METODOLOGIE E TECNOLOGIE PER LO SVILUPPO DI UN NUOVO VELIVOLO

Computational Fluid Dynamics and Wind Tunnel Testing

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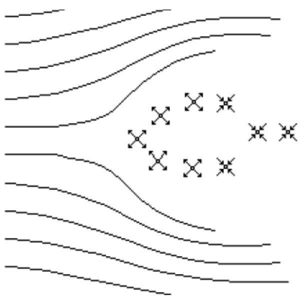
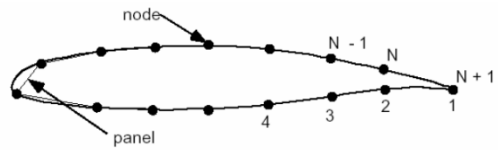
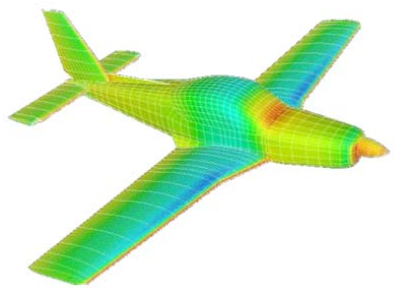
CFD – Historical notes

- Lewis Fry Richardson (**“W**eather prediction by numerical process“, **1922)**
- Early CFD calculations during the 1940s using ENIAC (first electronic general-purpose computer)
- Francis H. Harlow, Los Alamos National Lab
- A.M.O. Smith of Douglas Aircraft in 1967 (Panel Methods)
- PanelCodesBoeing(PANAIR),Lockheed(Quadpan),Douglas(HESS),McDonnellAircraft(MACAERO),NASA(PMARC) and AnalyticalMethods(VSAERO)
- Profile (Eppler) , XFOIL(Drela), (1980)
- Transonic modeling (Jameson) 1975
- MGAERO cartesian mesh code. NASA CART3D code, Lockheed's SPLITFLOW code and Georgia Tech's NASCART-GT. 3-D AIRPLANE code (Jameson) whith unstructured tetrahedral grids.



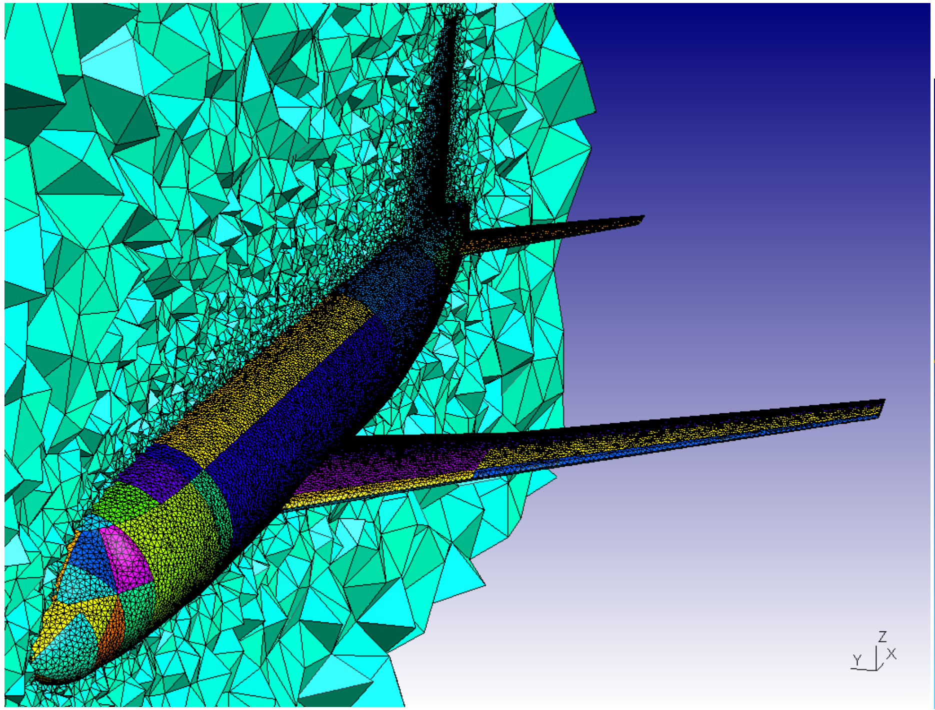


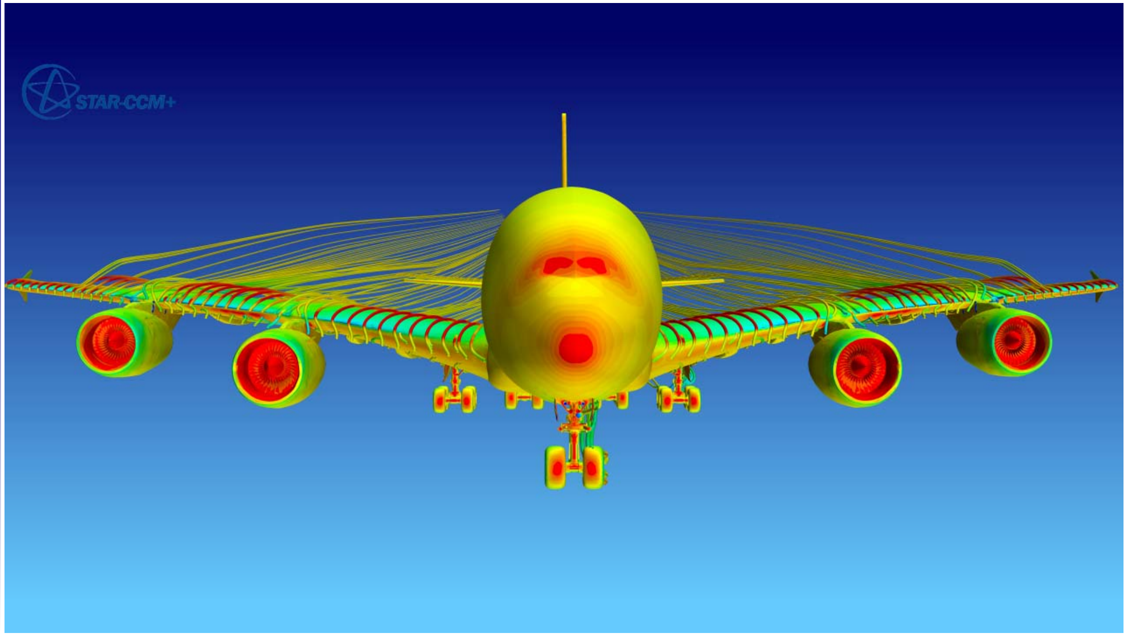
$$A_{N+1,j} = \frac{1}{2\pi}\begin{bmatrix} \sin(\theta_1 - \theta_j)\beta_{1,j} + \sin(\theta_N - \theta_j)\beta_{N,j} \\ -\cos(\theta_1 - \theta_j)\ln\left(\frac{r_{1,j+1}}{r_{1,j}}\right) - \cos(\theta_N - \theta_j)\ln\left(\frac{r_{N,j+1}}{r_{N,j}}\right) \end{bmatrix}$$



CFD – Some Notes

- The **Reynolds-averaged Navier–Stokes equations** (or **RANS** equations) are time-averaged equations of motion for fluid flow. The RANS equations are primarily used to describe turbulent flows.

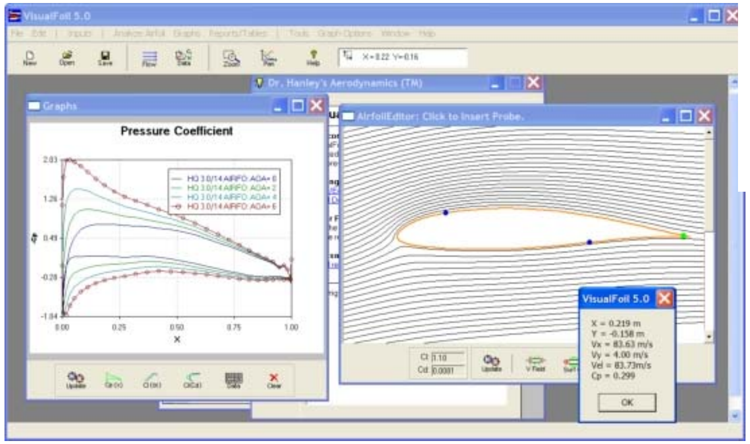


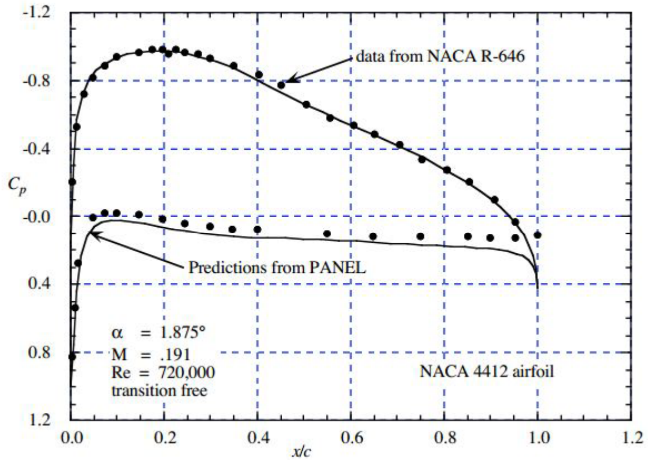


CFD – Tools

- ✈ Each model, each approach (potential, panel method, full potential, inviscid + b.l., viscous, 2-D or 3-D) can be extremely useful to perform the design and the analysis of an aircraft.

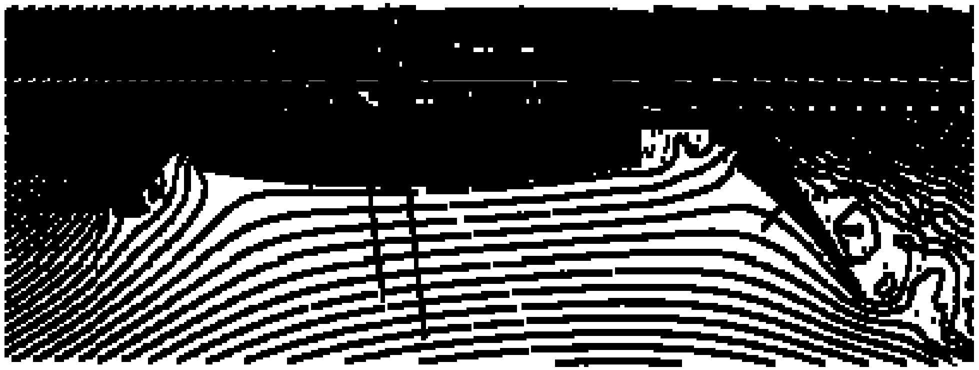
1) 2-D (inviscid+b.l.) airfoil analysis and design (XFOIL, MSES, JAVAFOIL, in house)



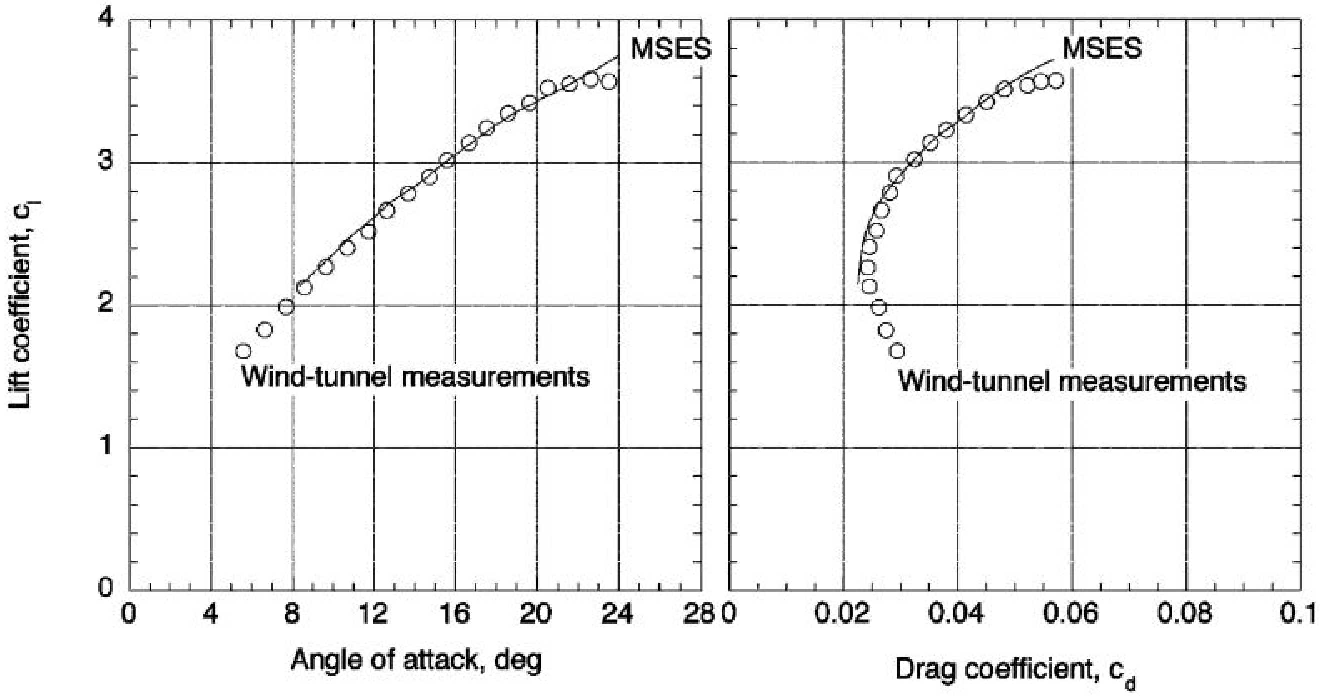


CFD – Tools

2) 2-D multi-component airfoil analysis and design



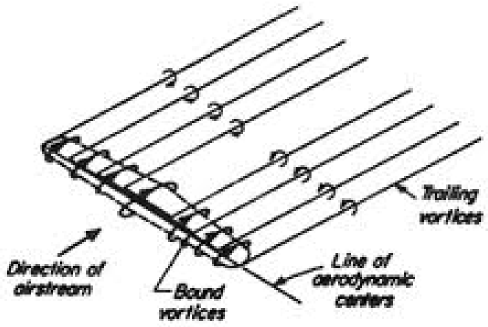
Drela M. Newton solution of coupled viscous/inviscid multielement airfoil flows. AIAA Paper 90-1470, June 1990.



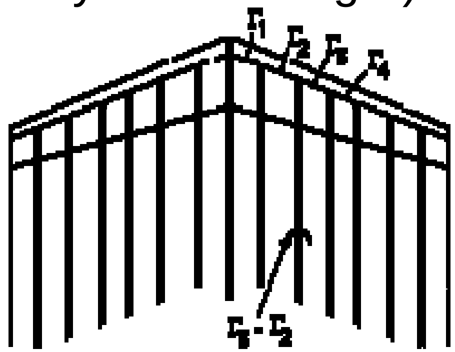
CFD – Tools

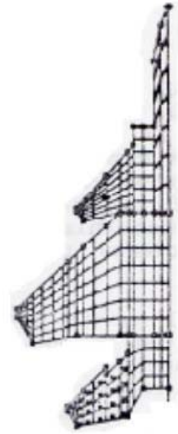
3) 3-D Aerodynamic analysis of lifting surfaces (lifting line theory or Weissinger)

(Prandtl, Munk, Schrenk, Multhopp



lifting line





Vortex Lattice
233 panels

NACA RM L51J19 (1952)

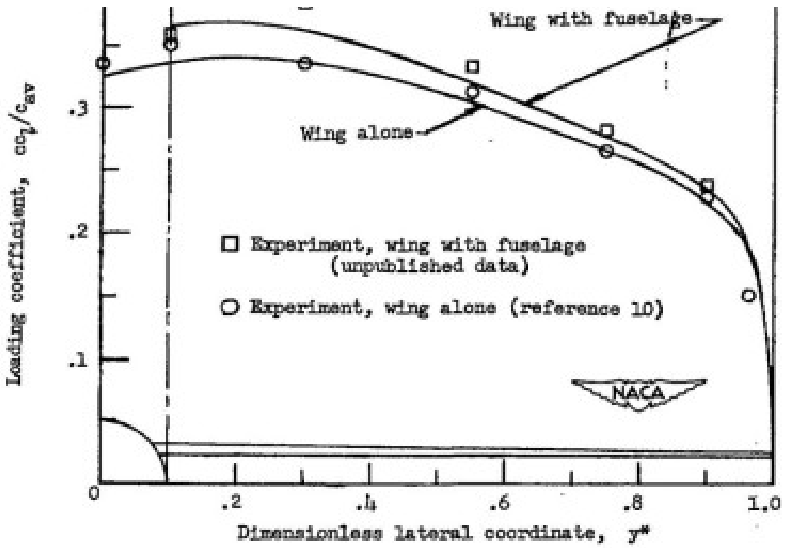
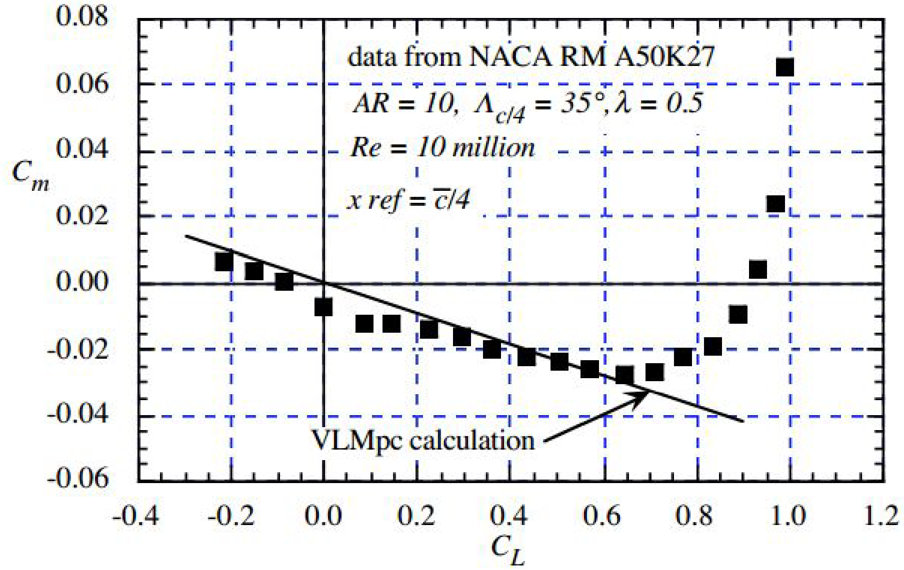


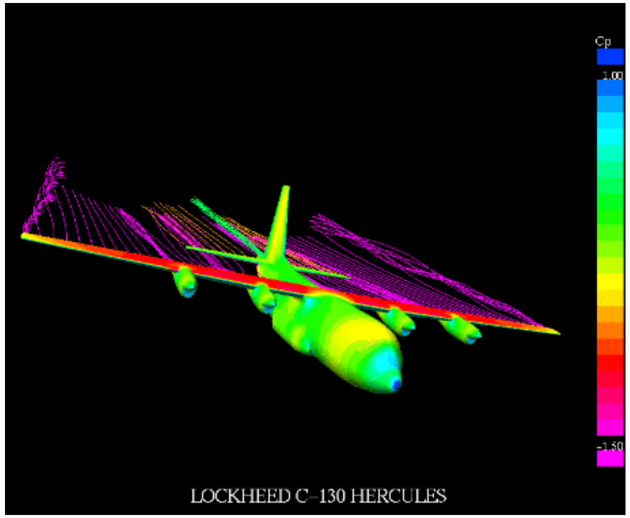
Figure 5.- Comparison of theoretical and experimental lift distribution on a swept wing with and without fuselage. $A = 8$; $\lambda = 0.45$; $\Lambda = 45^{\circ}$; $a^{*} = 0.1$; $\alpha = 4.7^{\circ}$.

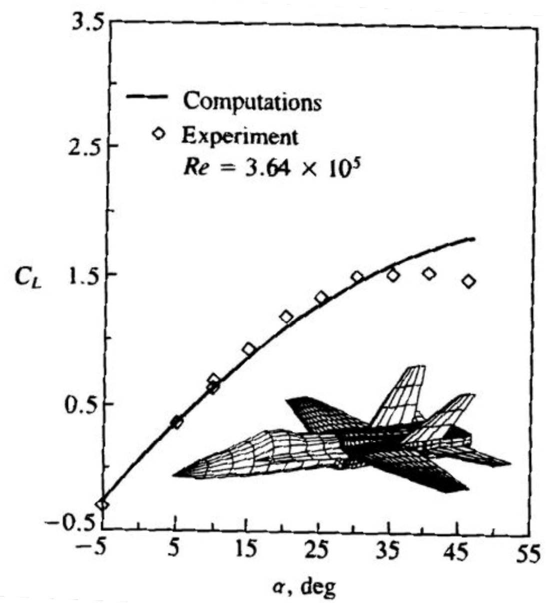


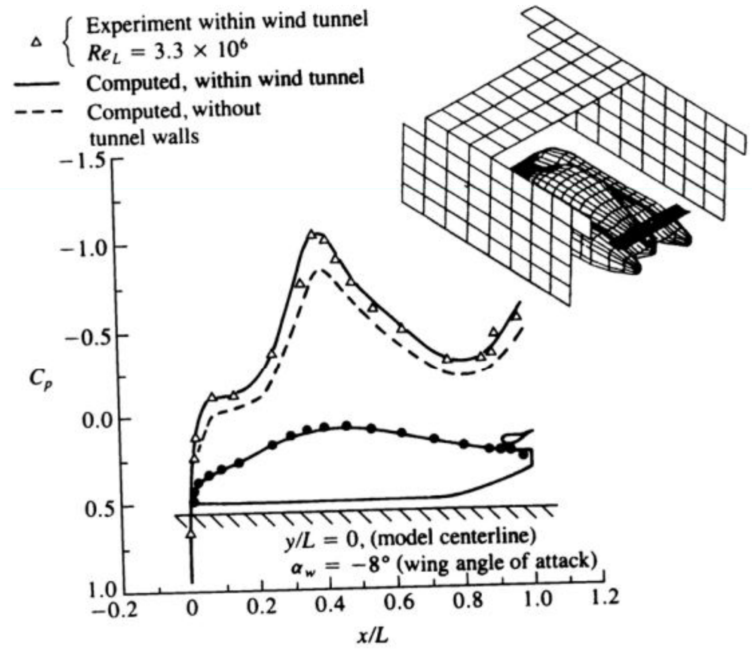
CFD – Tools

4) 3-D Panel Method + b.l. (ex. VSAERO)

- (Attached incompressible flow, complex geometry)
- Steady /Unsteady
- Skill required for meshing
- Large PC workstations
- Accuracy in prediction of longitudinal and lateral-directional derivatives (linear range), downwash, skin friction drag, vortex drag(winglet), propulsive effects
- Computing time (1 aoa, complex geometry) on workstation => about 1 hr.



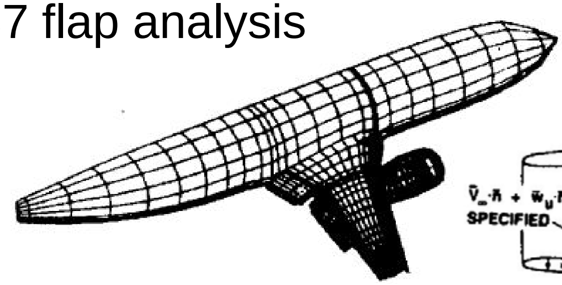


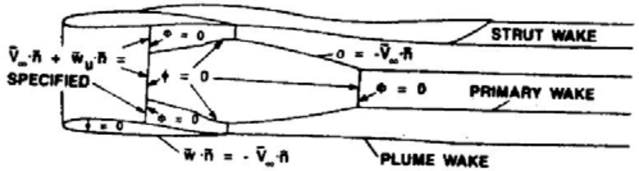


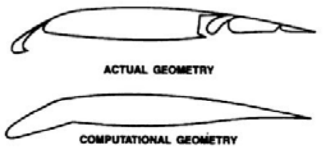
CFD – Tools

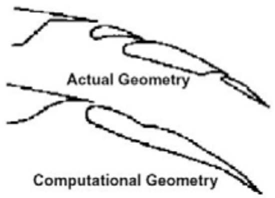
4) 3-D Panel Method + b.l. (ex. VSAERO)

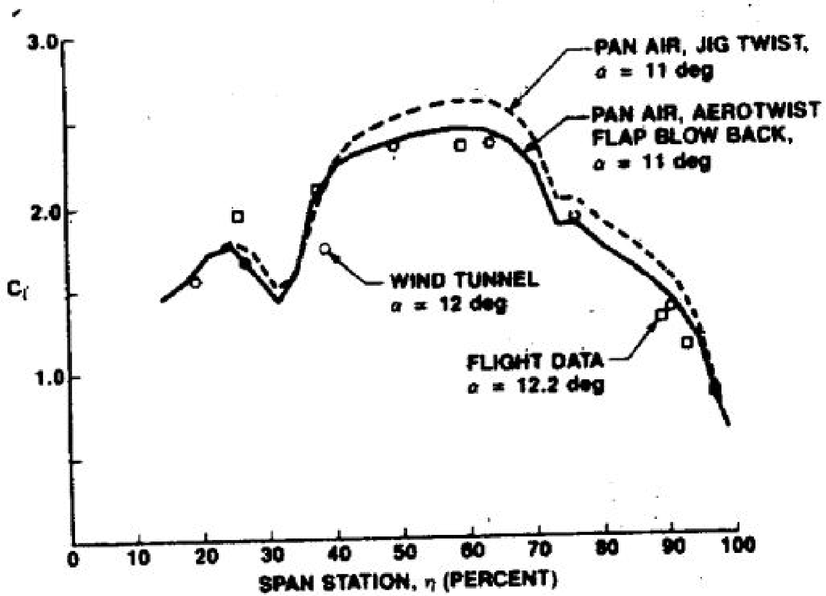
B737 flap analysis

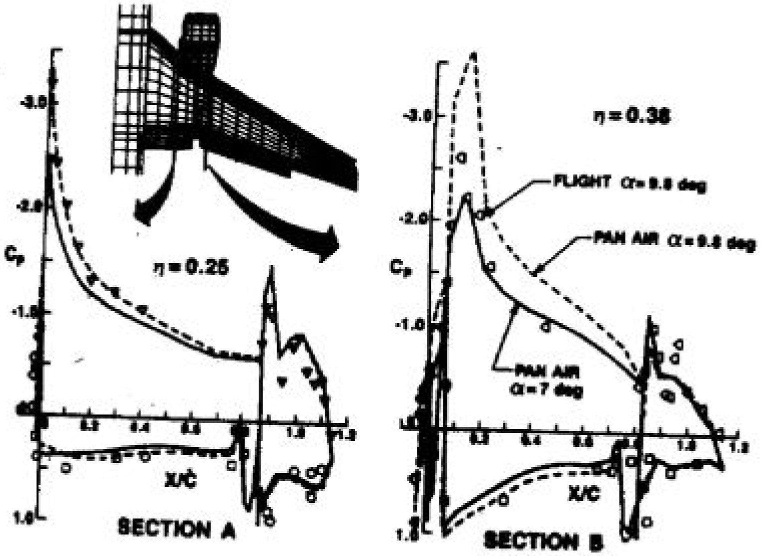


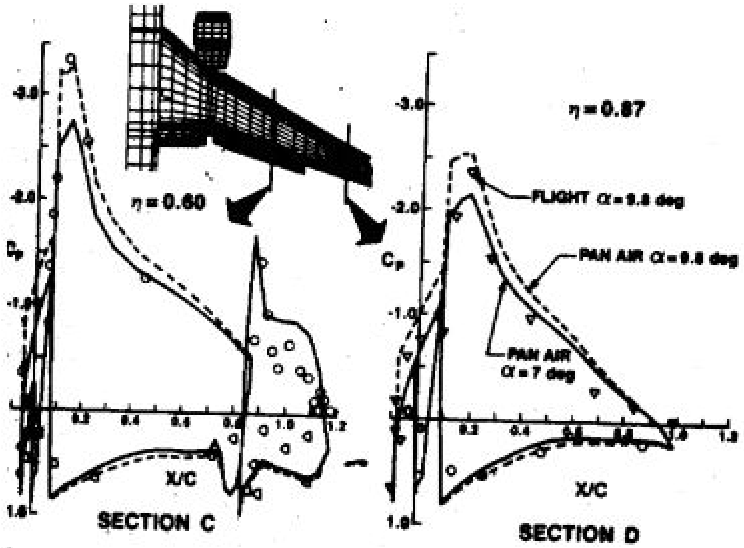








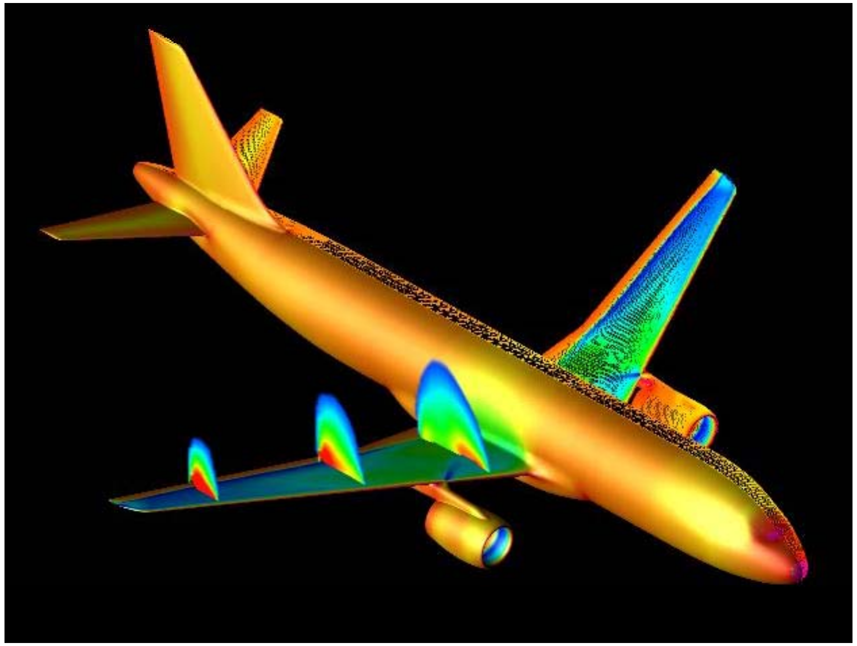




CFD – Tools

5) 3-D Euler

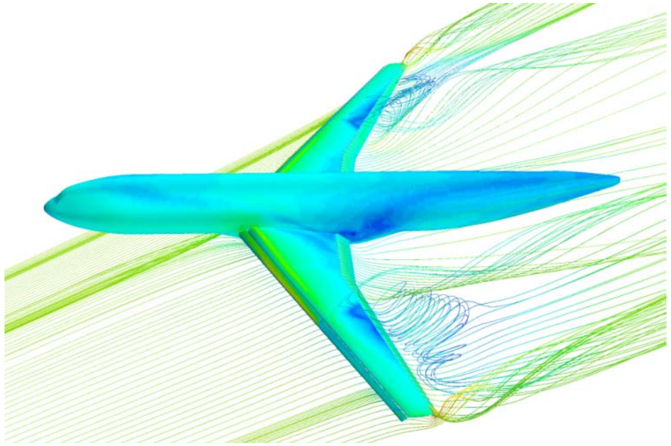
- (Attached compressible flow, complex geometry)
- Steady / Unsteady
- Skill required for meshing
- Large PC workstations or Parallel Computing
- Accuracy in prediction of longitudinal and lateral-directional derivatives (linear range), downwash, skin friction drag, vortex drag(winglet), propulsive effects and shock waves.
- Computing time (1 aoa, complex geometry) workstation => about 3 hr.

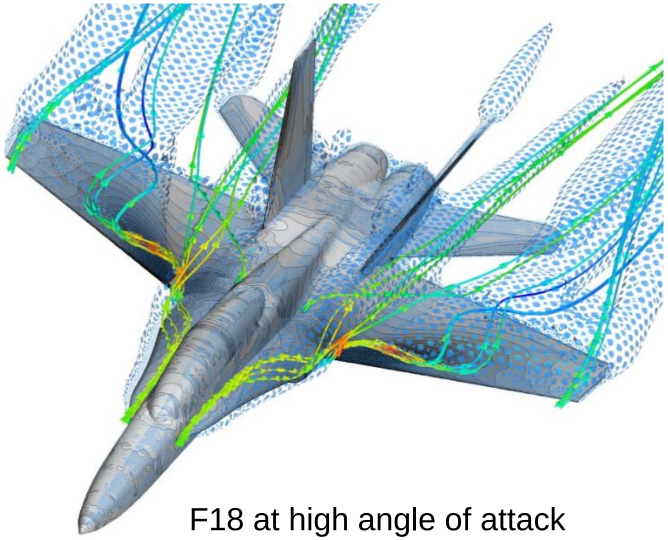


CFD – Tools

6) 3-D Navier-Stokes (RANS)

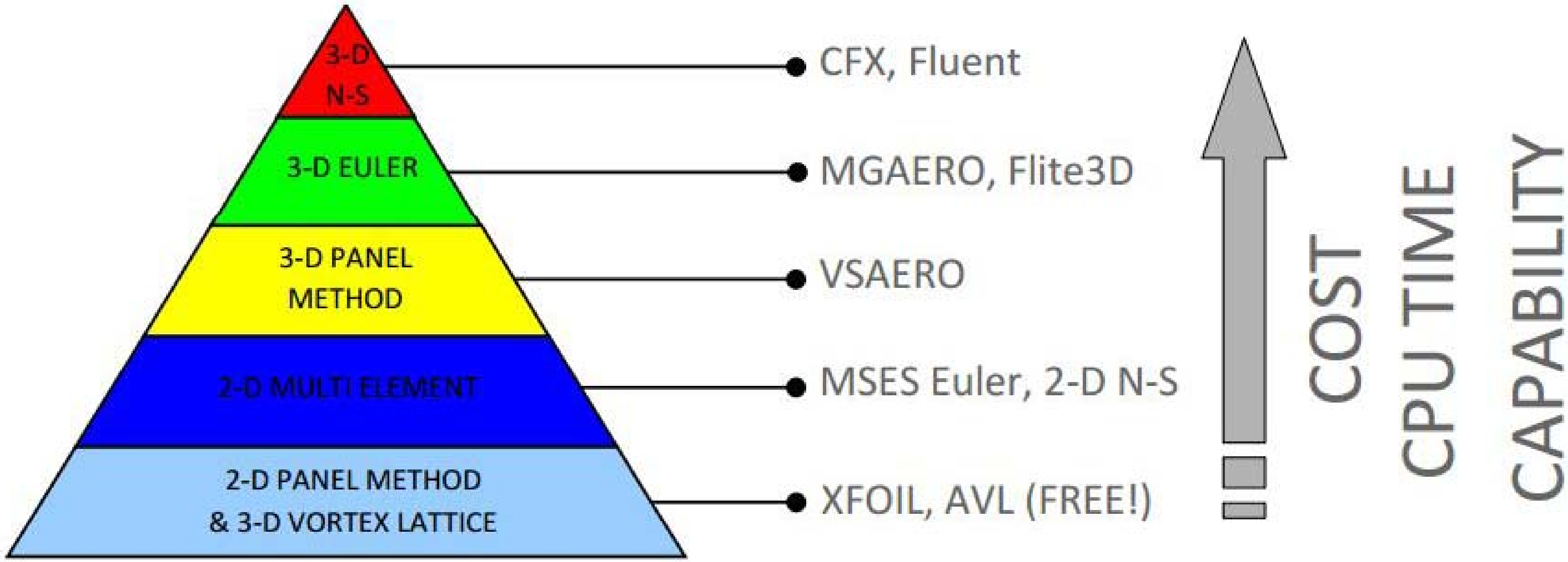
- (Turbulent and separated flow, compressible flow, complex geometry)
- Steady / Unsteady
- Very High Skill required for meshing
- Workstations or Parallel Computing
- Interaction between components, separated flow, stall, wake indirect effects.
- From CAD to results => about 10 days
- Computing time (1 aoa, normal case geometry) on workstation => about 3 hr.
- 128 CPU => about 1 hr



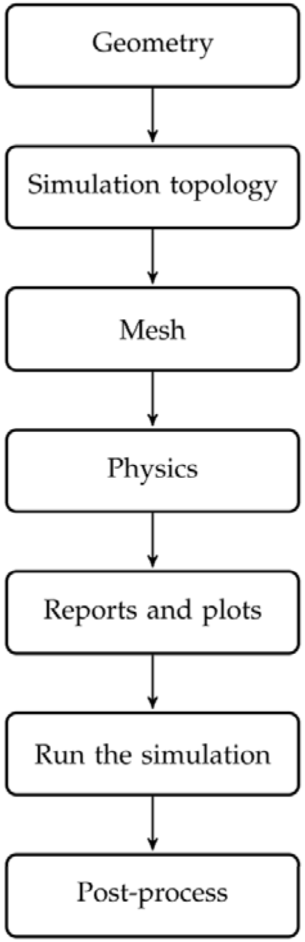


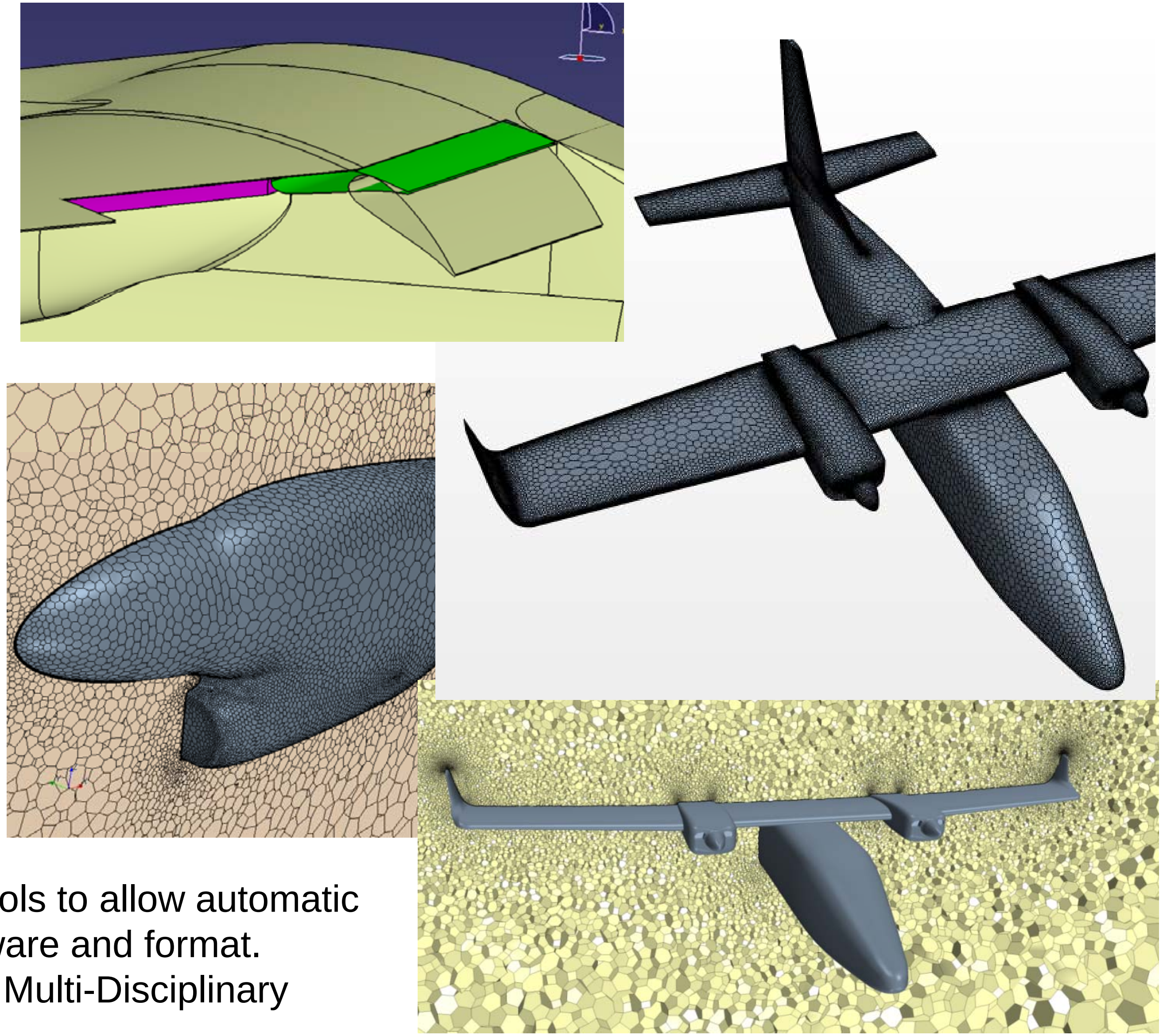
F18 at high angle of attack

CFD – Tools


3-D
N-S
3-D EULER
3-D PANEL
METHOD
2-D MULTI ELEMENT
2-D PANEL METHOD
& 3-D VORTEX LATTICE
CFX, Fluent
MGAERO, Flite3D
VSAERO
MSES Euler, 2-D N-S
XFOIL, AVL (FREE!)
COST
CPU TIME
CAPABILITY

CFD – The complete process

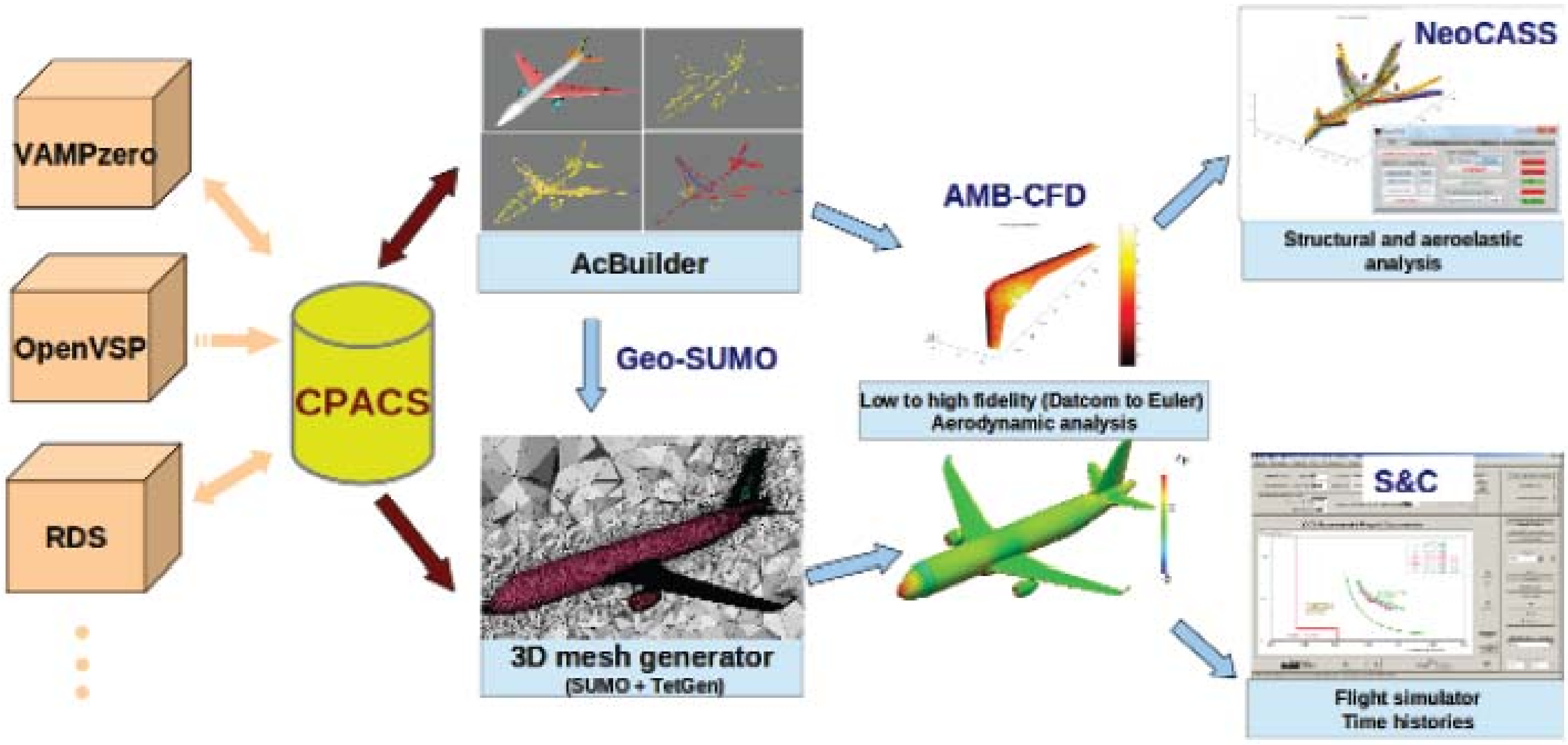




- It is very important to work on tools to allow automatic interface between different software and format.
- Possible integration of CFD in a Multi-Disciplinary Optimization Framework

CFD – The complete process

- Communication in Aircraft Design
- Development of a Design Framework coupling different tools and disciplinary analysis
- Concept-design and high-fidelity analysis

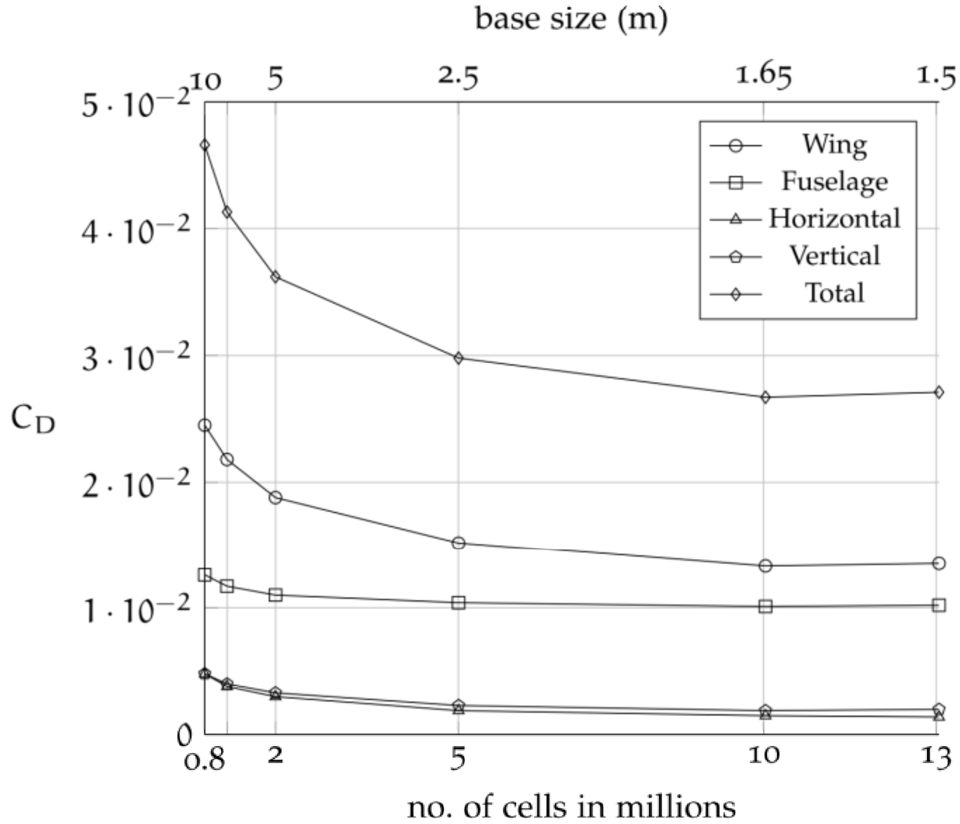


CFD – Computational Load

How the CFD mesh has to be detailed ?

How many Volume Cells ?

- For Longitudinal analysis in symmetrical condition half number of cells required
- For flapped configuration and analysis with propeller the number of cells should be increased
- Boundary layer modeling (Higher Re, thinner the b.l.)

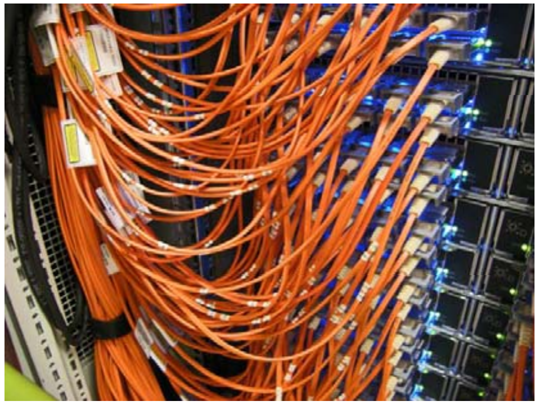


(b) *Drag coefficient.*

CFD – Computational Load

<u>Super Computing</u>

- Parallel Computing (i.e. 164 CPU)
- Fast upload and download
- RAM and Storage Capabilities (GB)
- VERY COMPLEX problem (steady condition) (i.e. Complete Aircraft with flap and propulsive effects) => about 17-20 mill. Cells., 1 angle of attack
- Comp. Time (8 CPU) => 2 days – 10 days (?)
  (128 CPU) => 8 hr. - 34 hr.



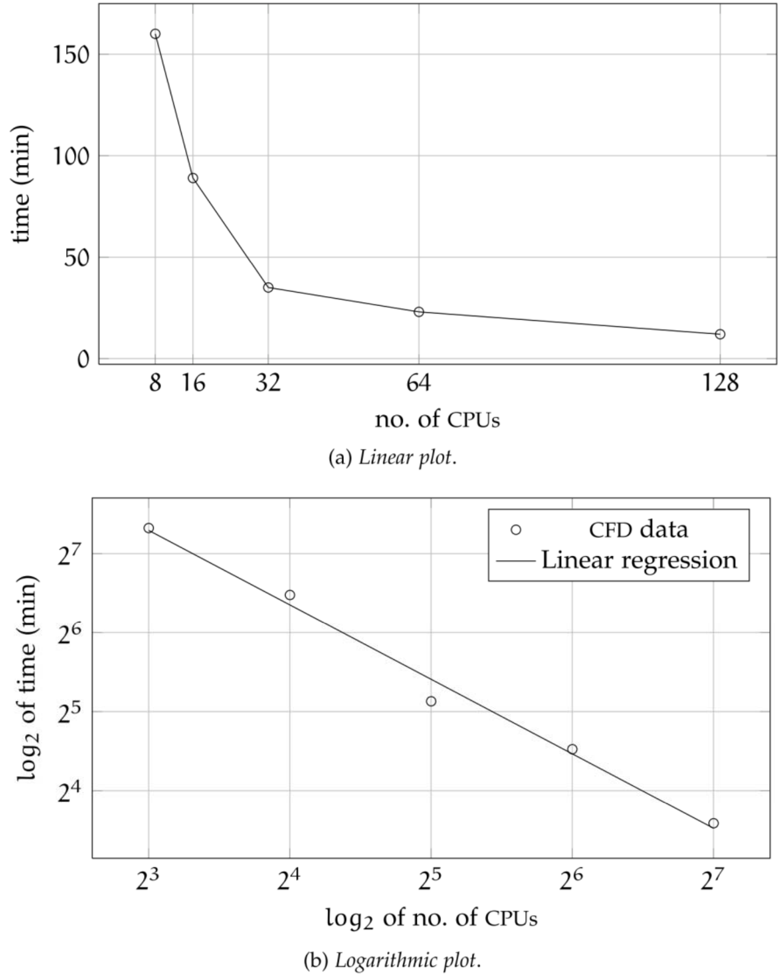


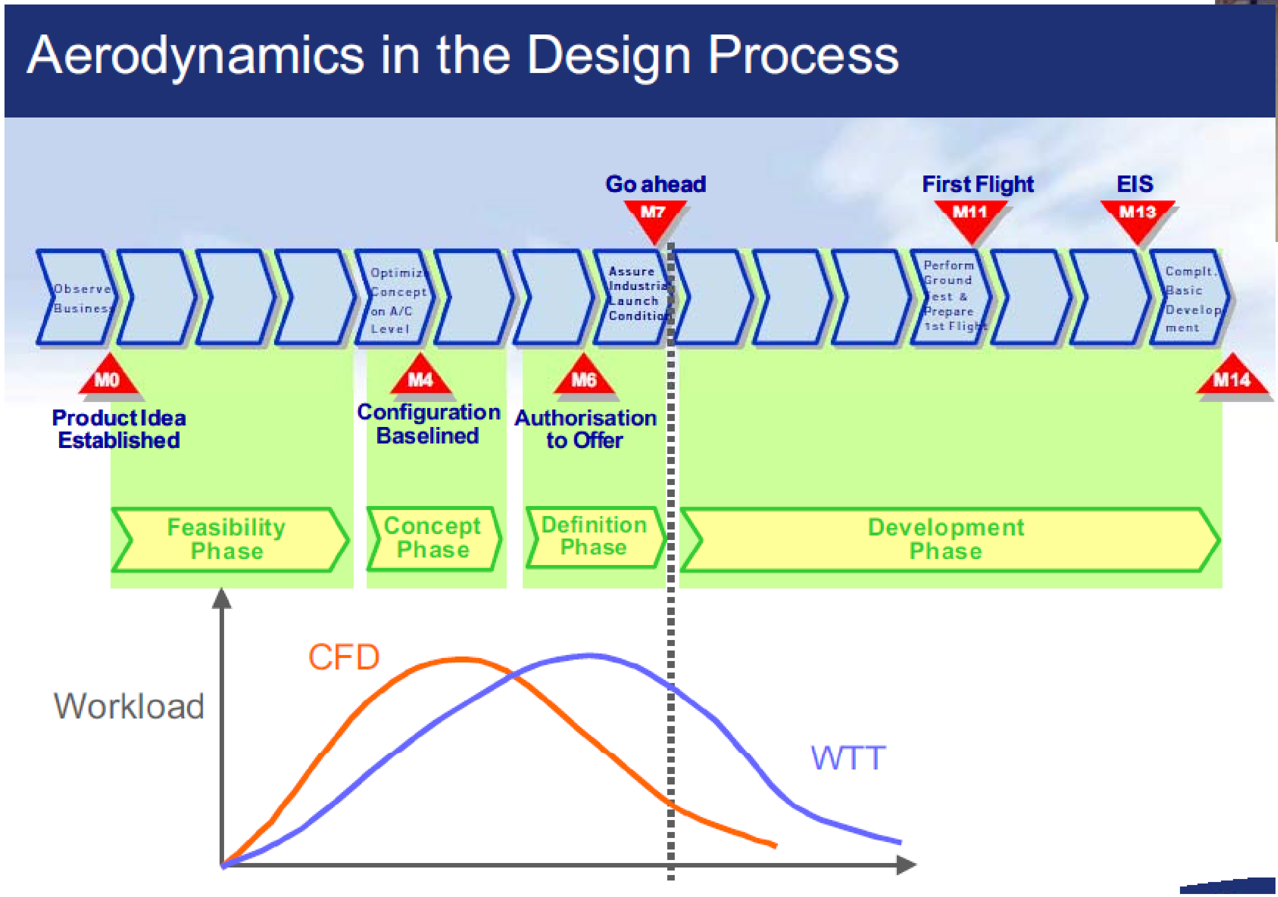
Figure 77: CPUs scalability for a body-vertical configuration with 1 800 000 polyhedral cells.

Wind-Tunnel tests

✈ **WIND-TUNNEL TESTS ARE CRUCIAL FOR NEW AIRCRAFT DEVELOPMENT**

Wind tunnel test: 5500 hrs for A380

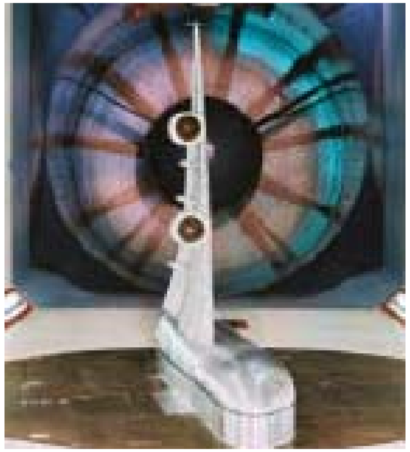
15000 hrs Boeing 787

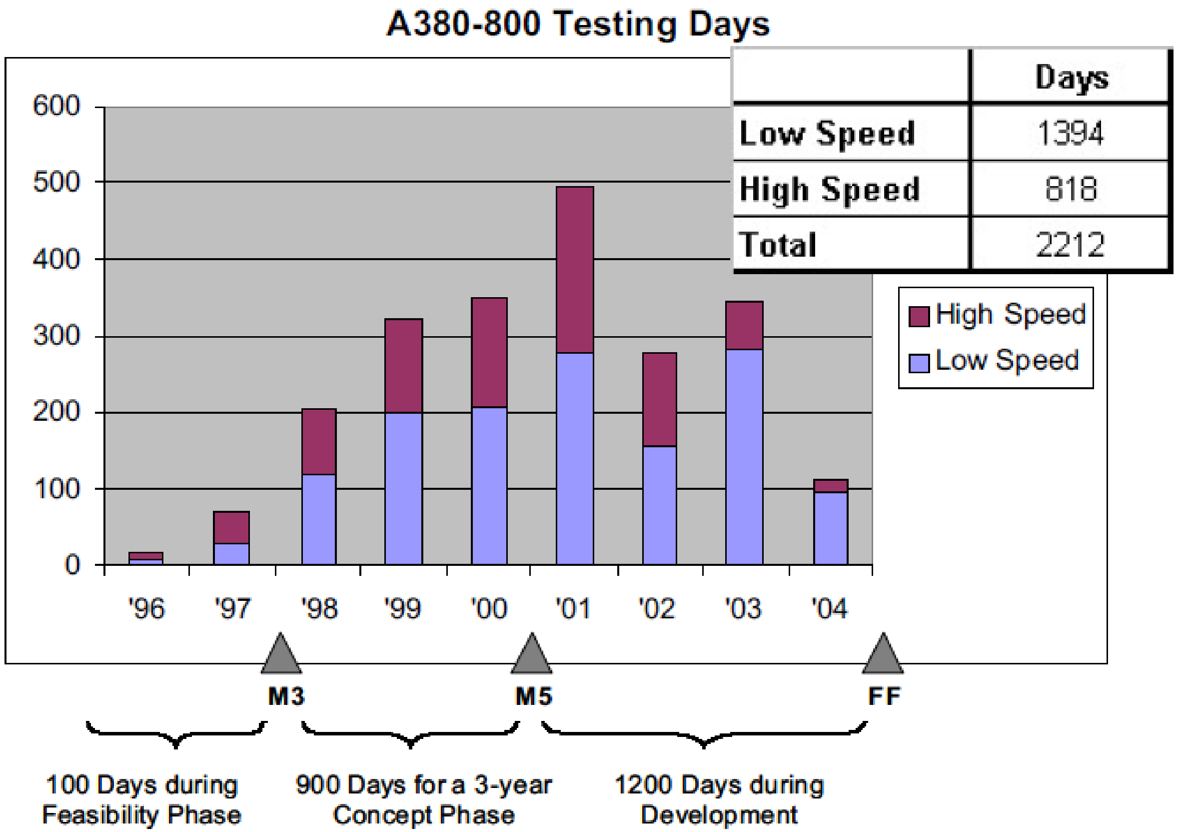


Wind-Tunnel tests

- **WIND-TUNNEL TESTS ARE CRUCIAL FOR NEW AIRCRAFT DEVELOPMENT**

  Through CFD complementary activity the goal is to reduce wind-tunnel test days => 1500 for A350





Wind-Tunnel tests

- ✈ **WIND-TUNNEL TESTS ARE CRUCIAL FOR NEW AIRCRAFT DEVELOPMENT**

Low-Speed Tests

ONERA F1

DNW

High-Speed Tests (Pressurized & Cryogenic)

ARA

ETW

ONERA S1

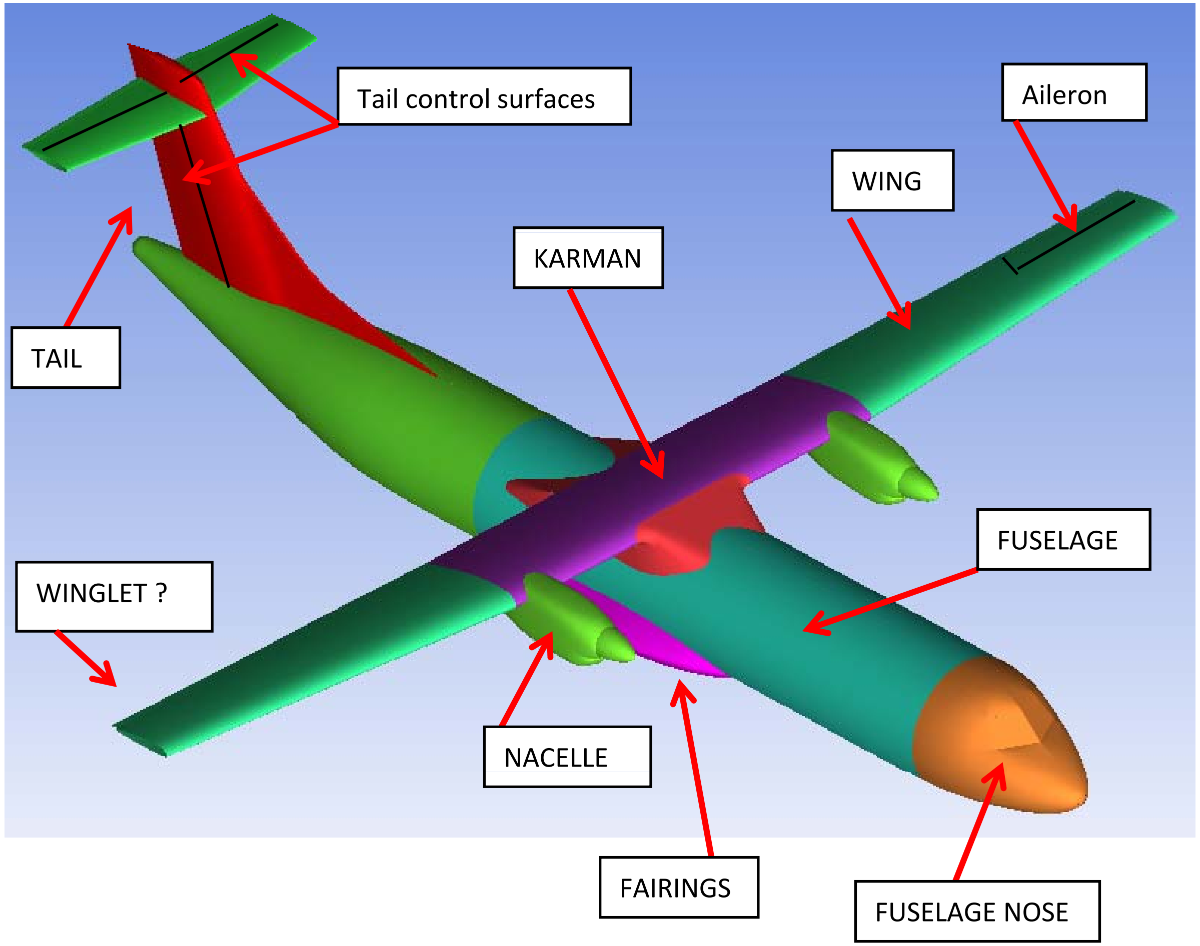
Dynamic Tests

Ground effect

Critical Aerodynamic Items

Aerodynamic Design of a Regional Turboprop - Critical Items

- **WING**
  - **Airfoils**
  - AR, taper ratio, twist
  - **Winglet**, Dihedral
- **HIGH-LIFT SYSTEM**
  - Flap (2-D and 3-D)
- **FUSELAGE**
  - Section and Fineness ratio
  - Nose and Tail
- **KARMAN/FAIRING**
  - Karman shape
  - Fairing shape and wheel bay
- **NACELLE** (and Prop. effects)
  - Nacelle shape
  - Prop. Effects on wing and tail
- **TAIL**
  - Vertical tail, dorsal fin
  - Horizontal tail



- **CONTROLS**
  - **Rudder**, Elevator
  - Aileron
- **LANDING GEAR**
  - Noise
  - Drag

CFD Application – WING AIRFOIL

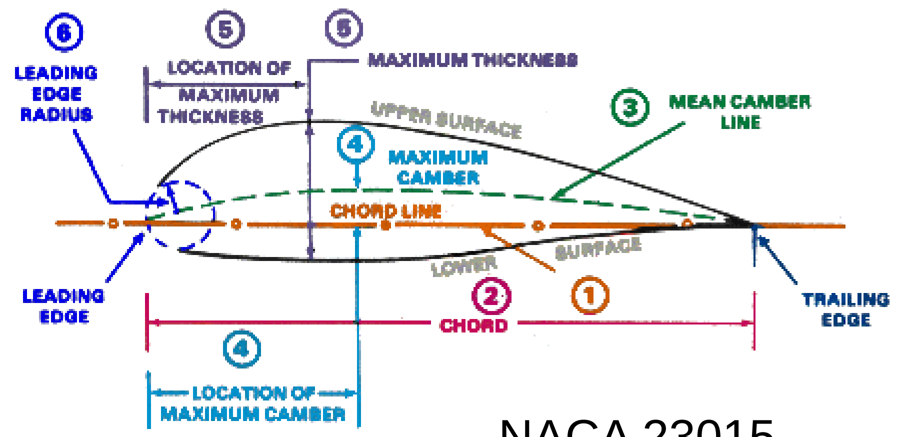
WING – Airfoil

- **Thickness ratio**
  - Cruise drag
  - Stall behavior
  - Wing weight
  - Fuel tank Volume

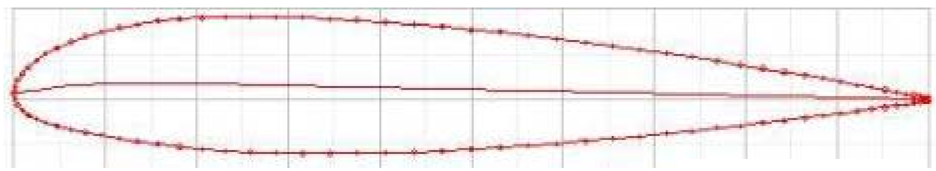
- **Airfoil shape**
  - Laminar flow ?
  - Cruise drag, climb drag, max lift

- **L.e. radius**
  - Clmax and stall behavior

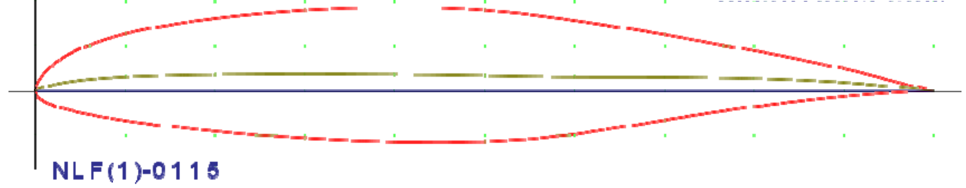
- **Airfoil camber**
  - Clmax and stall behavior
  - wing moment coefficient (tail eq. loads)

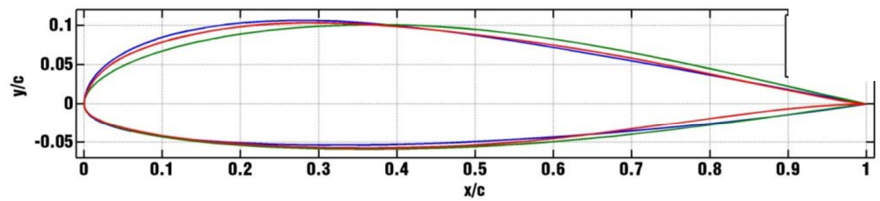


NACA 23015



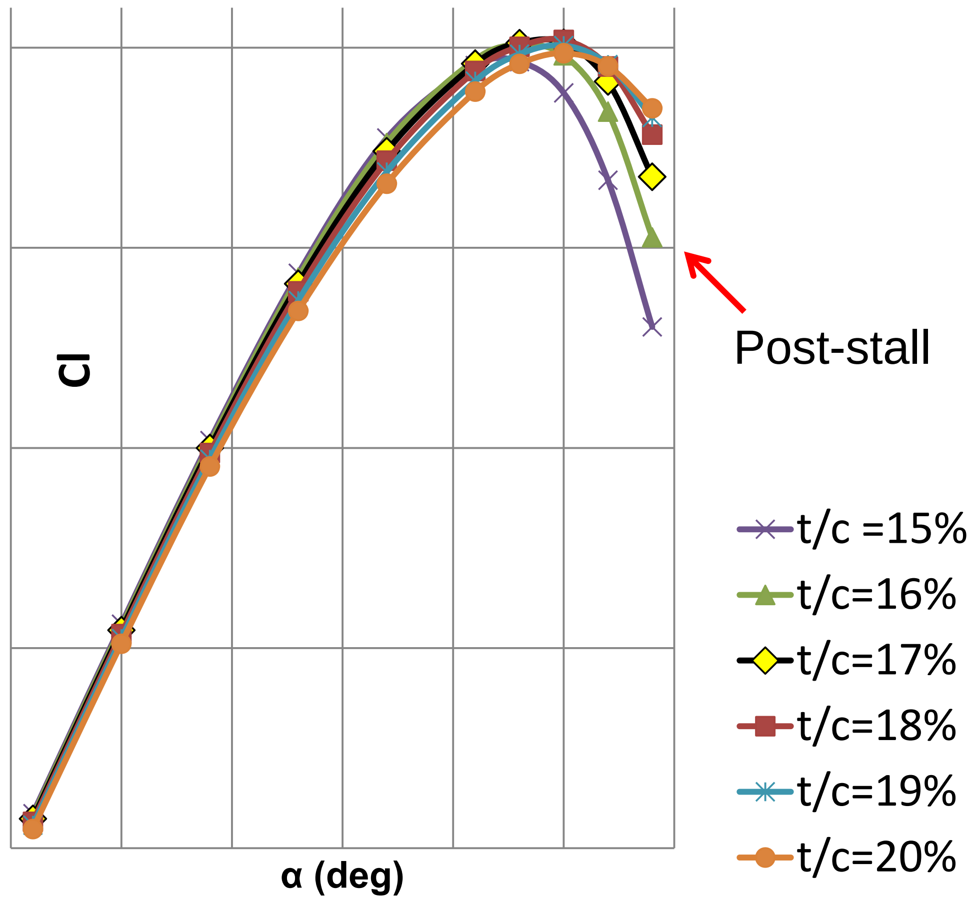
NLF 0115

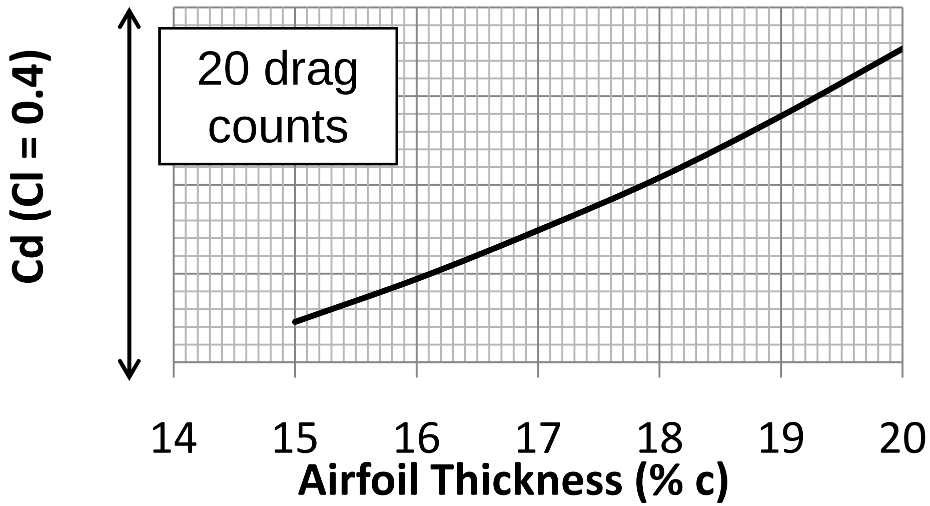




CFD Application – WING AIRFOIL

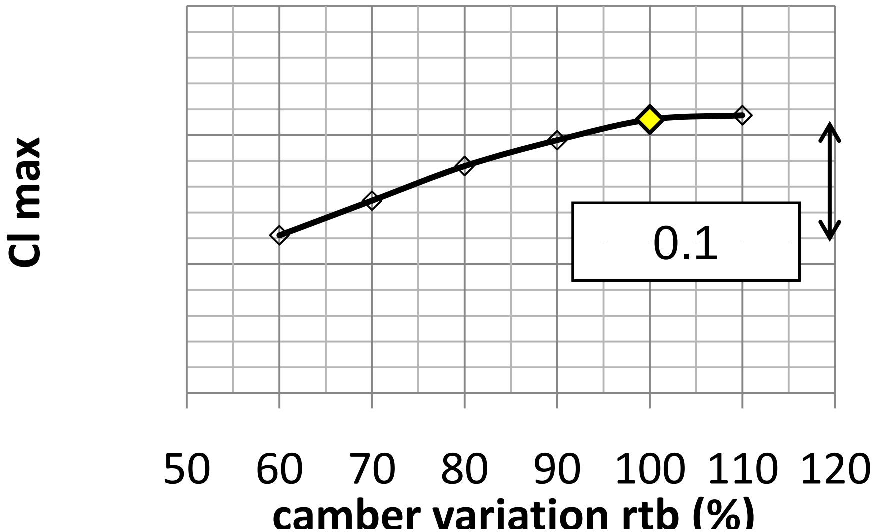
Airfoil thickness

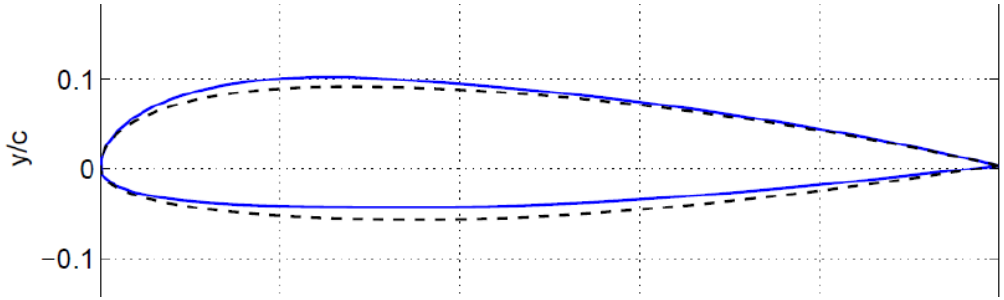


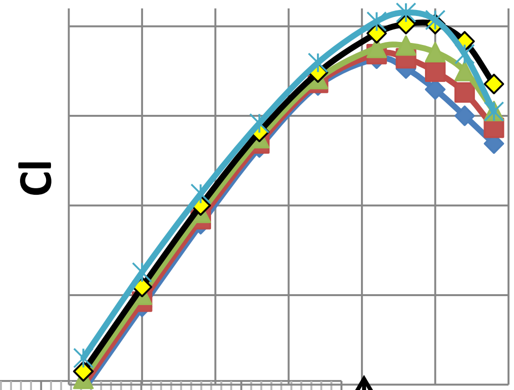


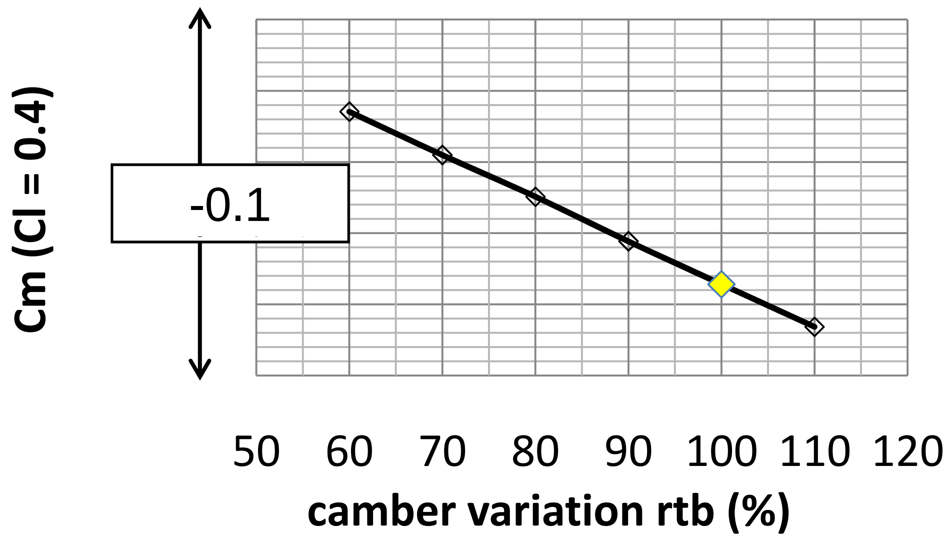
CFD Application – WING AIRFOIL

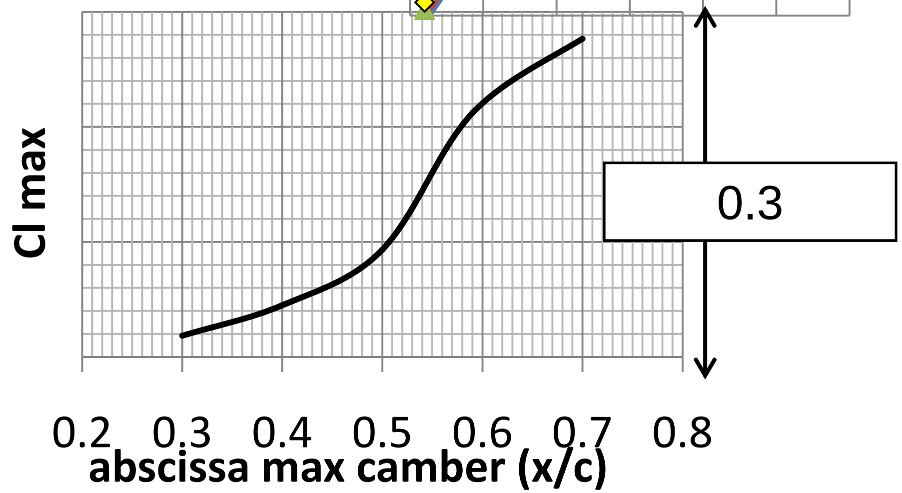
Airfoil camber





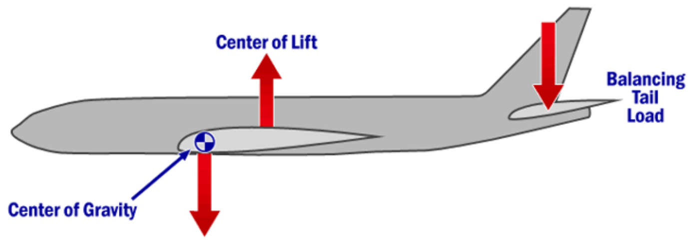


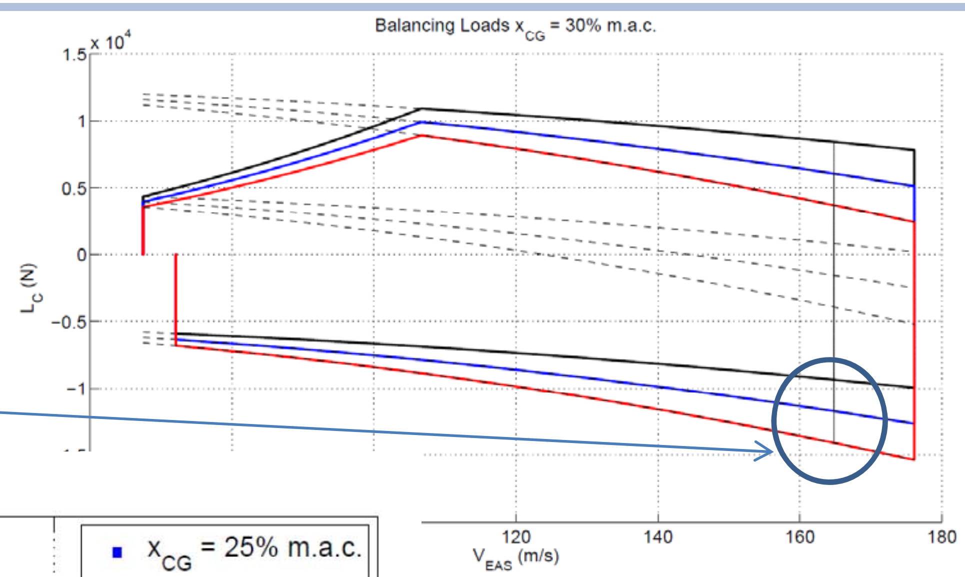




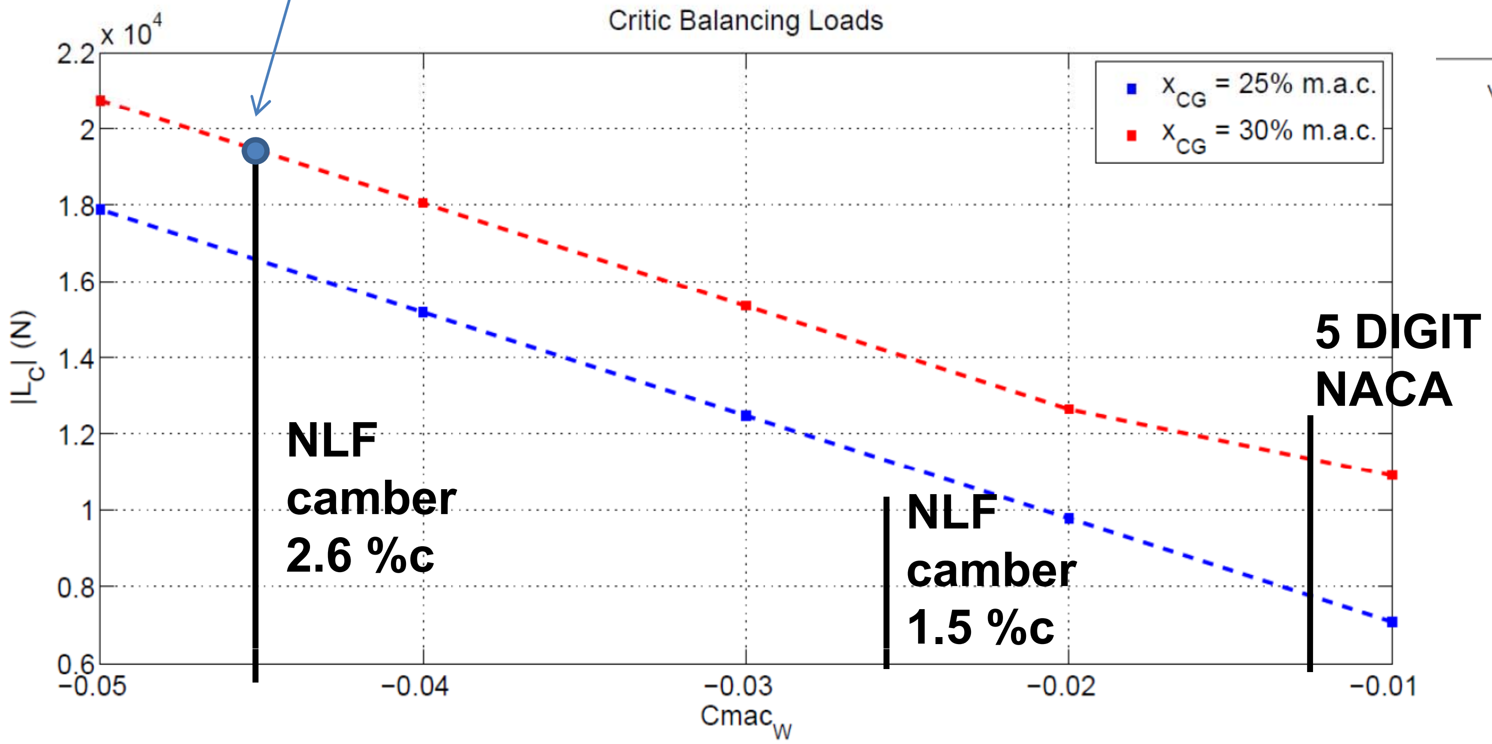
CFD Application – WING AIRFOIL

Airfoil Cm – Effect on Tail Loads



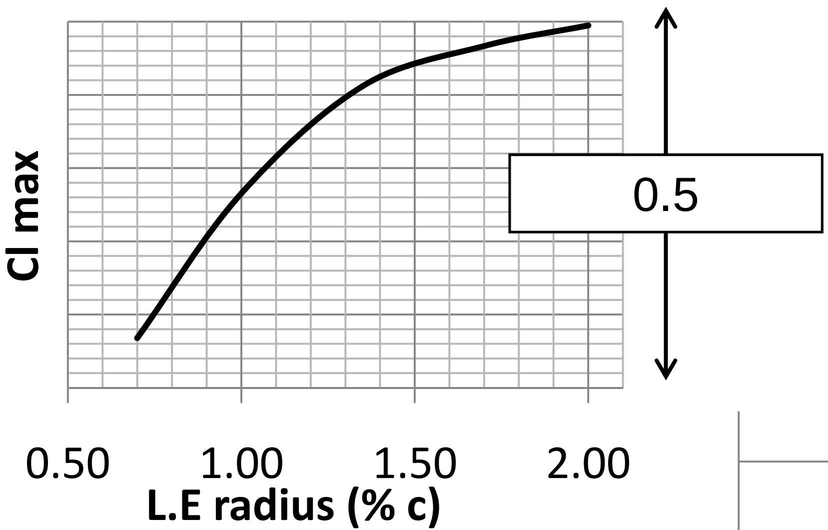


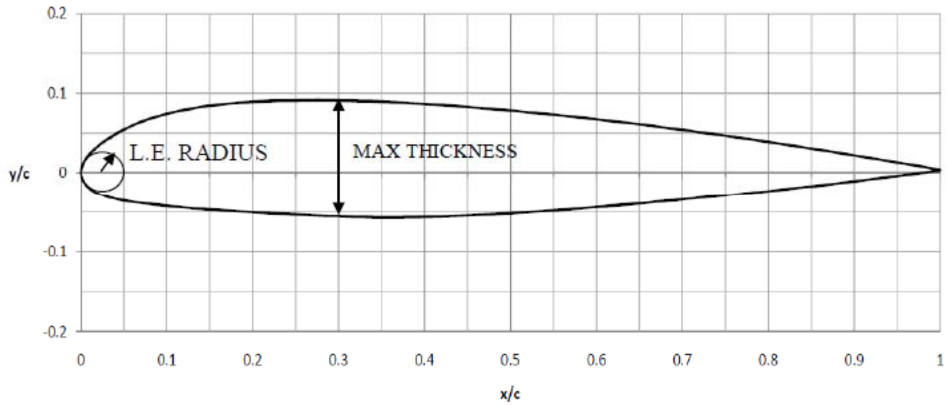
Tail Load Estimated about 2000 Kg

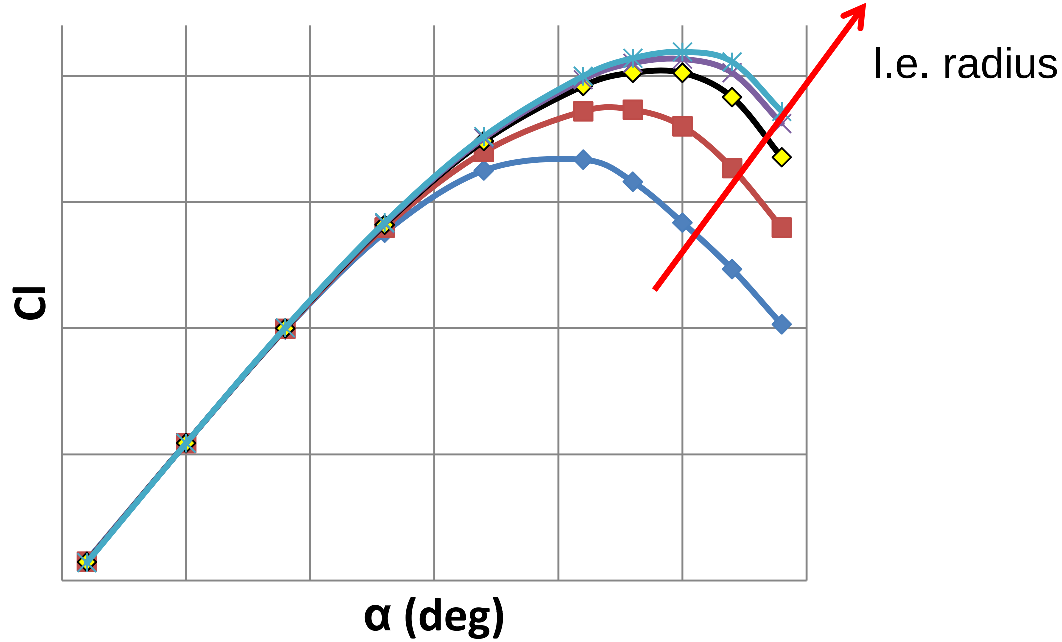


CFD Application – WING AIRFOIL

Airfoil l.e. radius

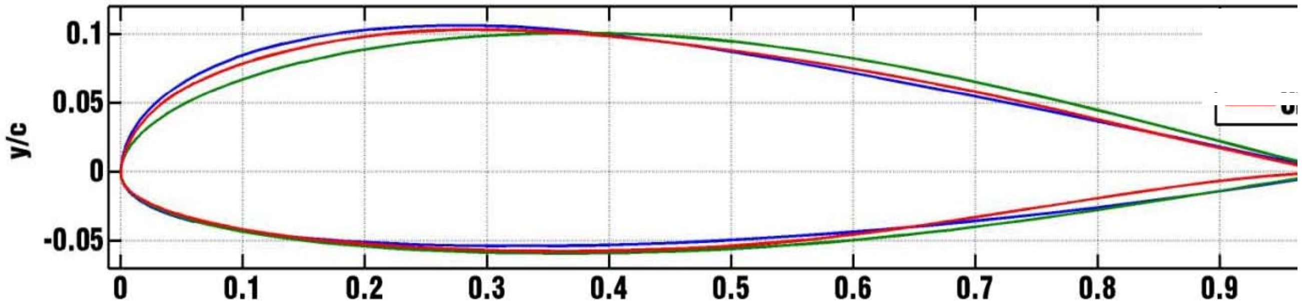


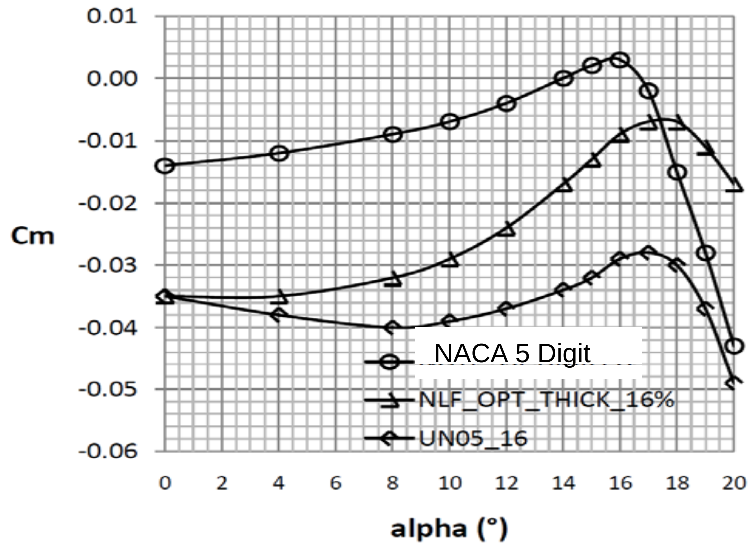


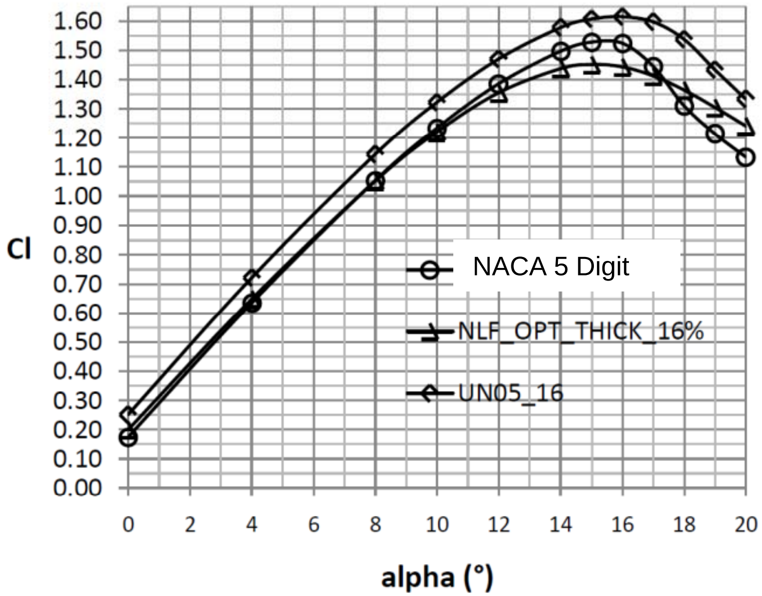


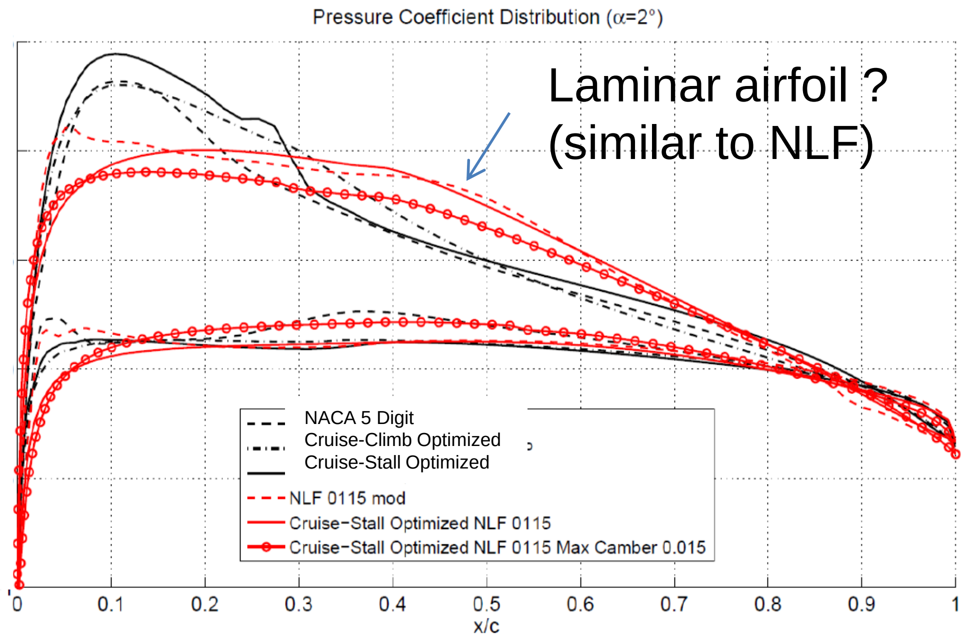
CFD Application – WING AIRFOIL

Airfoil shape









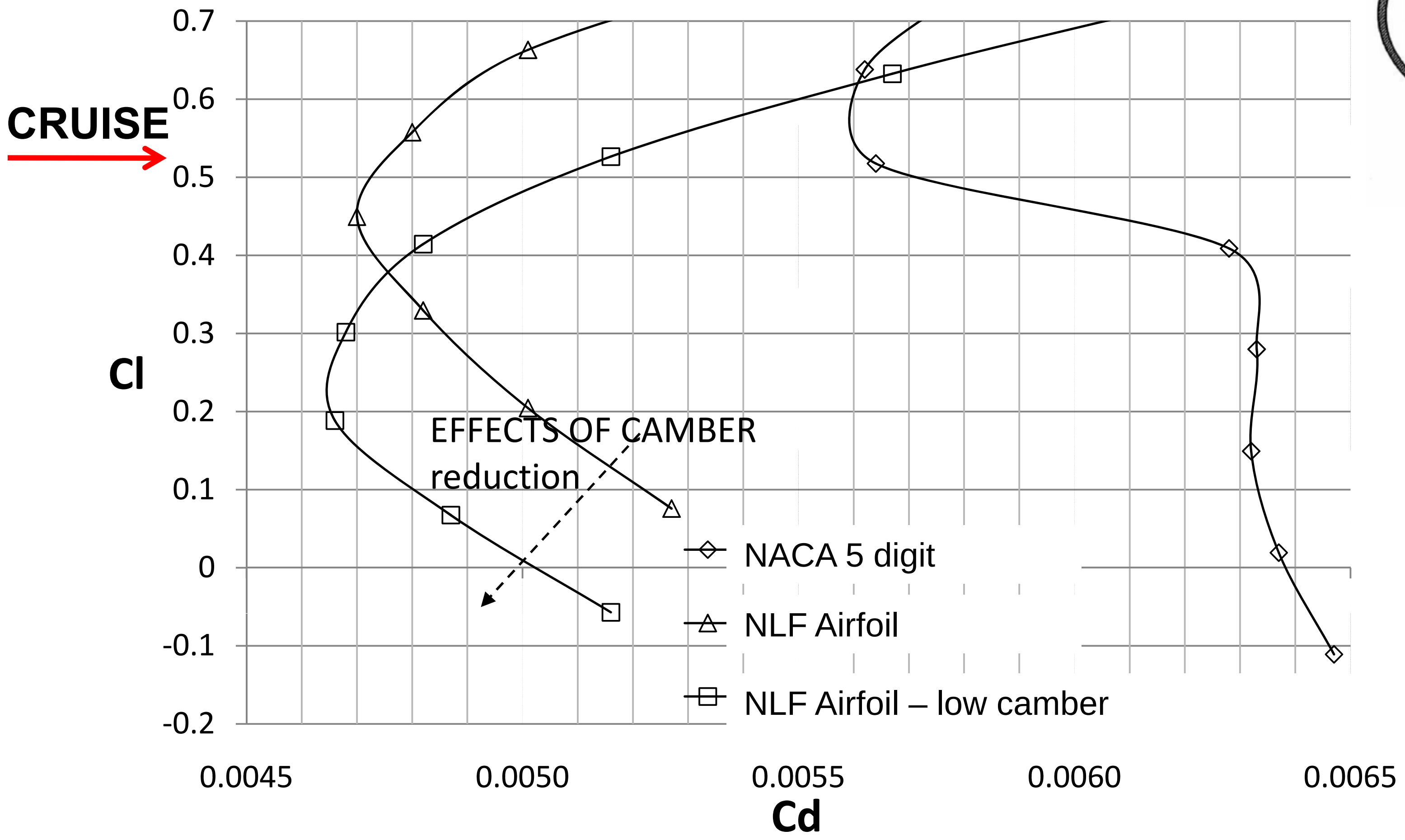
Laminar airfoil ?
(similar to NLF)

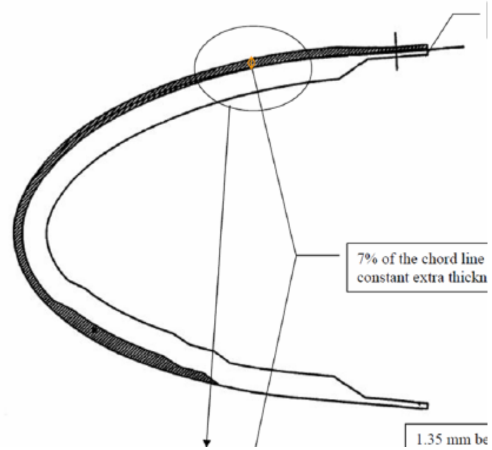
Low Cm (i.e. NACA 230XX) or
Cambered high-Cl ?

CFD Application – WING AIRFOIL

Airfoil shape

- **Cambered airfoil should be chosen**
- **Laminar Flow CAN BE achieved ?**

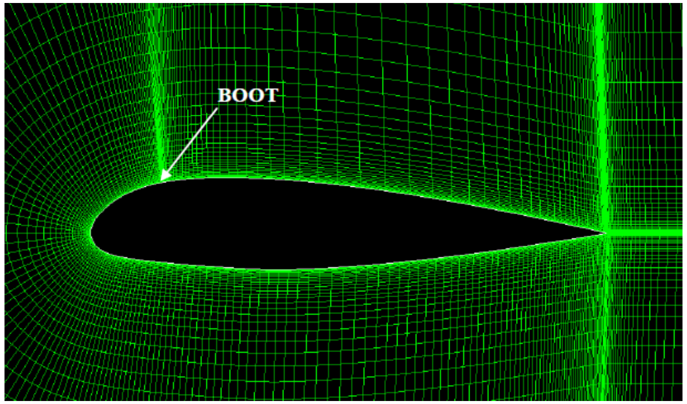


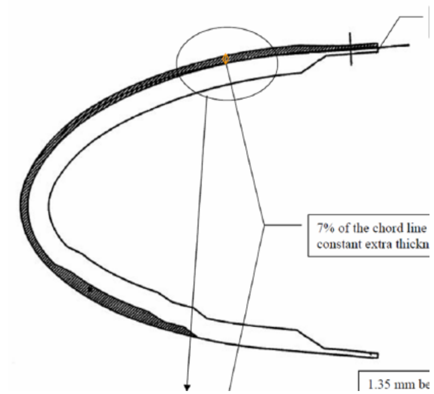


ATR 72 De-Icing Boot

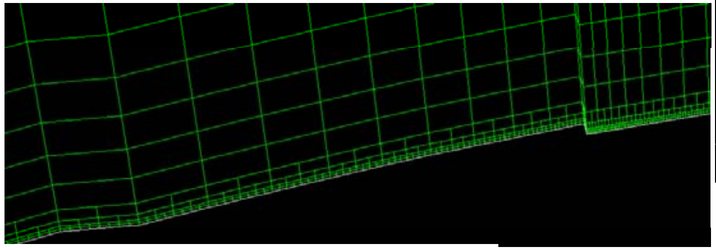
CFD Application – WING AIRFOIL

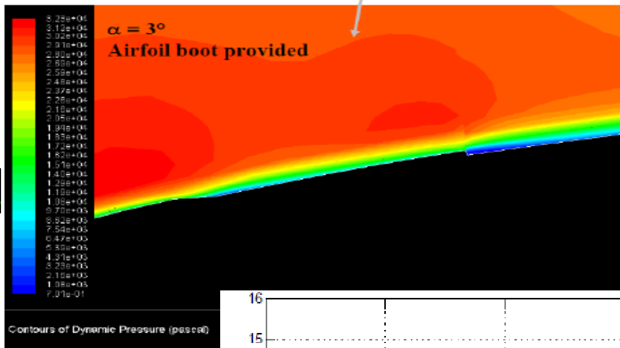
Effect of BOOT

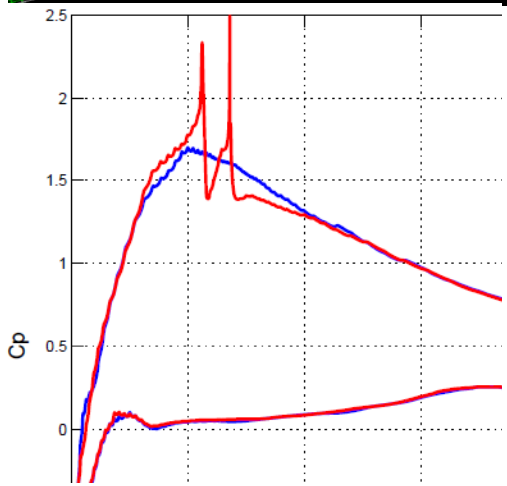




ATR 72 De-Icing Boot

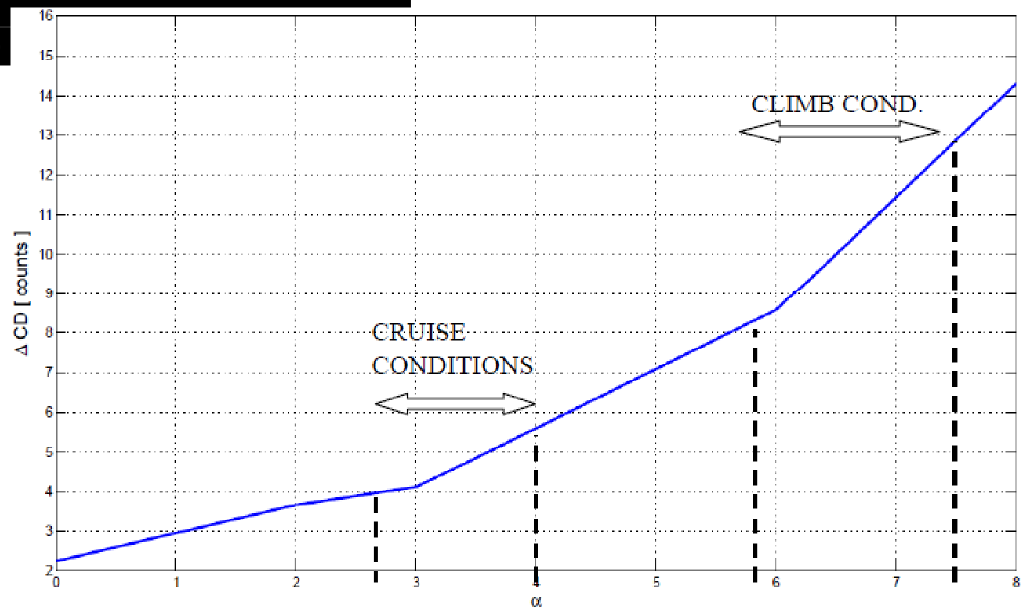






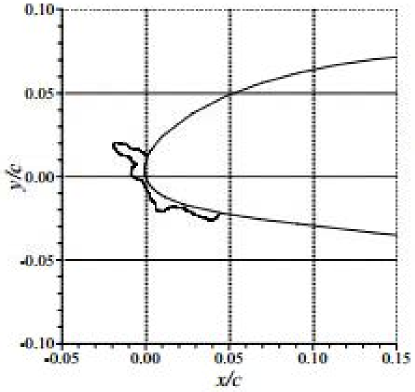
Delta CD AIRCRAFT:

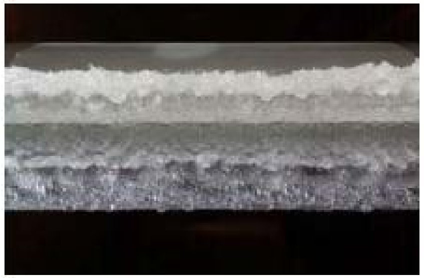
About 2-3 drag counts

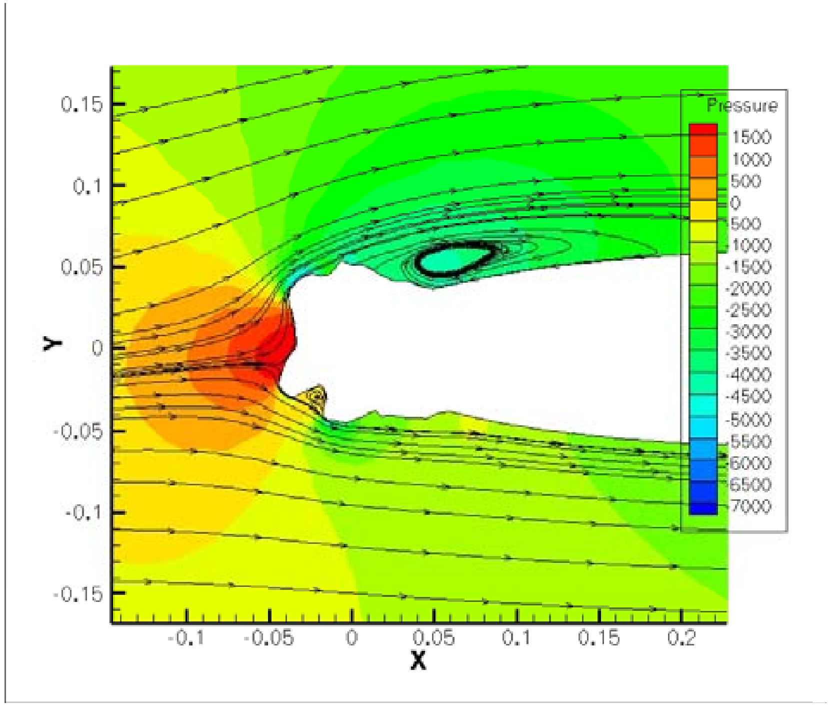


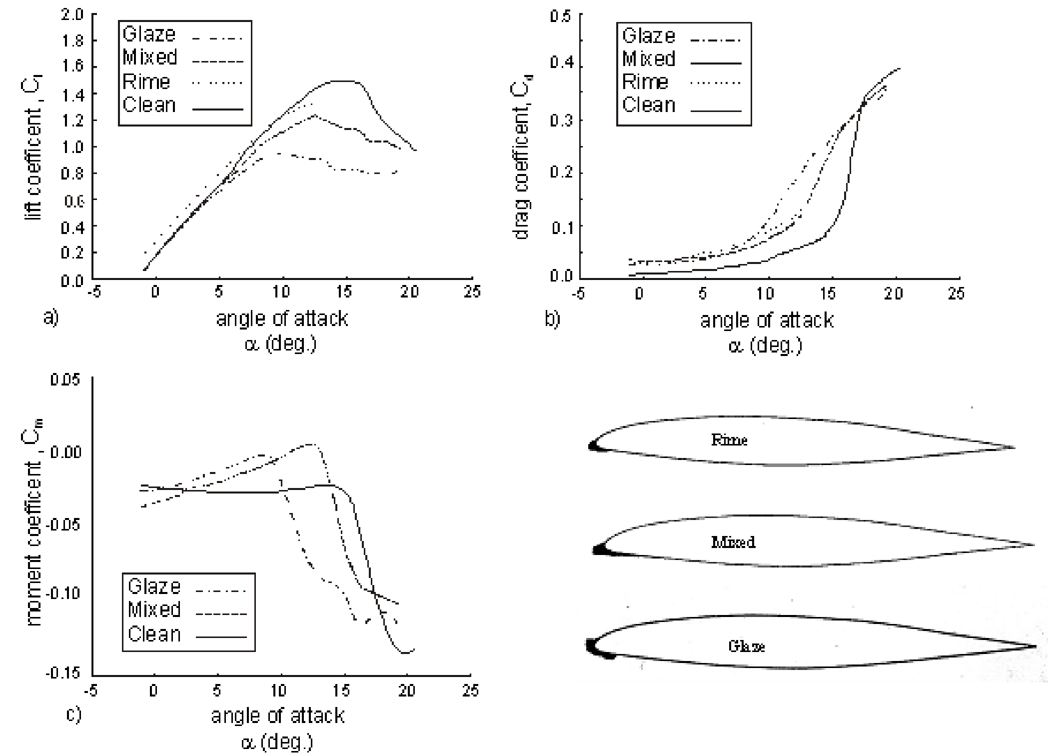
CFD Application for Regional Tprop

Airfoil aerodynamic analysis in ICE condition









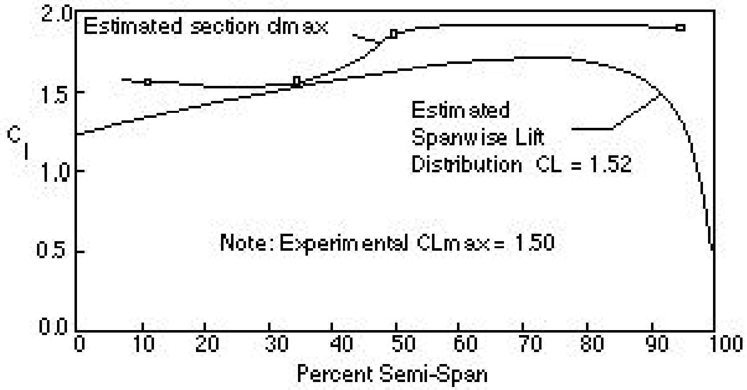
a) Lift coefficient, C_l, versus angle of attack for clean airfoil and for glaze, rime, and mixed ice
b) Drag coefficient, C_d, versus angle of attack for clean airfoil and for glaze, rime, and mixed ice
c) Moment coefficient, C_m, various the angle of attack for clean airfoil and for glaze and rime ice

CFD Application – WING

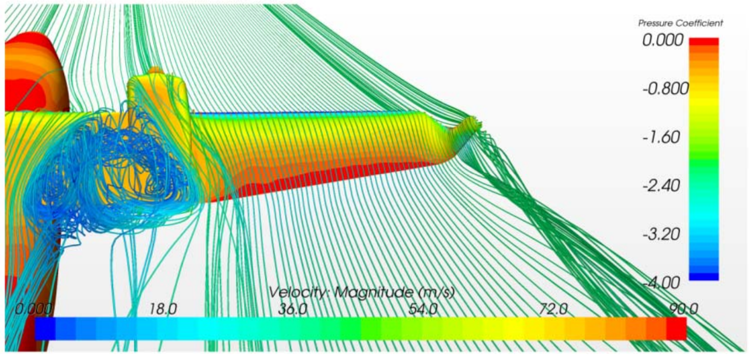
WING Aerodynamics

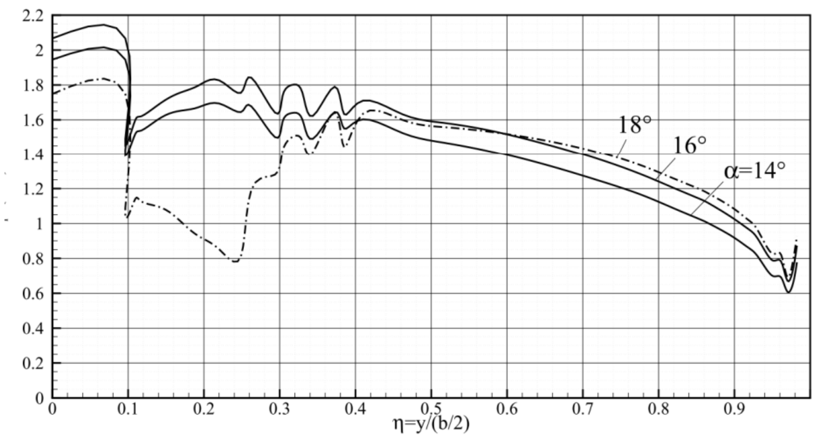
- **Wing Maximum Lift Coeff**
- **Wing stall path (Correct Twist)**
- **Effect at high-lift of propeller**

Possible preliminary estimation with panel method

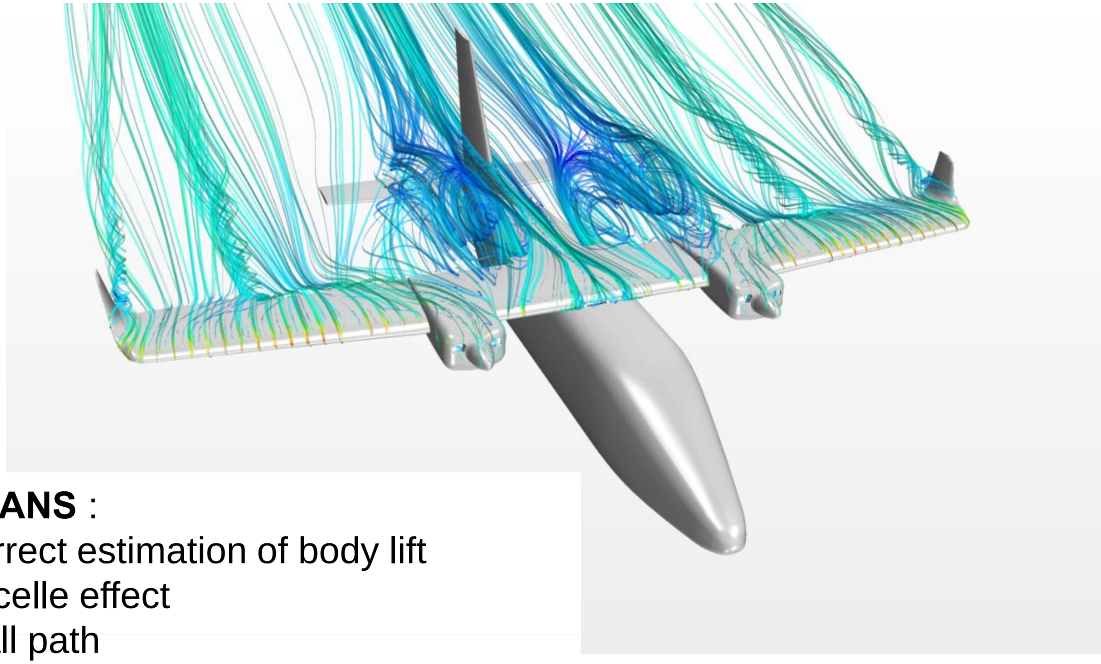


CFD RANS are also Important





P2012 – stall conditions



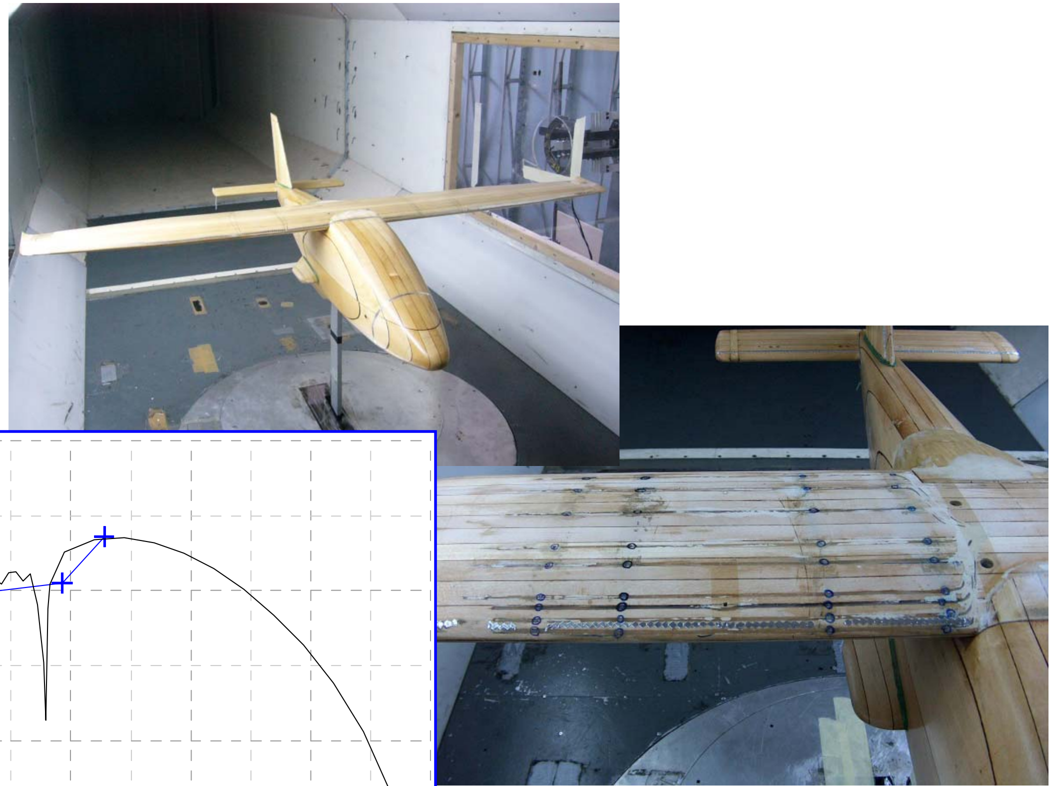
CFD RANS :

- Correct estimation of body lift
- Nacelle effect
- Stall path
- Load spanwise distr. at high angles

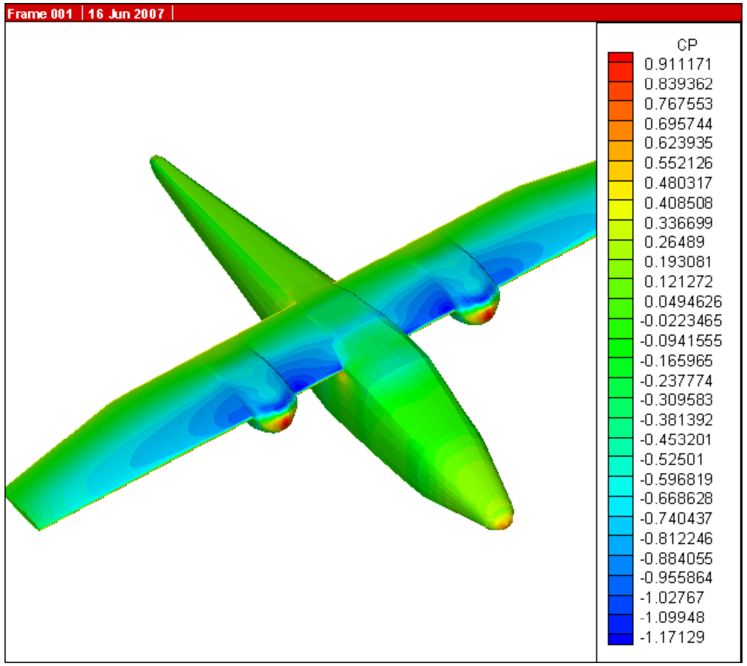
CFD Application – WING

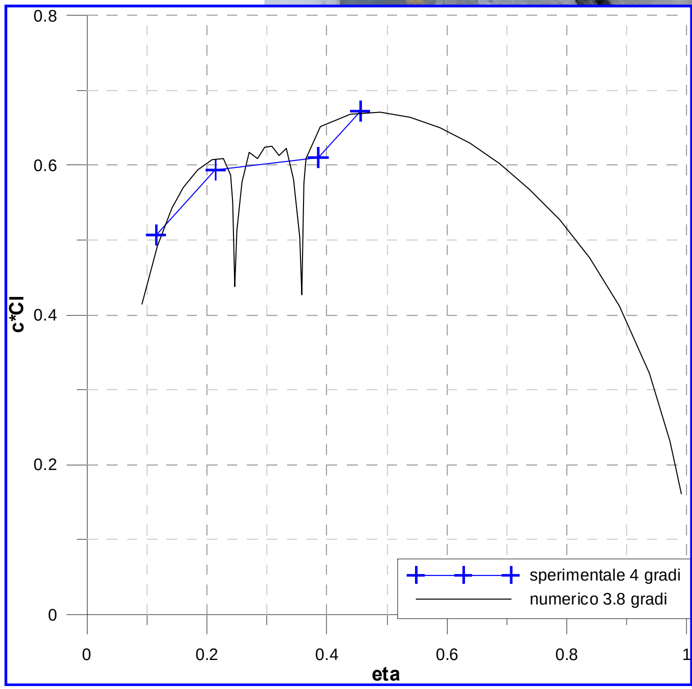
WING Aerodynamics

✈ **Wing spanwise aerodynamic load**
(Correct estimation of structural loads)



P2006T Aircraft



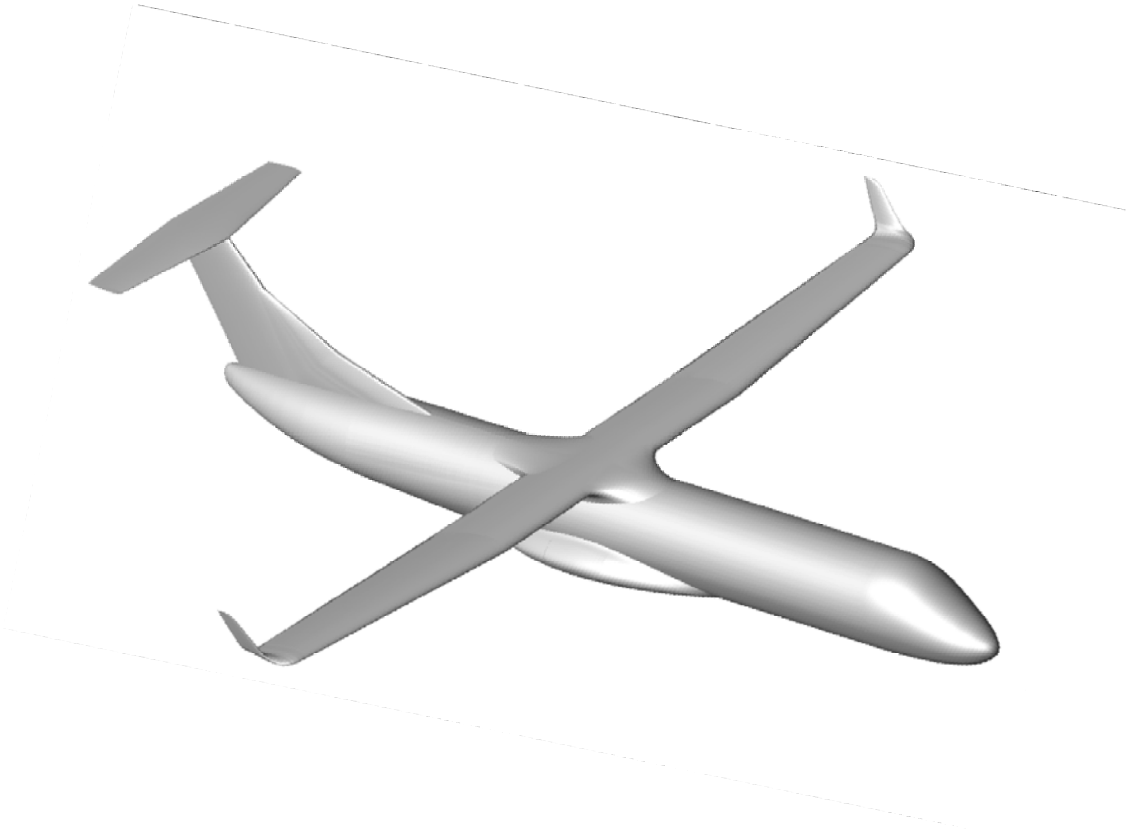


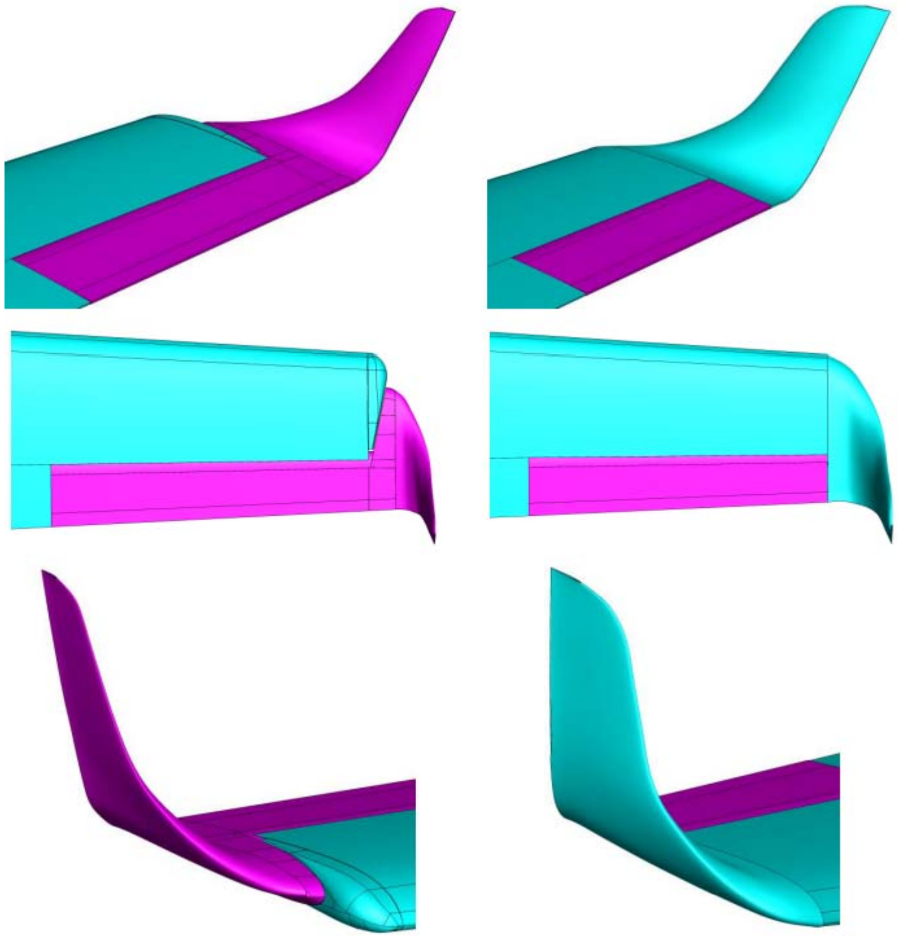
Nicolosi F., Pascale L. "*Design and Aerodyanmic analysis of a light twin-engine propeller aircraft*"
26th ICAS Congress, 2008

CFD Application – WINGLET

WINGLET Design

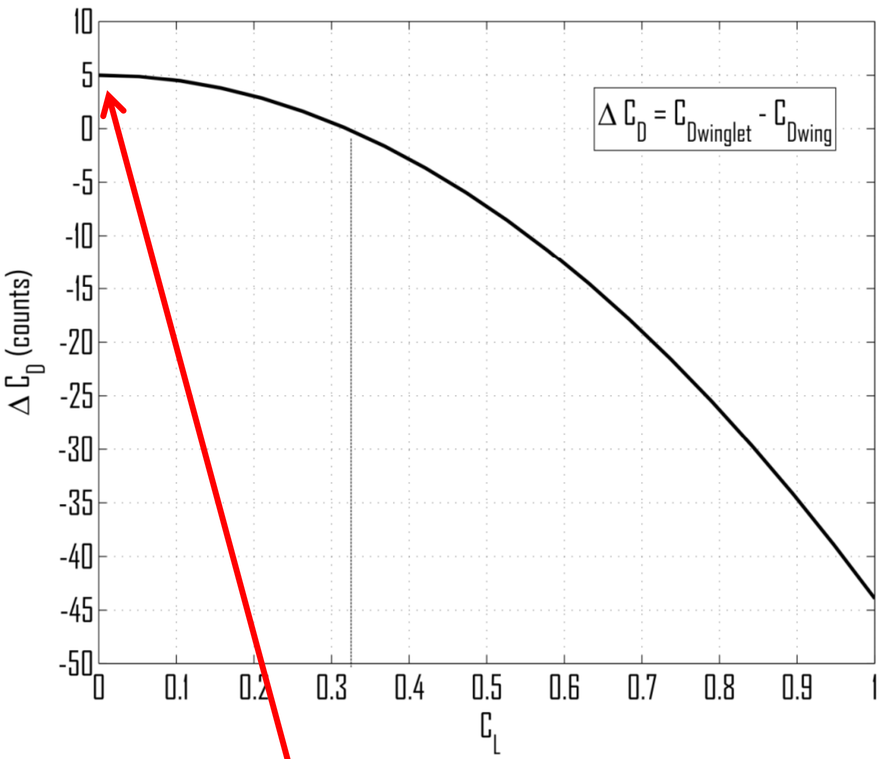
- ✈ **Induced drag reduction**
- ✈ **Improved Climb capabilities (OEI)**
- ✈ **For high wing-loading aircraft (like ATR) gain also in cruise condition**
- ✈ **Increased wing structural bending**

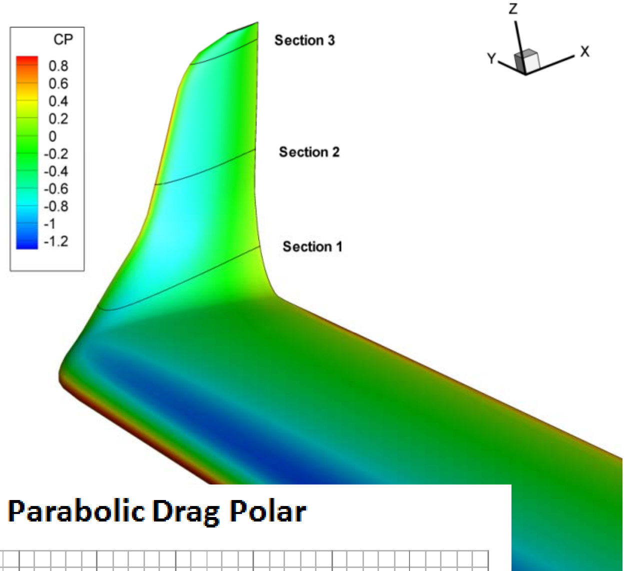


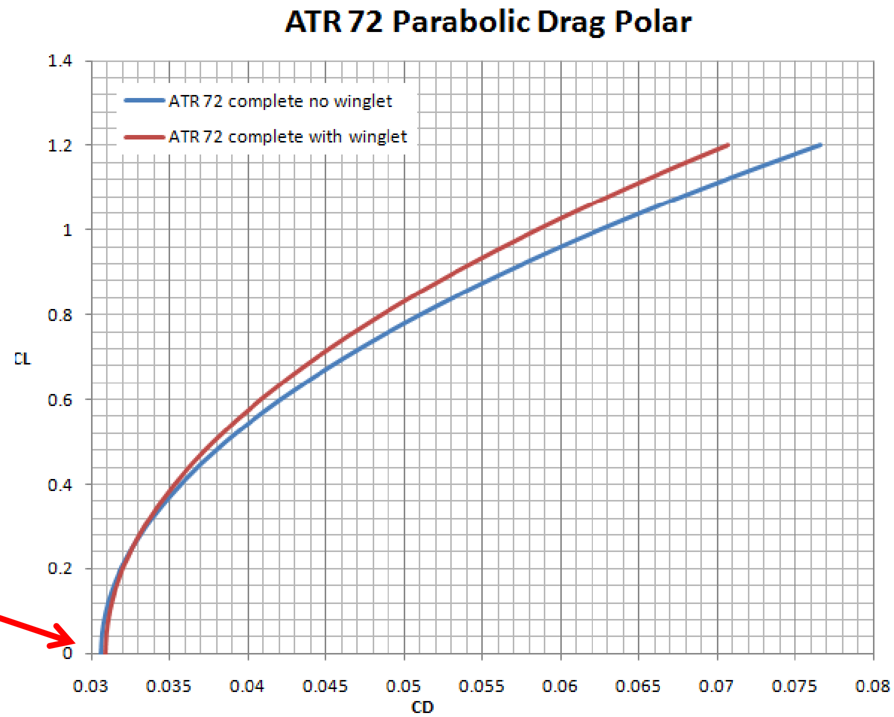


CFD Application – WINGLET

WINGLET Design



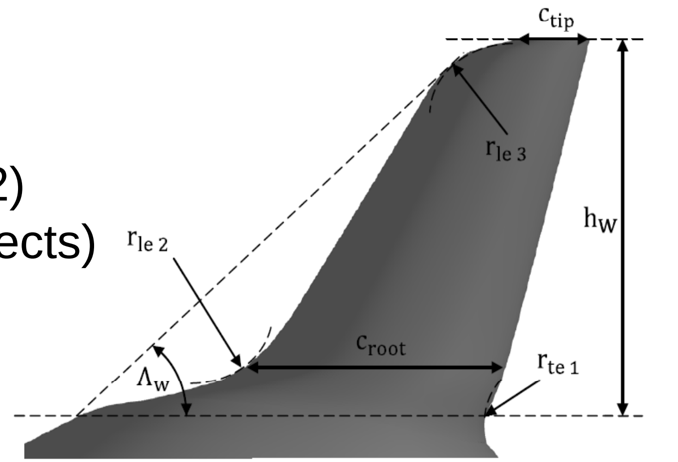




Aircarft Delta CDo = 4-5 drag counts

CFD Application – WINGLET

WINGLET Design

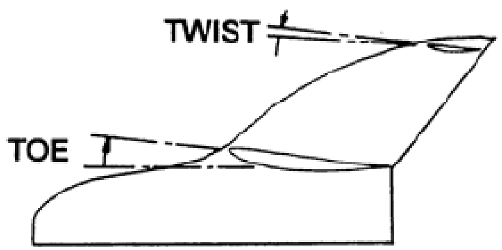


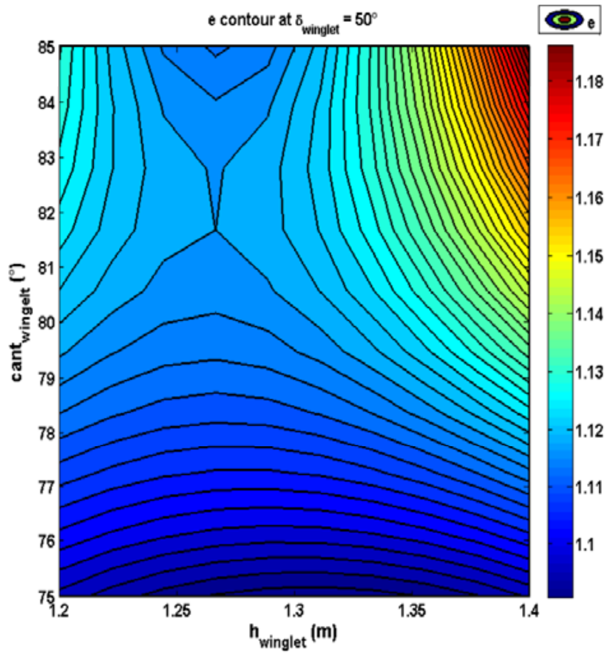
Winglet height:

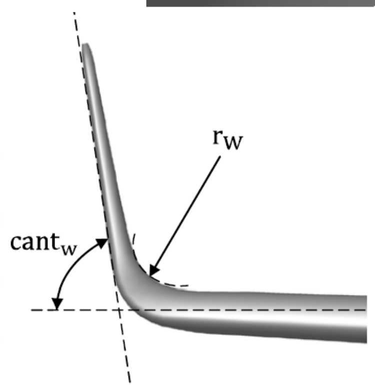
- About 15 % induced vortex drag reduction for hw=10% (b/2)
- About 9-10% lift dependent drag red. (including viscous effects)
- Limit in wing structural bending
- designed with appropriate cant and sweep

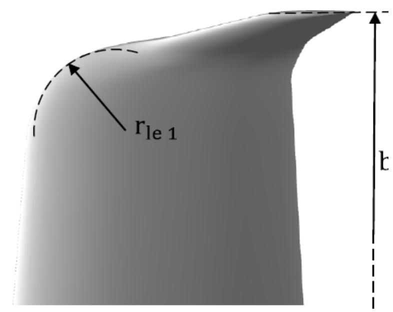
Toe angle:

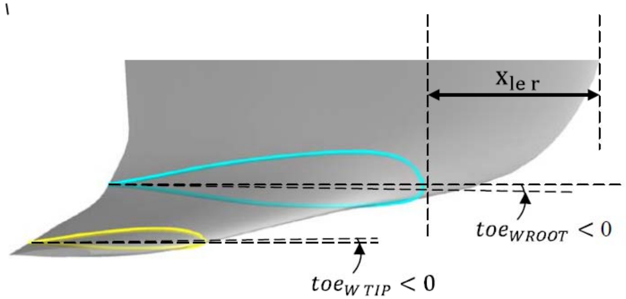
- Avoid winglet stall at root
- Reduce the induced drag gain







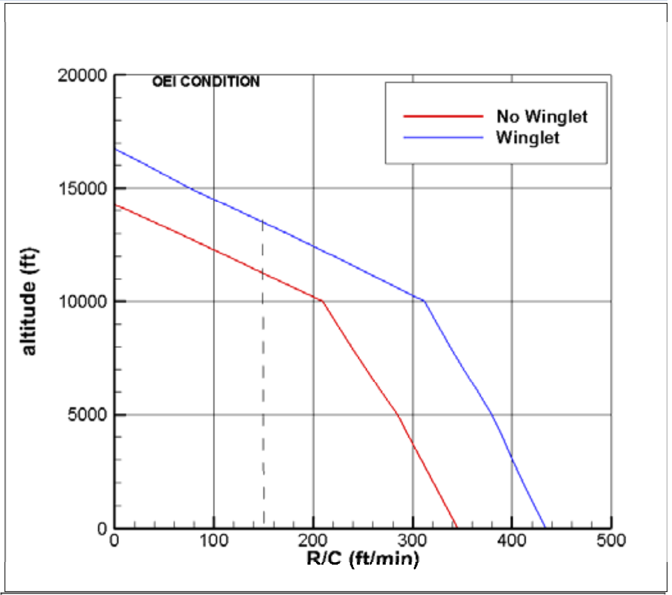




"*Aerodynamic guidelines in the design and optimization of new regional turboprop aircraft*»
F. Nicolosi, P. Della Vecchia, CEAS 2011 Conference

CFD Application – WINGLET

WINGLET – Possible Aircraft Performance Gain



Winglet effect on MAX RC OEI:

⇒ <u>Ceiling or Weight Limitations EXTENDED (hot & High)</u>

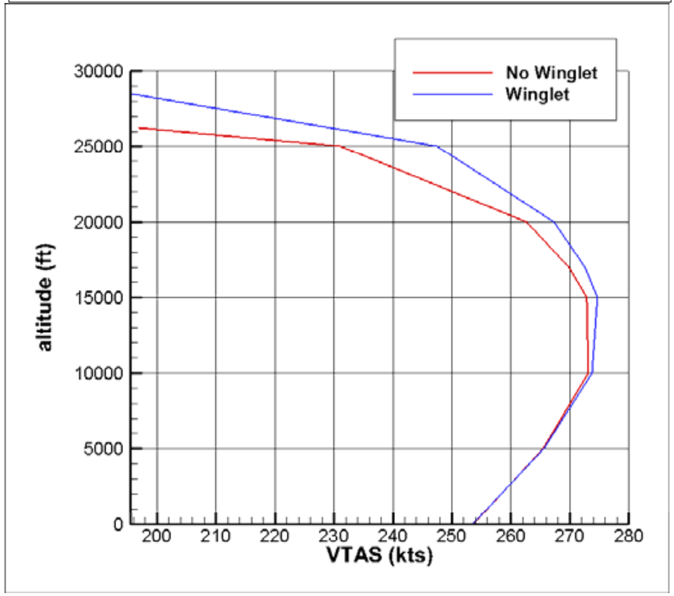
Winglet effect on OEI RC and ceiling:

OEI service Ceiling 12100 ft => 14500 ft

Winglet effect on max flight speed:

Possible gain => 3 kts @ 17000 ft

=> 5 kts @ 20000 ft



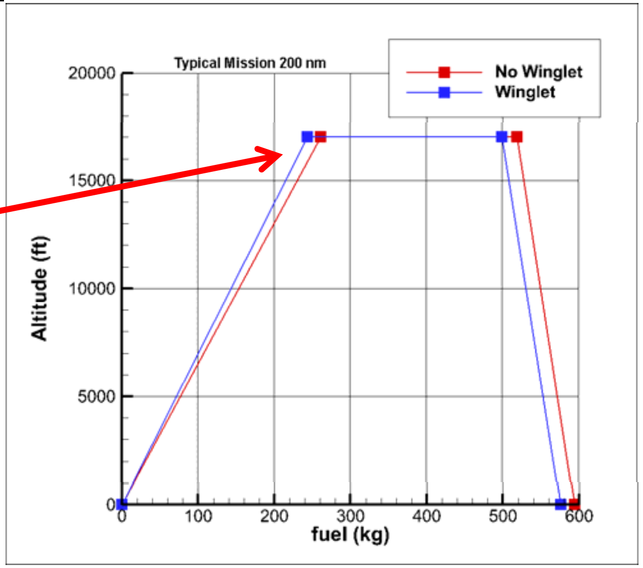
Winglet effect on FUEL consumption

(typical 200 nm mission):

30 Kg fuel saving per trip

(on about 600 kg) (5%)

Main fuel saving is obtained during climb



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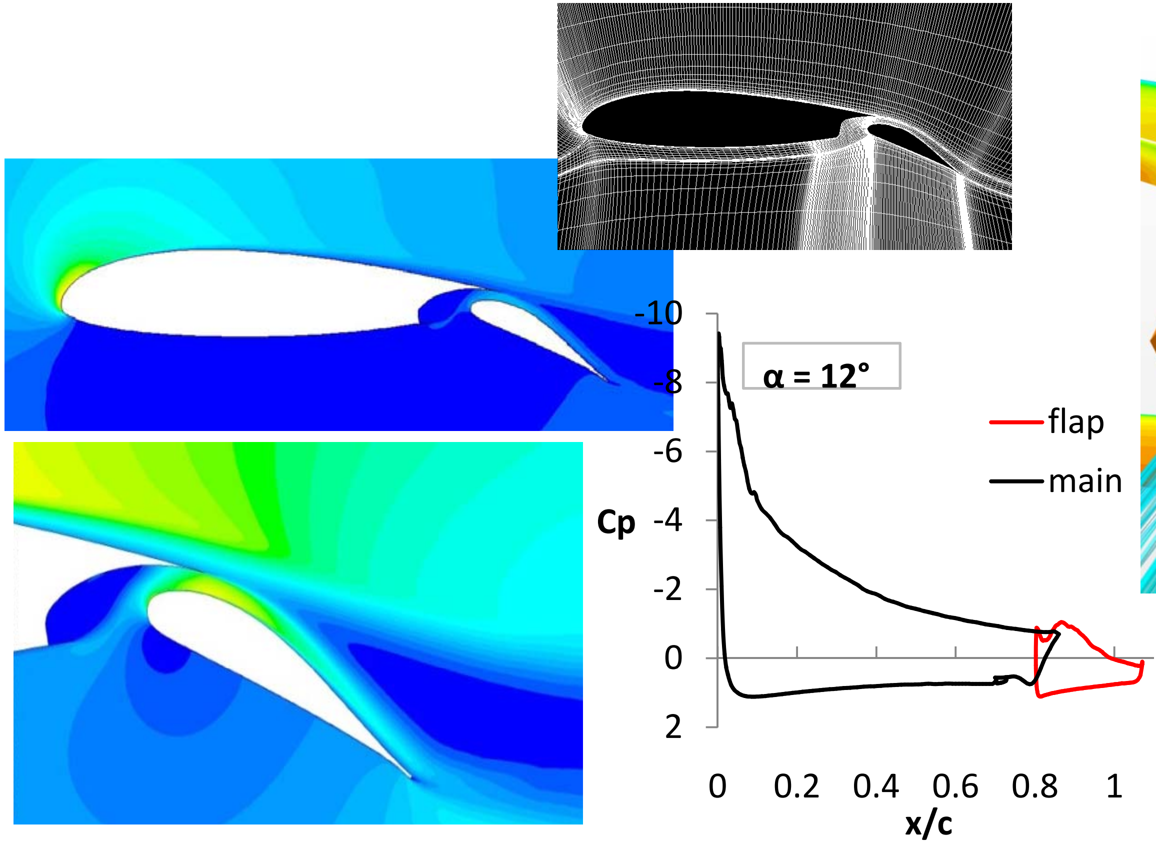
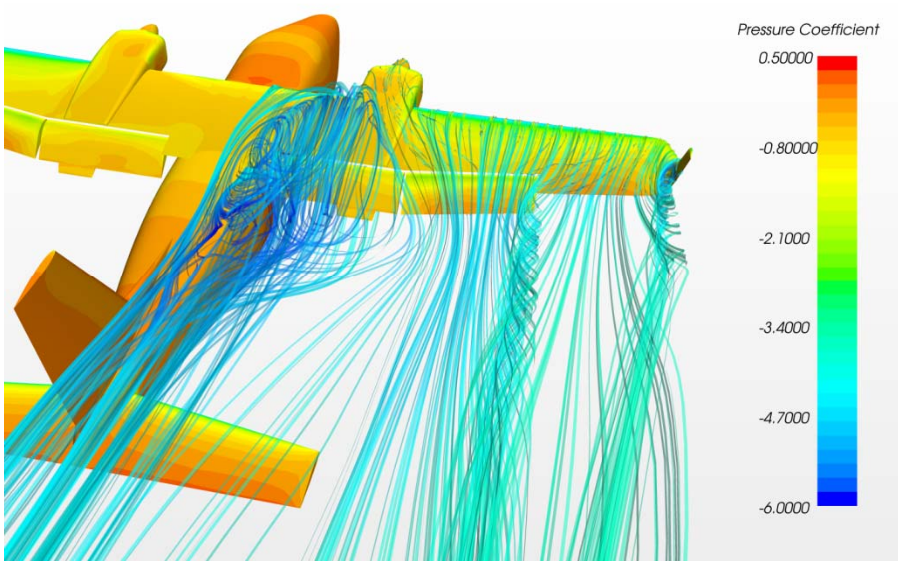
CFD Application – High lift

High Lift System

For a Regional Turboprop with 90 pax **<u>ground performances are particularly critical</u>**

- **Max lift coefficient in landing conditions (>2.6)**
- **Good aerodynamic efficiency in take-off setting (first seg. Climb)**
- **Single slotted flap vs Fowler flap (higher lift vs higher pitching moment ?)**
- **System and actuation (weight and costs) => Simple high lift system**

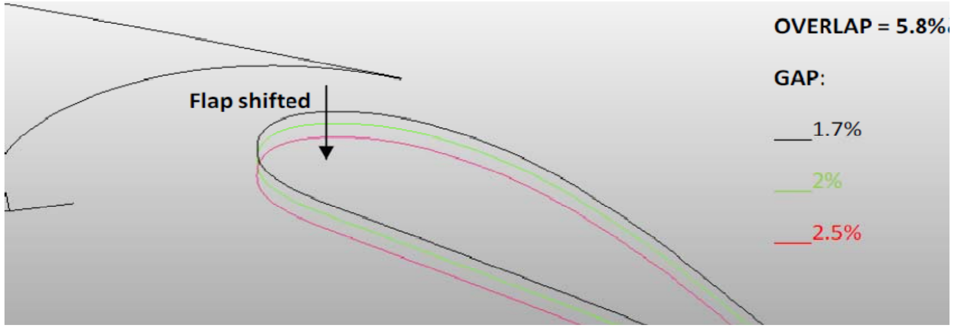


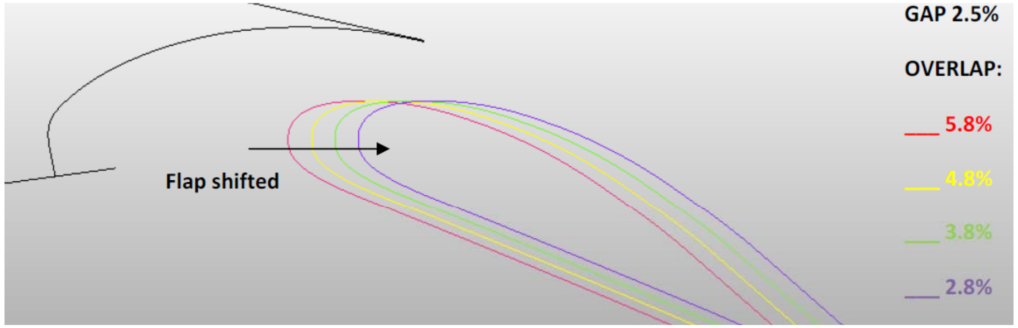


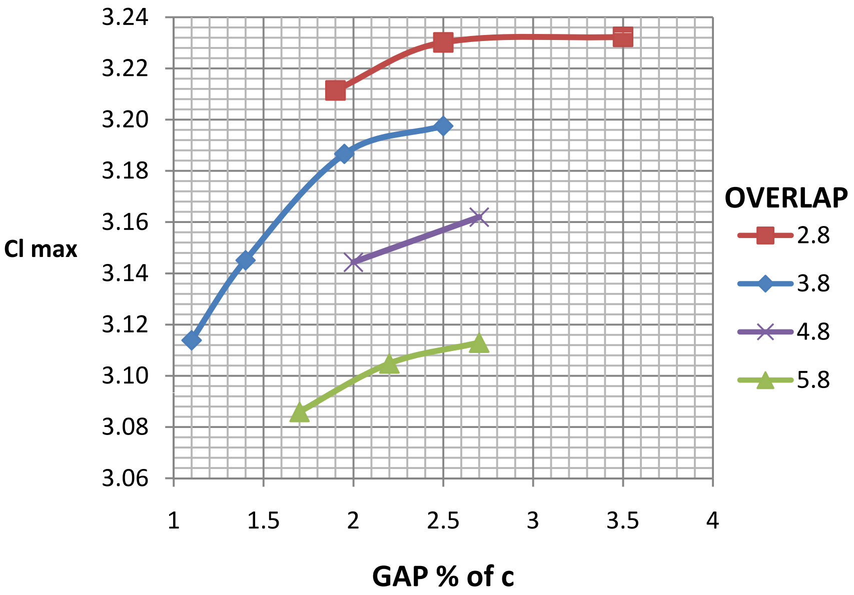
CFD Application – High lift

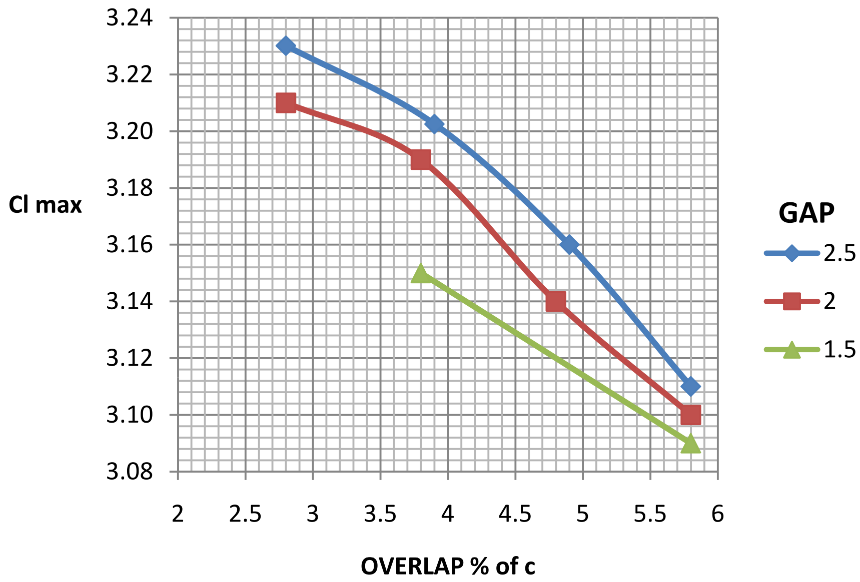
High Lift System Aerodynamic calculations … some example

✈ **Gap and Overlap Optimization**





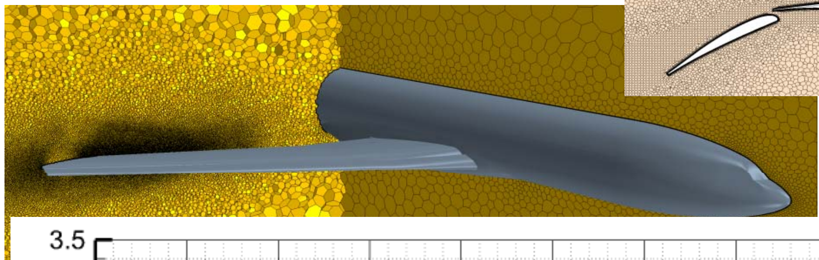


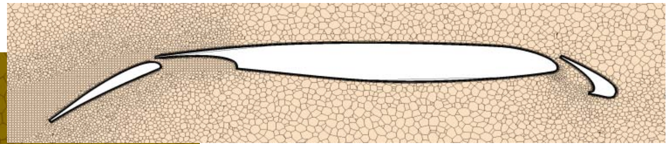


CFD Application – High lift

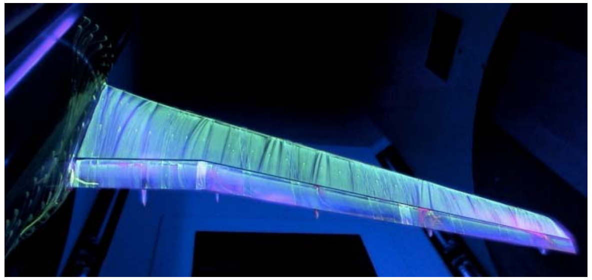
High Lift System Aerodynamic calculations … some example

- **3-D CFD RANS Calculations – AIAA Workshop on high-lift devices**

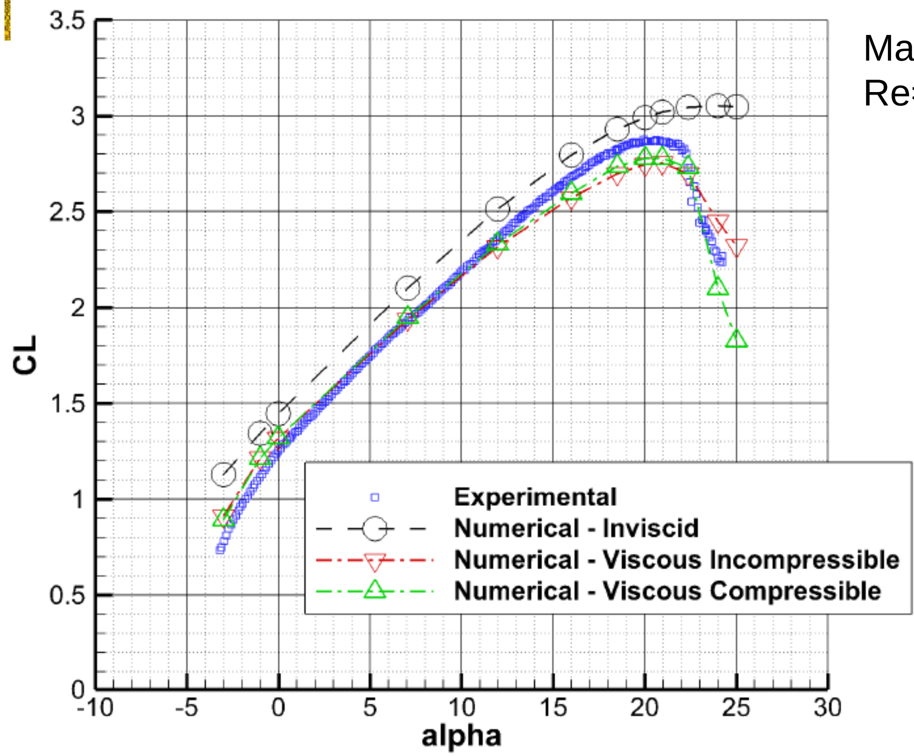


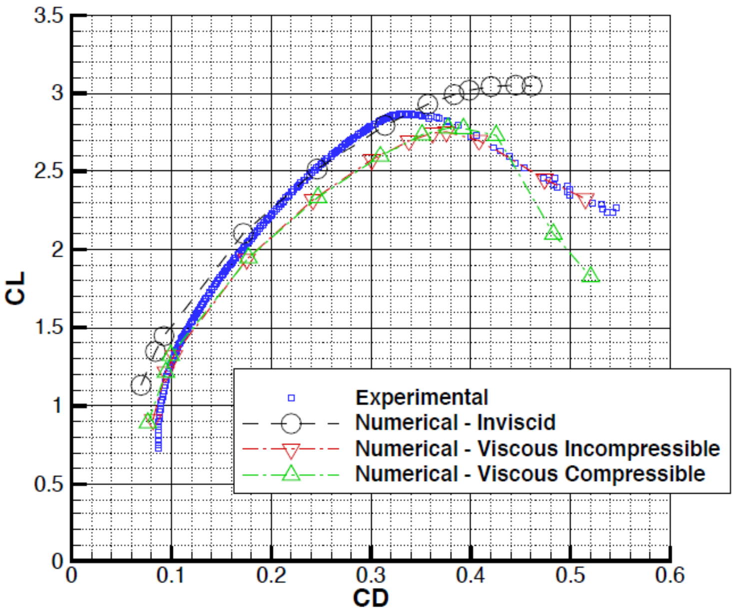


DLR F11- Model (Eurolift project)



Mach=0.17
Re=15 mill.





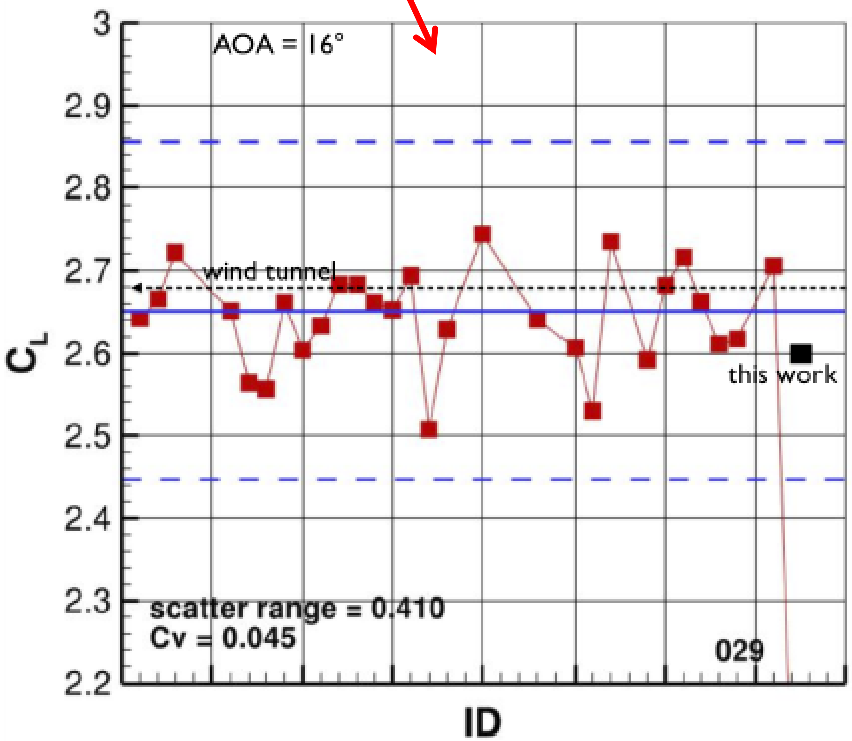
***Numerical Aerodynamic Analysis on a Trapezoidal Wing with High-Lift Devices : A Comparison with Experimental Data*.**
P. Della Vecchia, D. Ciliberti, AIDAA Congress, Sept 2013

CFD Application – High lift

High Lift System Aerodynamic calculations … some example

✈ **3-D CFD RANS Calculations – AIAA Workshop on high-lift devices**

Results obtained through CFD by several research centers and Universities with different software and turbulence model



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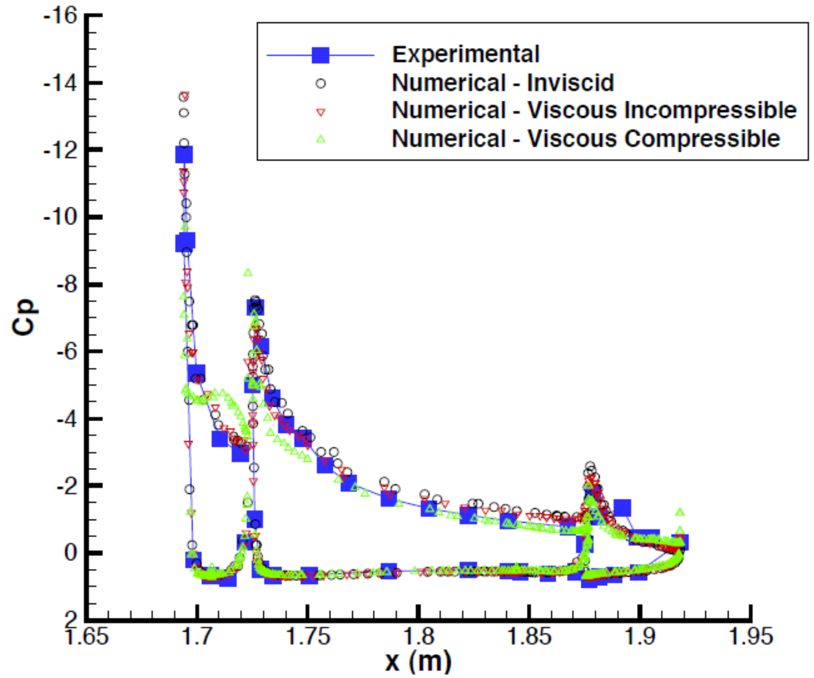

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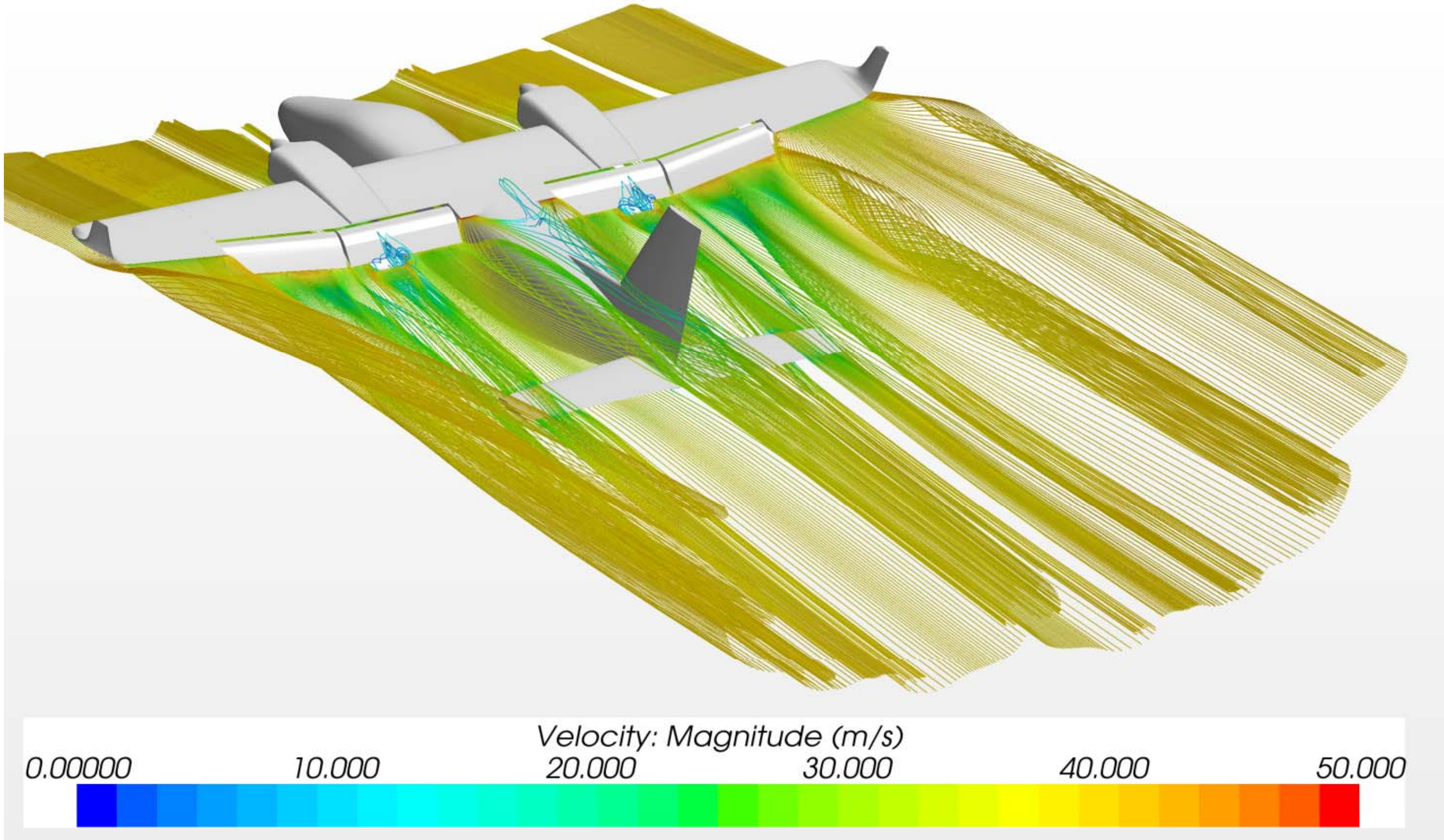
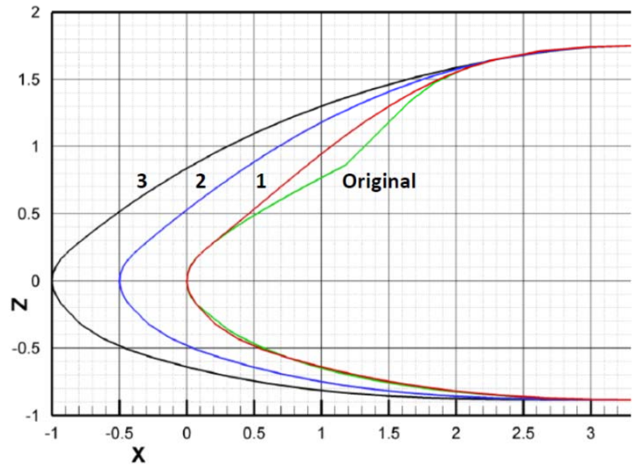
CFD Application – High lift

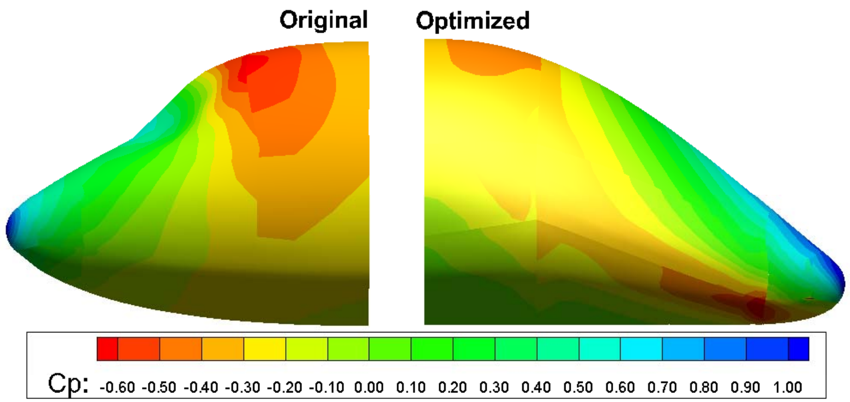
High Lift System Aerodynamic calculations … some example



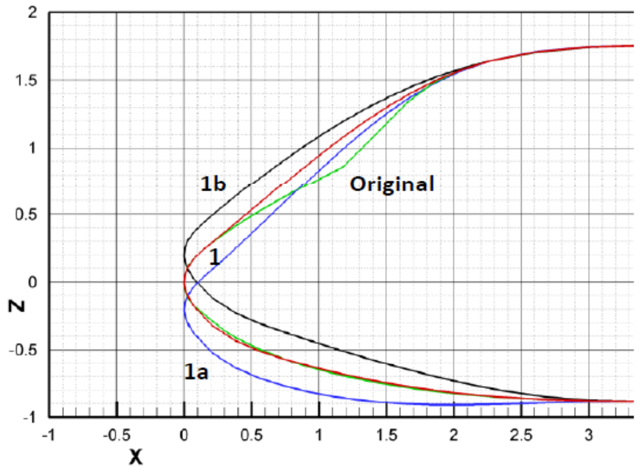
CFD Application – Fuselage Design

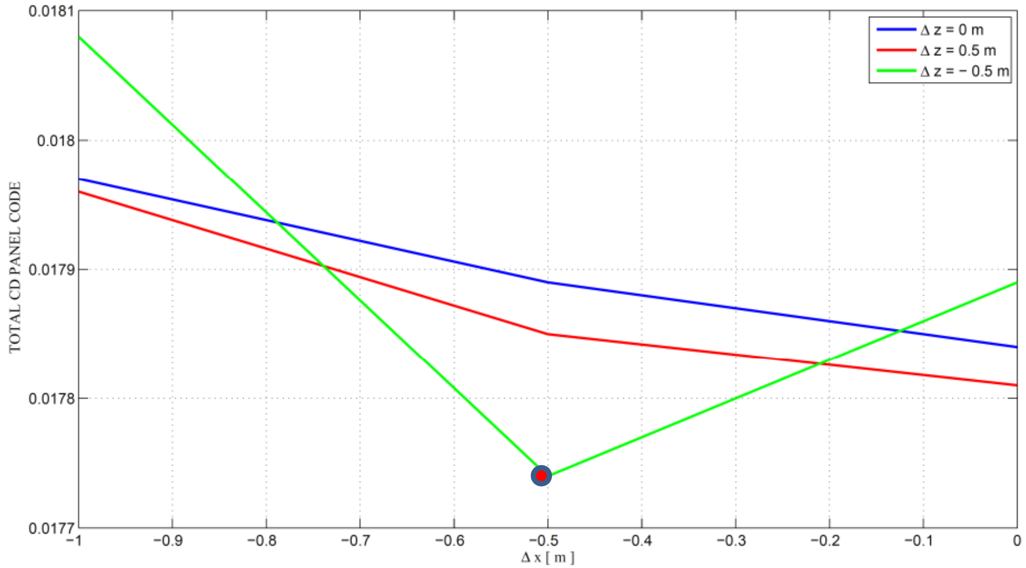
Fuselage Nose





Results obtained through panel code + b.l. calculations.
Skin friction + pressure drag.





Cruise Drag gain : about 3-4 drag counts

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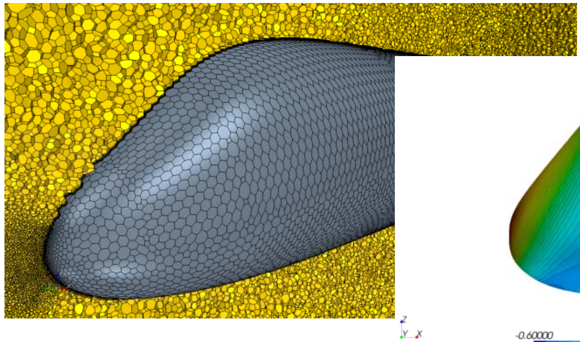
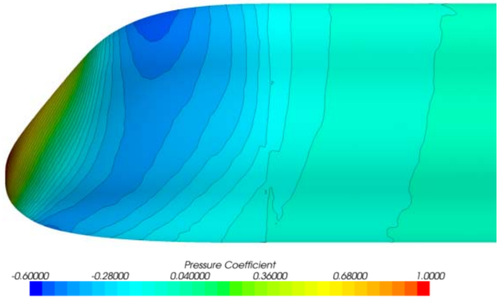
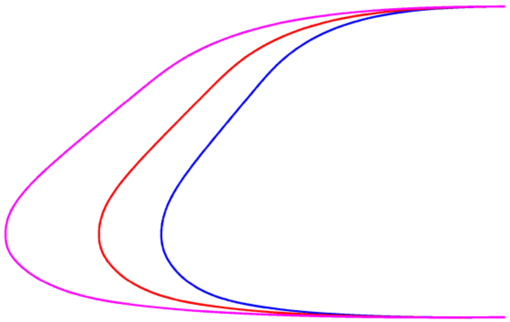
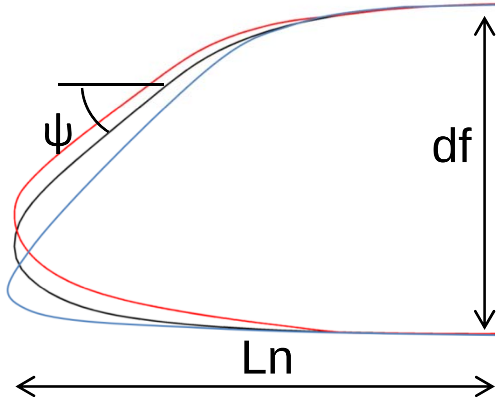
CFD Application – Fuselage Design

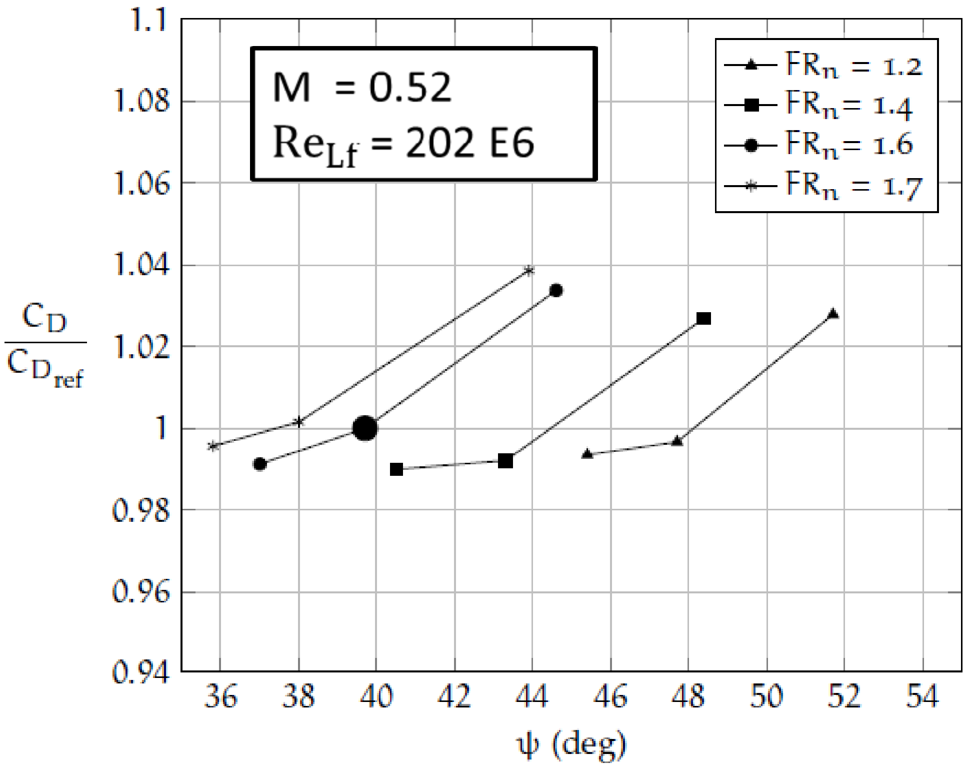
Fuselage Nose – Investigation for New Design Procedure

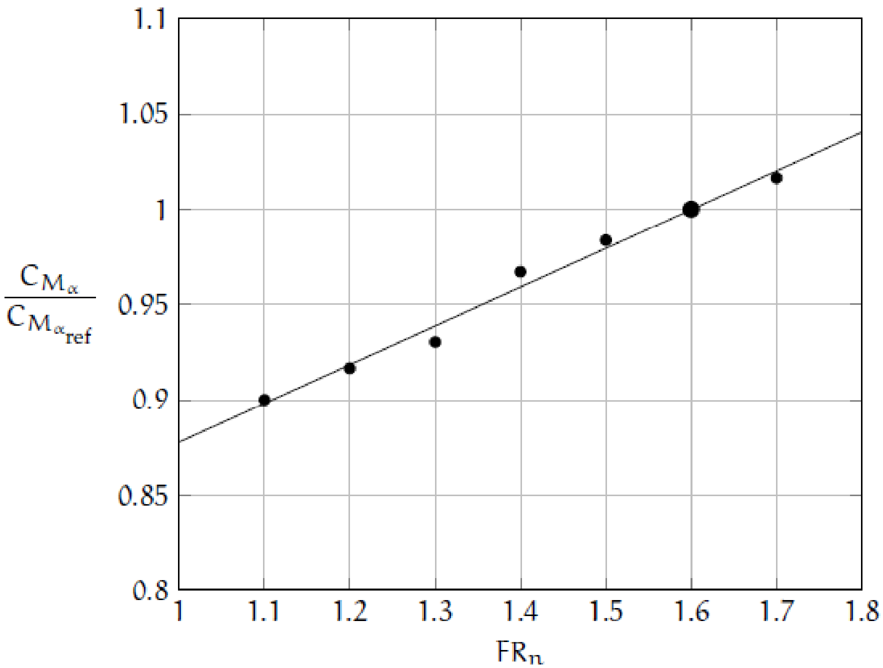






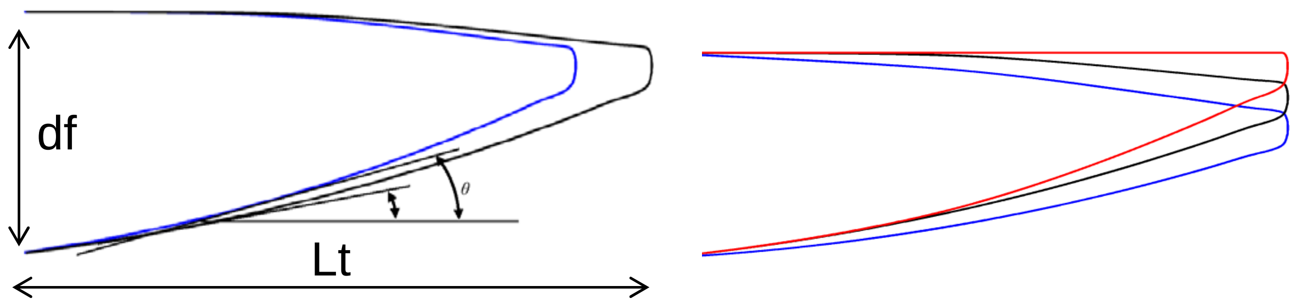


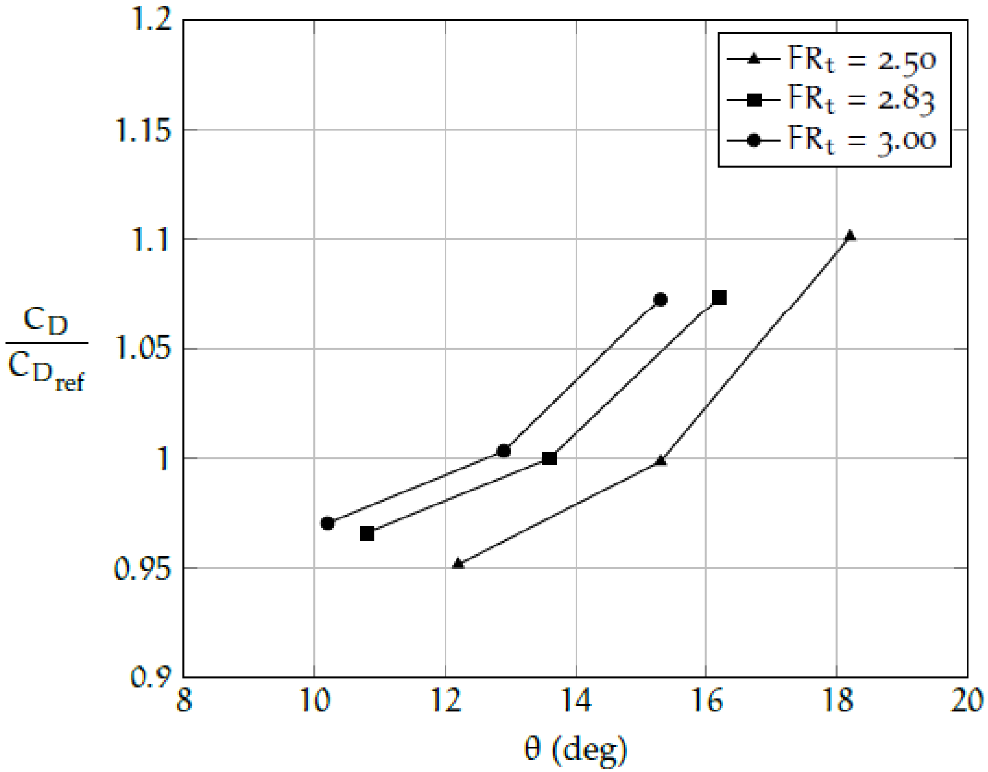


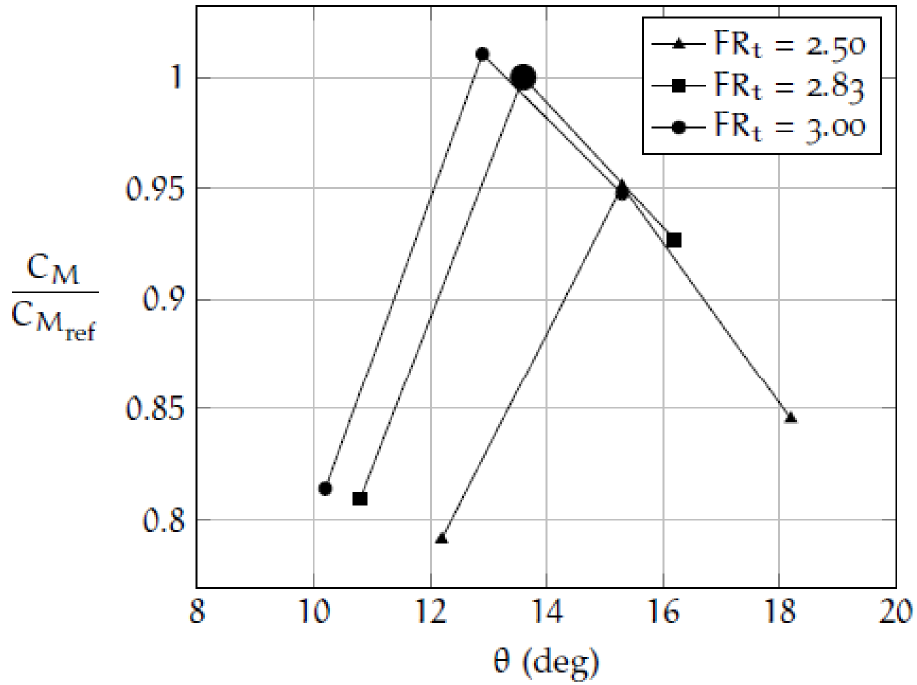


CFD Application – Fuselage Design

Fuselage Tail – Investigation for New Design Procedure



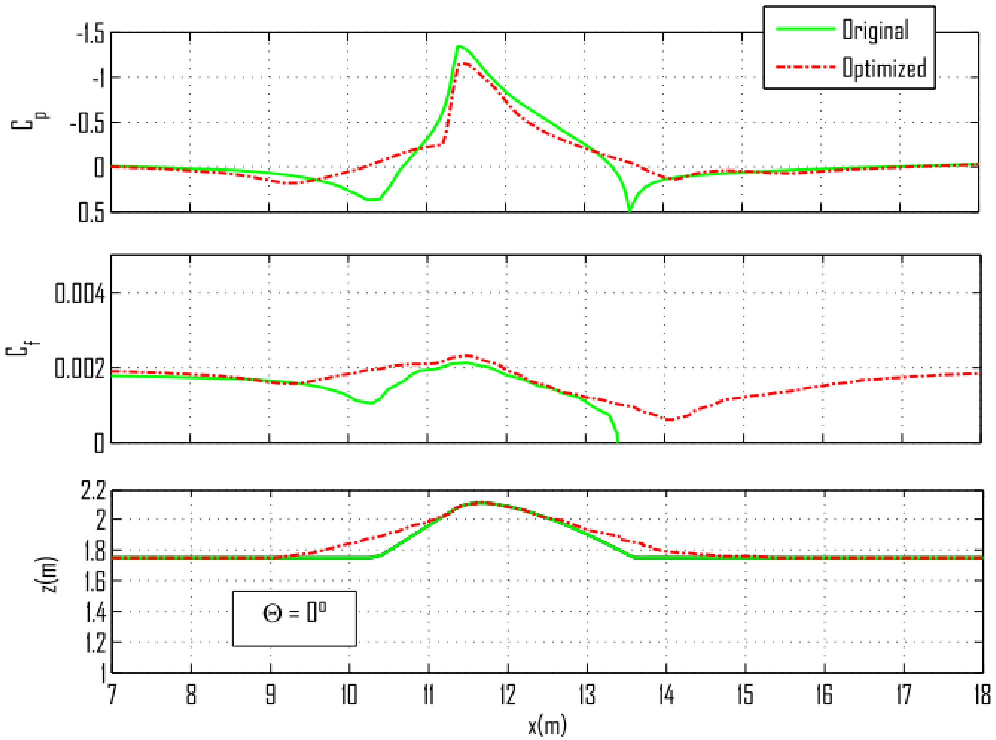


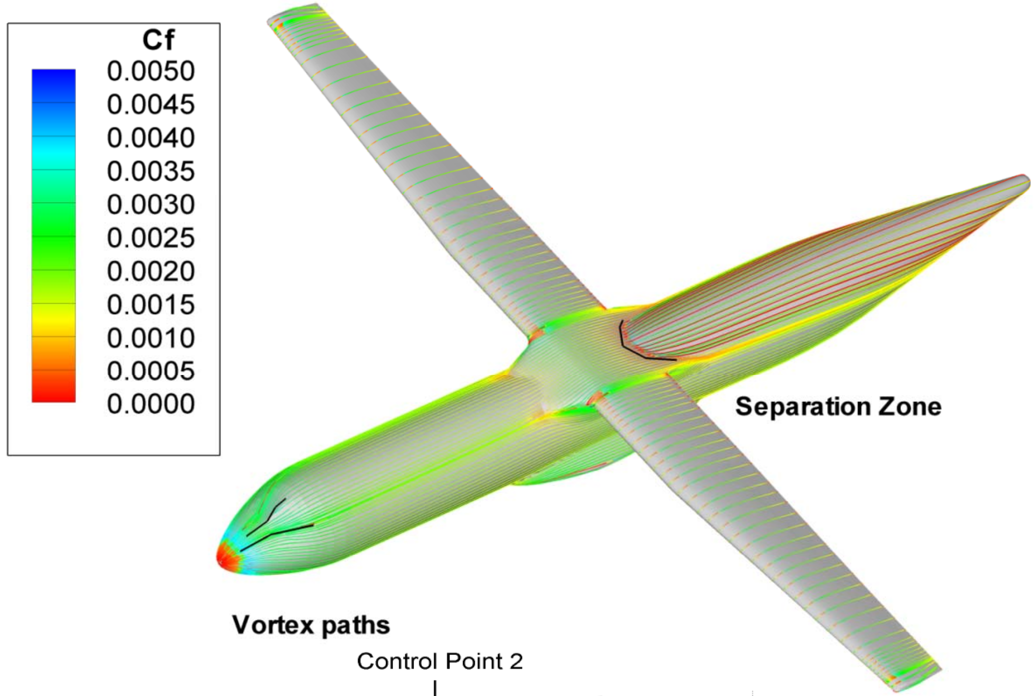


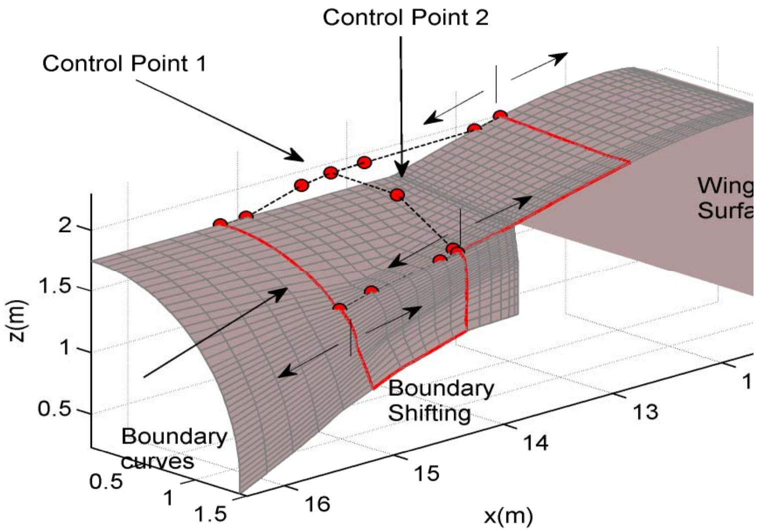
CFD Application – Fuselage Design

Fuselage Karman Design

- **3-D Panel method + b.l. analysis**
- **Original geometry characterized by possible flow separation**
- **Geometry modification through NURBS**
- **Aerodynamic Optimization**







“Aerodynamic guidelines in the design and optimization of new regional turboprop aircraft»
F. Nicolosi, P. Della Vecchia, CEAS 2011 Conference

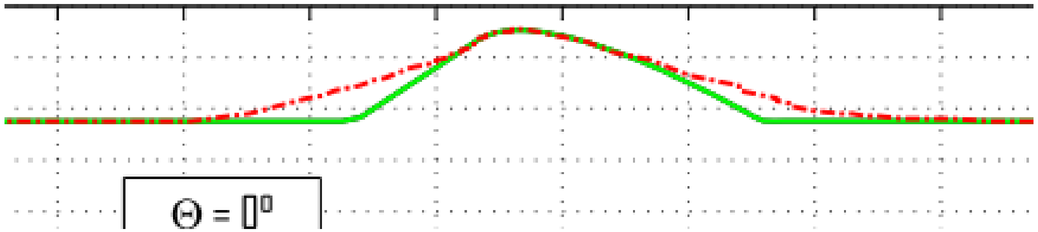
CFD Application – Fuselage Design

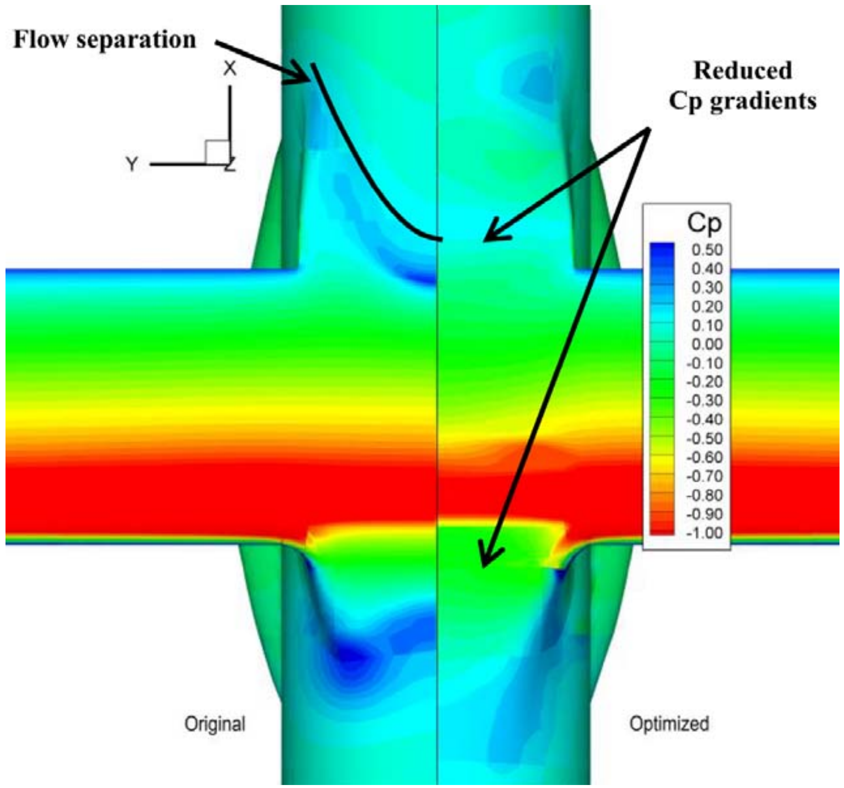
Fuselage Karman – Analysis and Design

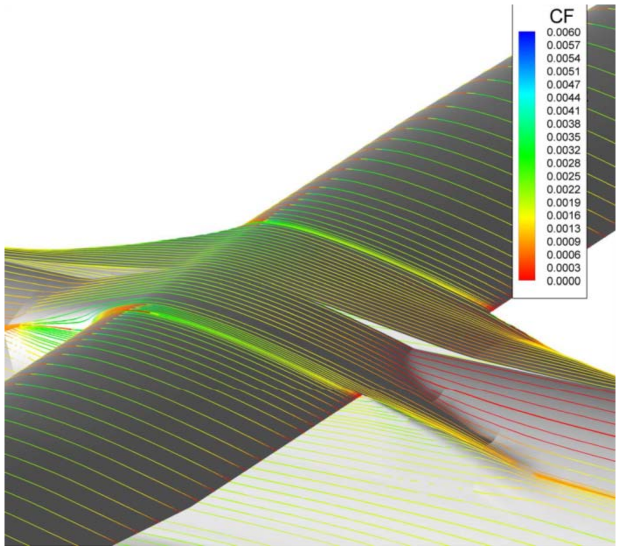
✈ **Drag Saving (drag counts):**

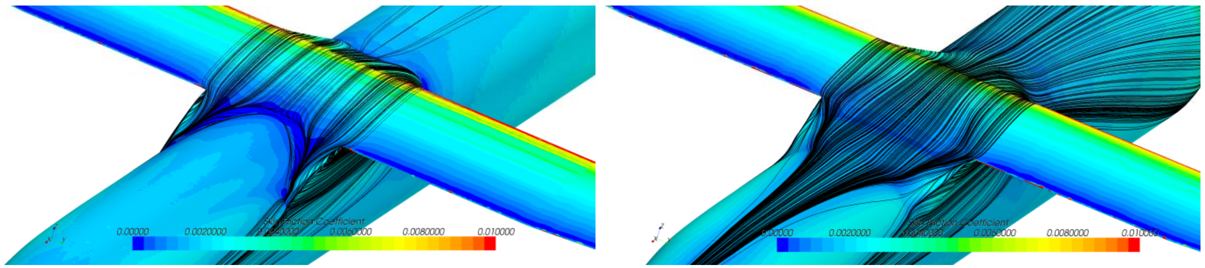
	Panel Method	**CFD RANS**
Cruise	- 3.6	- 3.4
Climb	- 6.0	- 5.6

The new geometry leads to lower drag but higher weight and manufacturing costs !









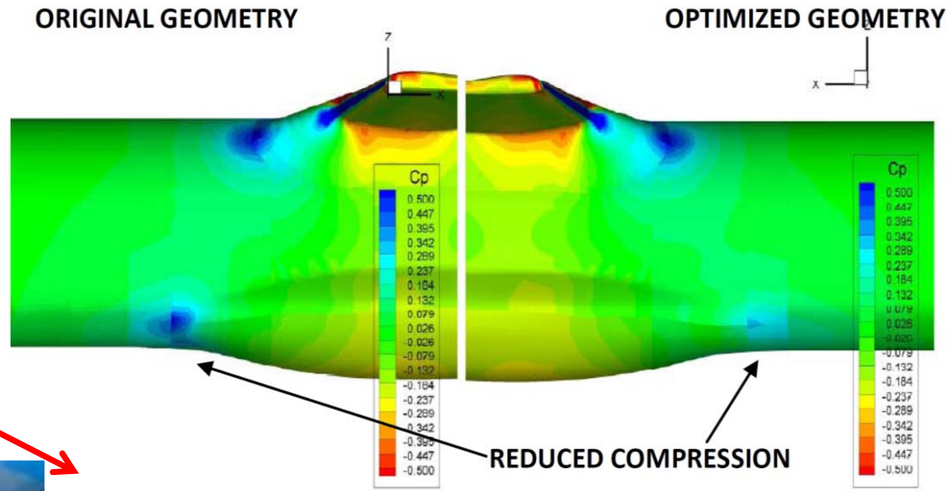
CFD RANS calculation (for validation)

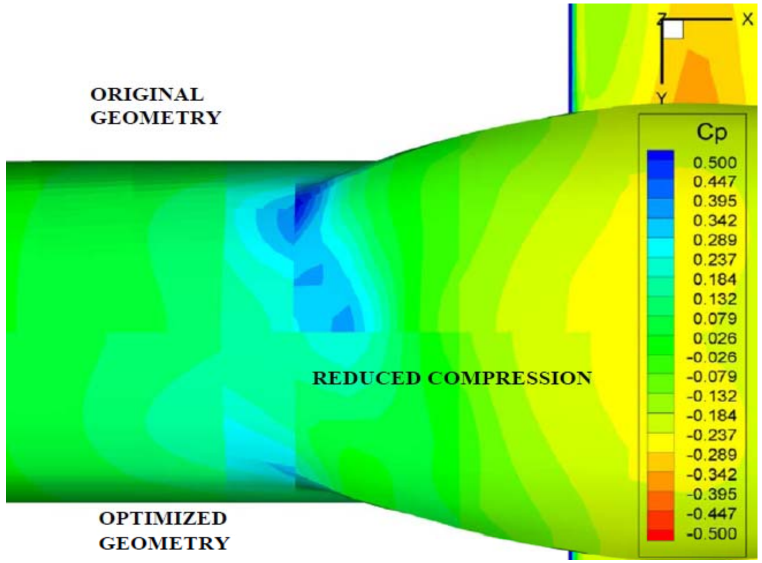
CFD Application – Fuselage Design

Fuselage Fairing

- **Drag Saving (drag counts):**
  Cruise - 2.0

CFD analysis of Open wheel bay should be performed





"Aerodynamic guidelines in the design and optimization of new regional turboprop aircraft»
F. Nicolosi, P. Della Vecchia, CEAS 2011 Conference

CFD Application – Fuselage Design

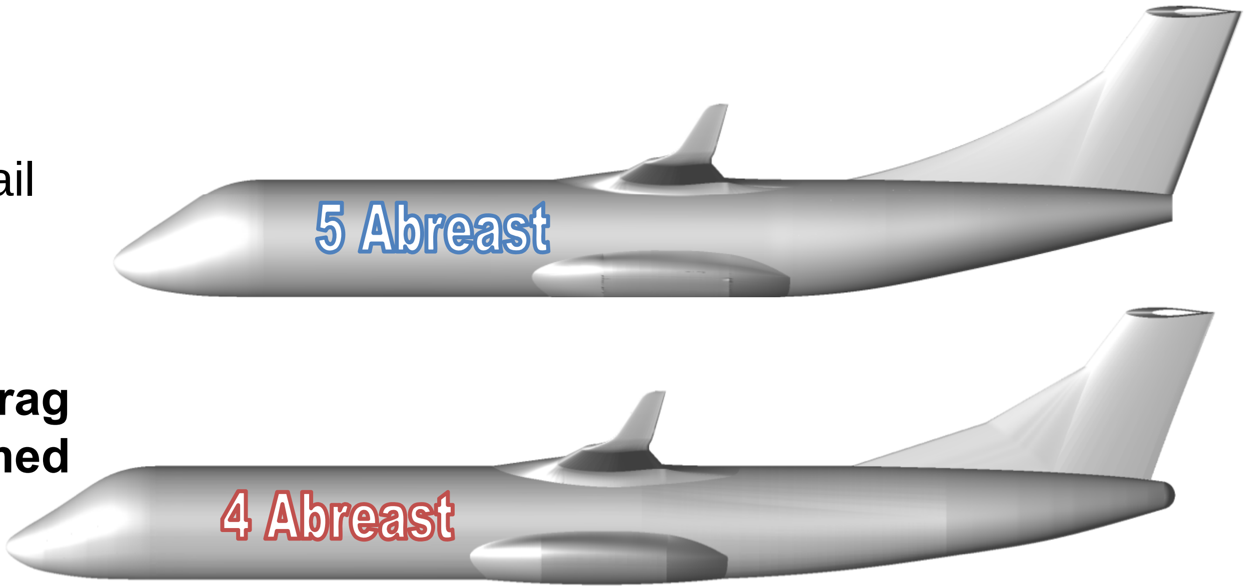
Fuselage fineness ratio

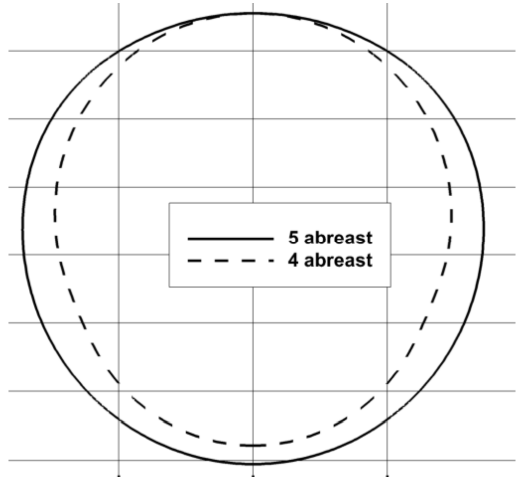
- **4 Abreast vs 5 Abreast**
  Horizontal and Vertical tail area must be resized

- **Preliminary Semi-Empirical Drag Calculation on assumed geometries**

	4-Ab	5-Ab
CDo	0.0260	0.0277

- **Detailed CFD analysis:**
  What is the price of higher comfort ?





CFD Application – Effect of Aerodynamic Impr.

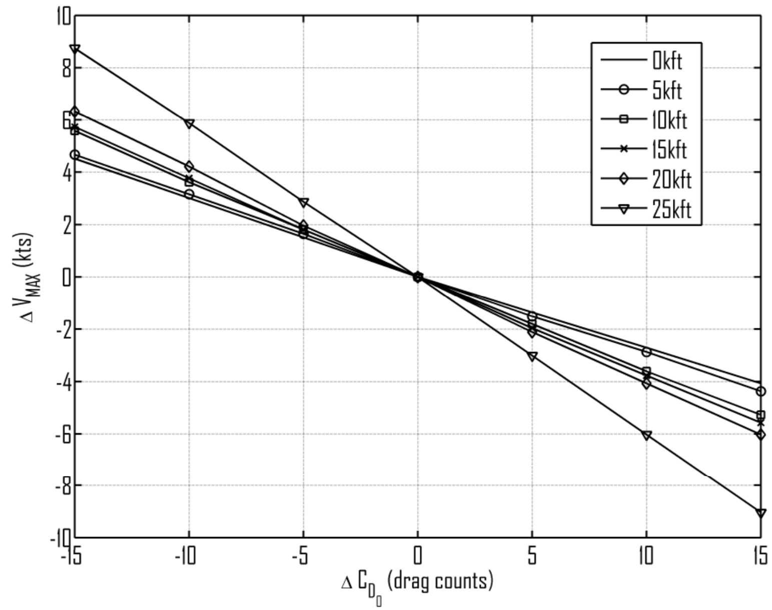
Global Aerodynamic Improvements

- **Flight Max Cruise Speed**
  @ 20 kft altitude 10 drag count => 4 KTAS

- **Obtainable drag saving (cruise, 20 kft)**

Fuselage Karman	-3.5 drag counts
Fuselage nose	-3.5
Fuselage fairing	-2.0
Fuselage tail	-2.0
Winglet	-8.0

TOTAL Drag saving about -20 drag counts



- **Possible Performance Improvements**

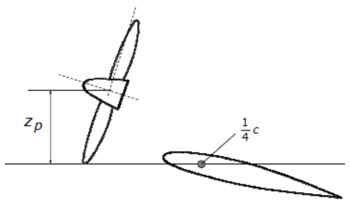
Cruise Flight Speed	+ 8÷10 KTAS
Global Fuel Mission Saving (same flight speed)	- 40 Kg (-6÷7 %)
Improved OEI Climb and Ceiling (Winglet)	

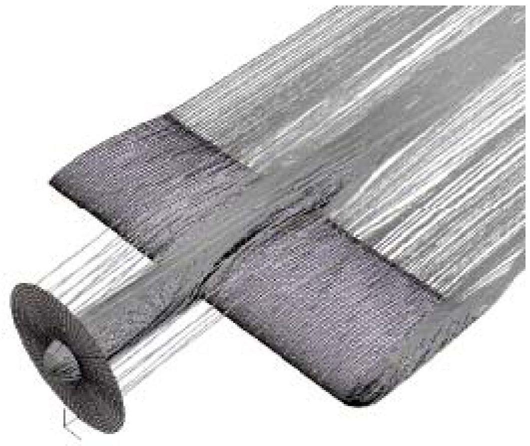
"Aerodynamic guidelines in the design and optimization of new regional turboprop aircraft»
F. Nicolosi, P. Della Vecchia, CEAS 2011 Conference

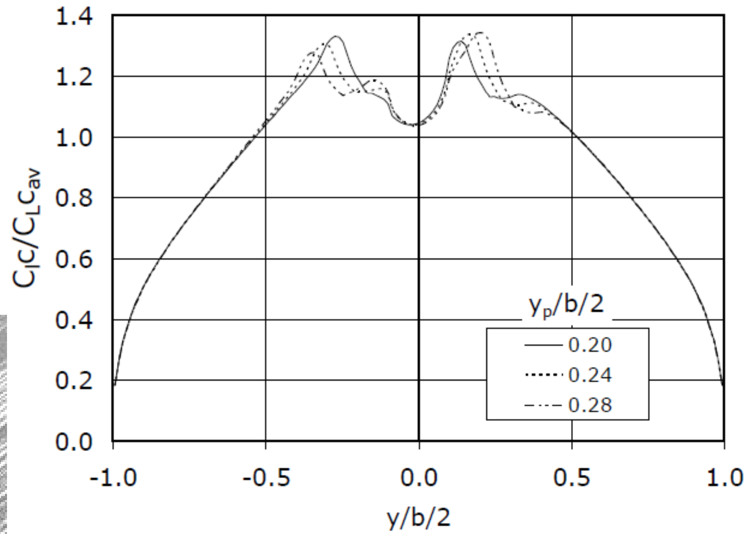
CFD Application – Nacelle and Propeller Effects

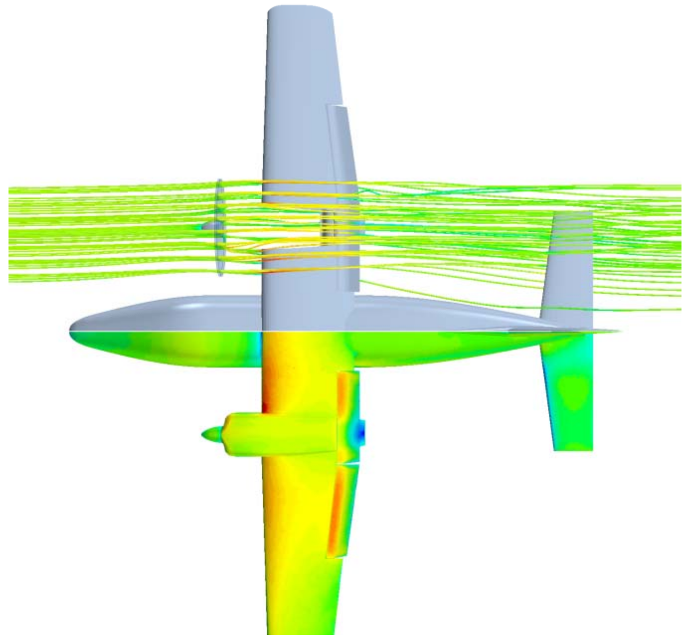
Nacelle and propeller

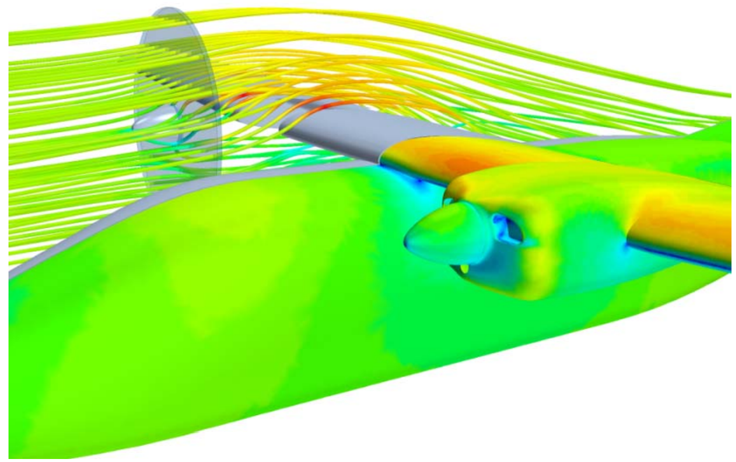
- **CFD RANS Calculations**
  - Nacelle shape Optimization
  - Effect of nacelle and propeller on wing aerod.
  - Detailed study of propeller position (streamwise, spanwise and vertical)
  - Propeller indirect effects on tail











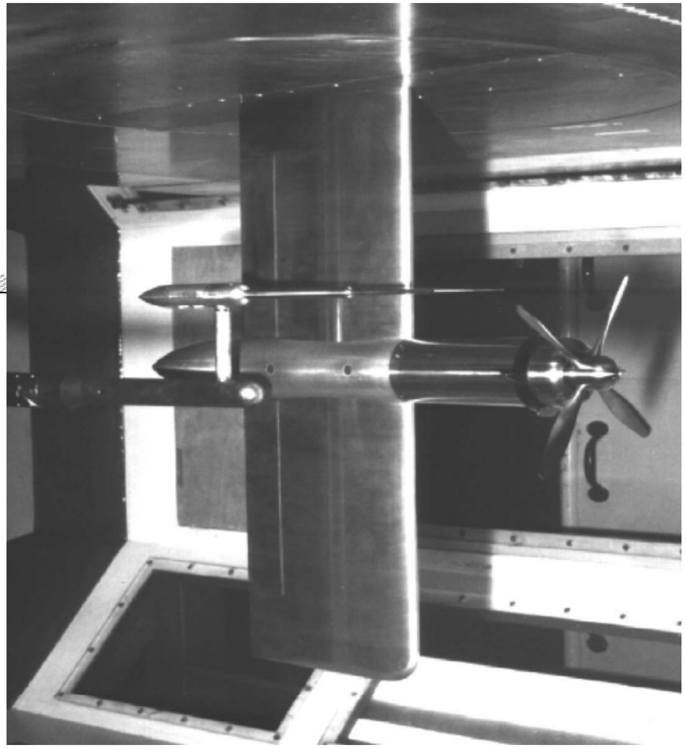
Wind-Tunnel Tests – Nacelle and Propeller Effects

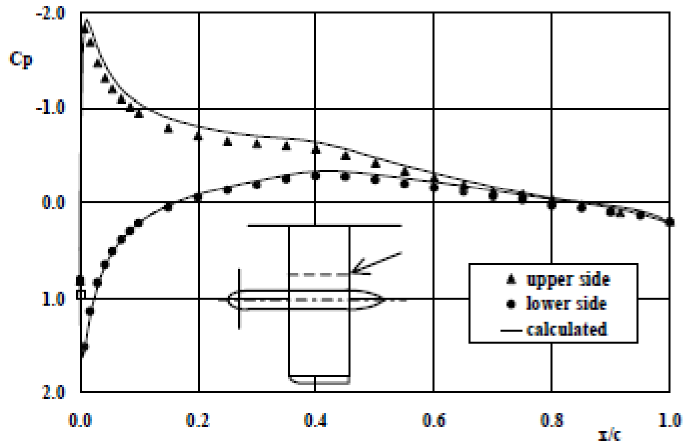
Nacelle and propeller

(“A Propeller-Integration Study …” – L. Veldhuis (ICAS 2000)

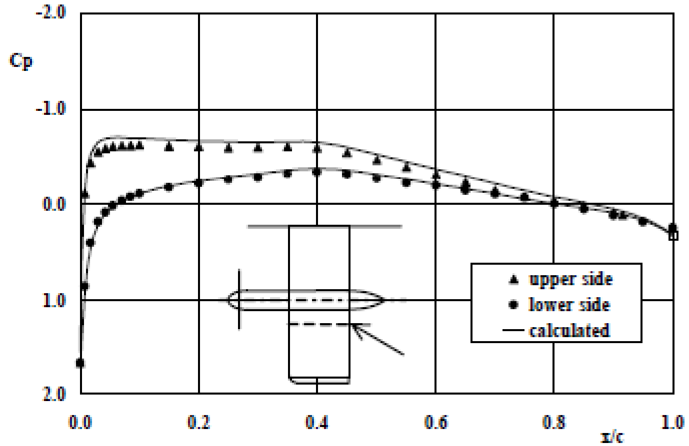
✈ **Wind-Tunnel Measurement**

- External Balance
- Measurement of forces on nacelle
- Surface pressure
- Wake Survey

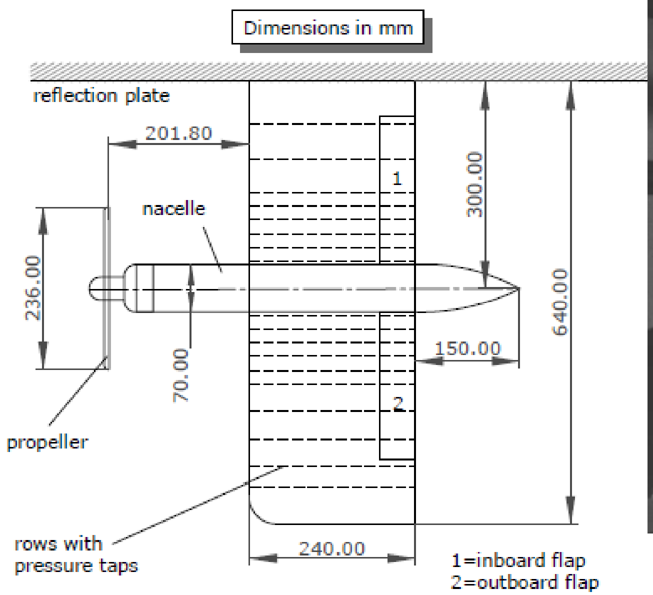




(a)



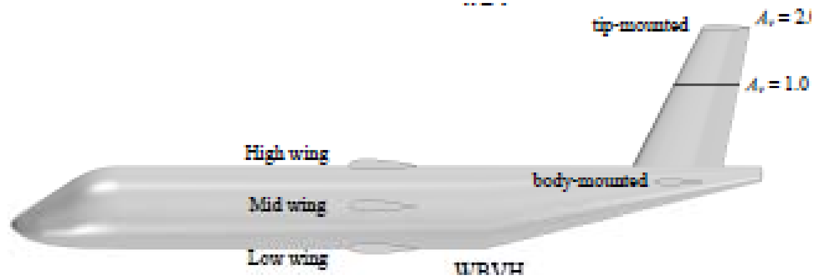
(b)



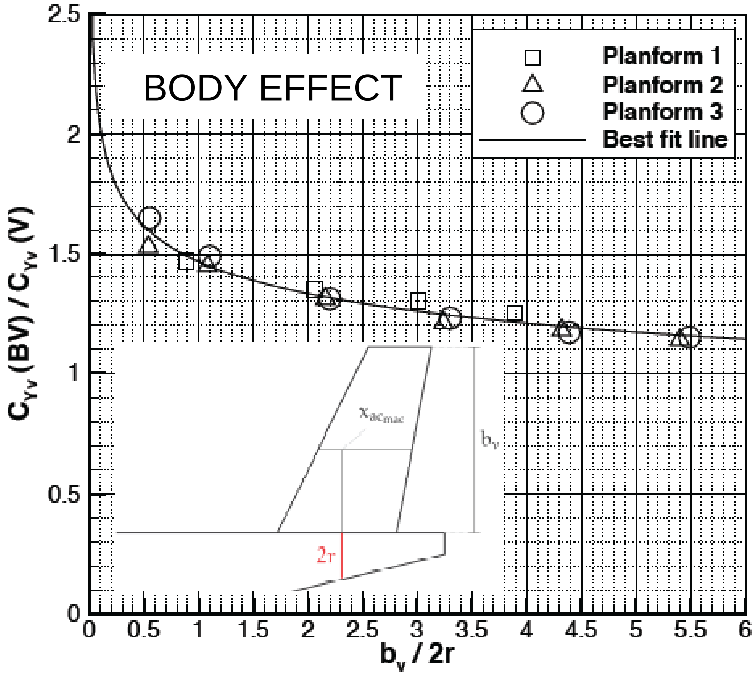
L. Veldhuis (TU Delft) – PROWIM Project

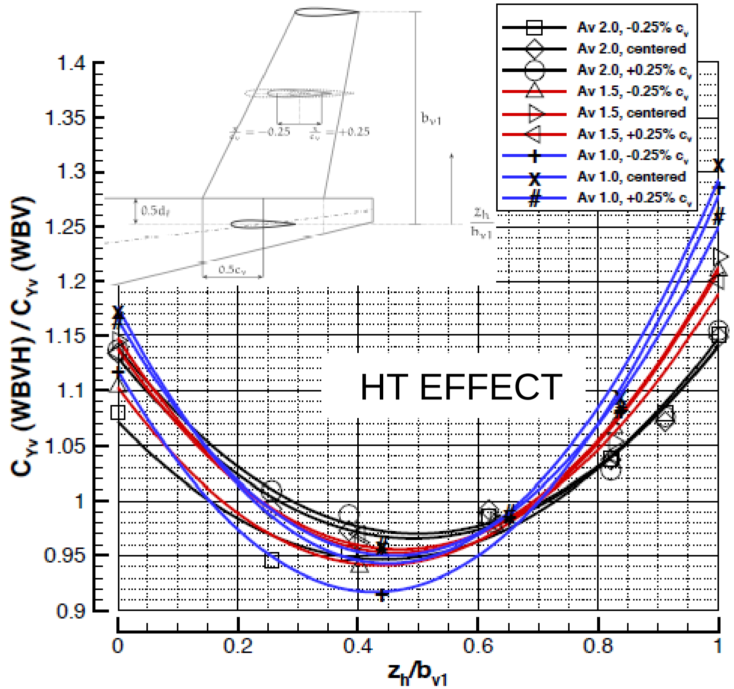
CFD Application – Tail Design

Vertical Tail Design Methodology



- ✈ **Development of an improved Design Method through CFD RANS Calculations**
  - ➢ Several Vertical tail shape analysed
  - ➢ Effect of VT Aspect ratio
  - ➢ Detailed estimation of positive effects due to fuselage, horizontal tail and wing



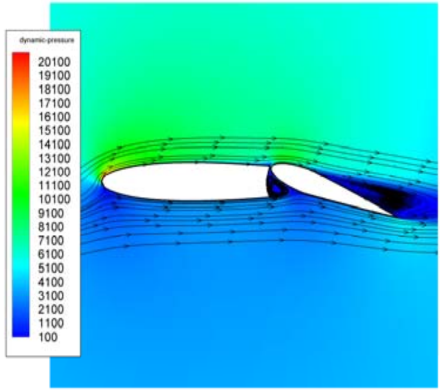


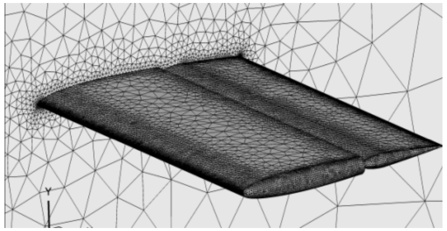
An investigation on vertical tailplane contribution to aircraft sideforce
F. Nicolosi, D. Ciliberti, P. Della Vecchia – Aerospace Science and Technology n. 28, January 2013

CFD Application – Tail Design

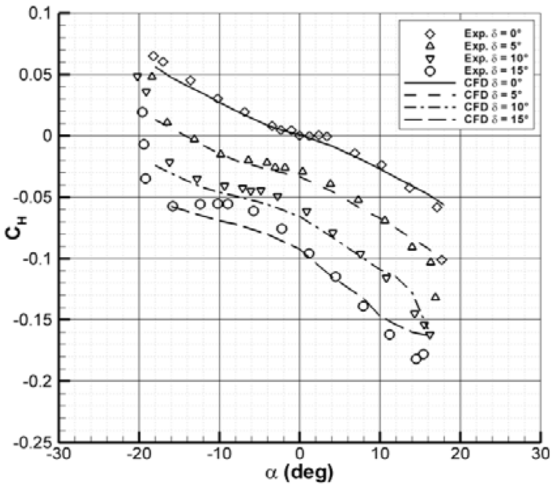
Control Surfaces

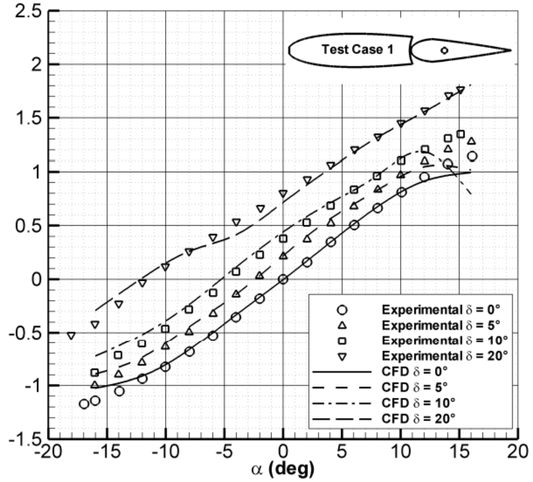
- ✈ **Detailed RANS analysis of control surfaces**
  - ➢ Control surfaces 2-D and 3-D efficiency
  - ➢ High angles (non-linearity)
  - ➢ Interference effects
  - ➢ Hinge moment measurement



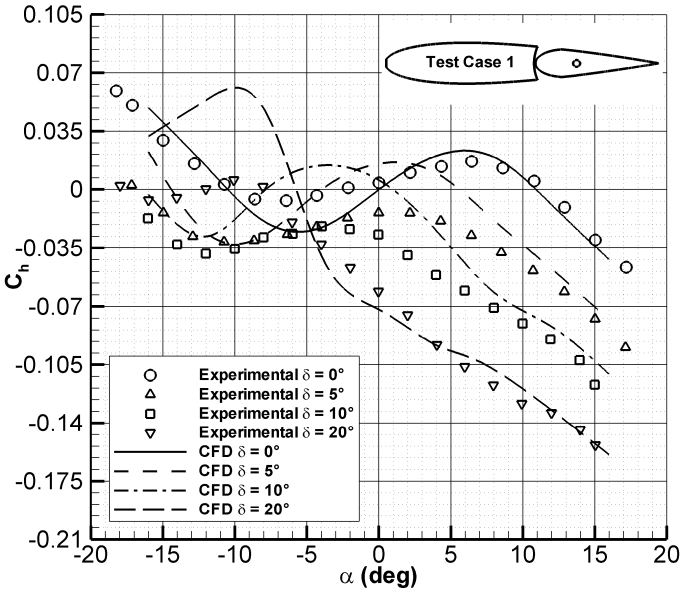


NACA Test 3-D





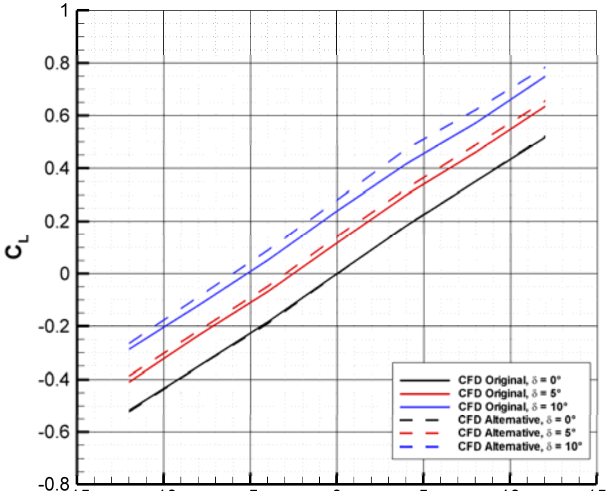
NACA Test 2-D

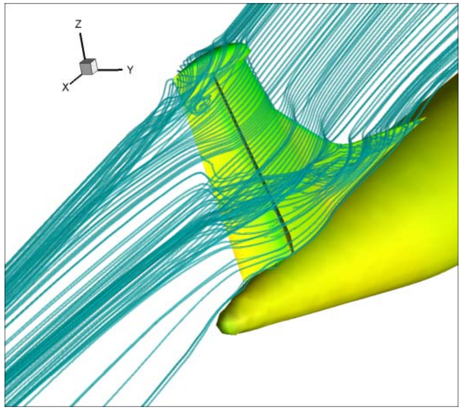


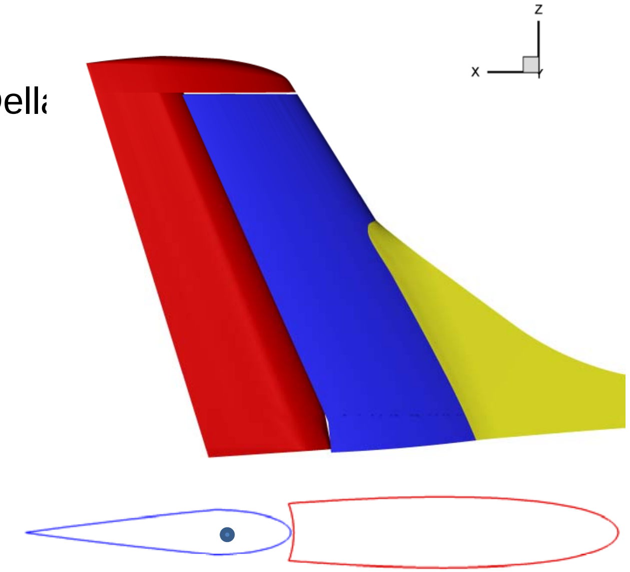
Nicolosi, F., Della Vecchia, P., Ciliberti, D. "*Aerodynamic interference issues in aircraft directional control*, " *ASCE's Journal of Aerospace Engineering*, Ref.: Ms. No. ASENG-649R2

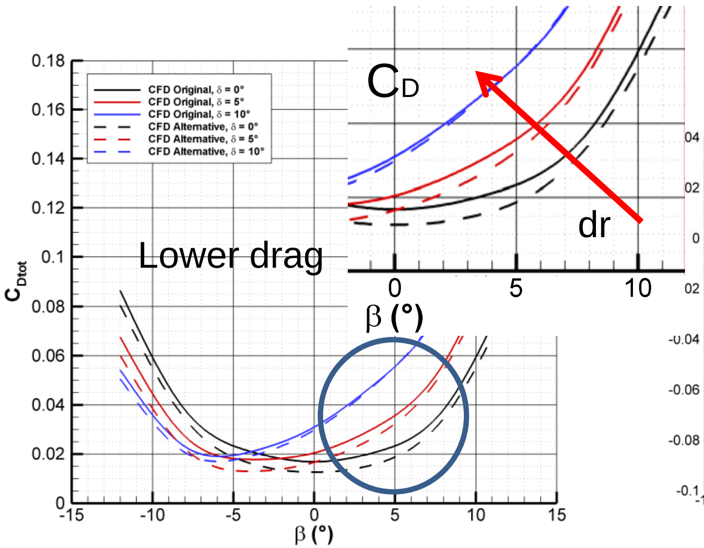
Control Surfaces

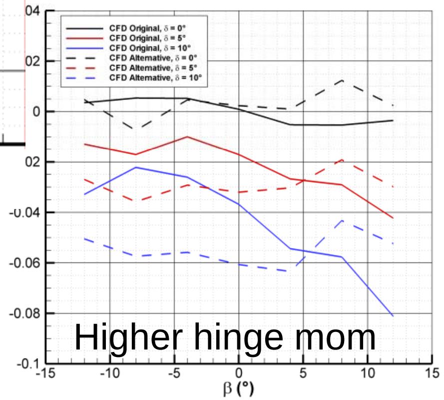
✈ **Design of an improved rudder for ATR72** (Nicolosi, Dell Corcione)

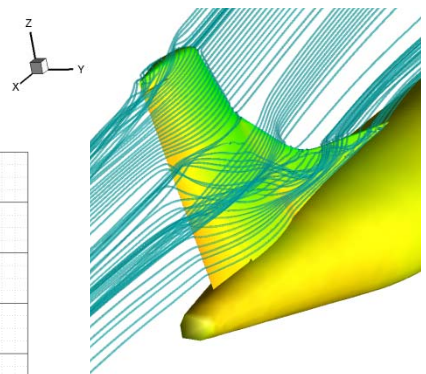


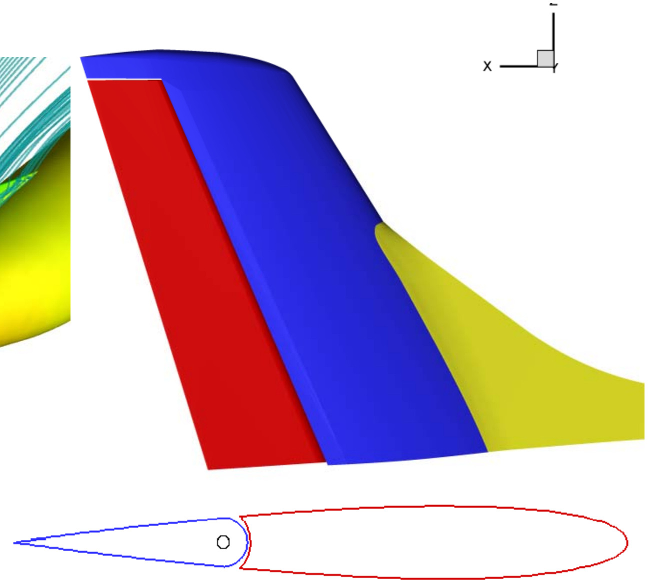










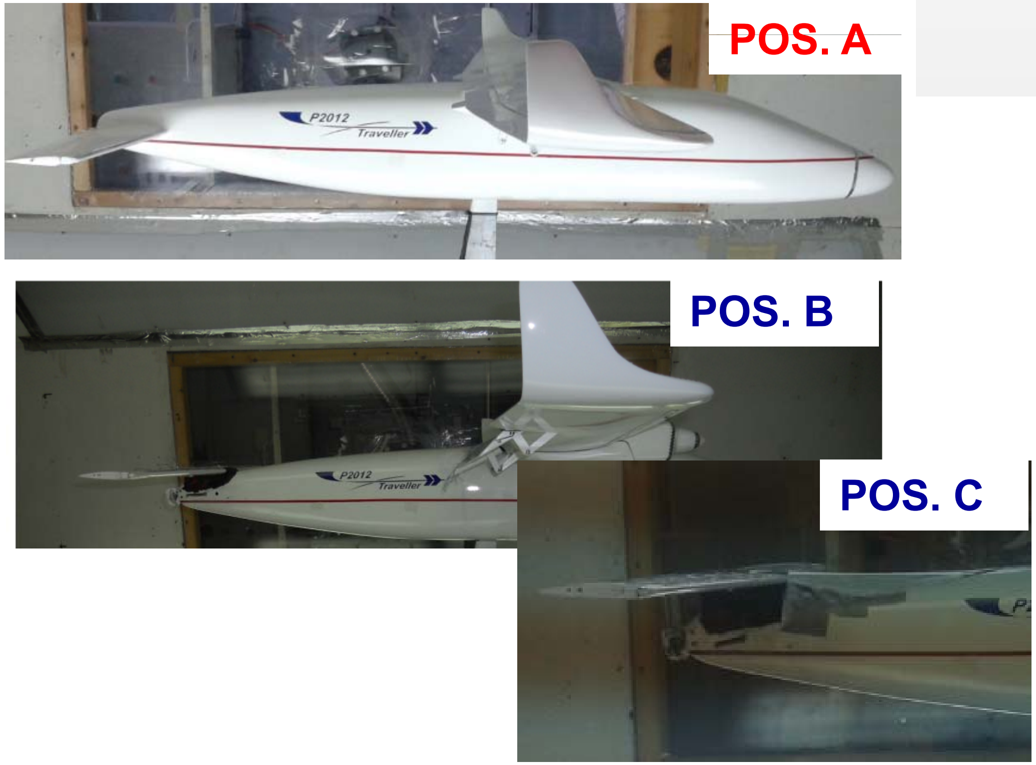


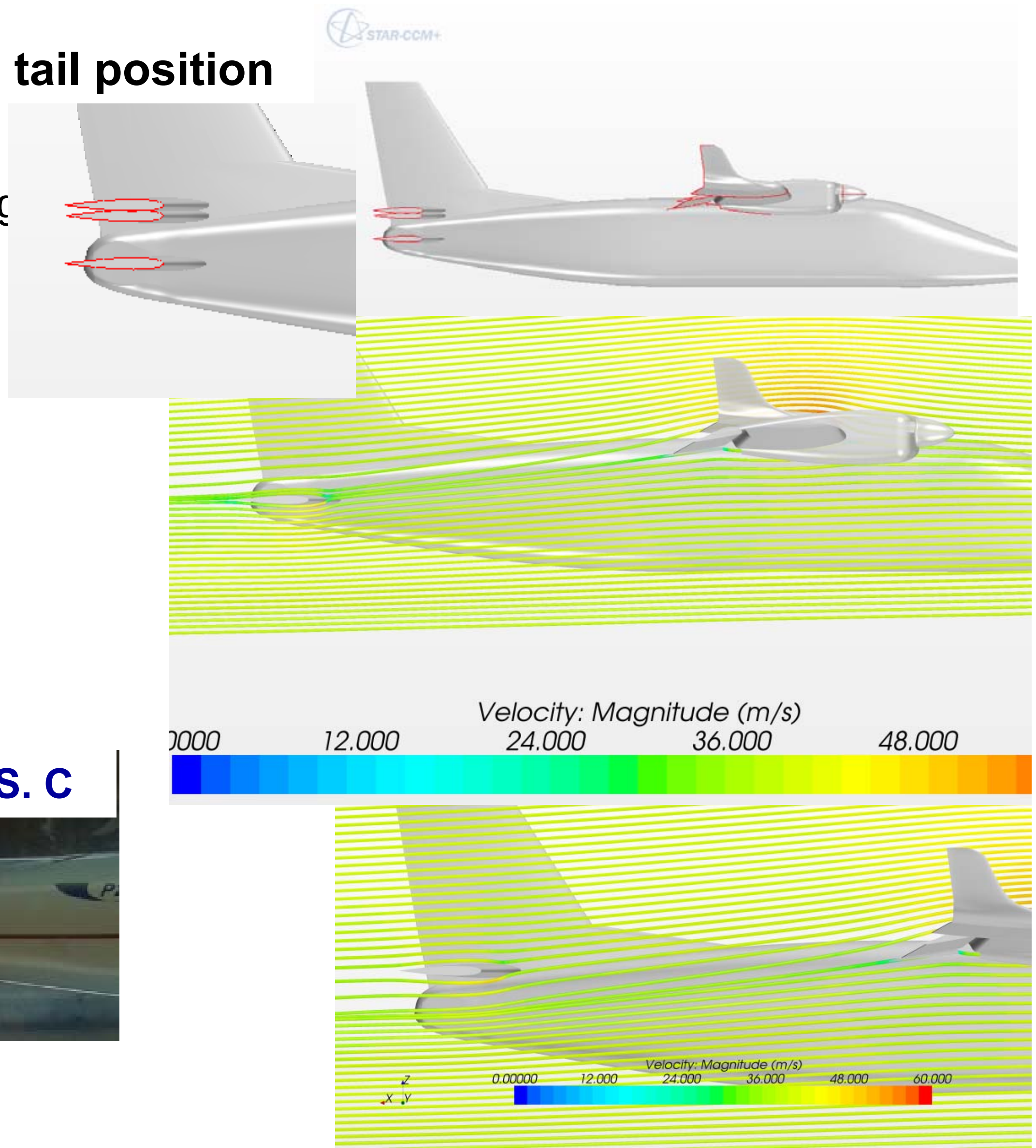
CFD Application – Tail Design

Horizontal tailplane

✈ **Design of P2012 Aircraft – Horizontal tail position**

- Different position investigated
- Wing wake interaction for different flap setting
- CFD RANS and Wind-Tunnel Tests





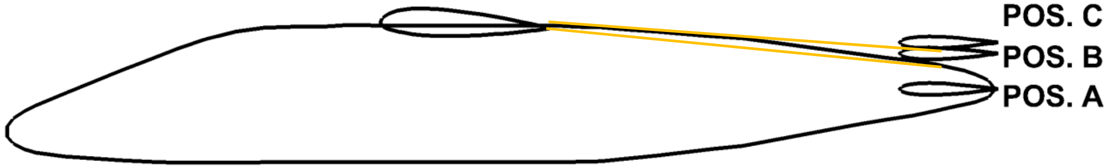
"***Wind Tunnel Tests of a New Commuter Aircraft***",
Nicolosi F., Corcione, S., Della Vecchia P. 4th CEAS Conference, 2013

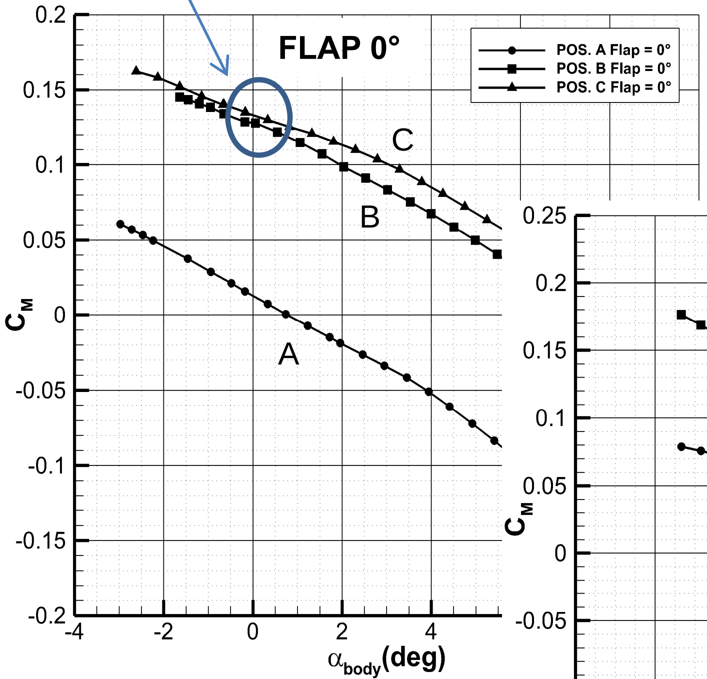
Wind-Tunnel Tests – Tail Design

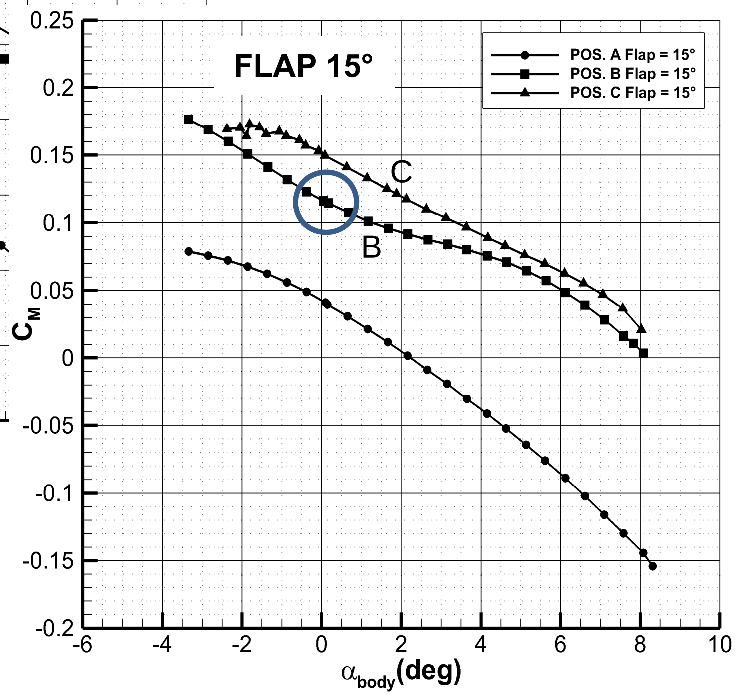
Horizontal tailplane

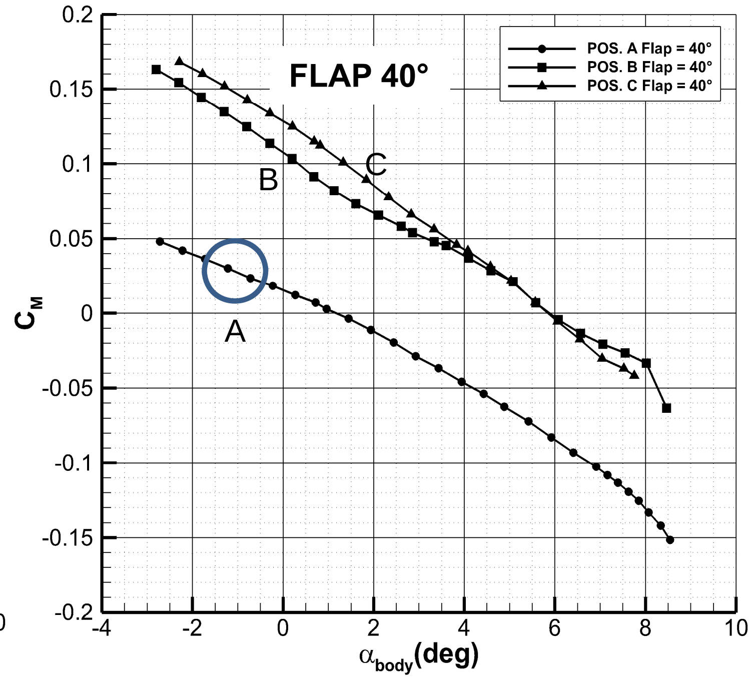
✈ **Design of P2012 Aircraft – Horizontal tail position**

- Each position can be critical at an assigned flap setting
- Pos. B and C to be avoided (wing turbulence on tail at high speed)









Wind-Tunnel Tests

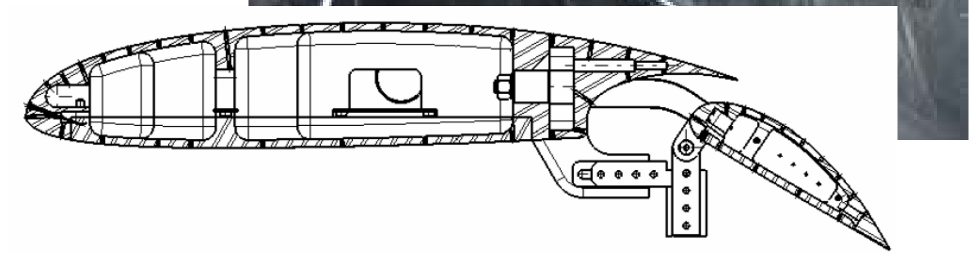
Critical Experimental Activities for Tprop

- **Airfoil tests (high speed) (M=0.50)**
- **Airfoil tests (low-speed)** (flap optimization)
- **Airfoil tests – ICE condition**
- **3-D Model Tests (cruise)**
  Lift, Drag, Stability Derivatives, Control Derivatives
- **3-D Model Tests (high-lift)**
  Max lift, stall path, wake effects, propeller effects.
  Aerodynamic effect of landing gear
  Tests in ground effect
- **3-D HALF Model Tests (cruise)**
  Wing lift distribution, propeller effects, winglet effects
- **3-D HALF Model Tests (high-lift)**
  Flap effects, lift distribution, propeller effects
- **Dynamic Model Tests**
  Aeroelastic effects, flutter
- **Airframe Noise Tests**
  Noise Measurement

MODULAR MODELS to test separate effects

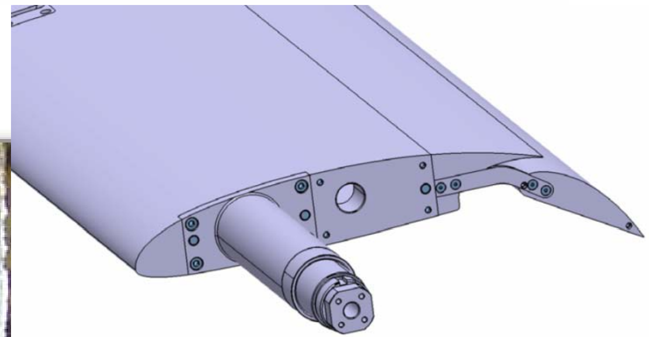
Wind-Tunnel Tests

Tests



- **Airfoil tests (high speed) (M=0.50)**
  - Aerodynamic characteristics (lift, drag, cm)
  - Pressure distribution
  - Critical Mach number
  - Transition (Low Turbulence Tunnel)
  - Behavior with contaminated l.e.

- **Airfoil tests (low-speed)** (flap optimization)
  - Flap position optimization
  - Tests of different flap system
  - Pressure distribution
  - Hinge moment measurement
  - Behavior with contaminated l.e.



- **Airfoil tests in ICE conditions**
  (Ice accretion measurement)

Wind-Tunnel Tests

Tests

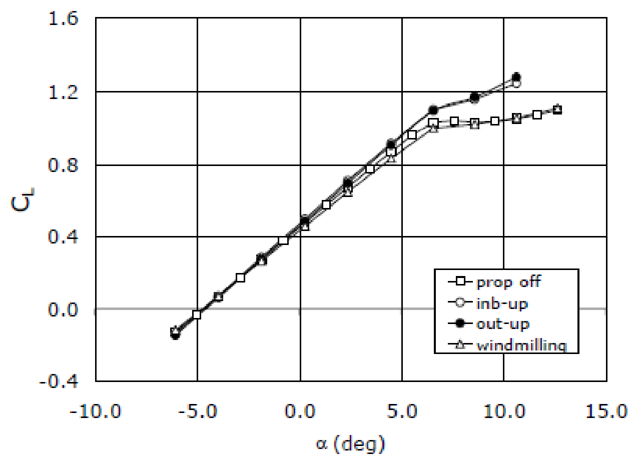
✈ **Complete Aircraft Powered Wind-Tunnel Model**

- **stability and control** at <u>different thrust conditions</u>
- different engine nacelles
- take-off and approach conditions
- control surfaces, winglets, Landing gear
- Modular model (prop on/off, tail on/off, l.gear in/out)
- Engine Simulation

Fokker F27 powered model (TU Delft)

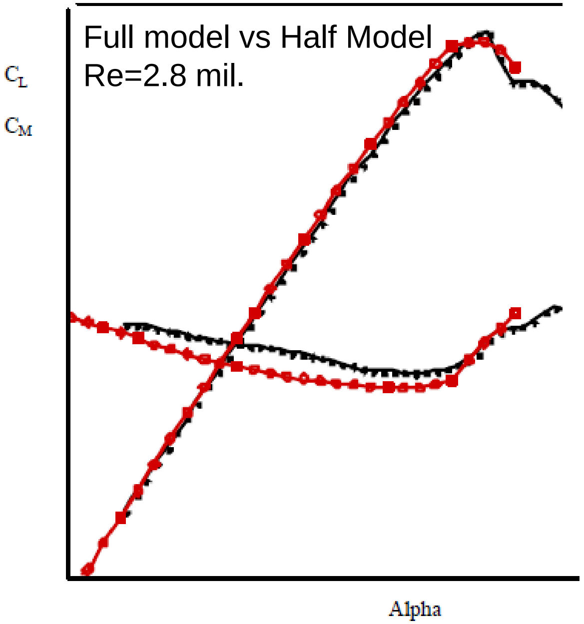
It is very important to measure the propeller effects
Some aerodynamic derivative can be influenced by propeller effects

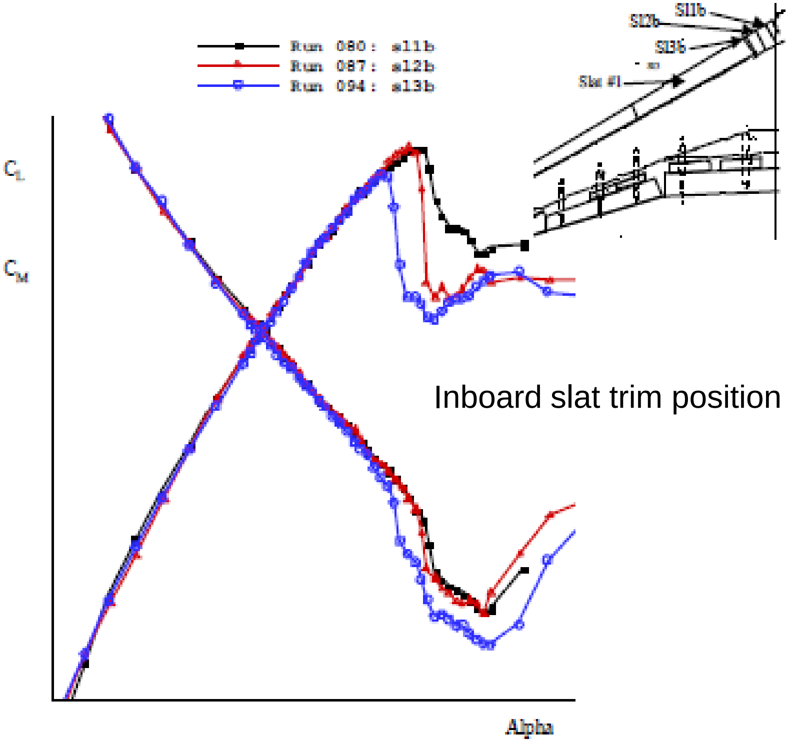
The A/C high-lift design performances
(Low Noise while High Lift maintain)



Wind-Tunnel Tests

- **3-D High-Lift (Low Speed Configuration) , Re 3 and 6 mil., Mach=0.15-0.20**
  - 3-D Tests and Half-Model Tests
  - Tail off and Tail on measurements
  - Measurement of max lift coeff., pitching moment
  - Drag/Efficiency (take-off)
  - Reynolds number effects





Inboard slat trim position

DEVELOPMENT OF HIGH-LIFT SYSTEMS FOR THE BOMBARDIER CRJ-700
Kafyeke, Pépin , Kho (Bombardier)
ICAS 2002 Conference

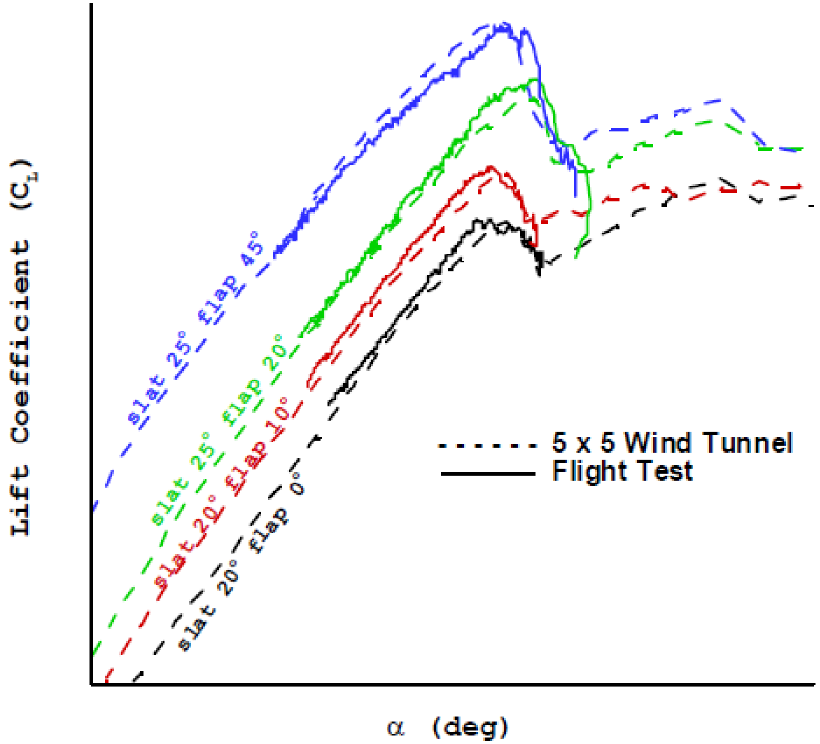
scale half model of the CRJ-700

7% scale full model of the CRJ-700

Wind-Tunnel Tests

✈ **Wind-Tunnel Tests vs Flight Tests**

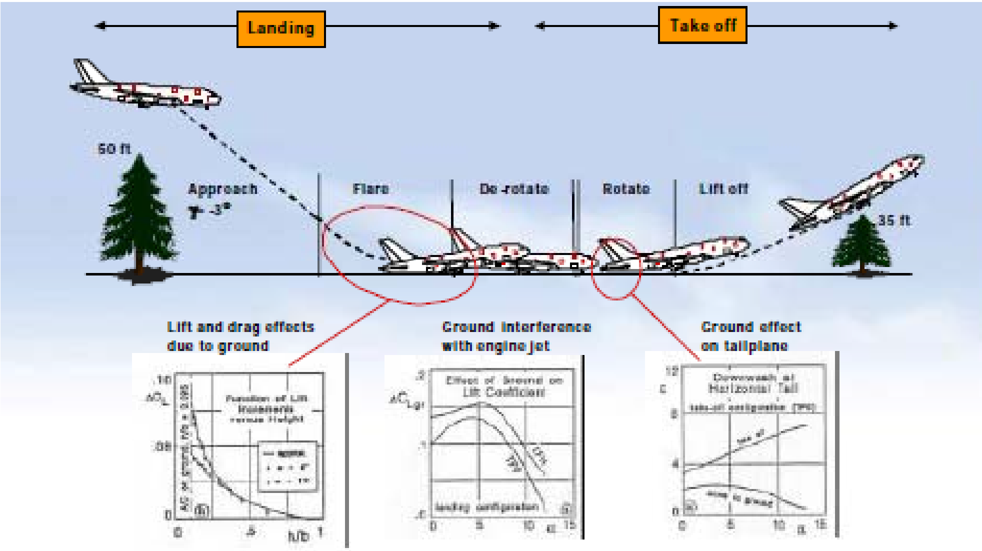
Trimmed lift curves

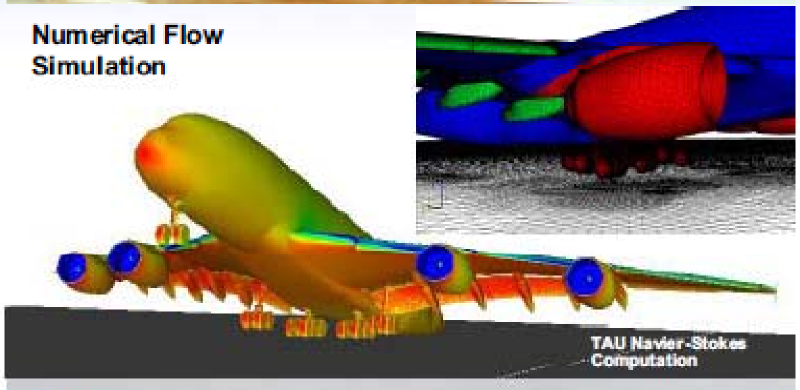


DEVELOPMENT OF HIGH-LIFT SYSTEMS
FOR THE BOMBARDIER CRJ-700
Fassi Kafyeke, François Pépin and Cedric Kho (Bombardier)
ICAS 2002 Conference

Wind-Tunnel Tests

- **Tests in ground effect**

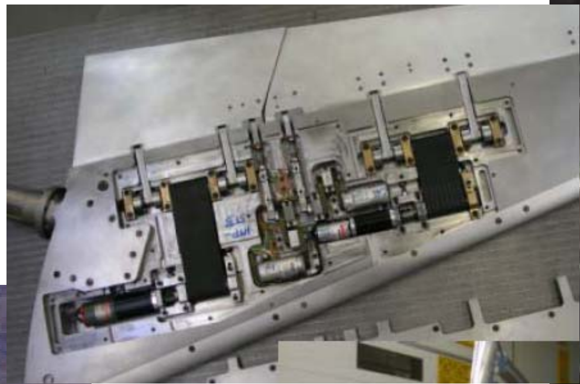




- A380 complex high-lift configuration incl. landing gear

Wind-Tunnel Tests

- **Dynamic Testing**
  - Wing deformation measurement
  - Aeroelastic Tests
  - Flutter
  - Instrumented model



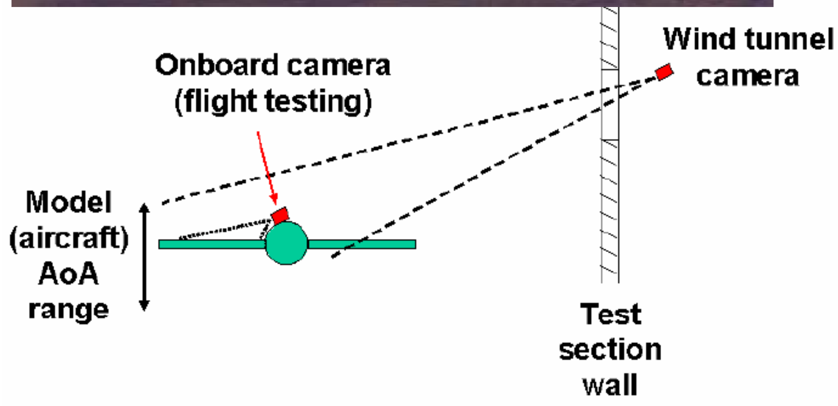


Figure 1: Comparing wind tunnel and in-flight geometries.

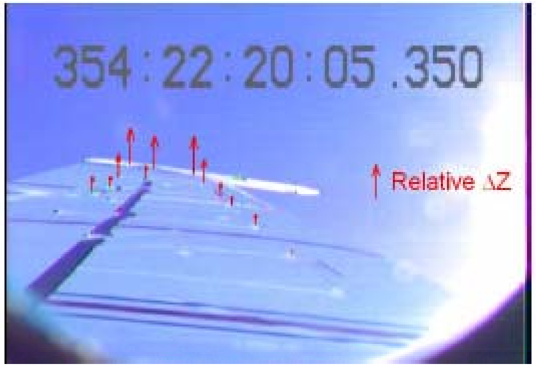


Figure 9: Relative *Z*-deflection overlaid on video image of wing.

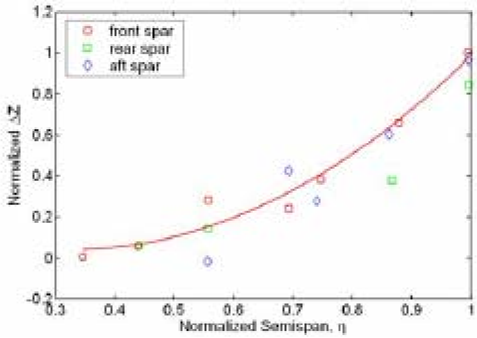
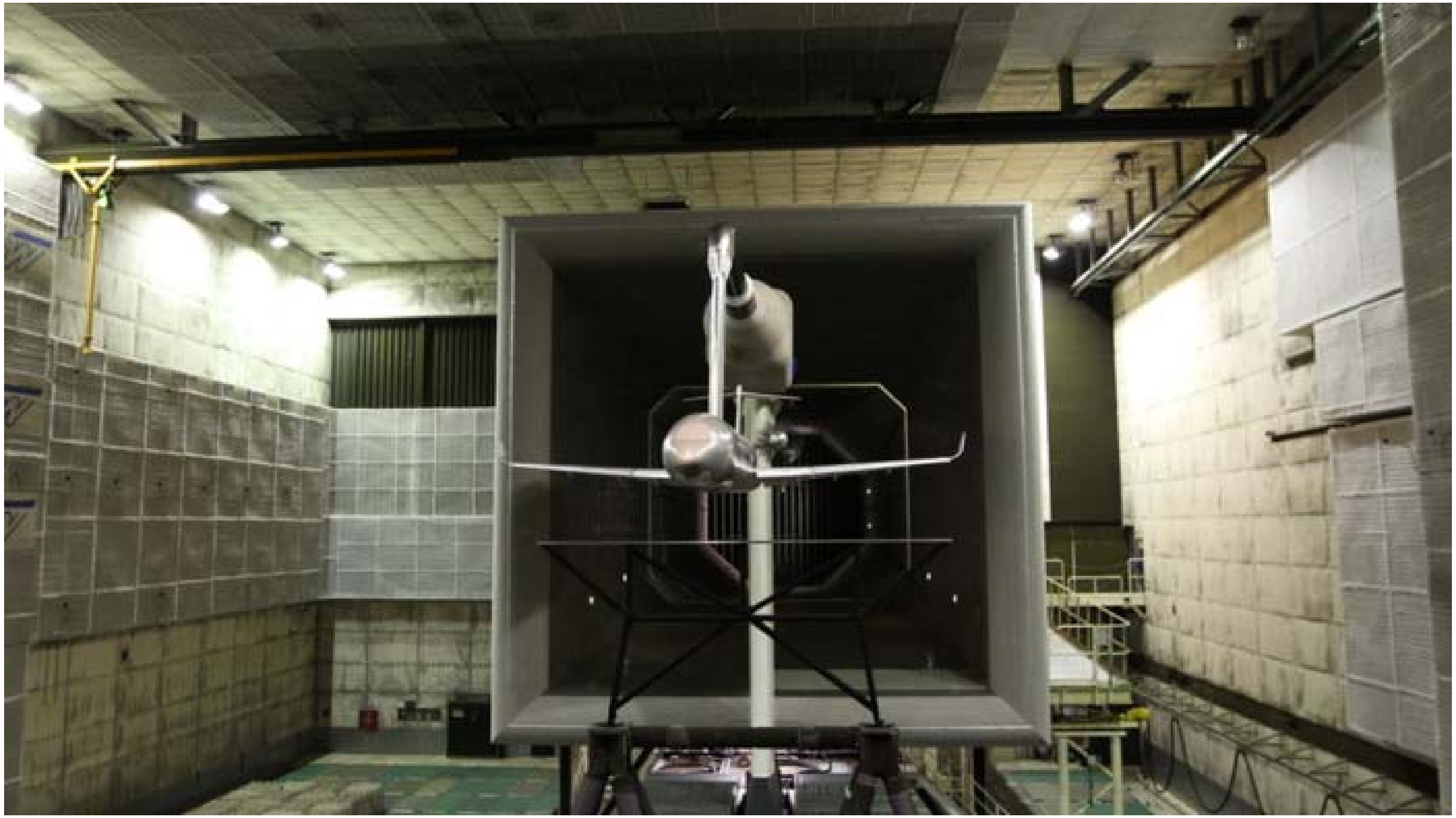


Figure 10: Normalized deflection versus semispan.

NASA FA-18 wing deflection (WT vs Flight Data)

Wind-Tunnel Tests

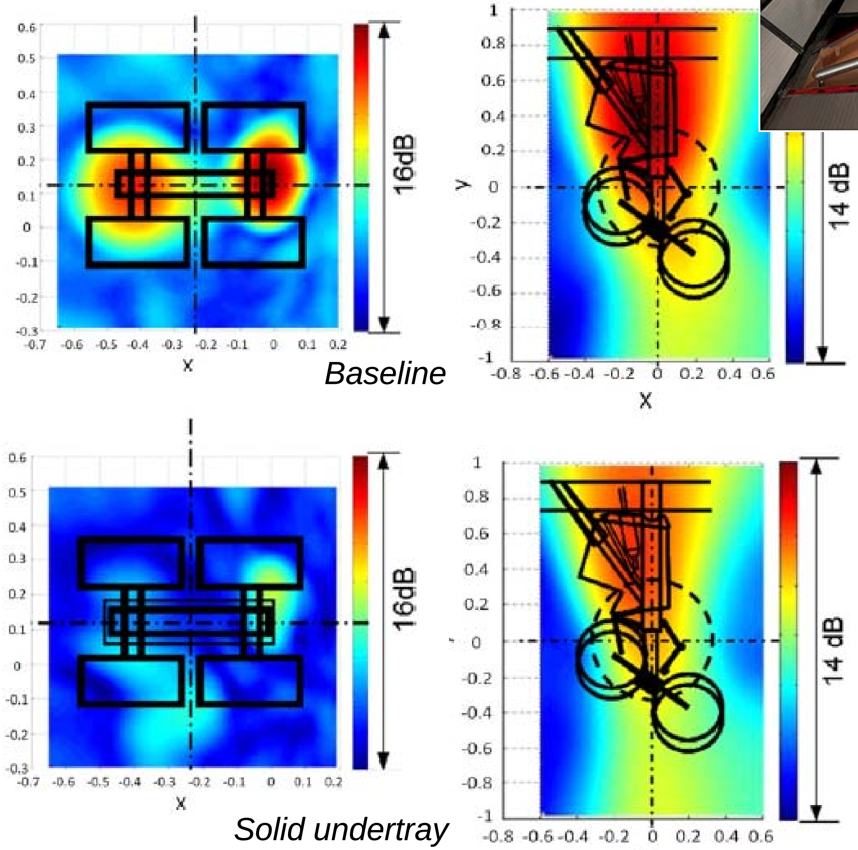
- ✈ **3-D Aeroacustic Tests**



Recent AIRBUS Noise Tests

Wind-Tunnel Tests

- **Landing Gear Tests**
  - Different scale
  - Drag measurement
  - Noise Measurement

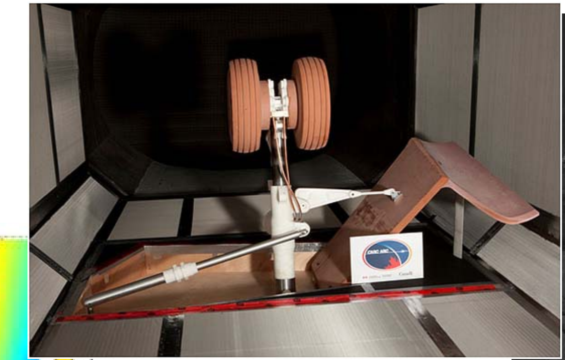


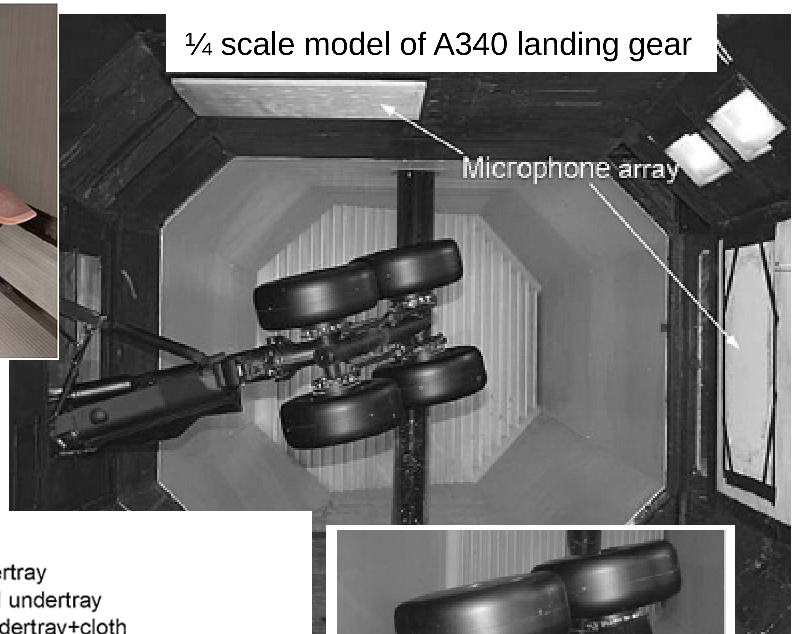
Baseline

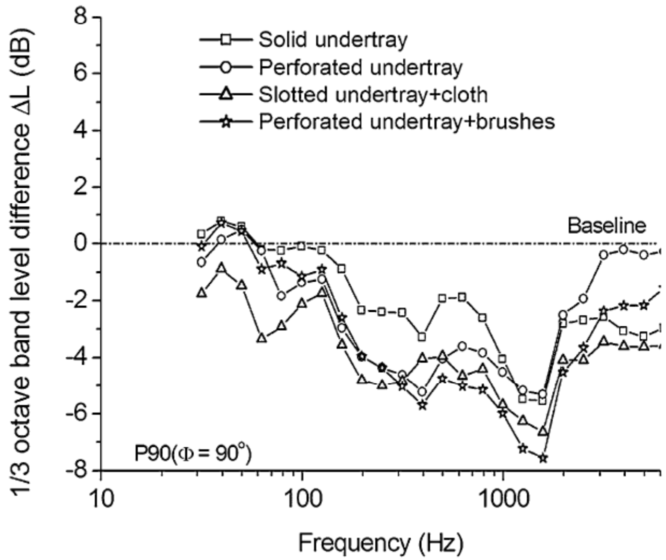
Solid undertray

Ground view

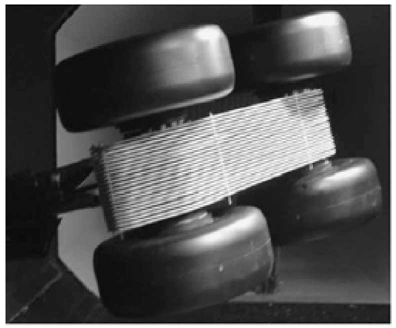
Side view








(a) Solid undertray

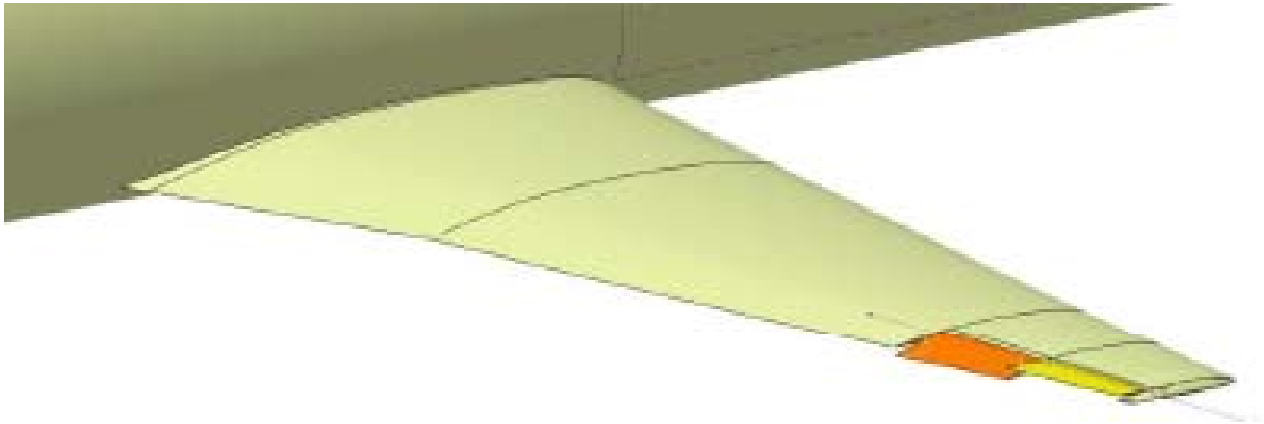

(c) Slotted undertray

Measurement and control of aircraft landing gear broadband noise
Yong Li a,∗,1, Malcolm Smithb, Xin Zhanga, Aerospace Science and Technology, 2012

Wind-Tunnel Tests

✈ **Advanced WT Tests: Gust Load Alleviation (GLA) CONTROL SYSTEM**

a) A/C with flexible wing WT model
b) Model gust alleviation devices active
c) Model system sensors models active in the loop with control laws
d) Model control law engineering model in the loop with GLA devices
e) Wind tunnel gust generator (wind tunnel air flow direction changes).



Conclusions

- **All CFD Methods (from 2-D panel method to complex 3-D unsteady RANS) are extremely useful for the preliminary and detailed design of new aircraft**
- **Computational tools allow the analysis of very complex phenomena**
- **In the preliminary design phase it is very important to build a Multi-Disciplinary Design Framework linking CFD tools with CAD, Structure, Weight, Systems, Aeroelasticity, Flight Mechanics and Flight Dynamics**

- **Possibility to reduce wind-tunnel tests work**
- **Wind-tunnel tests to exploit several critical items (i.e. ICE, Propeller effects, etc.)**
- **Wind-tunnel tests addressed to the assessment of an optimal configuration**

CFD, WIND-TUNNEL and FLIGHT TESTS

MUST BE CONSIDERED

COMPLEMENTARY TOOLS

Industrial Remarks

Prediction and analysis of the low-speed stall characteristics of the Boeing 747.
W. McIntosh, J.K. Wimpress, Boeing Company

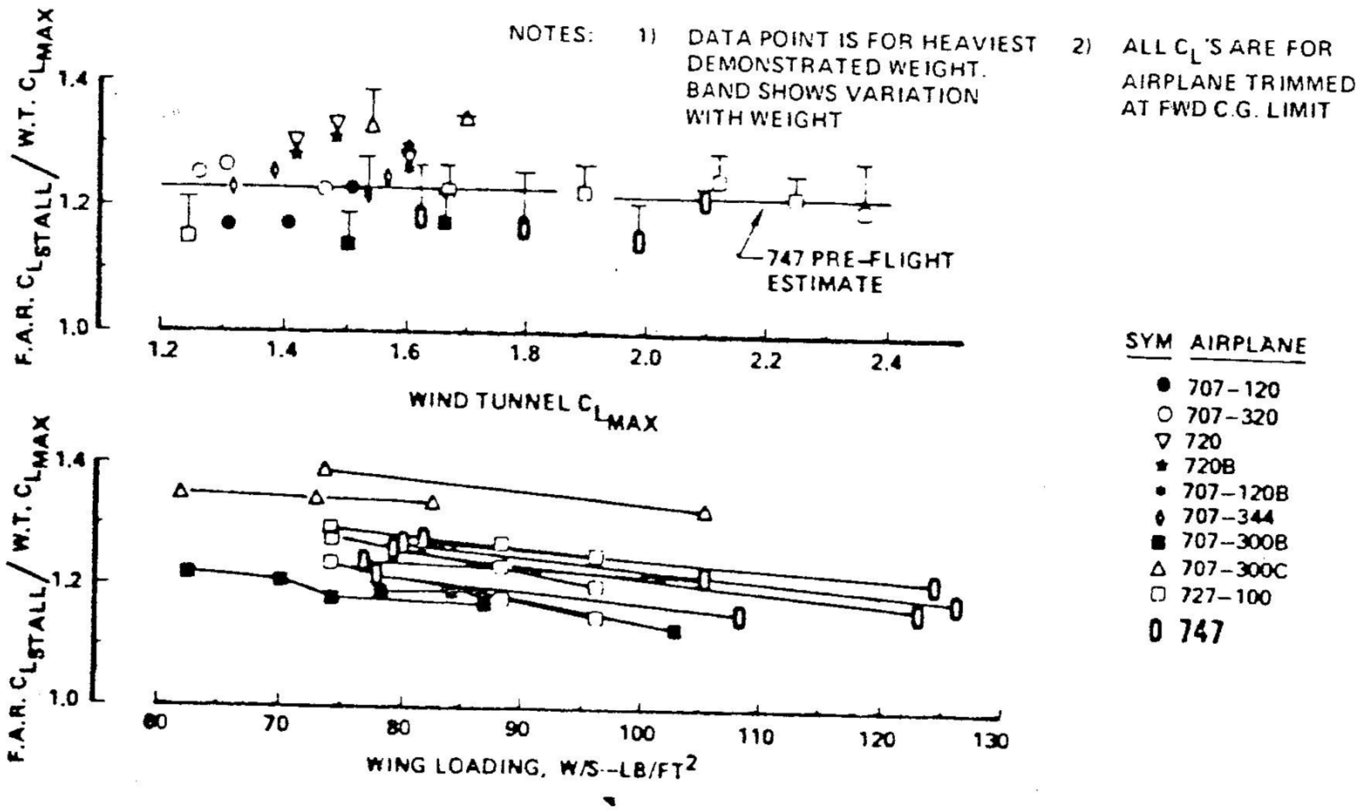


FIGURE 5: COMPARISON OF FLIGHT FAR $C_{L_{STALL}}$ AND WIND TUNNEL $C_{L_{MAX}}$

- **The matured experience and the data-base of an aircraft producer is really relevant to have good estimation of the aerodynamics and to get a successful design**
- **Many aerodynamic characteristics can not be calculated with CFD or measured in Wind-tunnels during the design phase.**

Industrial Remarks

The BWB concept will be converted in a real commercial aircraft project ?

- New Technologies must be tested extensively, however usually it is not so easy to translate them in safe and certifiable concepts.

- **Aerodynamic is not the only relevant item for an aircraft !**

A New Turboprop ?

RITMO, 1980

Nuova Fiat 500, 2014

ATR 72, 1986

PW 127M

ATR 72-600, 2012

A NEW AIRCRAFT ?

Questions ?

"Nella società, sia gli ottimisti che i pessimisti hanno un ruolo. L'ottimista inventa l'aereo, il pessimista il paracadute."
George Bernard Shaw

La tecnologia non tiene lontano l'uomo dai grandi problemi della natura, ma lo costringe a studiarli più approfonditamente.
Antoine de Saint Exupéry

"Inventare un aereo è nulla. Costruirne uno è qualcosa. Farlo volare è tutto."
Otto Lilienthal, pioniere dell'aviazione

THANK YOU

ANY QUESTIONS ?

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