Aerodynamic design of sailplanes

How is it done?

12-11-2016

Annemiek Koers

About me

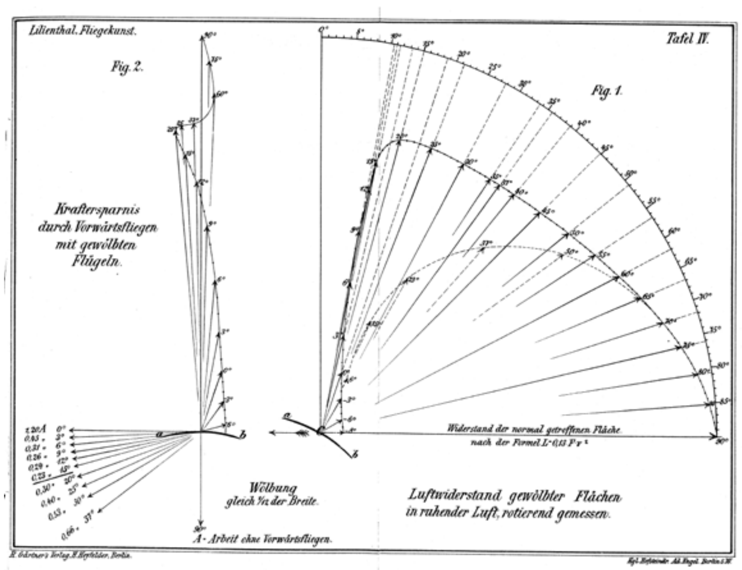
- Annemiek Koers
- Gliding at international competition level
- Student at Delft University of Technology
  - Master in Aerodynamics
- Internship at Jonker sailplanes
- Applied aerodynamics in solar car project

First gliding flights

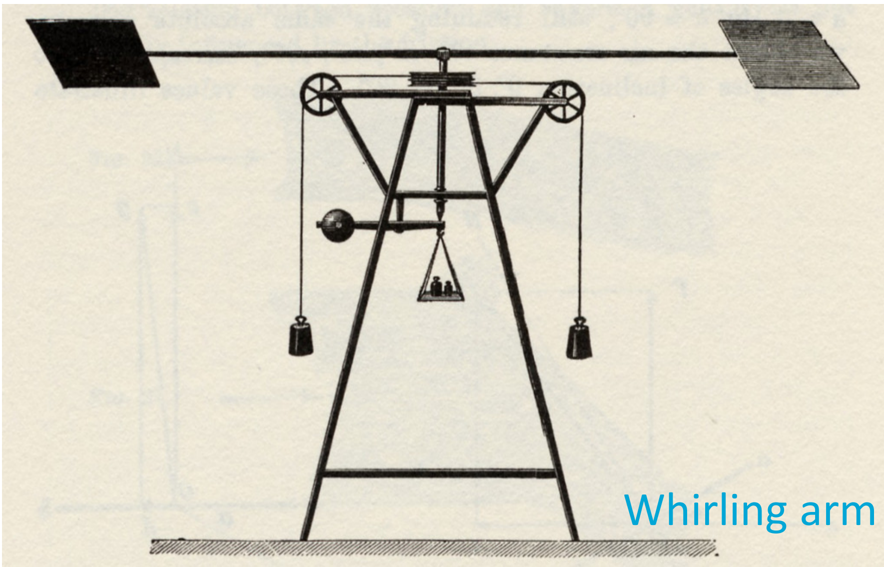
- Otto Lilienthal, late 1800
- Founder of glider aerodynamics
- Fundamentals from bird flight

Lilienthal aerodynamics

- First performance polars
- Trial and error
- Full scale test gliders
- Very applied aerodynamics



Performance polar


Whirling arm

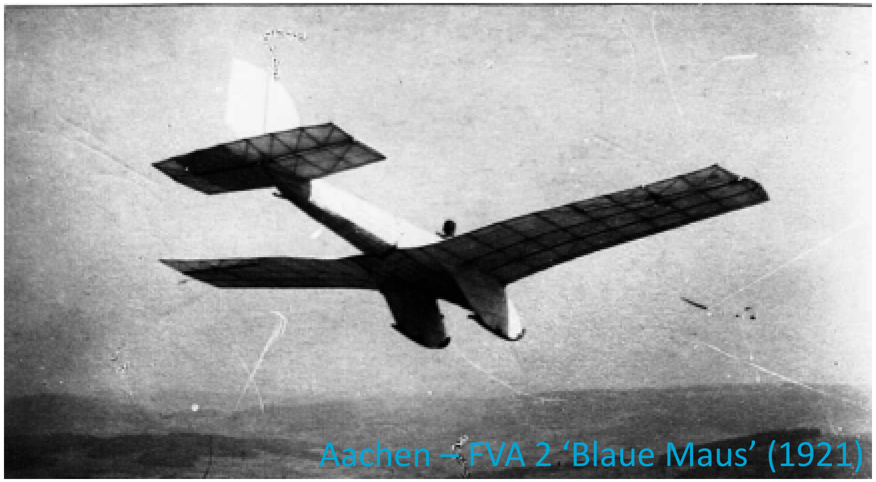
Akaflieg

- After WW1 Versailles Treaty ~1920
- Continuation of trial and error
  - New and unconventional designs
- Design methods available from Universities and DLR
- Also in other glider-engineering fields

idaflieg

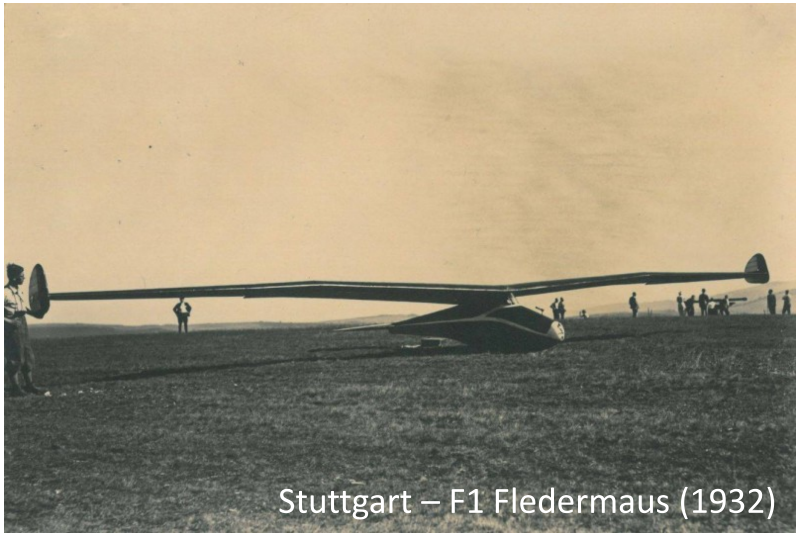
INTERESSENGEMEINSCHAFT DEUTSCHER
AKADEMISCHER FLIEGERGRUPPEN e.V.

Akaflieg - old

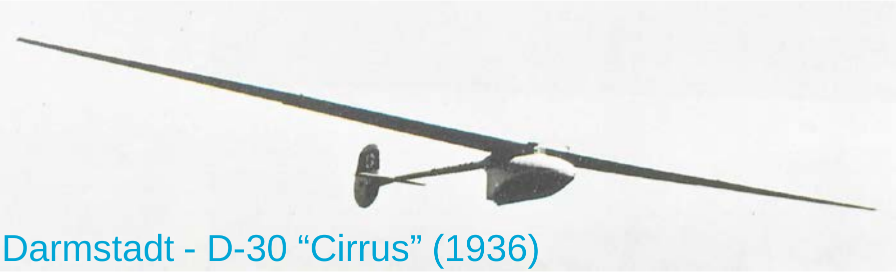


Aachen – FVA 2 'Blaue Maus' (1921)

Esslingen – E11

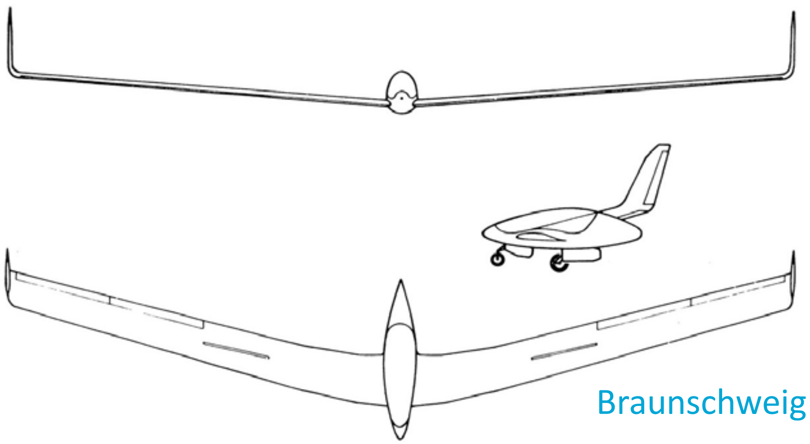


Stuttgart – F1 Fledermaus (1932)

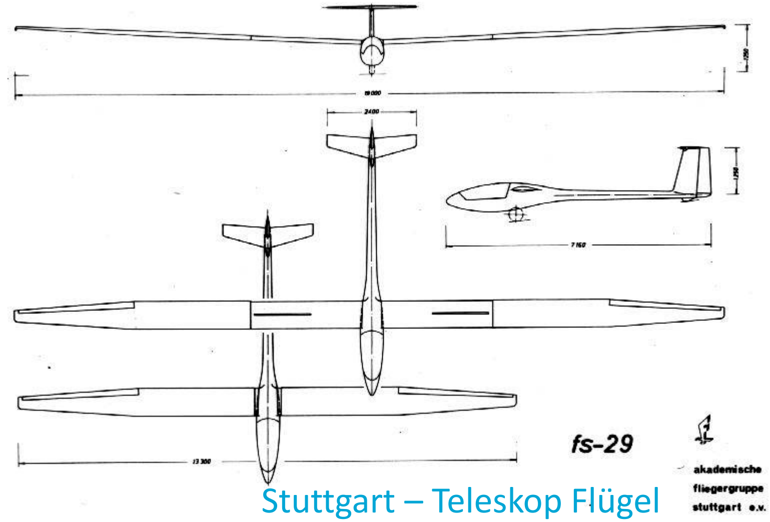


Darmstadt - D-30 "Cirrus" (1936)

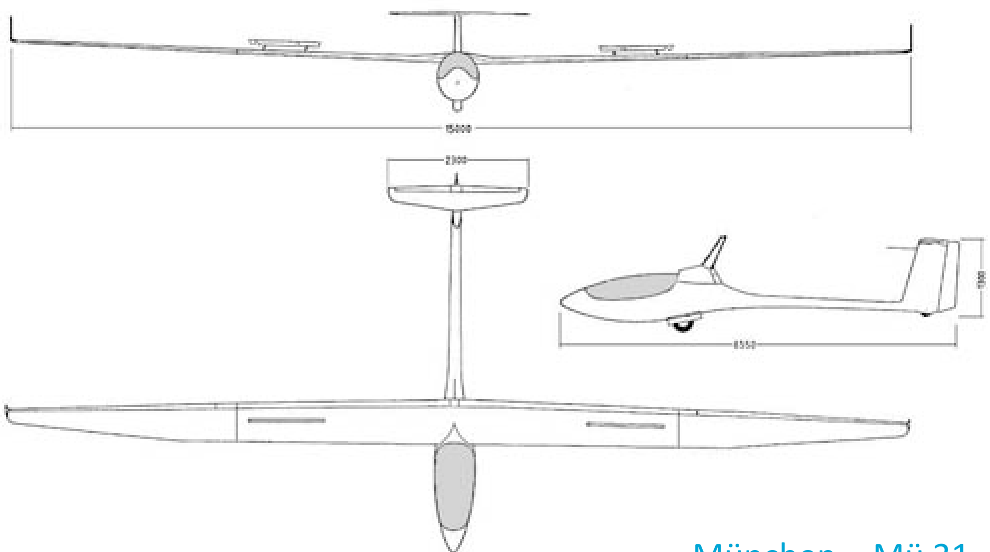
Akaflieg - New



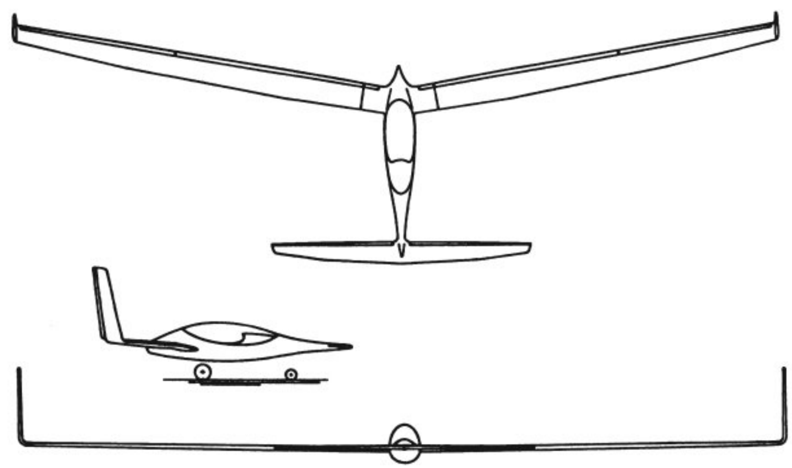
Braunschweig – SB 13



Stuttgart – Teleskop Flügel



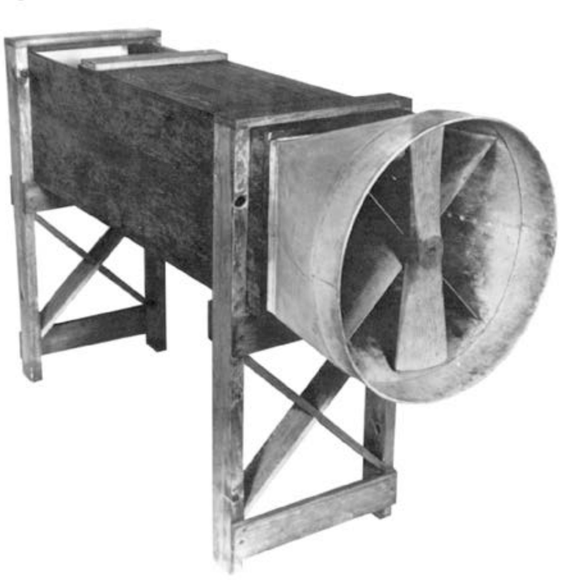
München – Mü 31



Aachen – FVA 27 Canard

Wind tunnels

- Successor of whirling arm, late 1800
- Scale test of full size model or airfoil
  - Different stages of design
- Simple change in velocity and angles of attack
- Wide range of measurement techniques



Wright brothers wind tunnel

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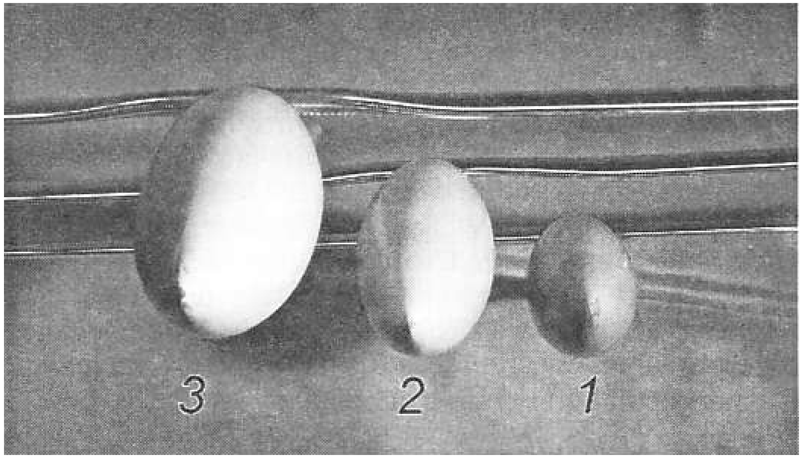
Balance Measurements

- Different models
  - comparison in performance
- Direct force measurements
- Influence of laminar / turbulent flow

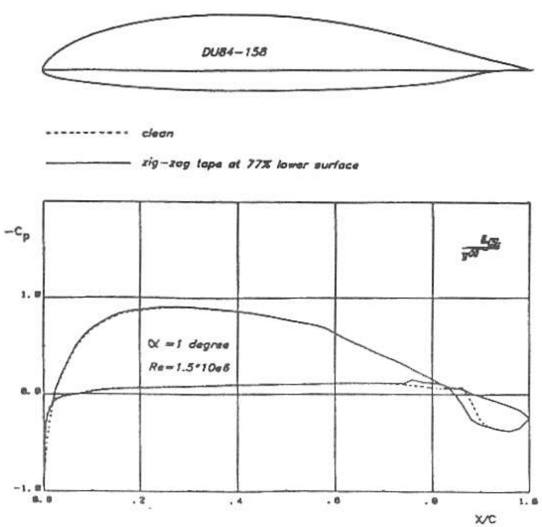


Mü31 wind tunnel models

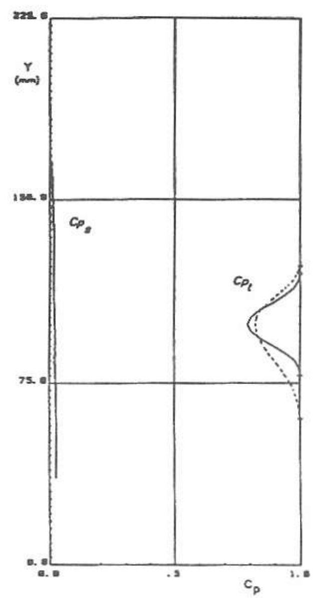
TUDelft

Pressure Measurements

- Alternative method to determine loads
- Pressure taps
- Wake rake behind model



Airfoil pressure distribution



wake pressure distribution

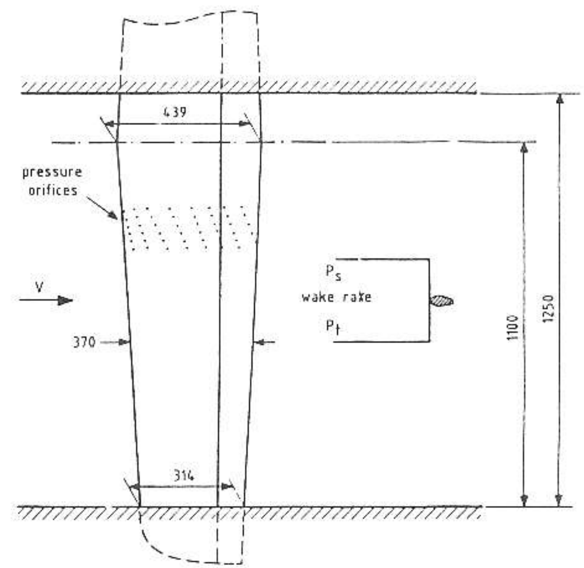
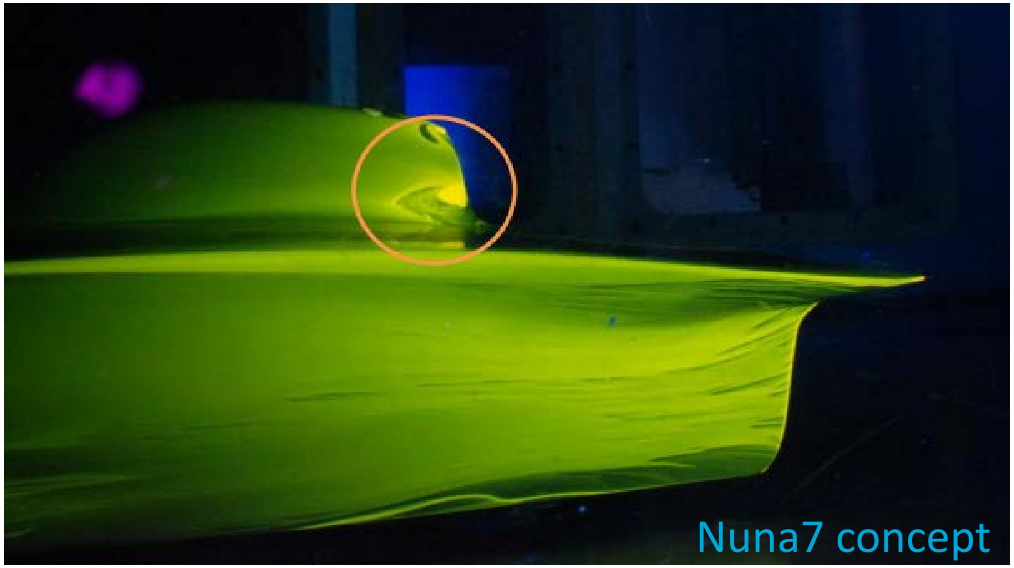


FIGURE 4. Test set-up of ASW-24 horizontal tailplane

Oil flow visualization

- Fluorescent dye in oil
- UV-camera
- Identification of:
  - laminar / turbulent area
  - Flow separation



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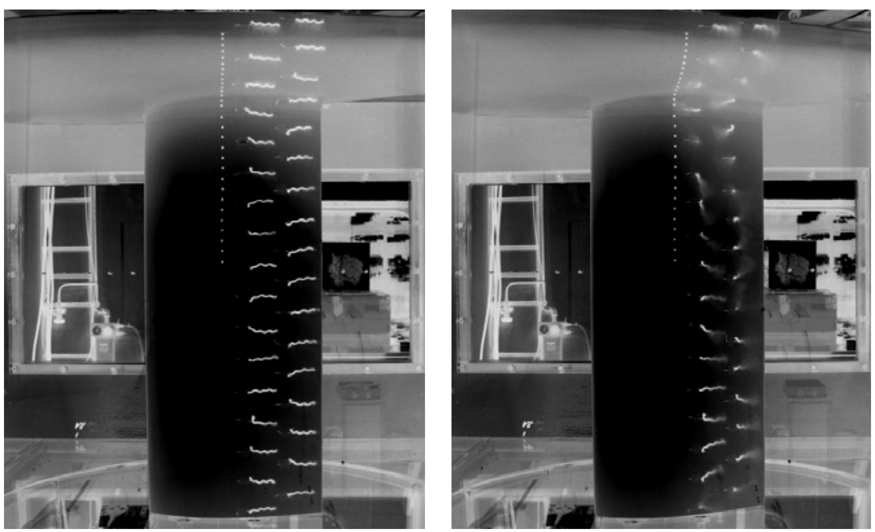
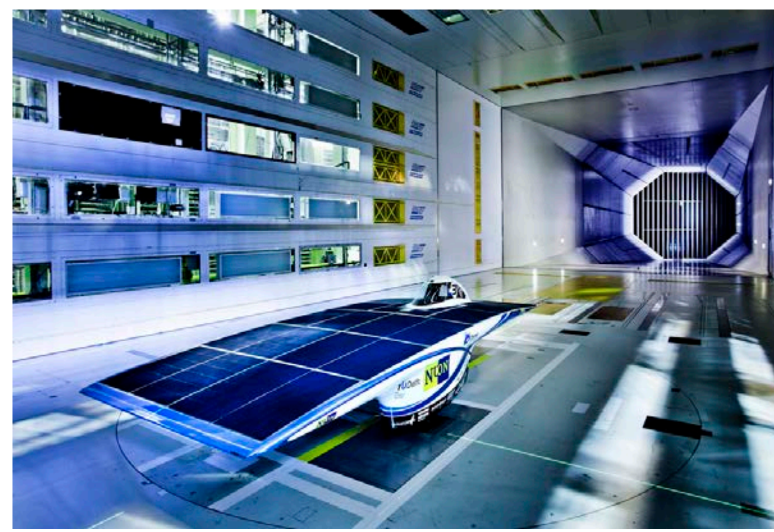
Other Qualitative Methods

- Microphone in boundary layer
  - Laminar versus turbulent
- Tufts on surface or probe
  - Attached versus separated



1:5 TST10a model

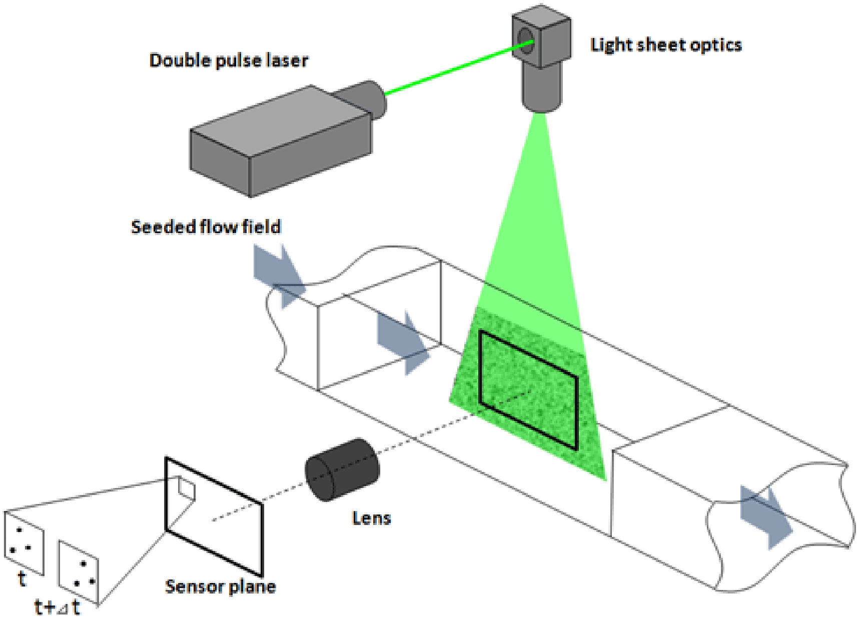


Nuna6 in DNW tunnel

Advanced Measurement Techniques - PIV

- Particle Image Velocimetry
- Qualitative and quantitative
- Smoke + laser + camera
- Cross-correlation of image pairs to obtain velocity fields

OJF tunnel PIV



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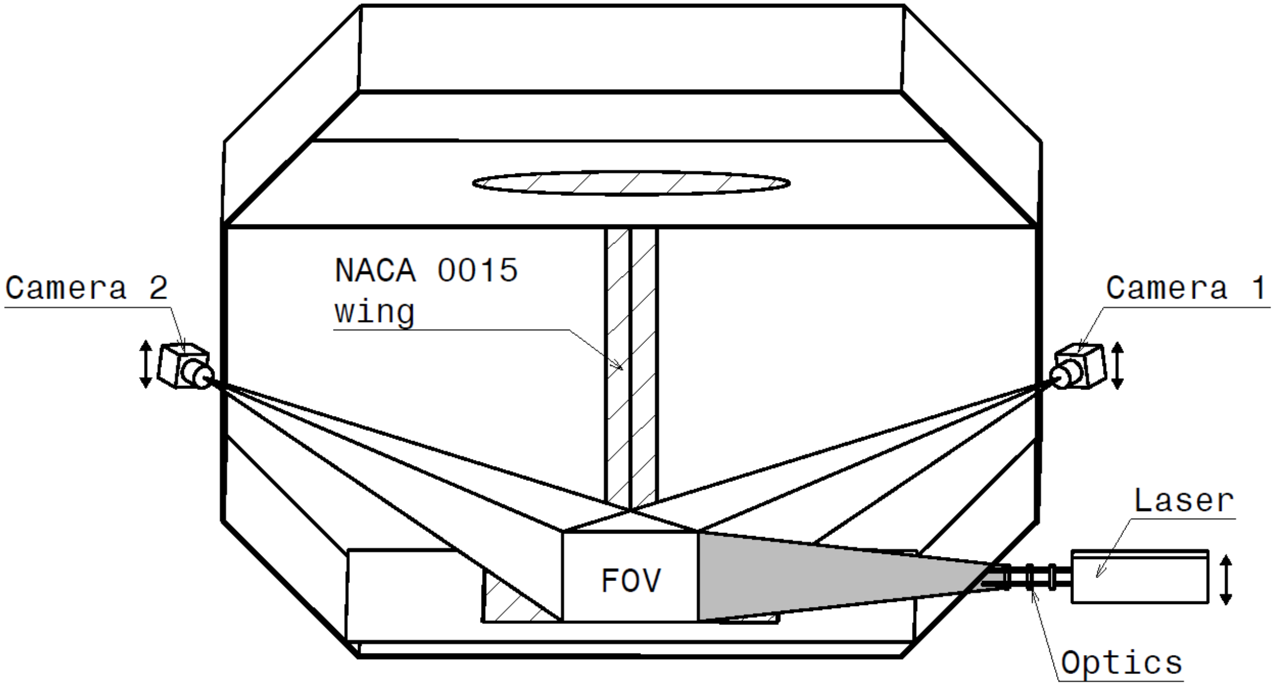
Advanced Measurement Techniques - PIV

- Flow behind a wing body junction
- 2 cameras → 3 velocity components



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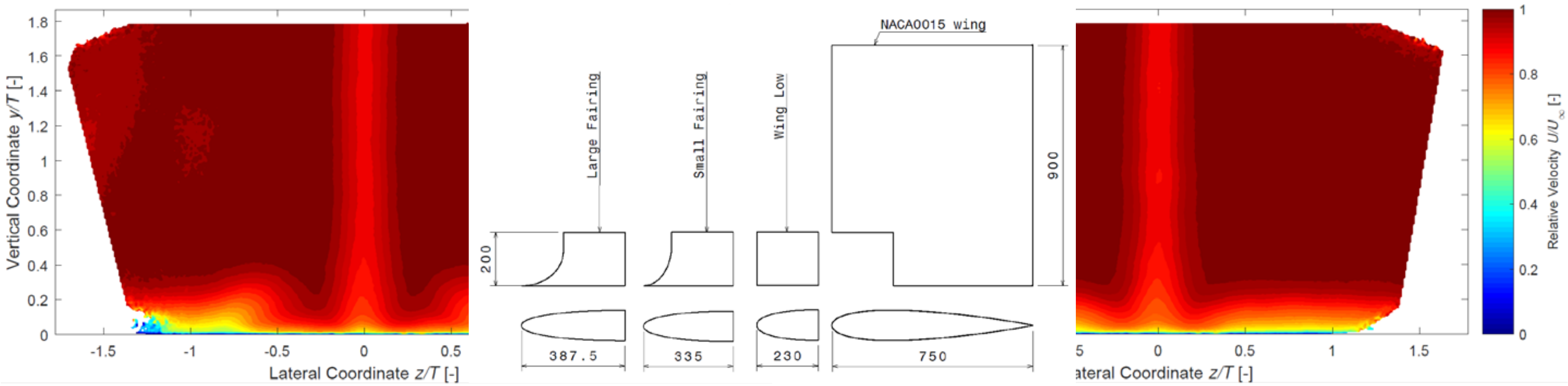
Advanced Measurements Techniques - PIV

- Difference in wake for configurations
- Fairing gives a reduction of the vortex

Wing without fairing

Wing with fairing



Limitations/disadvantages wind tunnels

- Slow process, building time of models
- Expensive
- Time consuming
  - Different configurations
  - Different flow conditions
- Scaling and blockage effects

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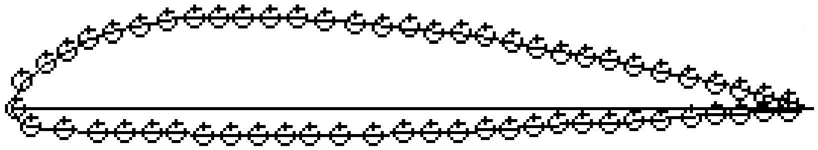
Numerical methods

- Alternative to wind tunnel with increase in performance of computers
- Insight into details of the flow
- Easy configuration and flow characteristic change

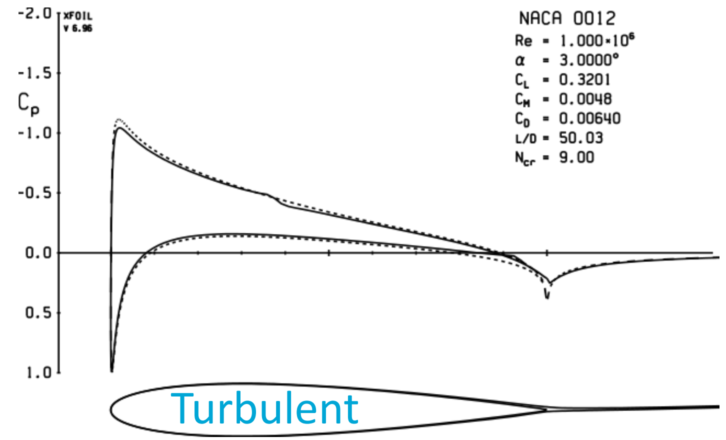
Xfoil

- Mark Drela, 1988
- 2D panel method
- Creating the pressure distribution for an optimal lift over drag performance of an airfoil
- Quick preliminary design tool

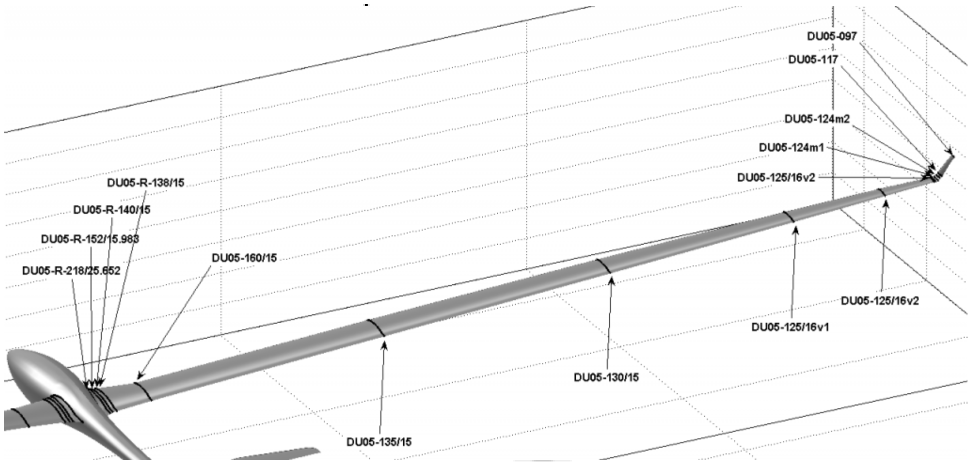


Airfoil with panels

Airfoil design



- Multiple airfoils over span of the wing
- Varying
  - Thickness
  - Twist
  - Laminar / turbulent
  - Chord



- 13 different airfoils for Concordia

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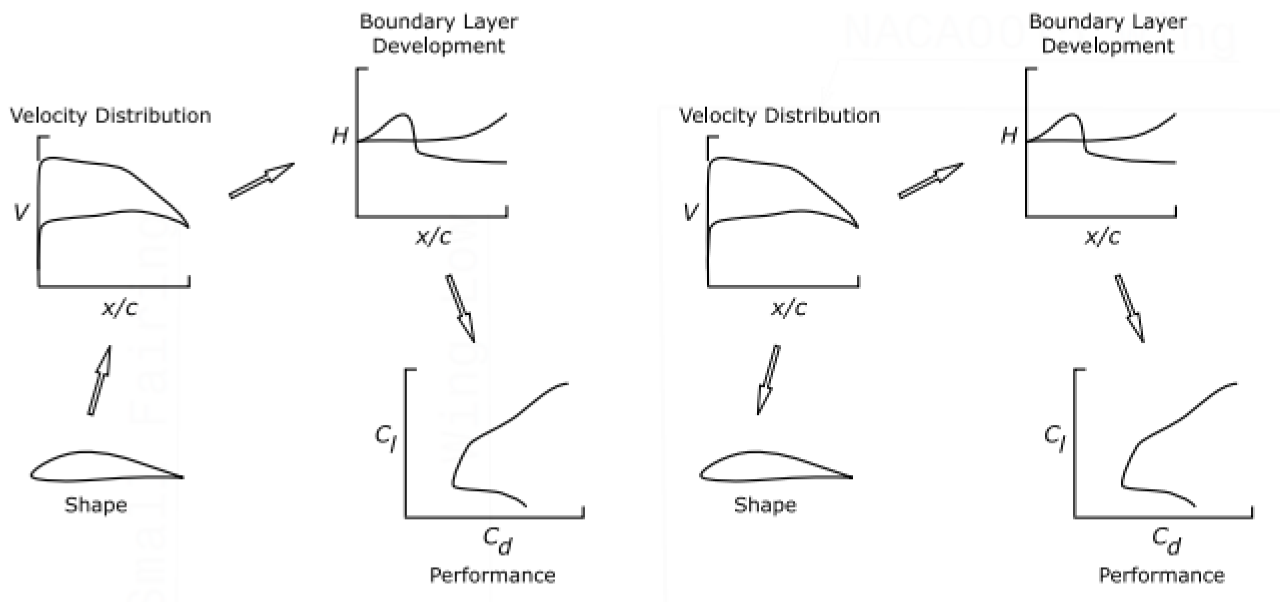
Direct and Inverse design

- Direct method
  - From shape to performance
- Inverse method
  - From performance to shape



(a) Direct design methods (b) Inverse method via velocity distributions

3D Panel methods

- First codes late 1960
- On-body 3D
- Suitable for regions without viscous and compressible effects
- No separated flow
- No around body information

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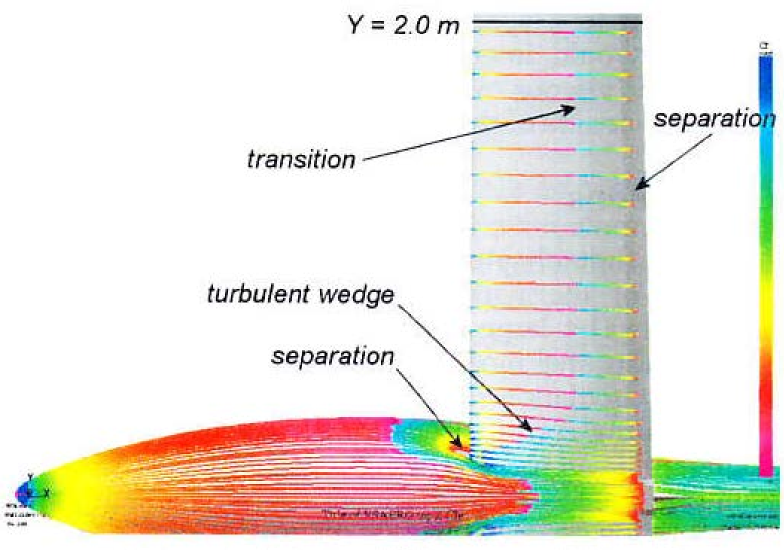
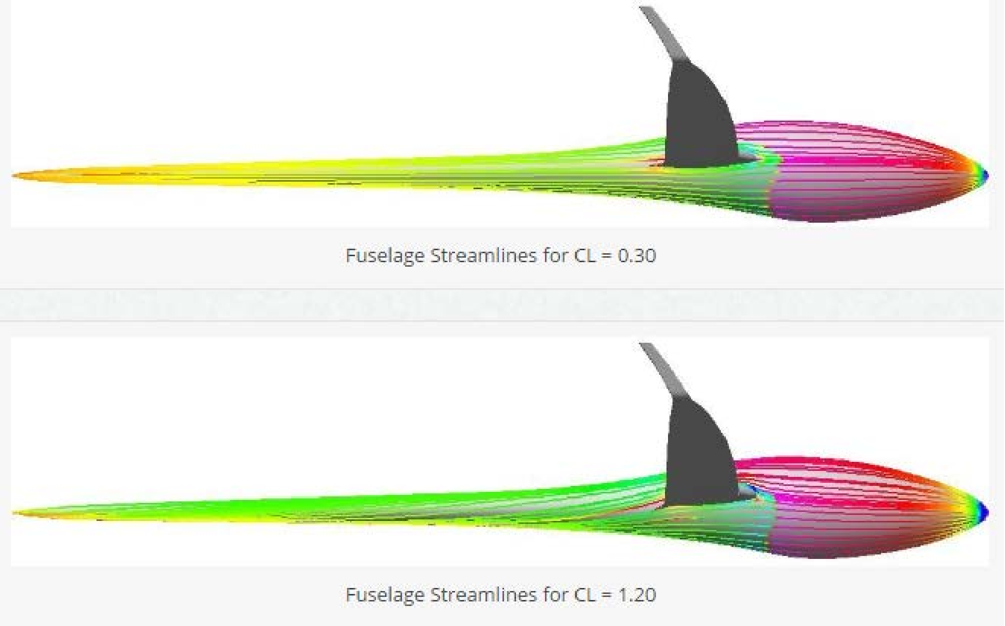
VSAERO

- Laminar – turbulent area
- Separation regions
- On-body streamlines



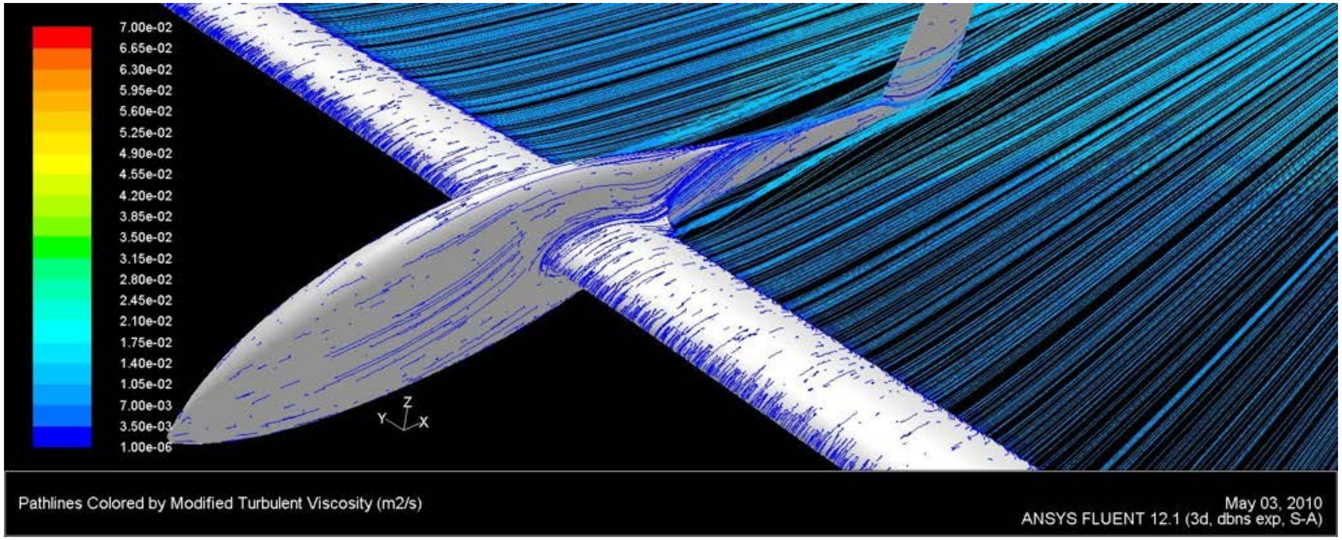
Mü31



Concordia

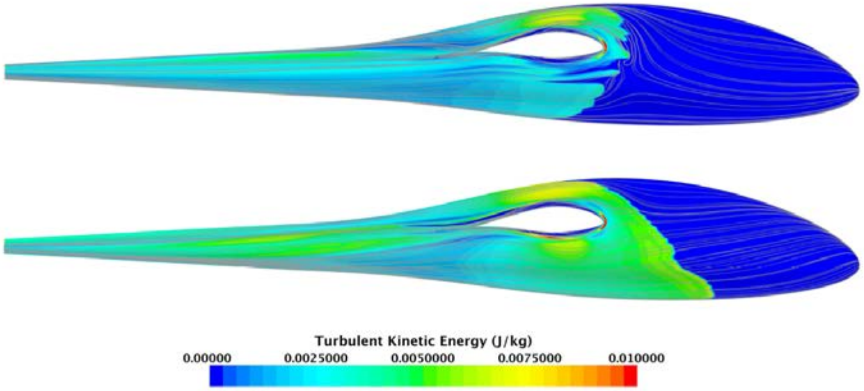
Computational Fluid Dynamics

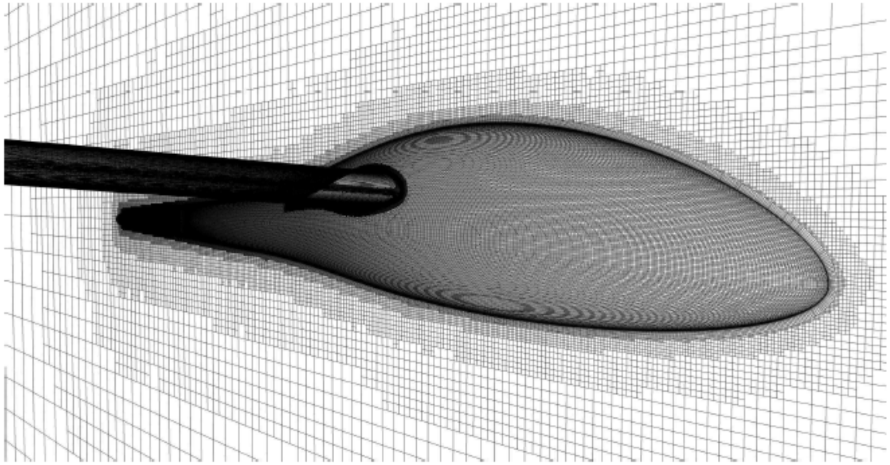
- Fully 3D flow
- Dependency on models
- Still needs validation

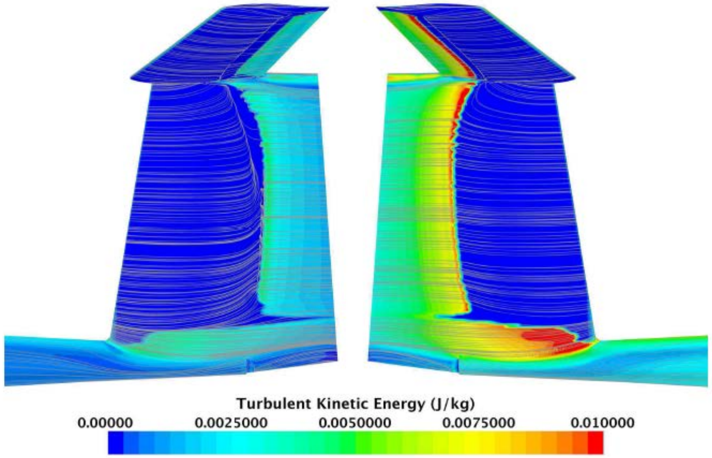


Standard Cirrus – Thomas Hansen

- Grid generation
- Full flow domain
- Transition prediction
- Influence of intersections



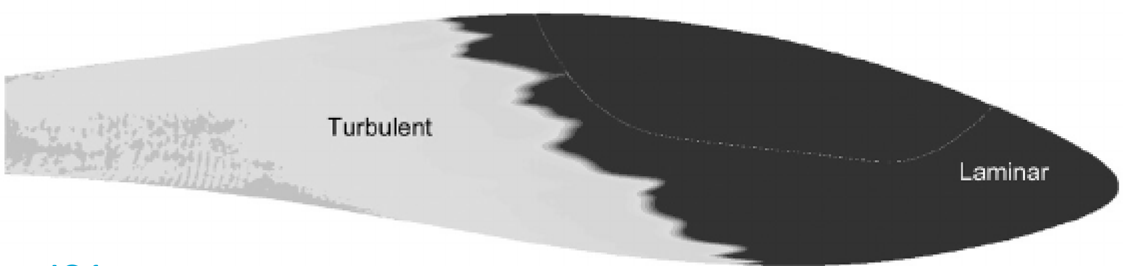




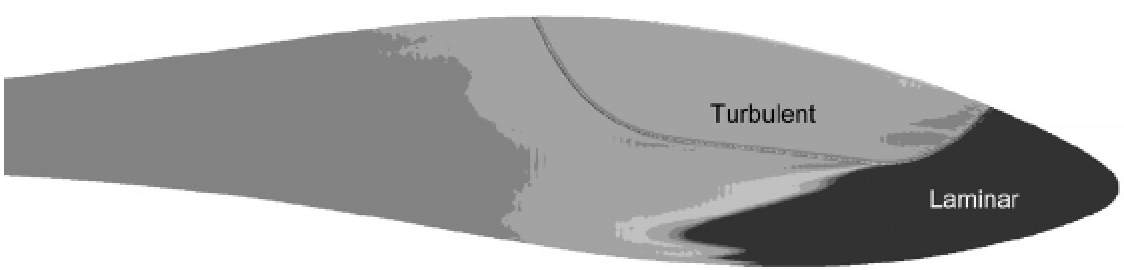
TUDelft

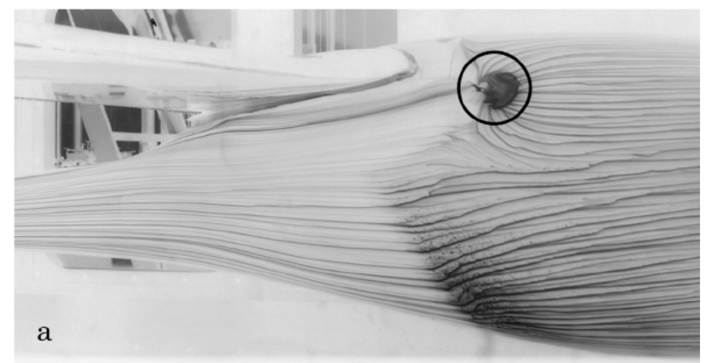
Flow Over a Glider Canopy – Johan Bosman

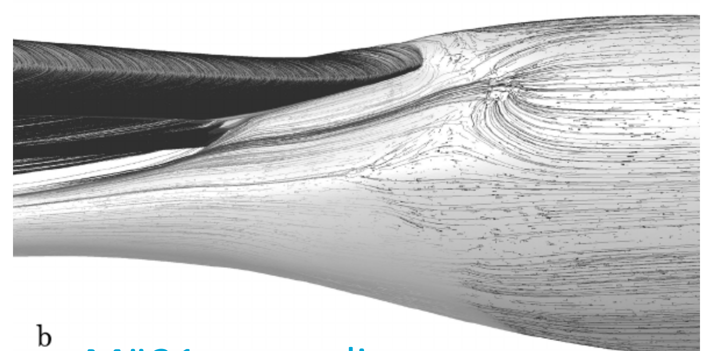
- Influence of the canopy gap on transition
- Comparison to flow visualization



JS1 canopy





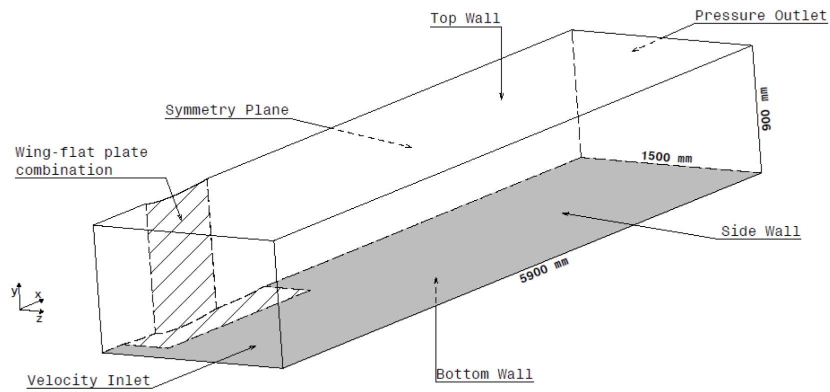


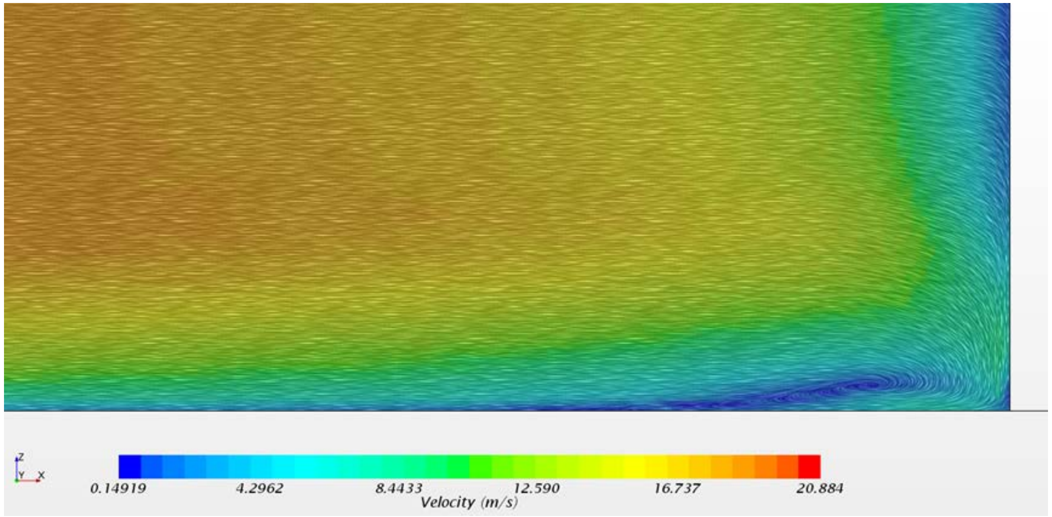
b

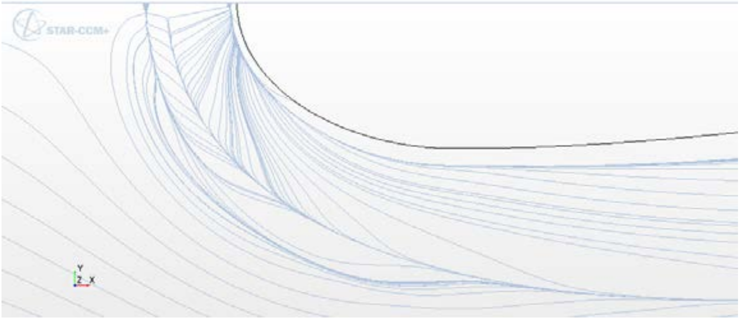
Mü31 streamlines

Thesis example – Wing-flat plate junction

- Addition to wind tunnel
- Full flow field available

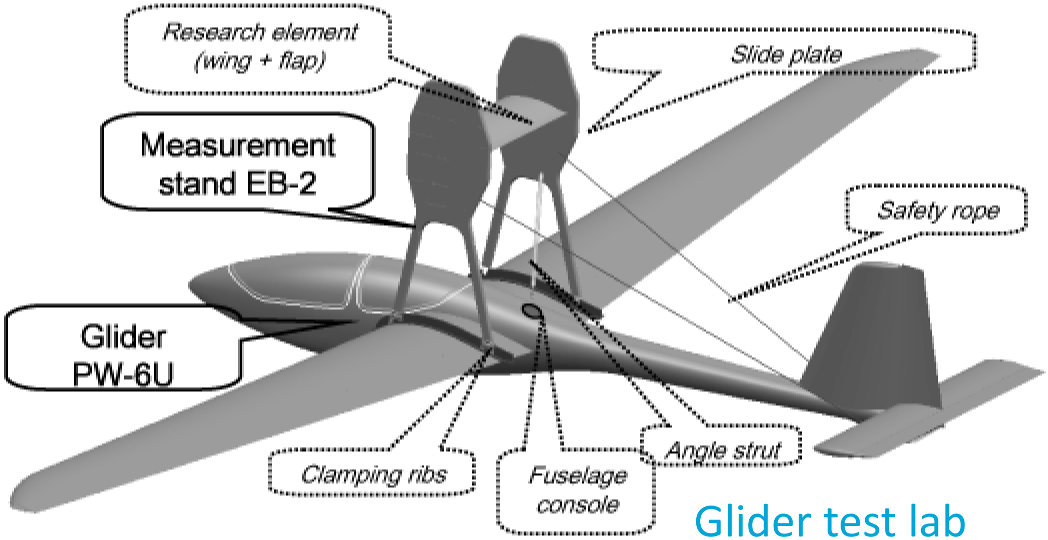






In-Flight Testing

- No scaling issues
- Real circumstances
- Difficult to perform
  - Constant flight condition
  - Influence of weather



Glider test lab

Qualitative Methods

- Separated or attached flow
- Microphone transition

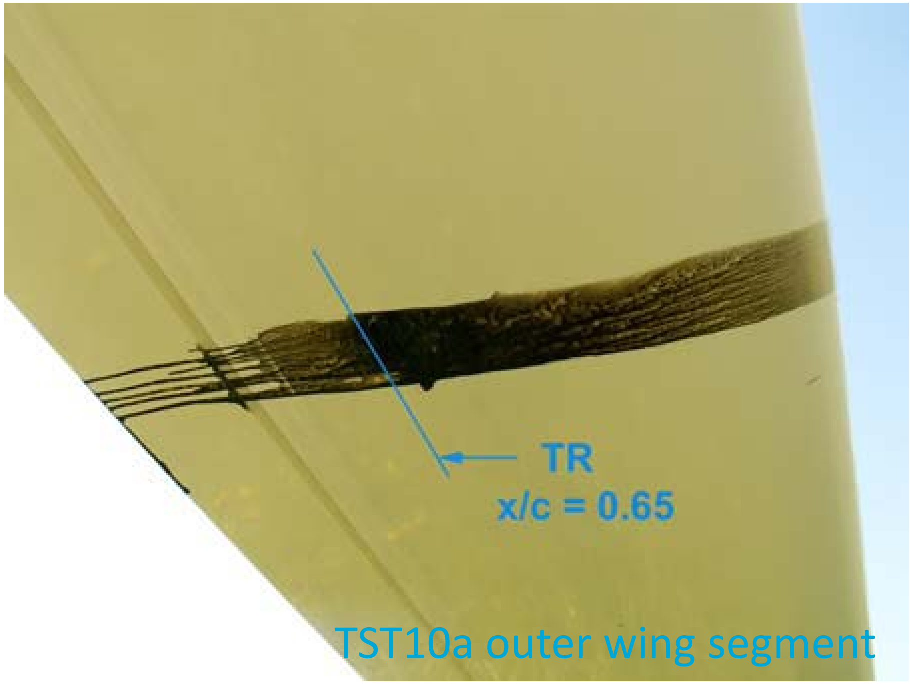
TST10a tufts

JS1 microphone test

Oil flow visualization

- Transition locations
- Fuselage to tail influence

Std. Cirrus fuselage



TST10a outer wing segment

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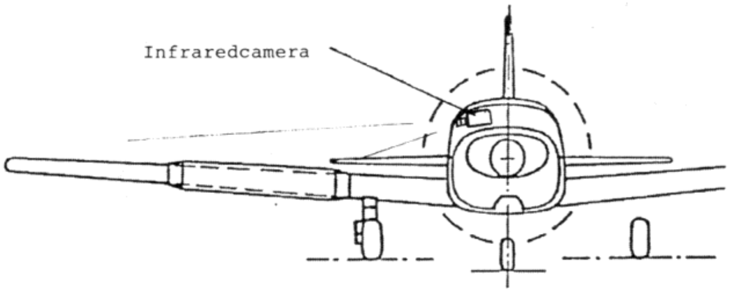
Wake Rake

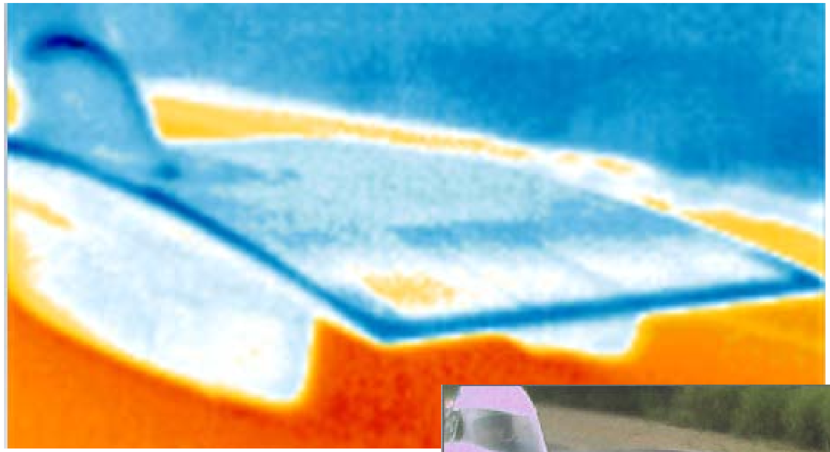
- In-flight profile characteristics
- Influence of real scale turbulence

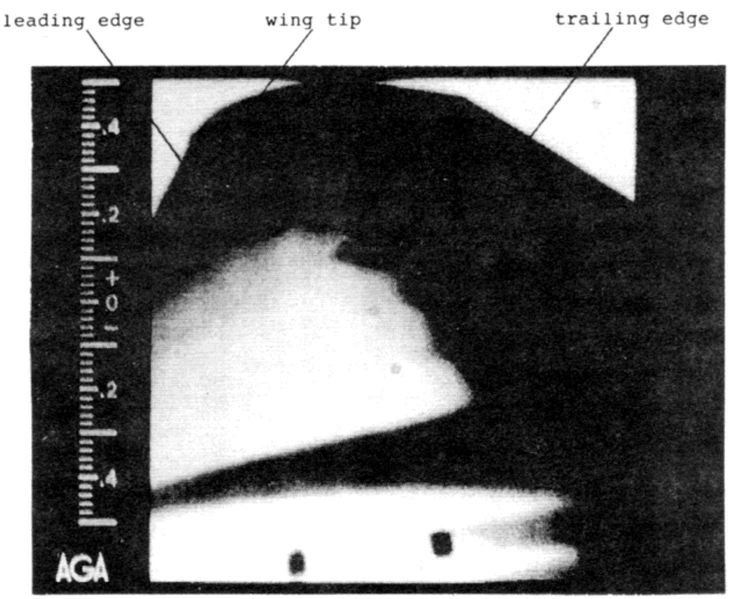

HPH304S wake rake

Thermal Imaging

- Difference in heat transfer
- Infrared camera
- Turbulent wedge

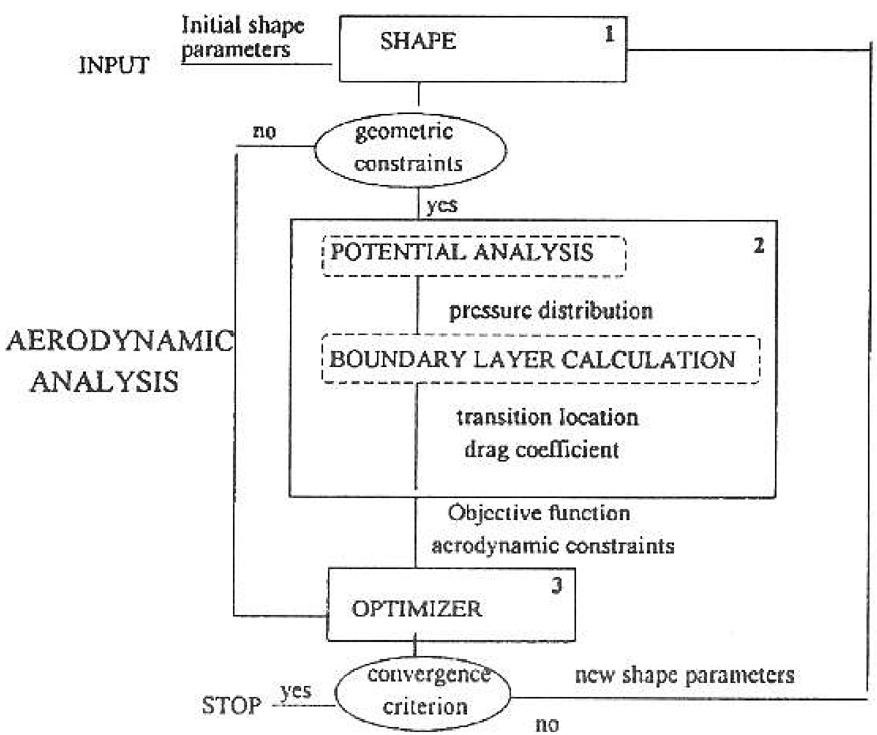




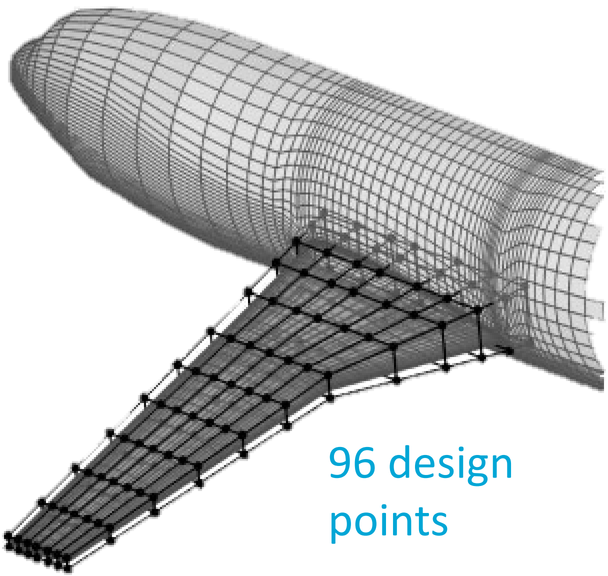


Design Optimization

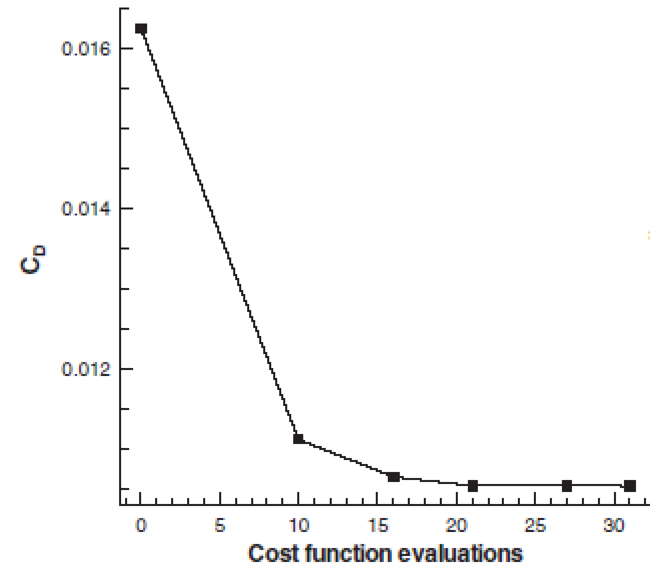
- Objective function
  - minimum drag
- Iterative design

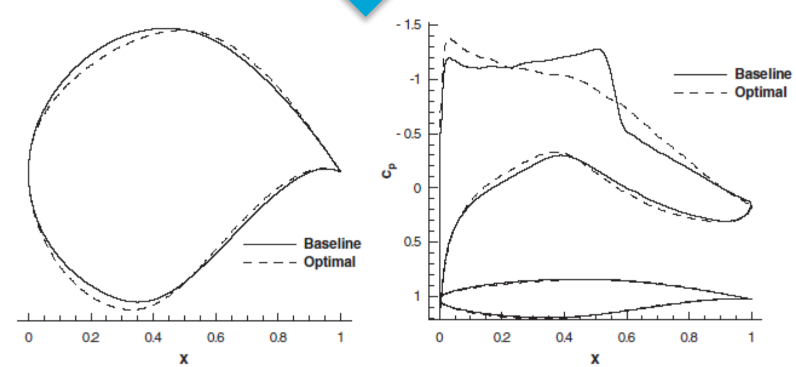


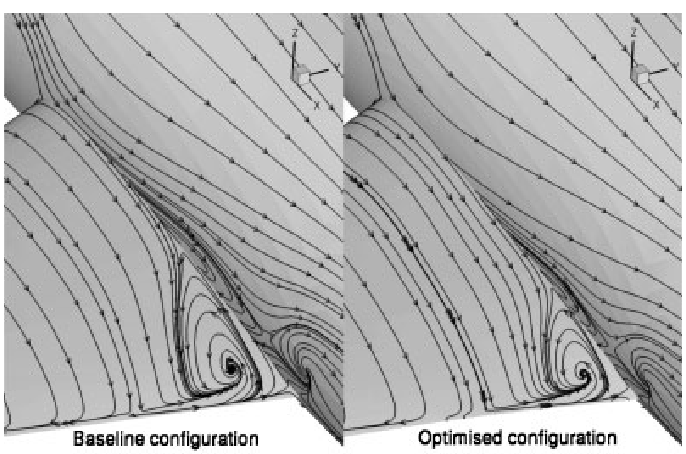
Wing-Body Optimization DLR – Dwight



96 design points



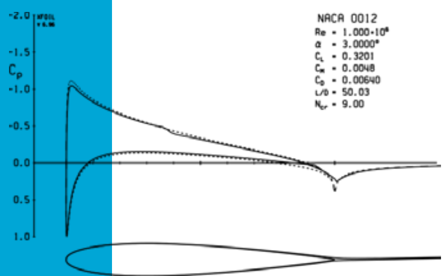


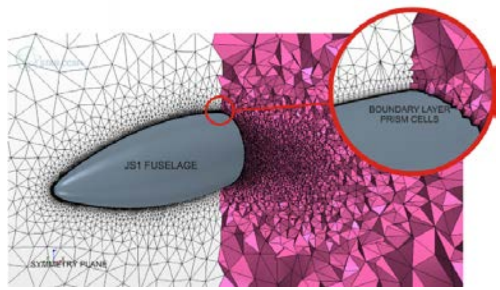


Improved root airfoil

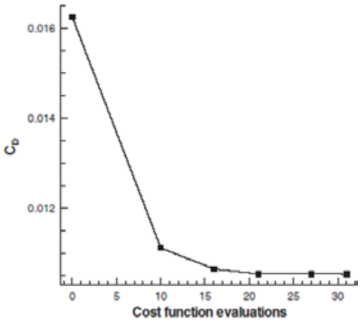
Design Process

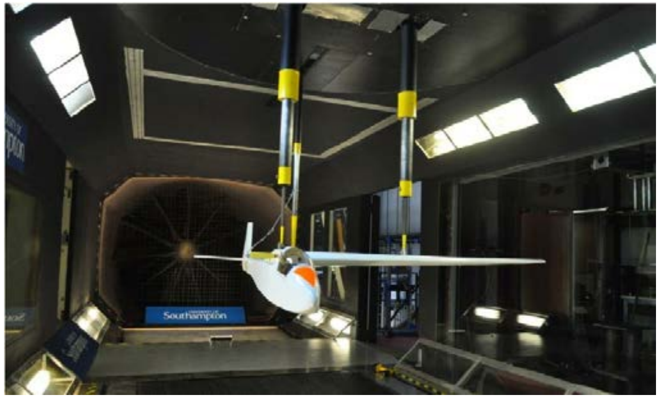
- Integrating different methods





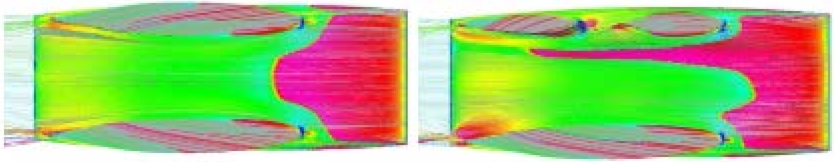
Airfoil Design → Optimization → CFD / VSAERO → Wind tunnel testing → Full flight test



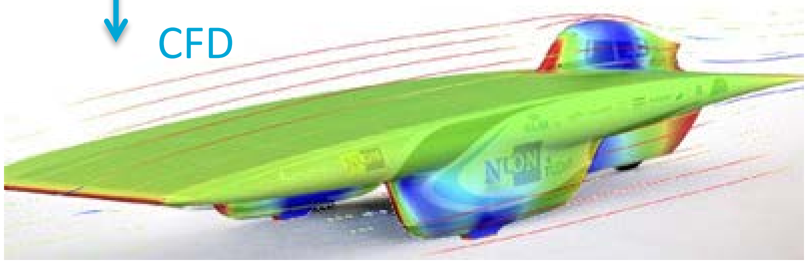


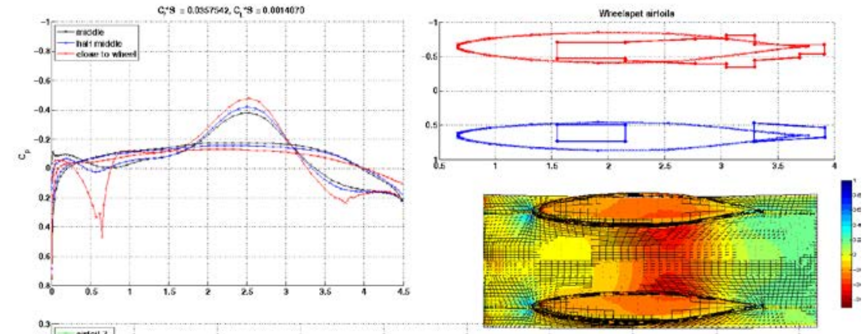
Solar Car Example

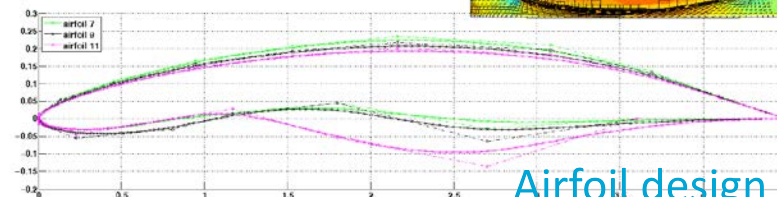
Panel methods



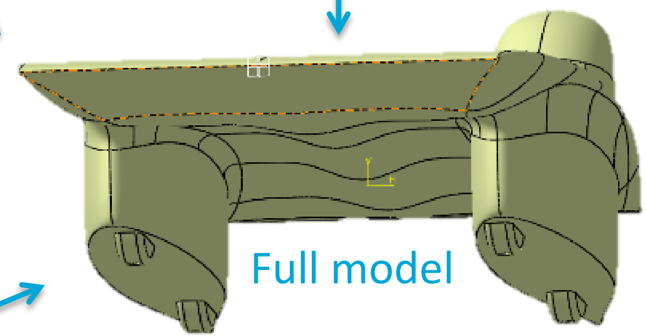
CFD







Airfoil design and optimization



Full model

Wind tunnel

Full scale testing

So now you know how they do it – any questions?