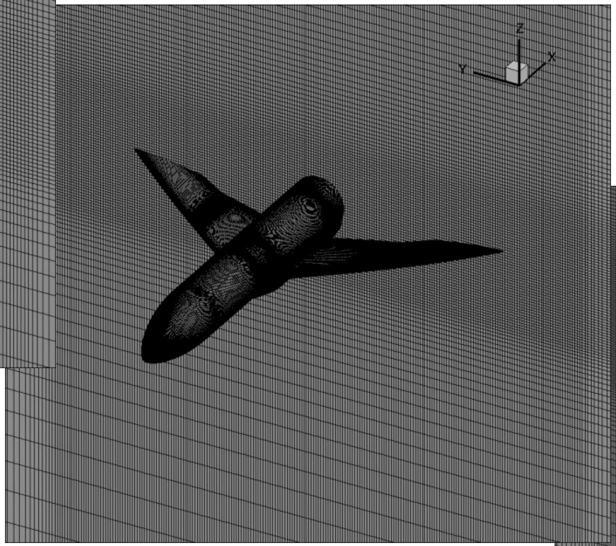
[3] Hue et al., "Validation of a near-body and off-body grid partitioning methodology for aircraft aerodynamic performance prediction," Computers & Fluids, Vol. 117, 2015, pp. 196-211

Structured Overset Grids

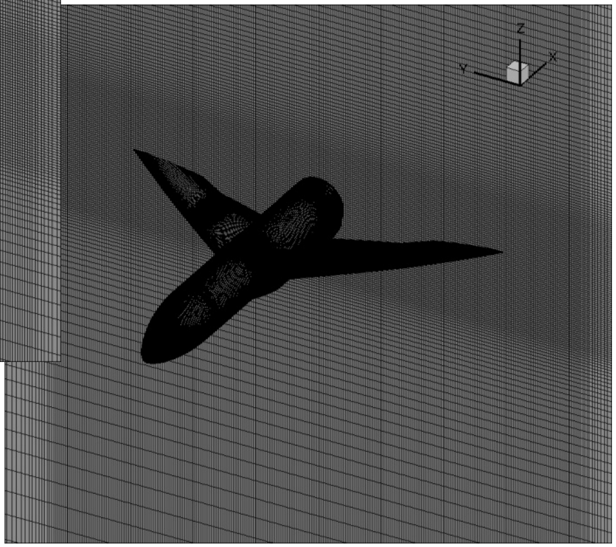
- **Illustration of the WB grid refinement levels:**



Tiny



Medium



ExtraFine

NS solver: elsA

Software for simulations in Aerodynamics

elsA [4]:

Structured solver - RANS / URANS / ZDES computations

Cell-centered finite volume on multiblock / overset / hybrid grids

Time integration : backward-Euler scheme with LU-SSOR relaxation

Spatial discretization : central Jameson scheme

Multigrid techniques

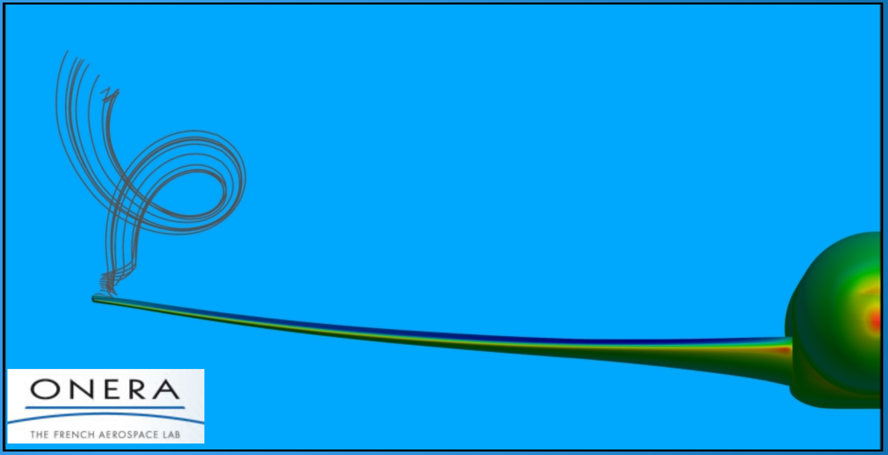
Fully turbulent computations

Spalart-Allmaras turbulence model

QCR-2000 correction when specified

SGI ICE 8200 (48 to 256 proc.)

≈ 10 hours / 1 full calculation



[4] Cambier, L., Heib, S., and Plot, S., "The ONERA elsA CFD Software: Input from Research and Feedback from Industry," Mechanics and Industry, Vol. 15(3), pp. 159-174, 2013

Far-Field software: ffd72

Post-processing software using solver solutions

Far-Field Drag extraction ffd72 [5]:

CDnf = CDp + CDf

CDff = CDv + CDw + CDi

CDv = CDf + CDvp

CDsp = CDnf - CDff

CDp : pressure drag

CDf : friction drag

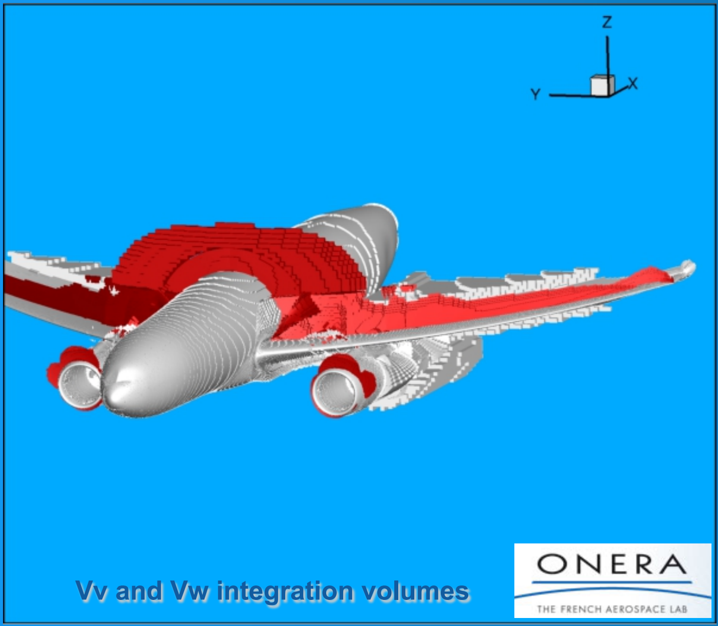
CDvp : viscous pressure drag

CDv : viscous drag

CDw : wave drag

CDi : lift-induced drag

CDsp : spurious / artificial drag



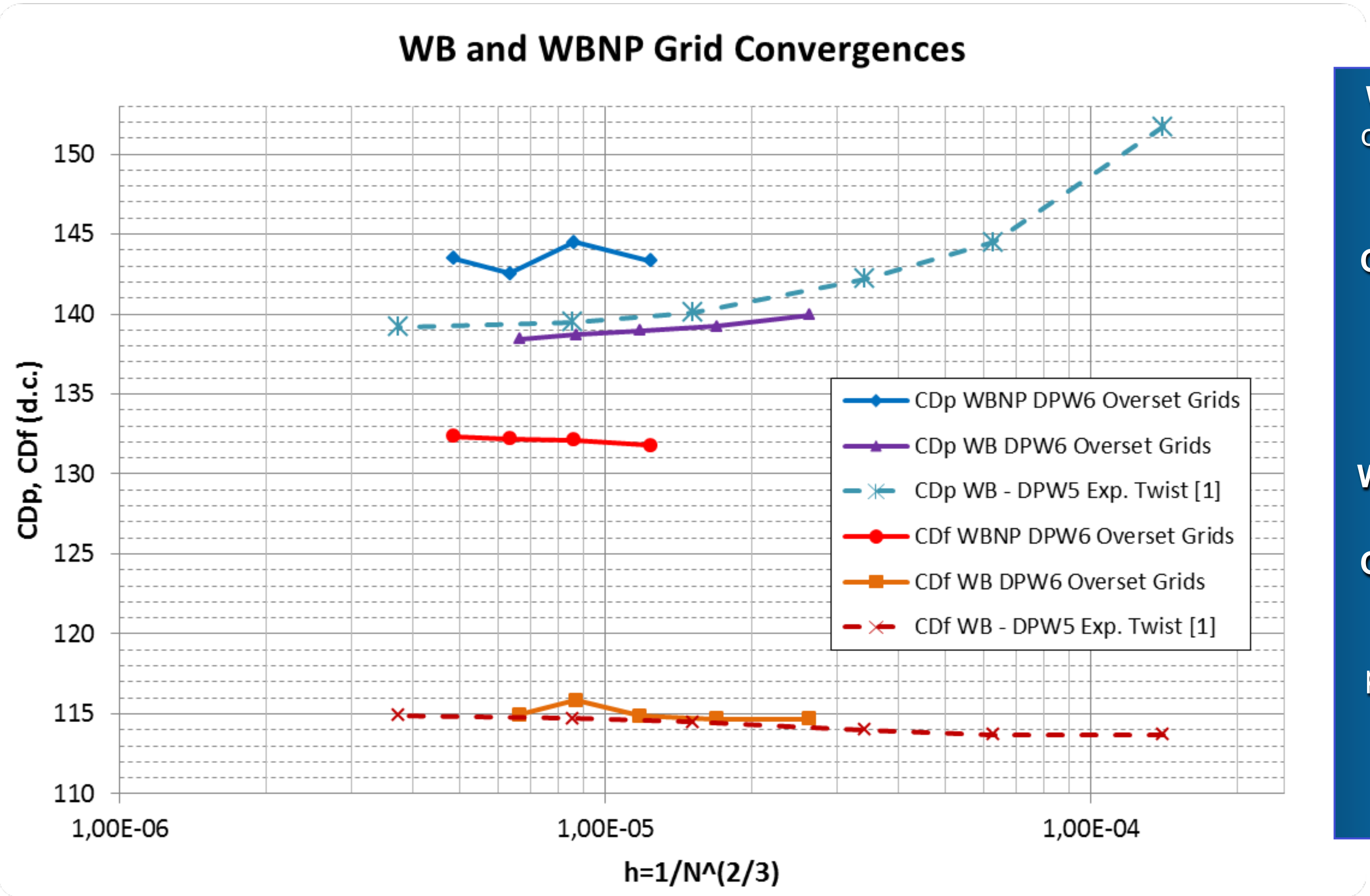
Vv and Vw integration volumes

[5] Destarac, D., "Far-Field / Near-Field Drag Balance Applications of Drag Extraction in CFD", VKI Lecture Series 2003-02, von Karman Institute, Rhode-Saint-Genèse, Belgium, Nov. 3-7 2003

Test-Case 2
CRM Nacelle-Pylon Drag Increment

CRM Nacelle-Pylon Drag Increment

NASA-CRM – Ma = 0.85, CL = 0.5, $Re_{/c}$= 5.10^6



WB: drag value close to 253,5 counts in very good agreement with [1] (DPW5 MB Common Grids with Exp. Twist)

CD Pressure: 138,5 d.c – 55% of total drag

CD Friction: 115,0 d.c – 45% of total drag

WBNP: drag value close to 276 counts

CD Pressure: 143,5 d.c – 52% of total drag
more variation in cv process probably due to more complex flow / Overset grid / interp.

CD Friction: 132,5 d.c – 48% of total drag

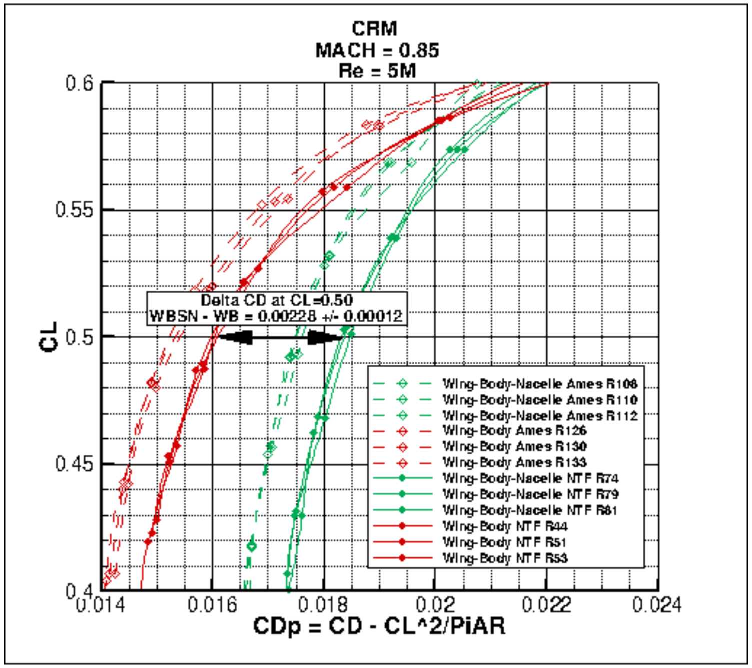
[1] Hue, D., "Fifth Drag Prediction Workshop: ONERA Investigations with Experimental Wing Twist and Laminarity," Journal of Aircraft, vol.51(4), pp. 1311-1322, 2014

CRM Nacelle-Pylon Drag Increment

NASA-CRM – Ma = 0.85, CL = 0.5, $Re_{/c}$ = 5.10^6

	WB med.	WBNP med.	Delta
Alpha	2,437	2,622	**0,186**
CL	0,500	0,500	**0,00**
CDnf	253,8	276,7	**22,9**
CDf	114,8	132,0	**17,2**
CDvp	42,0	47,2	**5,2**
CDv	156,9	179,3	**22,4**
CDw	5,4	5,8	**0,5**
CDi	91,7	91,1	**-0,6**
CDff	253,9	276,3	**22,4**
CDsp	-0,1	0,4	**0,5**
CM	-0,0958	-0,0915	**0,004**

ONERA Far-Field analysis of NP Increment



elsA-ffd72 NP increment: **22.4 d.c. +/- 1 d.c.**

Exp. (NTF-Ames) NP increment: **22.8 d.c. +/-1.2 d.c.** (data analysis by Ed Tinoco)

Very good CFD / WT agreement on Nacelle-Pylon Increment

CDf: increase of about 17 drag counts – CDf represents 48% of WBNP drag

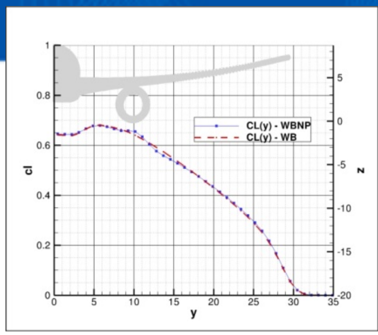
CDvp: increase of about 5 drag counts – CDvp represents 17% of WBNP drag

77% of NP drag increment due to friction and 23% due to viscous pressure

CDw: very limited impact – CDw represents only 2% of WBNP drag

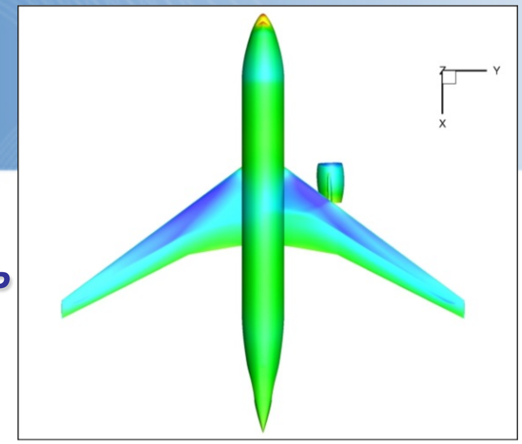
CDi: very limited variation – CDi represents 33% of WBNP drag

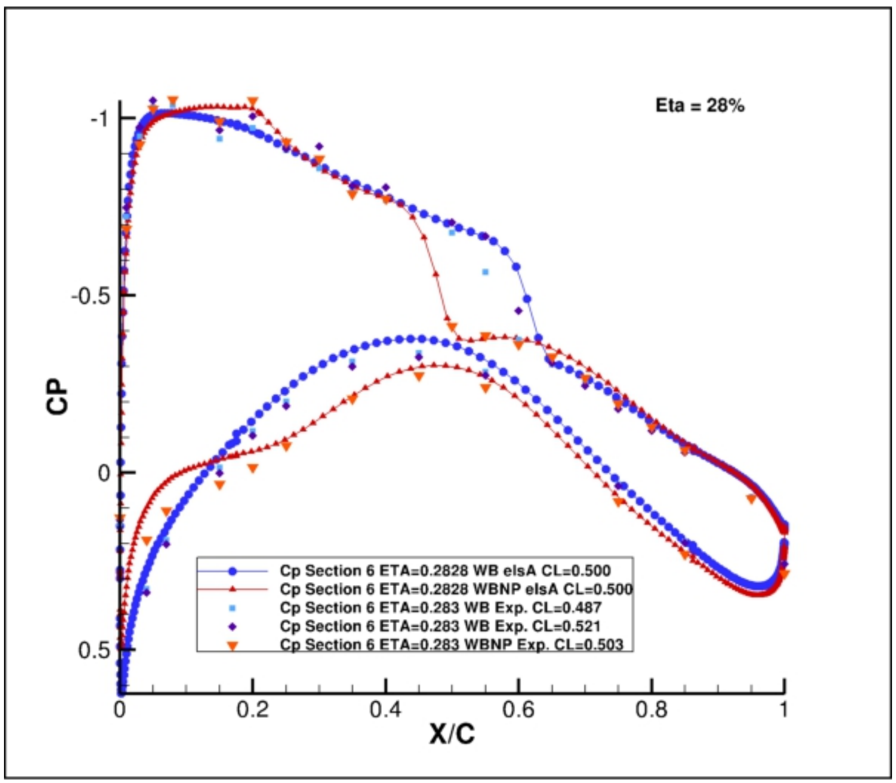
CRM Nacelle-Pylon Drag Increment

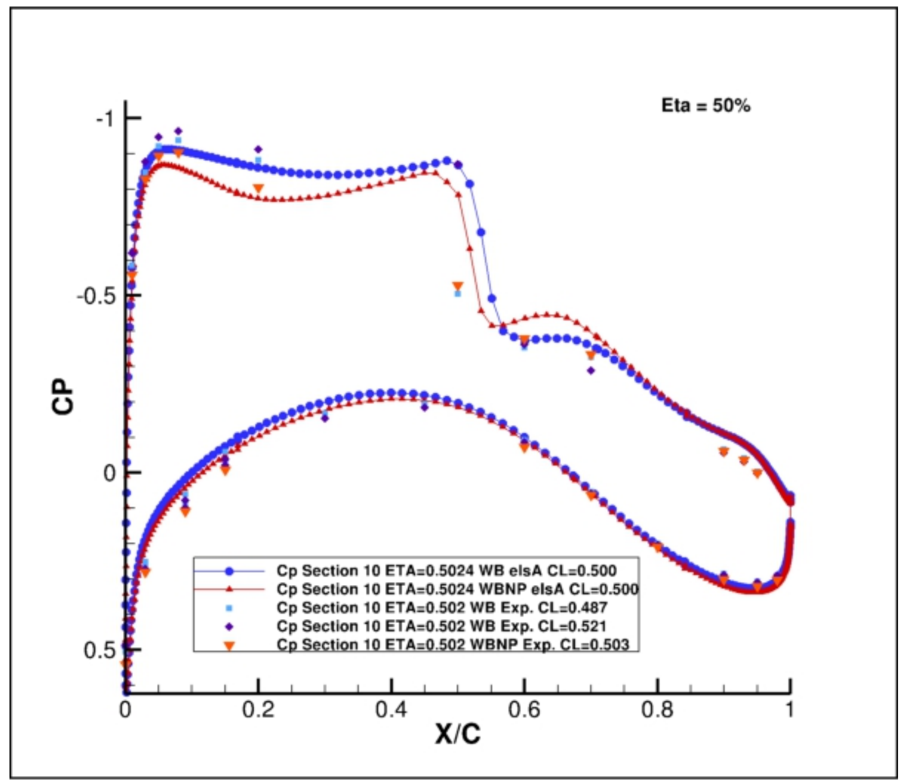


NASA-CRM – Ma = 0.85, CL = 0.5, $Re_{/c}$= 5.10^6

CFD and WT Cp distributions - WB versus WBNP







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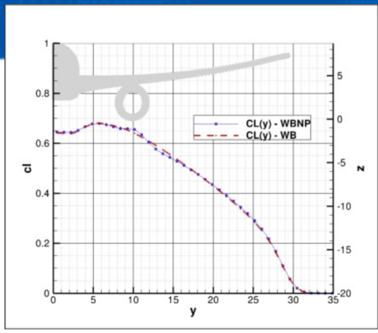

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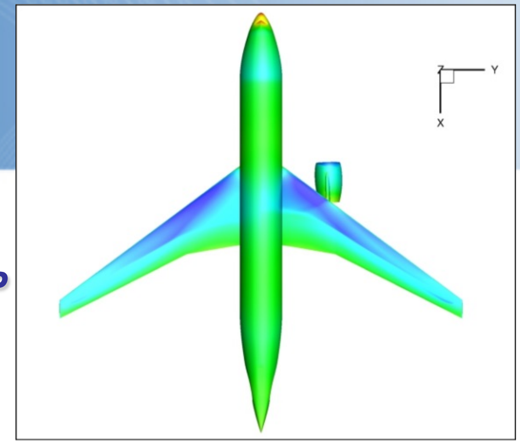
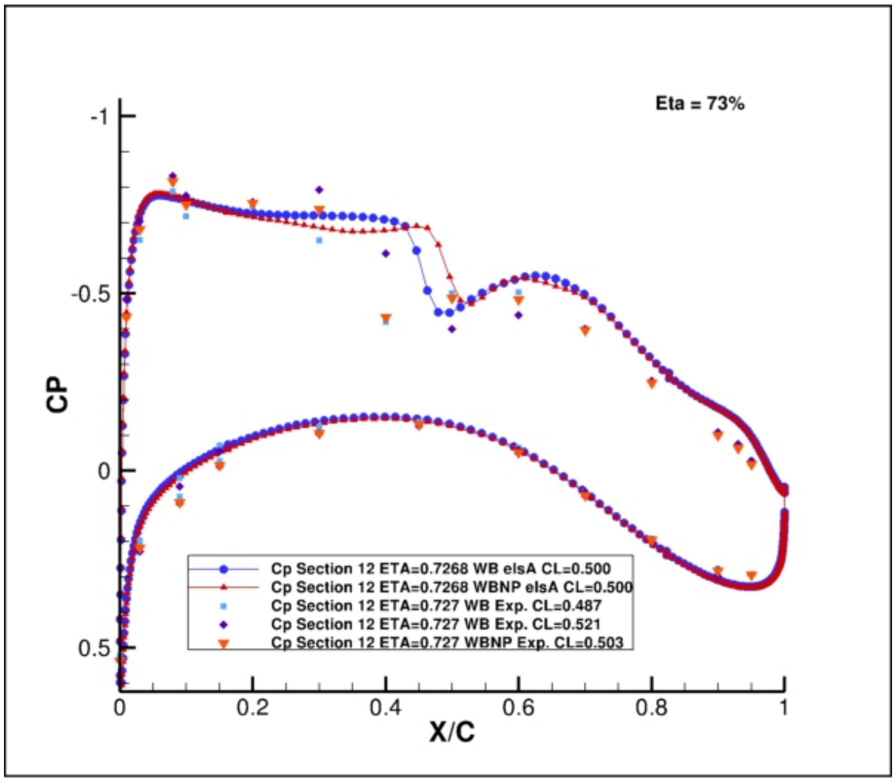
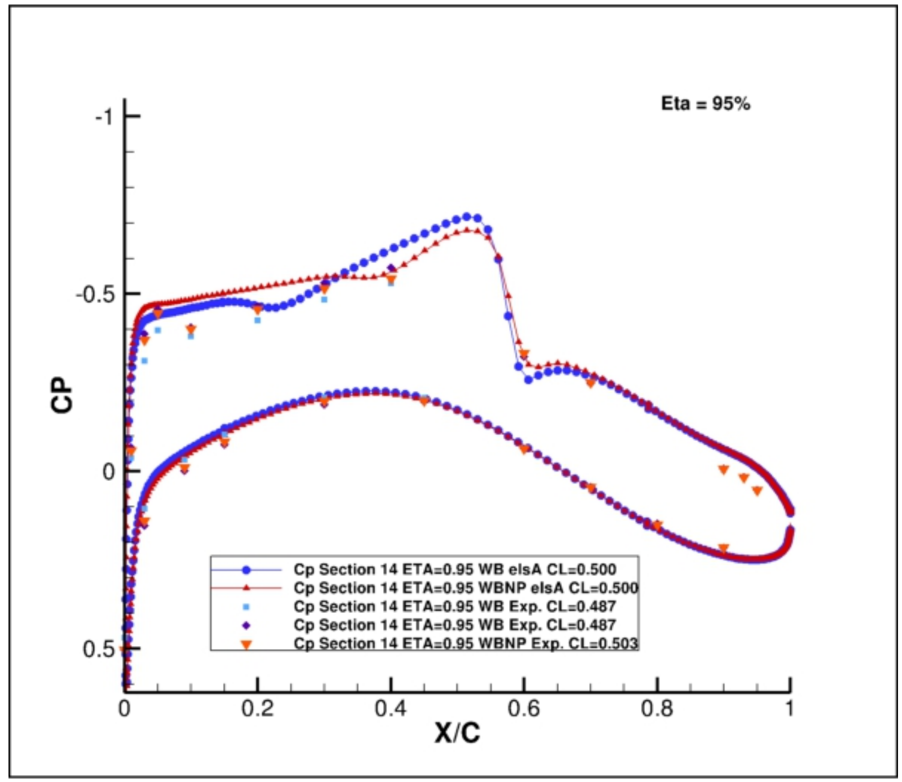


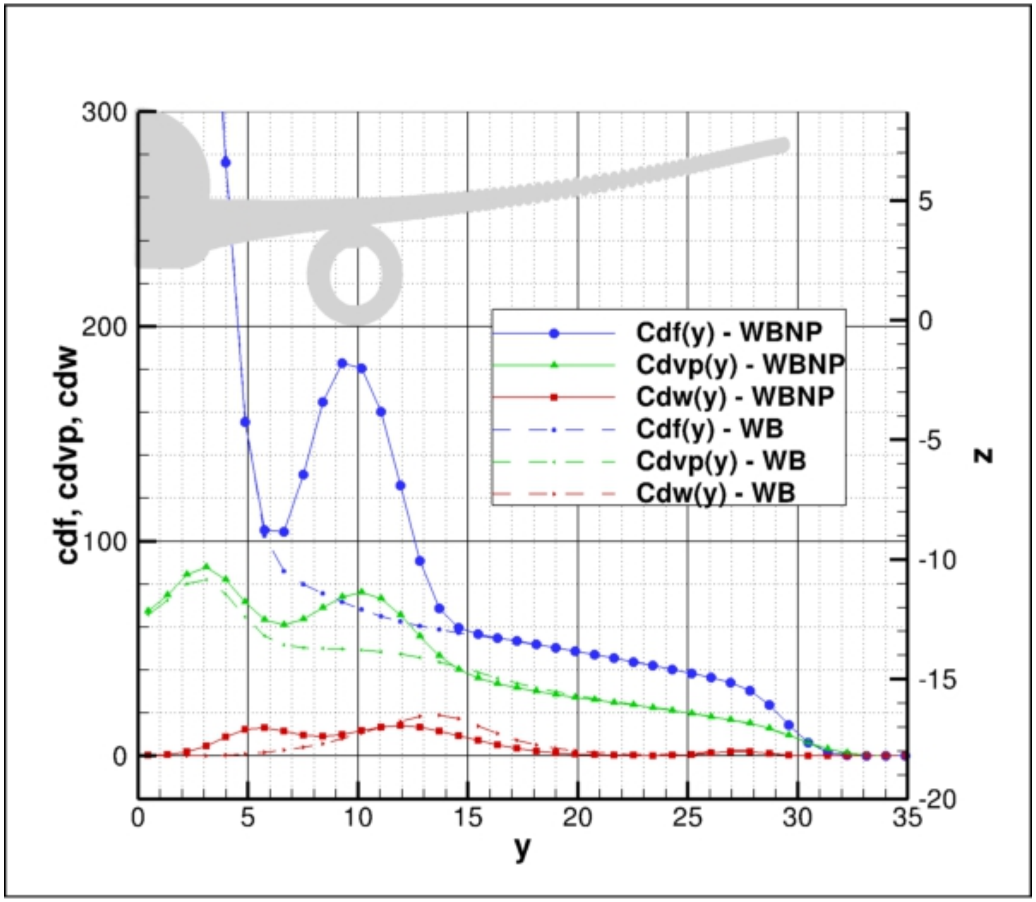




CRM Nacelle-Pylon Drag Increment

NASA-CRM – Ma = 0.85, CL = 0.5, $Re_{/c}$= 5.10^6

Far-Field Analyses



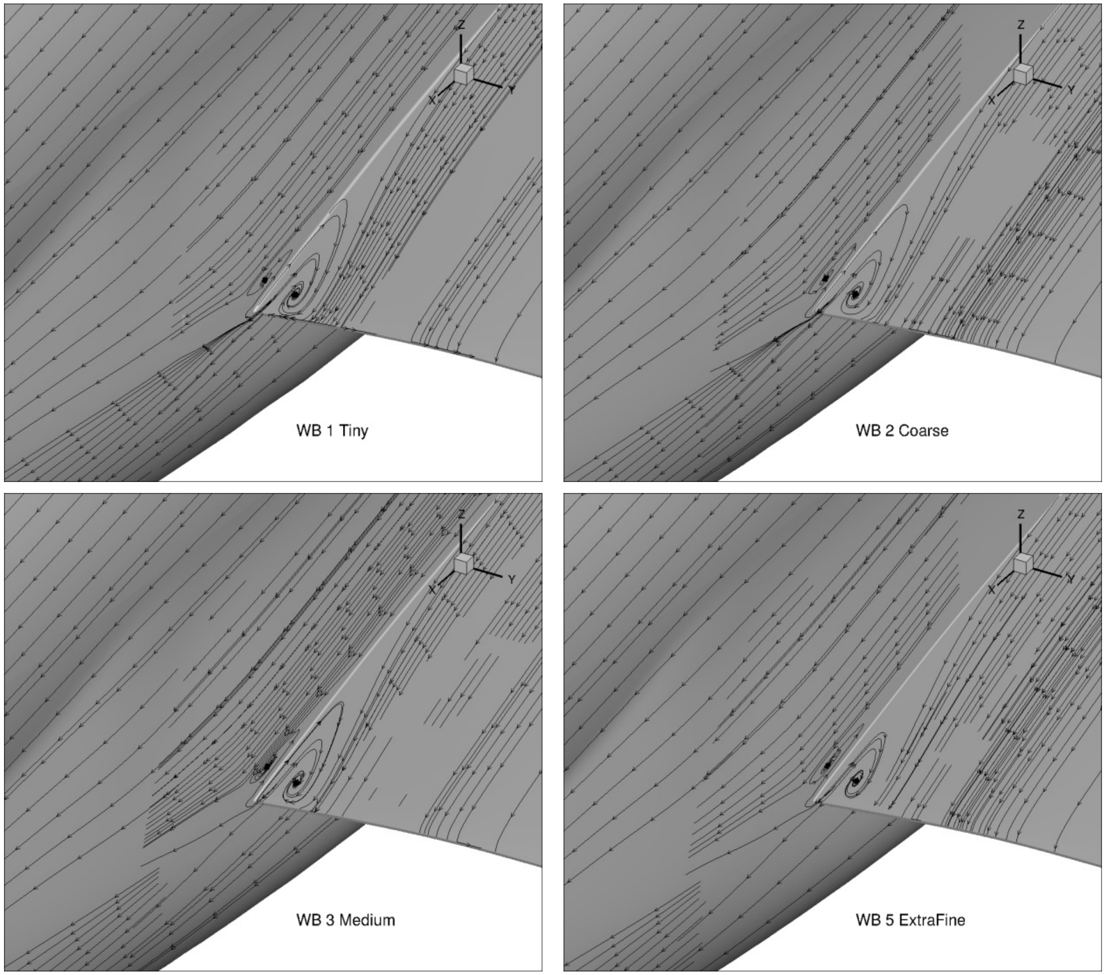
CDf, CDvp, and CDw spanwise productions
WB versus WBNP

ONERA presentation, DPW 6, june 2016 – Washington D.C.

CRM Nacelle-Pylon Drag Increment

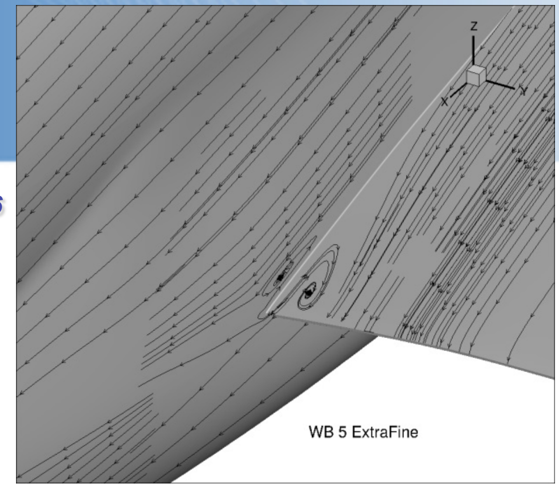
NASA-CRM – Ma = 0.85, CL = 0.5, $Re_{/c}$= 5.10^6

SOB separation on WB Configuration



No significant influence of refinement
Size about 25cm (less than 1% of semispan)

CRM Nacelle-Pylon Drag Increment



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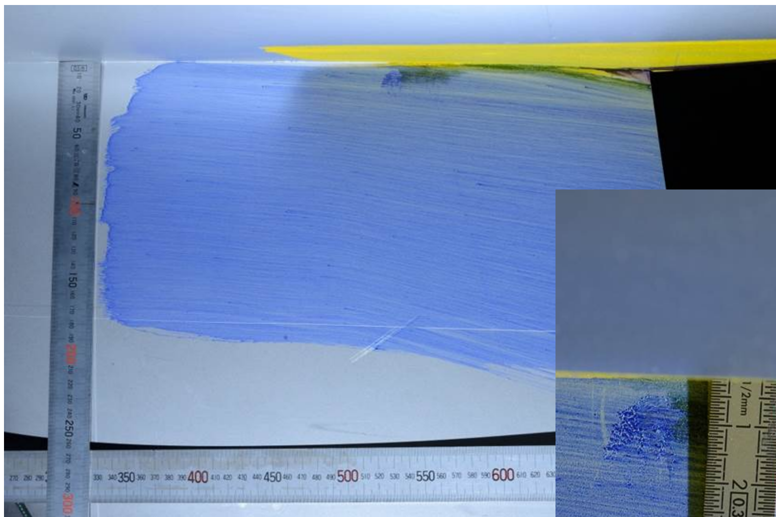
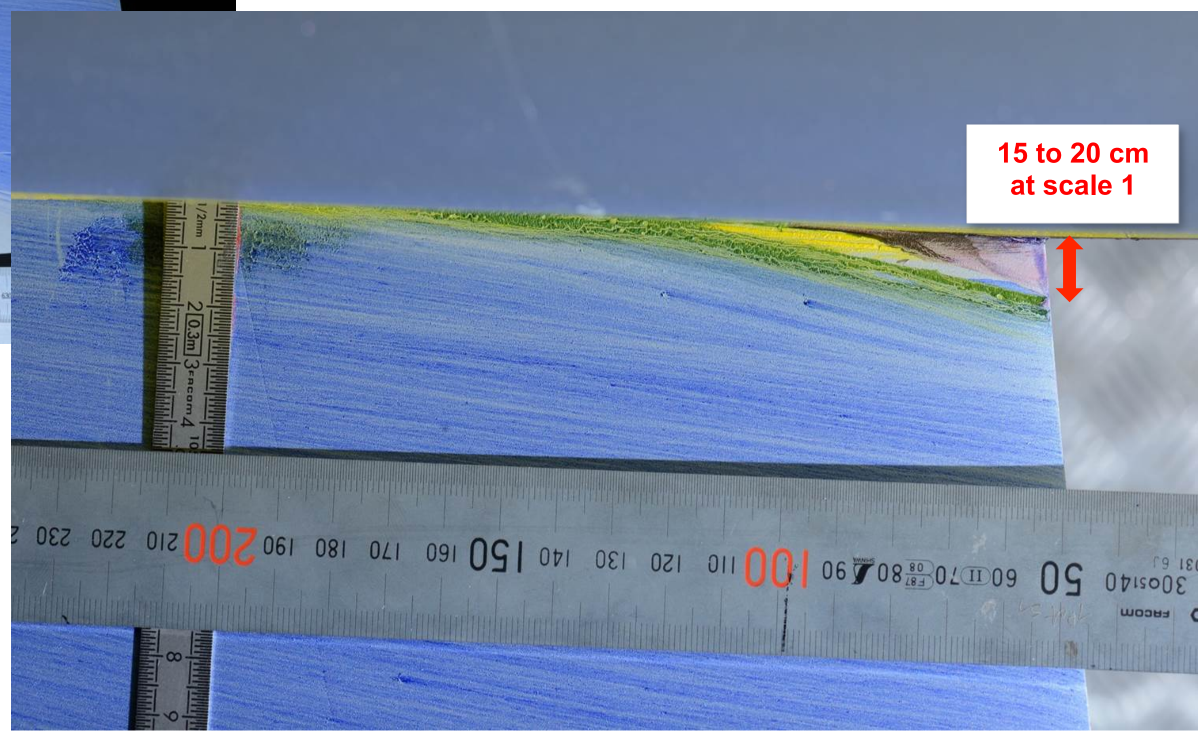
SOB separation on WB Configuration



Oil visualization on ONERA CRM model in ONERA-S1 Wind Tunnel (GMT CMA)



Publication to come [N1]

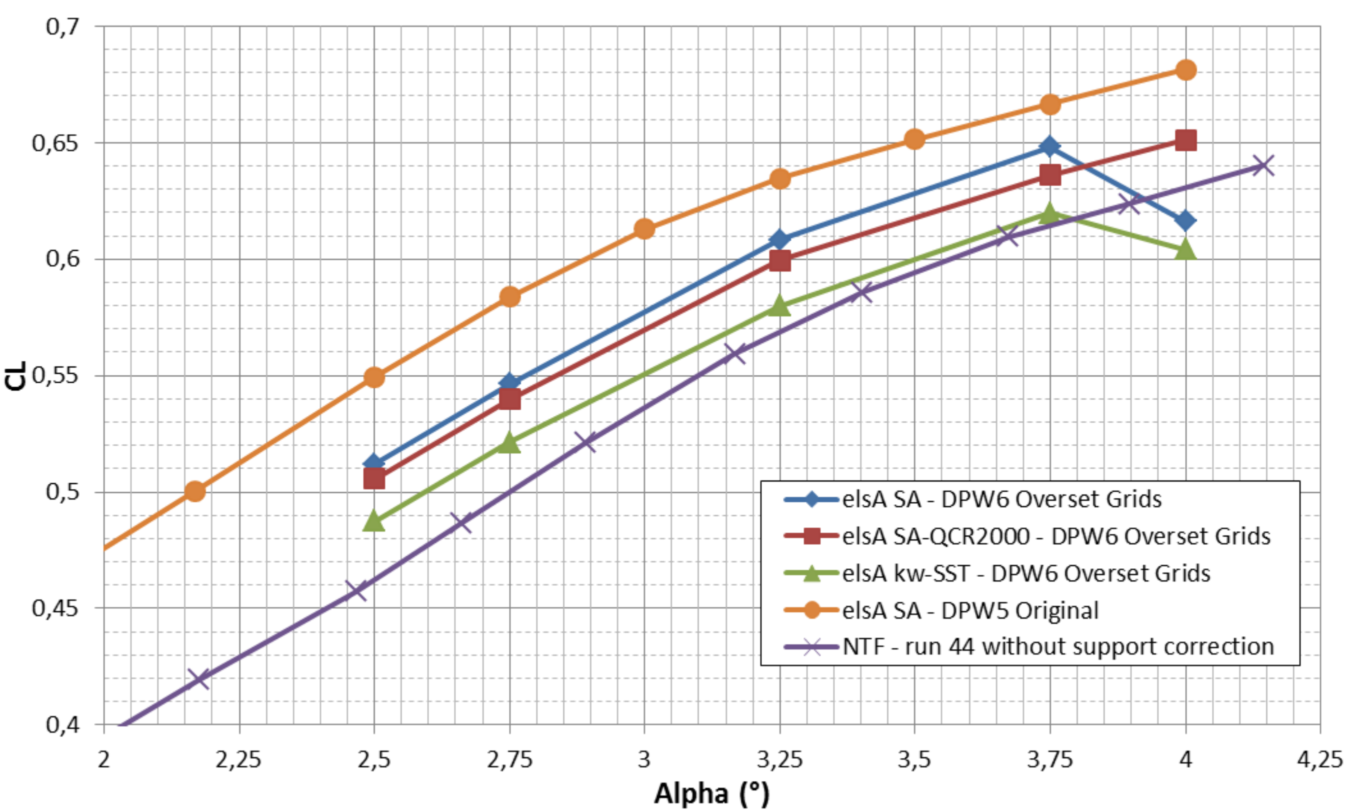
[N1] Cartieri, A., Hue, D., Chanzy, Q., “Analysis of the first ONERA-S1 Wind Tunnel Test Campaign of the CRM Configuration”

Test-Case 3
CRM WB Static Aero-Elastic Effect

CRM WB Static Aero-Elastic Effect

NASA-CRM Wing-Body – Ma = 0.85, $Re_{/c}$ = 5.10^6 – Medium Grid – Alpha sweep from 2.5 to 4°

Wing deformation from Exp. at each AoA



Better CFD / WT agreement achieved with the Exp. wing shapes

Non-negligible difference between SA and kw-SST models over whole polar

But SA and kw-SST models exhibit same CL drop at 4°

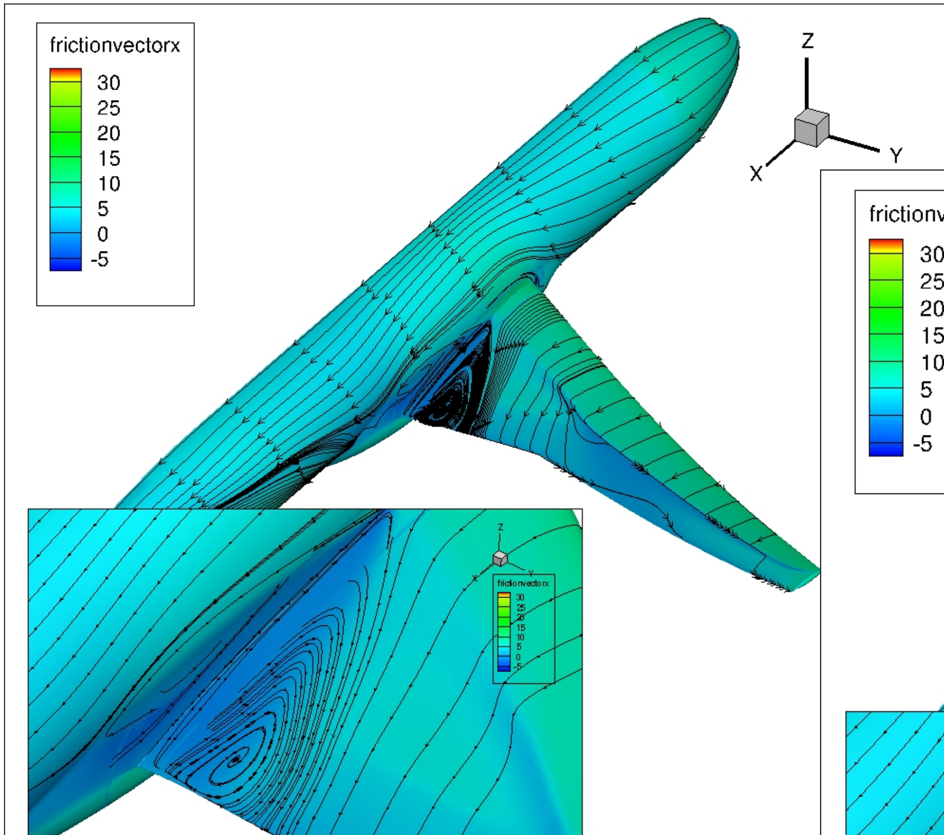
The Spalart QCR2000 version shows behavior closer to experiments

Quadratic Constitutive Relation, 2000 version SA-QCR2000 (from http://turbmodels.larc.nasa.gov/spalart.html):
nonlinear model version of Spalart-Allmaras is described in: Spalart, P. R., "Strategies for Turbulence Modelling and Simulation," International Journal of Heat and Fluid Flow, Vol. 21, 2000, pp. 252-263. The model is computed the same as SA, but instead of the traditional linear Boussinesq relation, the following form for the turbulent stress is used: $\tau_{ij,QCR} = \tau_{ij} - C_{cr1}\left[O_{ik}\tau_{jk} + O_{jk}\tau_{ik}\right]$

CRM WB Static Aero-Elastic Effect

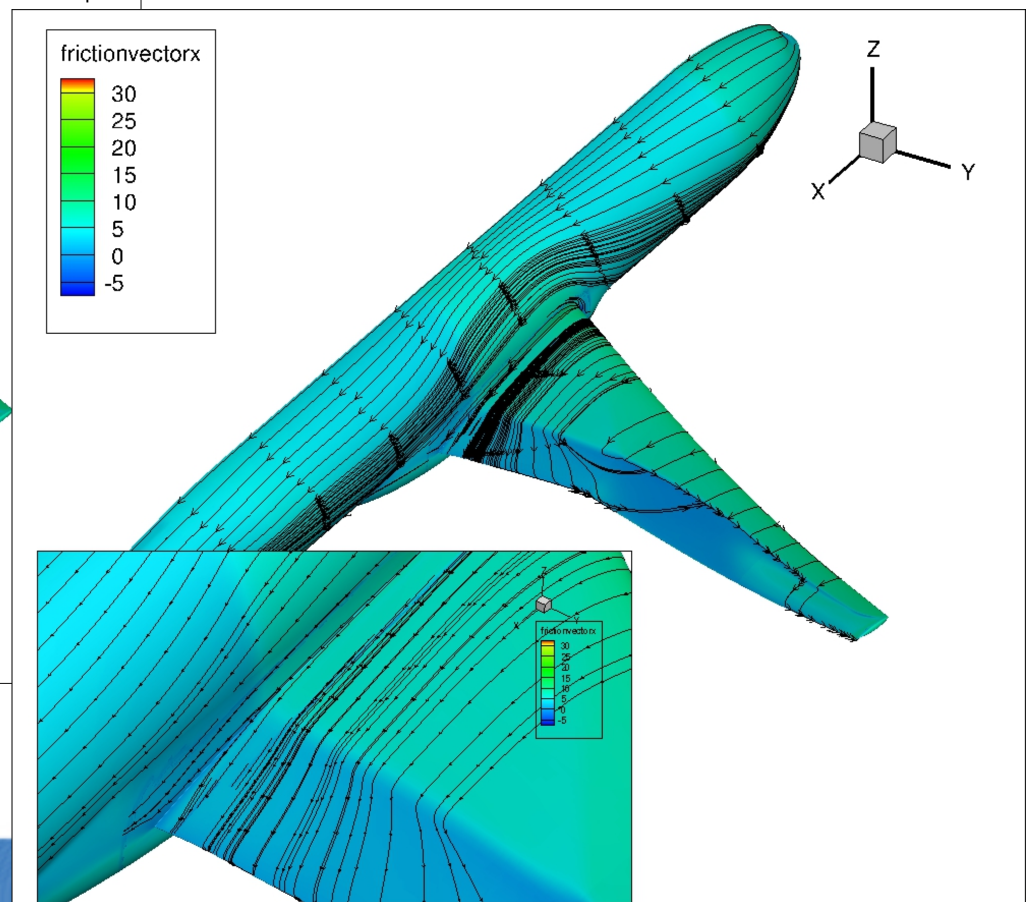
NASA-CRM Wing-Body – Ma = 0.85, $Re_{/c}$= 5.10^6 – Medium Grid – Alpha sweep from 2.5 to 4°

Focus at 4°



4° - SA model

4° - SA model with QCR2000 version



CRM WB Static Aero-Elastic Effect

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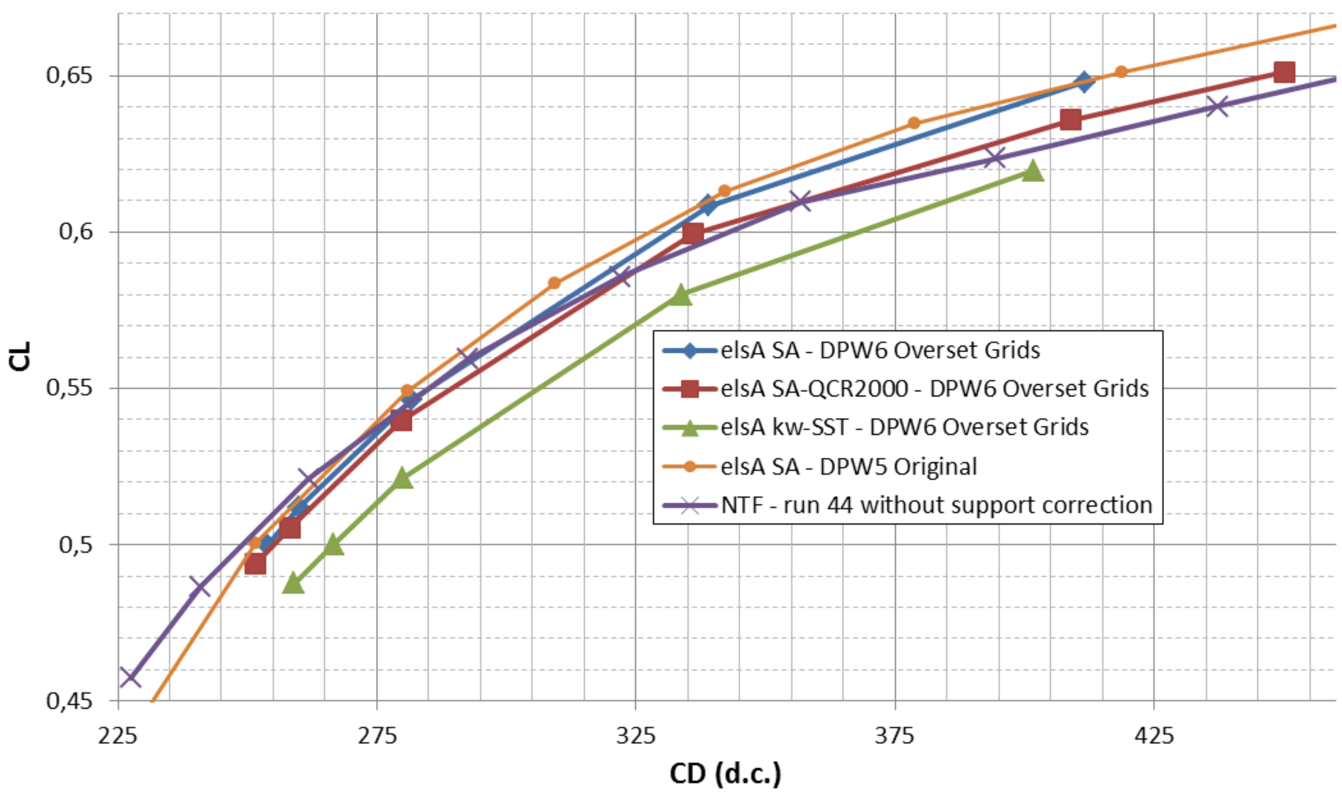
Wing deformation from Exp. at each AoA



Not Better CFD / WT agreement achieved with the Exp. wing shapes

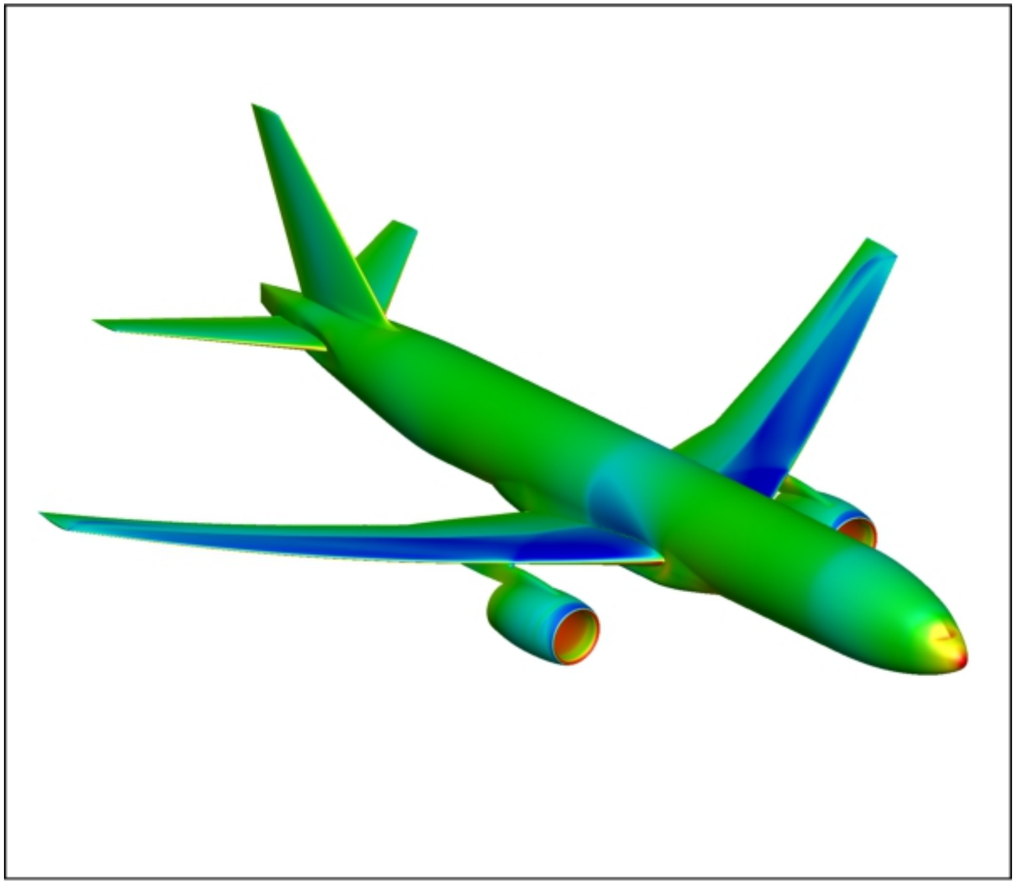
Significant drag difference between SA and kw-SST models over whole polar

The Spalart QCR2000 version significantly improves agreement with experiments at high AoA but very limited influence at CL = 0.5

Complete Configuration

Complete Configuration

NASA-CRM complete but not trimmed – Ma = 0.85, CL = 0.5, $Re_{/c}$= 5.10^6



	WBNP med.	Complete	Delta
Alpha	2,622	2,700	0,078
CL	0,500	0,500	0,00
CDnf	276,7	306,8	30,1
CDf	132,0	152,9	20,9
CDvp	47,2	56,1	8,9
CDv	179,3	209,0	29,7
CDw	5,8	6,7	0,9
CDi	91,1	90,6	-0,5
CDff	276,3	306,3	30,0
CDsp	0,4	0,4	0,0
CM	-0,0915	-0,0575	0,034

Beoing Overset Grids for WBNP Configuration and ONERA Overset Grids for HTP + VTP [3]

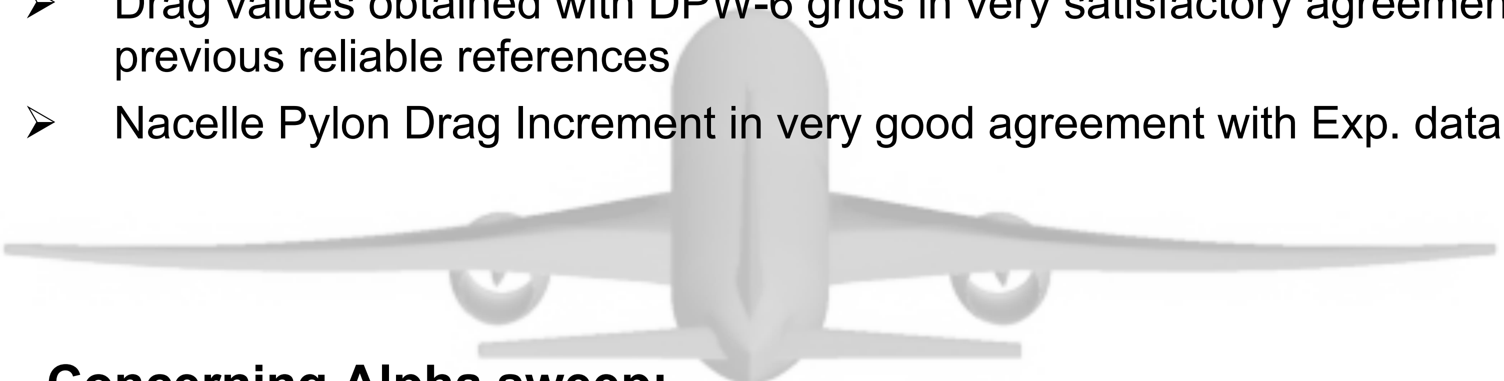
VTP geometry proposed by ONERA (available at http://commonresearchmodel.larc.nasa.gov) because needed in ONERA-S1 Wind Tunnel

HTP + VTP increment in agreement with [3]

[3] Hue et al., "Validation of a near-body and off-body grid partitioning methodology for aircraft aerodynamic performance prediction," Computers & Fluids, Vol. 117, 2015, pp. 196-211

Conclusions

- **Concerning Grid convergence studies:**
  - Good convergence behavior obtained with elsA / Cassiopee using the Boeing Overset family (low dissipation even on coarsest grids)
  - Drag values obtained with DPW-6 grids in very satisfactory agreement with previous reliable references
  - Nacelle Pylon Drag Increment in very good agreement with Exp. data



- **Concerning Alpha sweep:**
  - Better CFD / WT agreement achieved with the Exp. wing shapes and QCR

- **An article gathering at least all of the results presented here will be submitted to the Journal of Aircraft in the coming months [N2]**

[N2] Hue, D., Chanzy, Q., Landier, S., “CFD Drag Prediction of the DPW-6 Aircraft Configuration using the ONERA Far-Field Approach”

Thank you for your attention,
Questions?

ONERA
THE FRENCH AEROSPACE LAB

return on innovation

References and Publications to come

[1] Hue, D., “Fifth Drag Prediction Workshop: ONERA Investigations with Experimental Wing Twist and Laminarity,” Journal of Aircraft, vol.51(4), pp. 1311-1322, 2014

[2] Péron, S., Benoit, C., Landier, S., and Raud, P., “Cassiopée: CFD Advanced Set of Services In an Open Python EnvironmEnt,” 12th Symposium on Overset Grid and Solution Technology, Atlanta, 2014

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[4] Cambier, L., Heib, S., and Plot, S., “The ONERA elsA CFD Software: Input from Research and Feedback from Industry,” Mechanics and Industry, Vol. 15(3), pp. 159-174, 2013

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