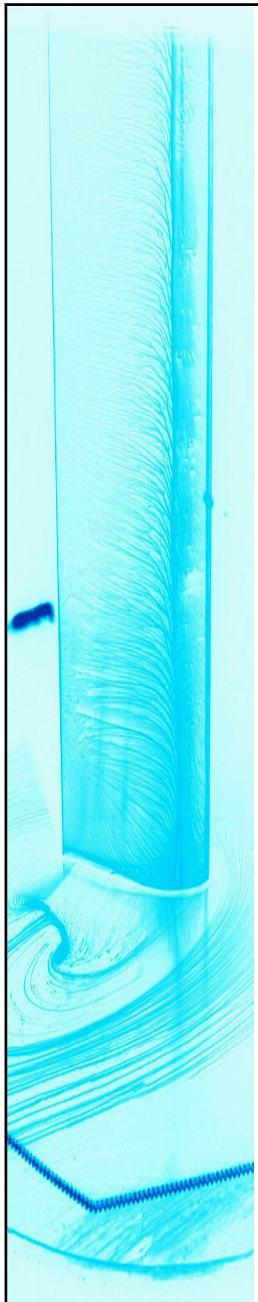


Design of Airfoils for Wind Turbine Blades

Ruud van Rooij

(r.vanrooij@citg.tudelft.nl)

Nando Timmer

Delft University of Technology

The Netherlands

Delft University of Technology

13200 Bsc+ Msc students, 4750 employees

DUWIND

Delft University Wind Energy Research Institute

(Coordinator: Section Wind Energy)

Faculties:

- **Civil Engineering and Geosciences** (**Wind Energy**, **Offshore**)

  http://www.windenergy.citg.tudelft.nl/home/flash/index.html

- **Information Technology and Systems** (**Electrical group**)
- **Design, Engineering and Production** (**Systems &Control**)
- **Aerospace Engineering** (**Aero, Aeroelastics**)

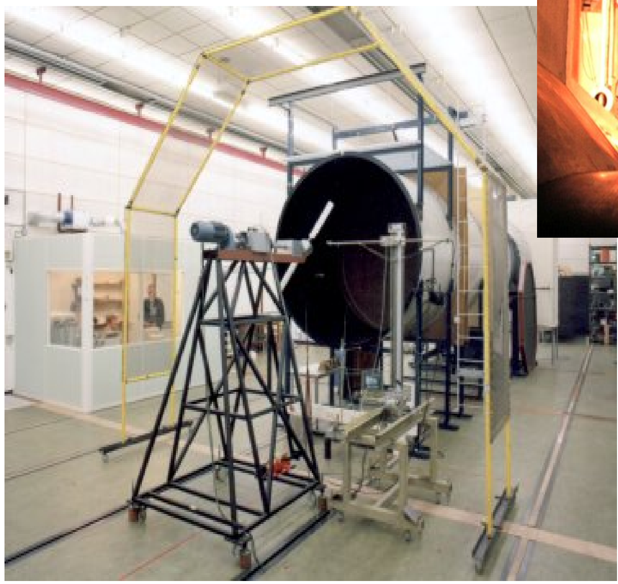
Section Wind Energy

(Civil Engineering and Geosciences => Aerospace Engineering)

Aerodynamic research

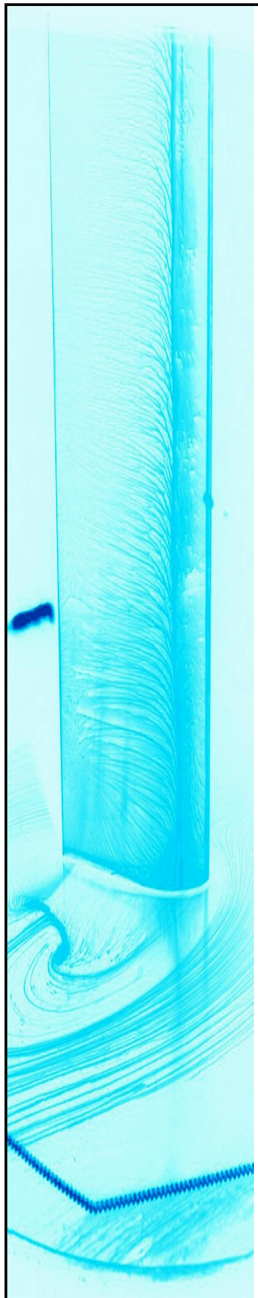
- Facilities

low speed
wind-tunnel



open-jet
wind tunnel

research wind turbine

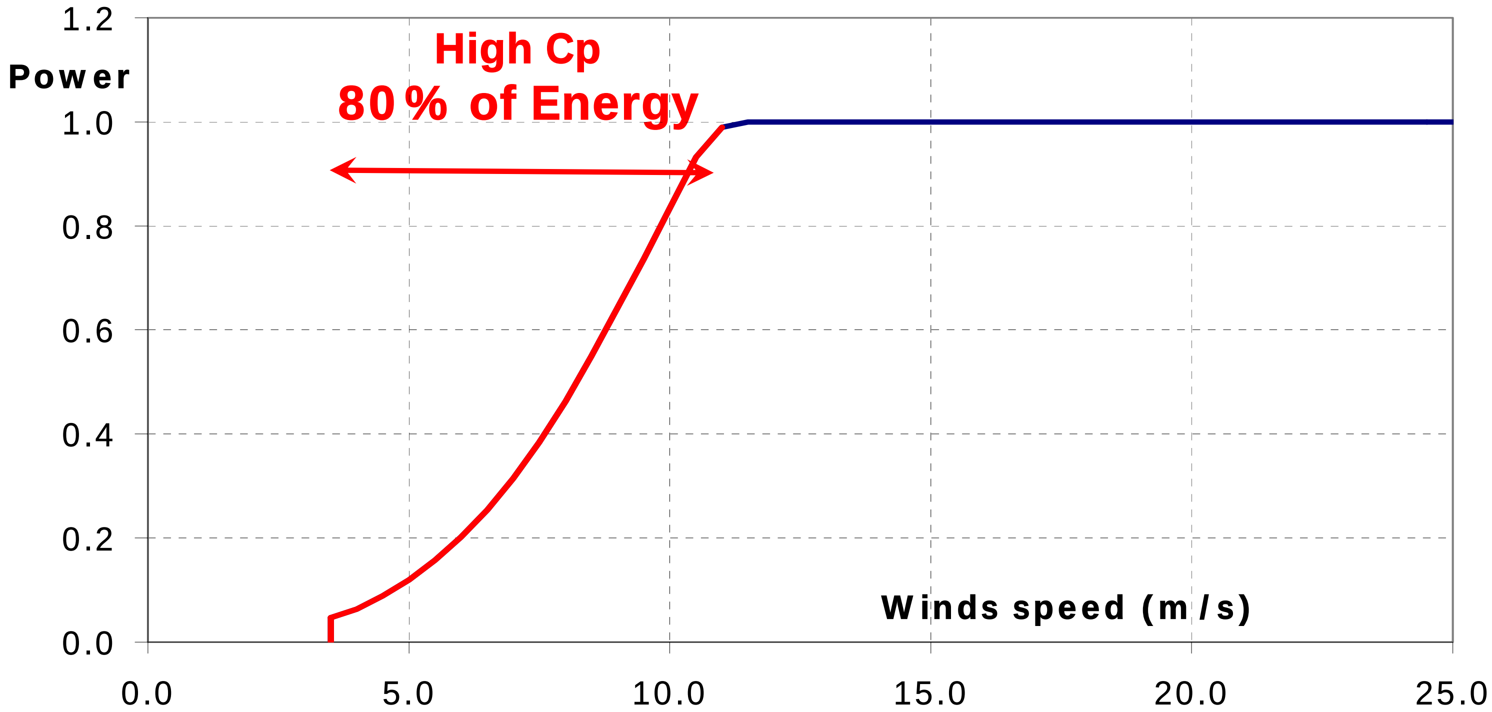


Contents

Background

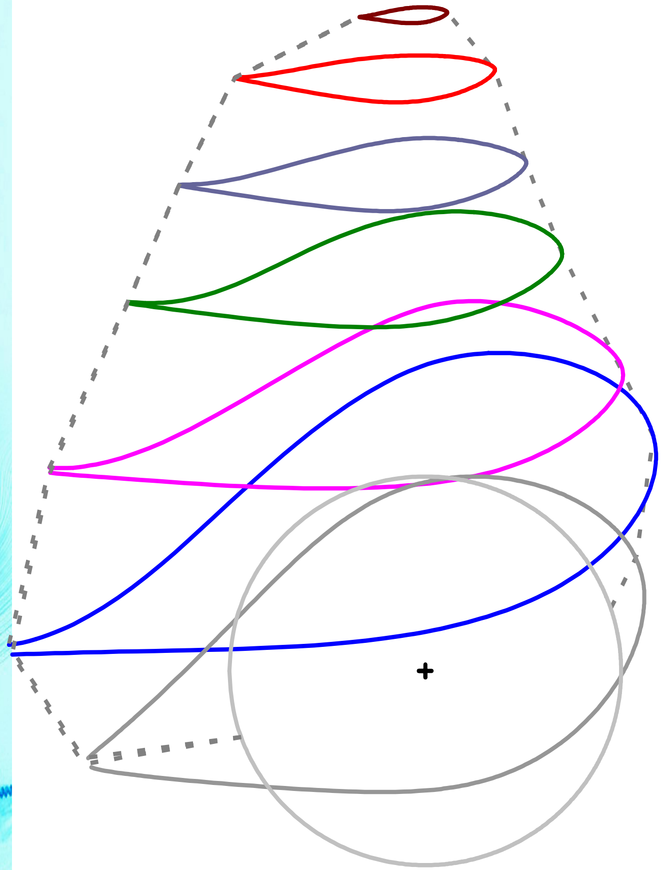
Operational area

Control: Variable RPM → Power restriction →



Airfoil: High max. L/D → Max. lift considerations →

Blade geometry



Structural:

Outboard: t/= .15-18

Mid span: t/= .25

Inboard: t/> .30

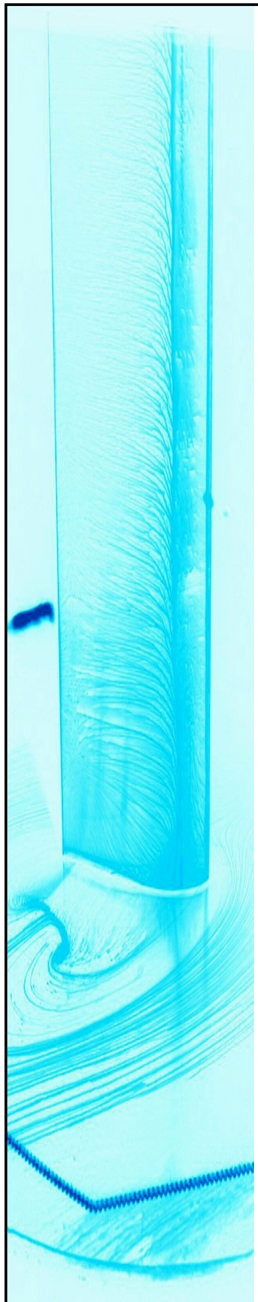
Transition piece

Airfoil:

- High max. L/D
- Insensitive to roughness
- Similar design angle

- High max. lift (Rot. Effects)

No Aerodynamic demands



Background

Effect of rotation

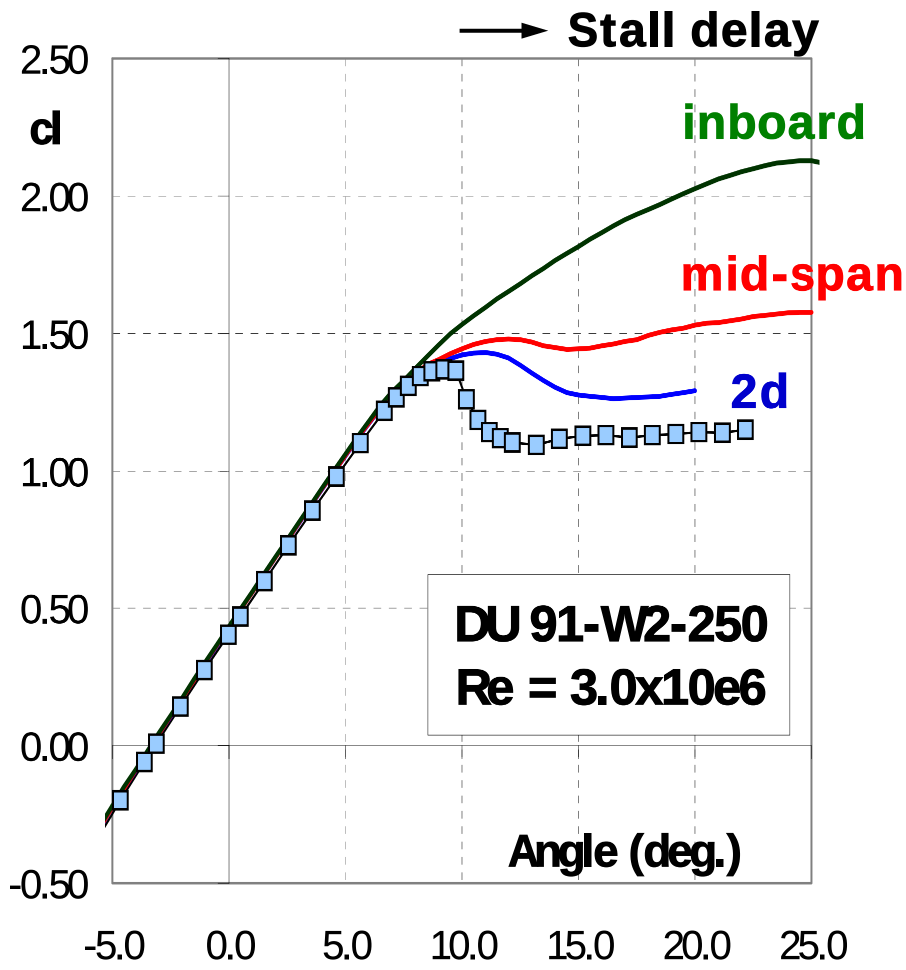
RFOIL code

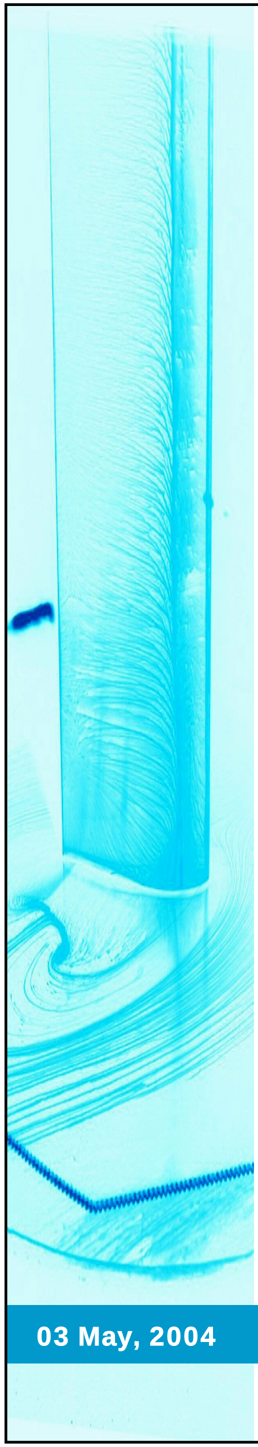
- Integral boundary layer eq.

- Extended for radial flow
  - Radial equations
  - Cross flow profile

parameter is c / r

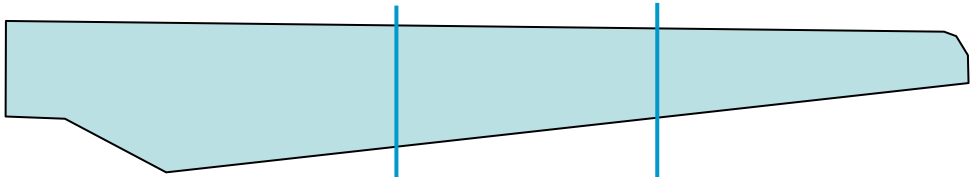
(= local solidity)





Design goals HAWT airfoils

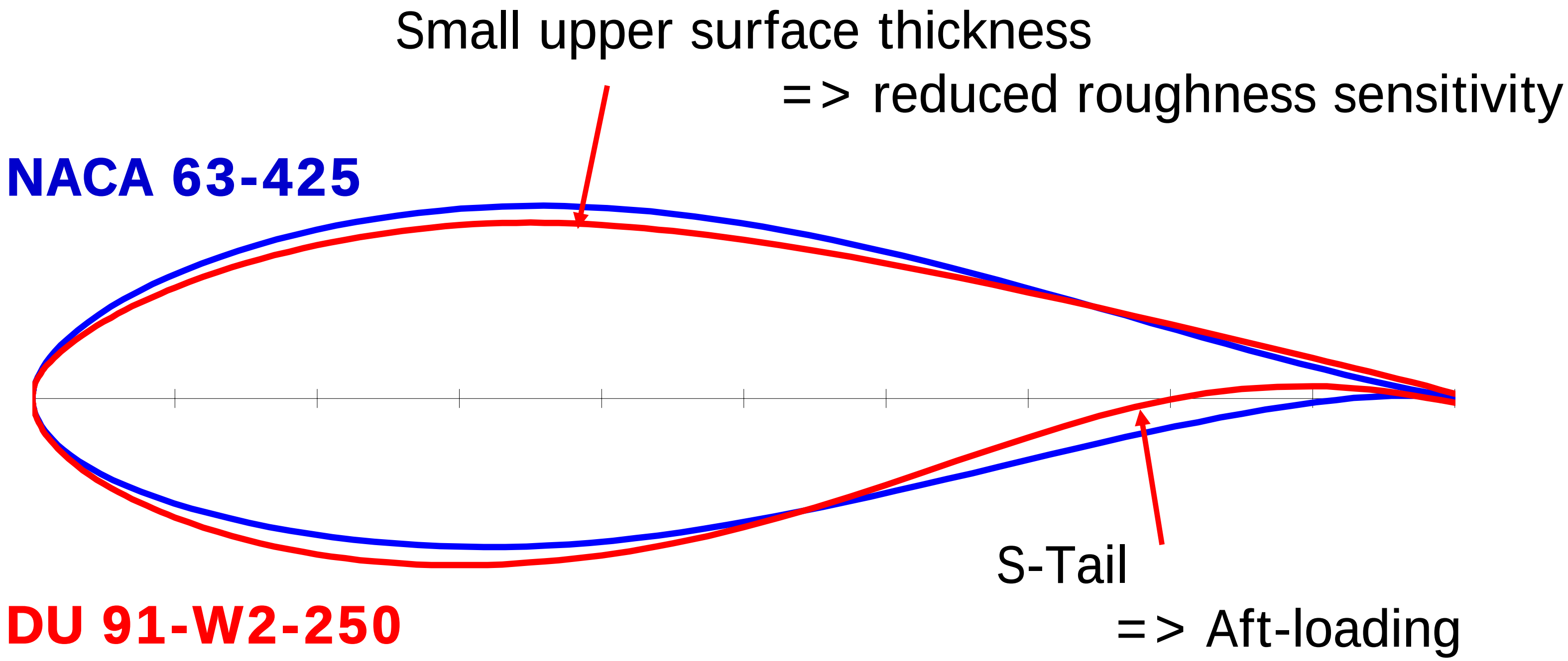
steady



Thickness-to-chord ratio	> .28	.28 - .21	.21 >
High maximum lift-to-drag ratio	●	●●	●●●
Low max. and benign post stall			●●
Insensitivity to roughness	●	●●	●●●
Low noise		●	●●●
Geometric compatibility	●●	●●	●●
Structural demands	●●●	●●	●

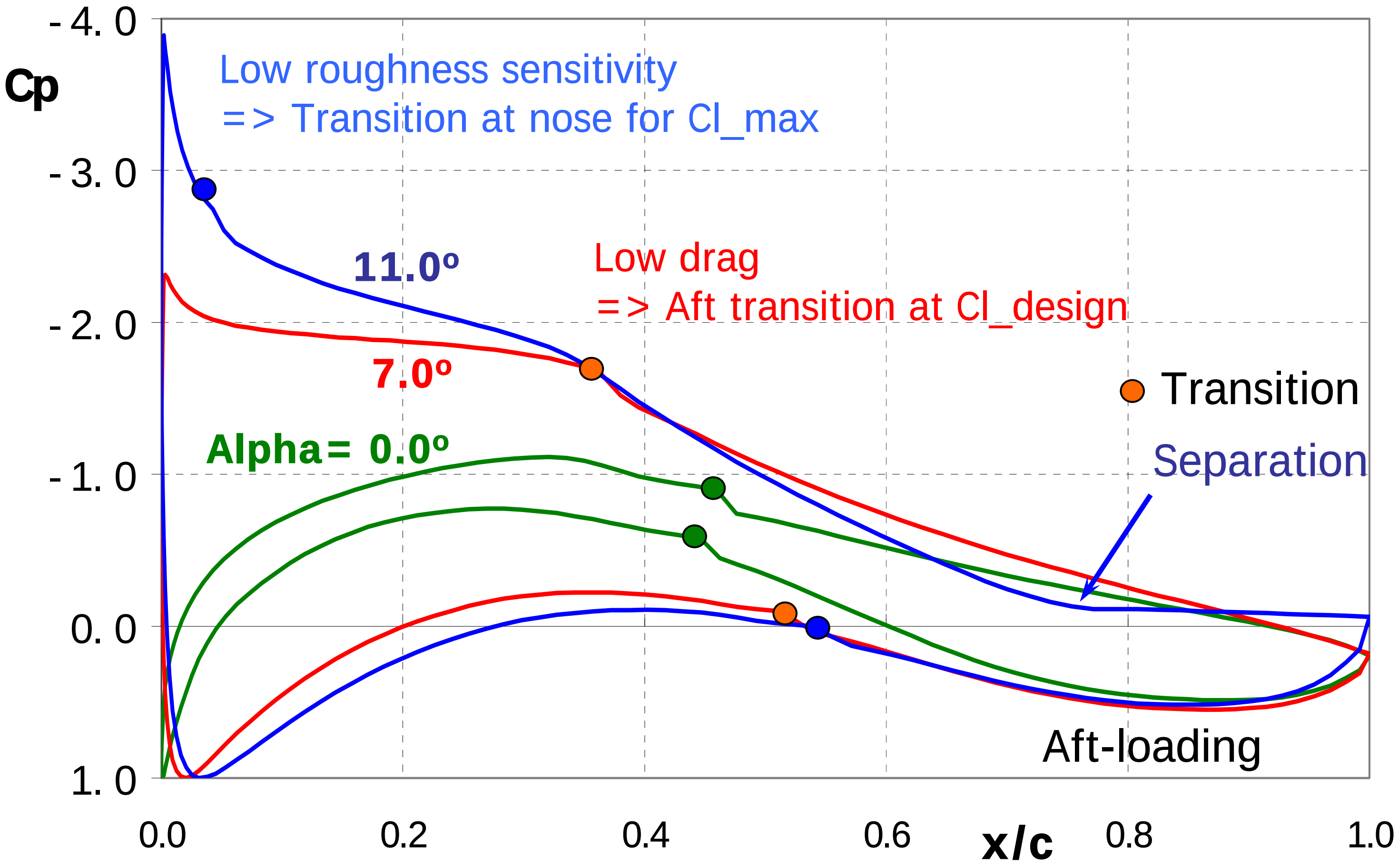
Design approach
(example DU 91-W2-250)

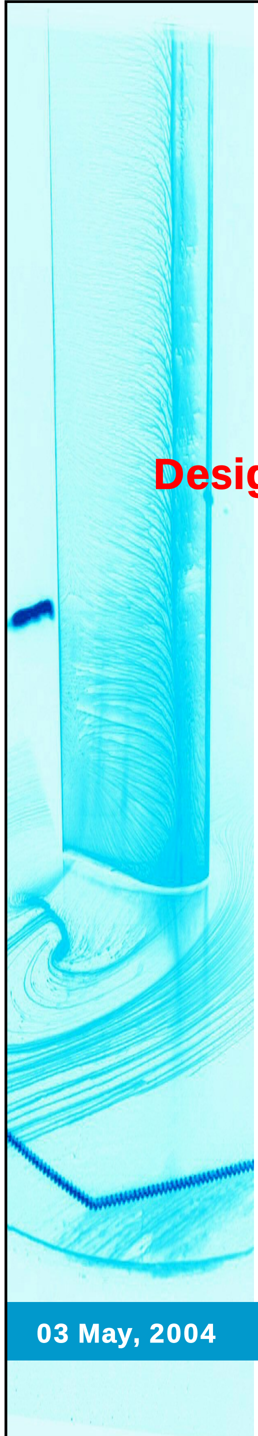
Main features



Design approach

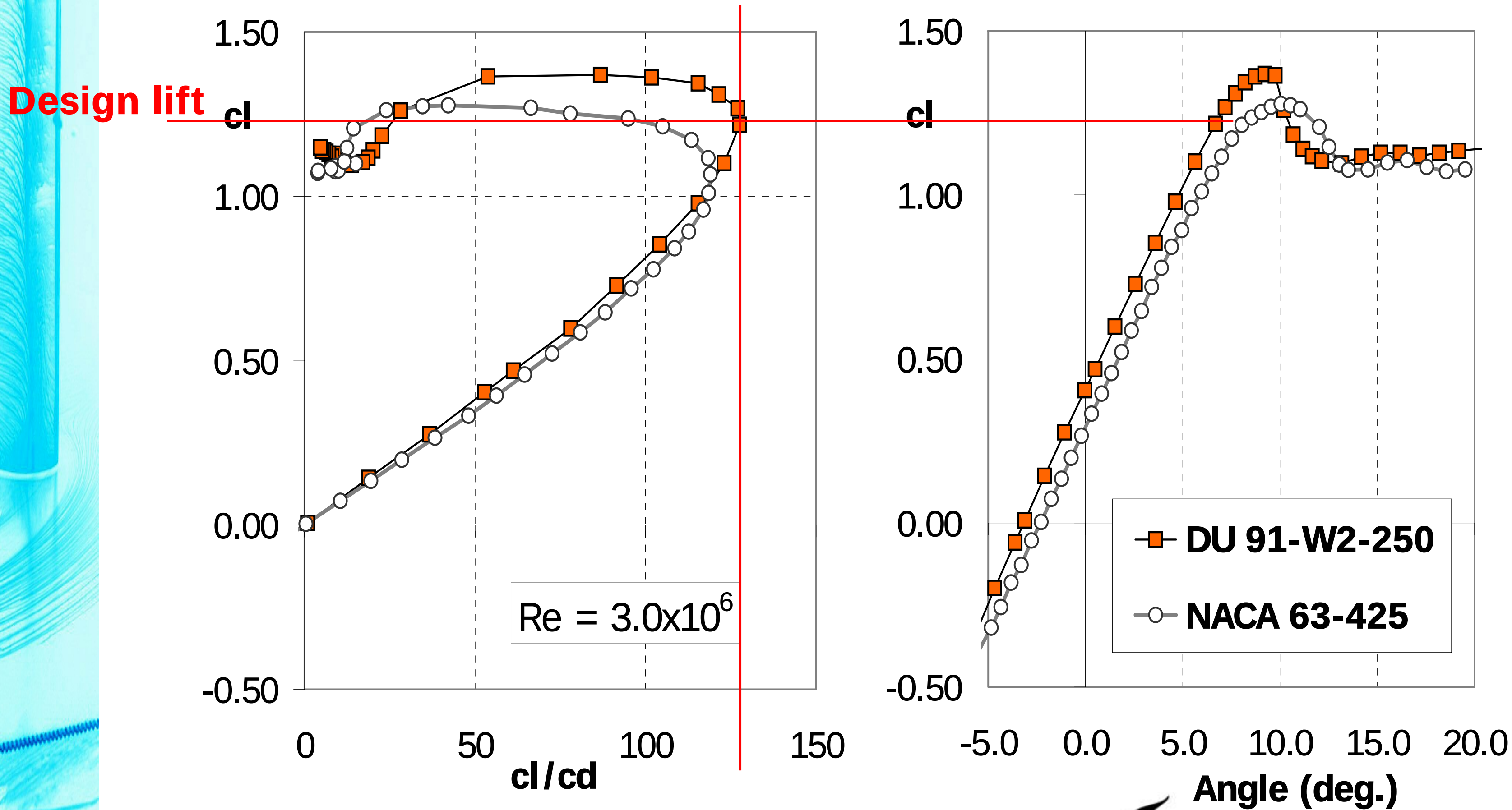
(pressure distributions DU 91-W2-250, Re = 3.0×10^6)

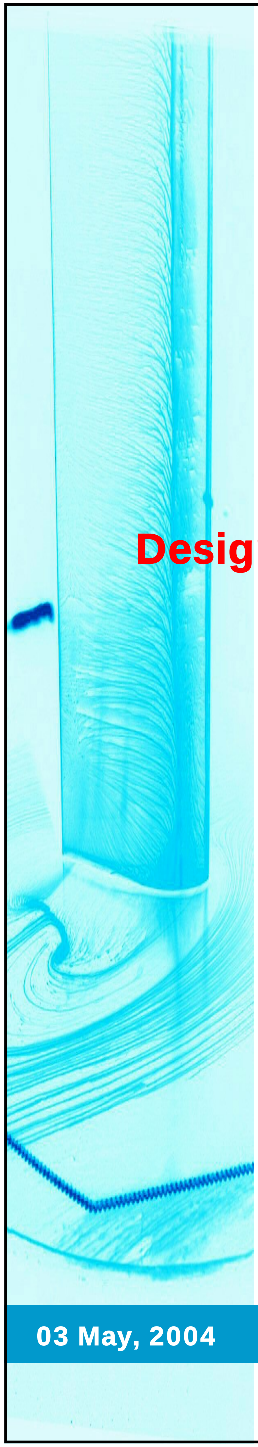




Airfoil design
(2d performance)

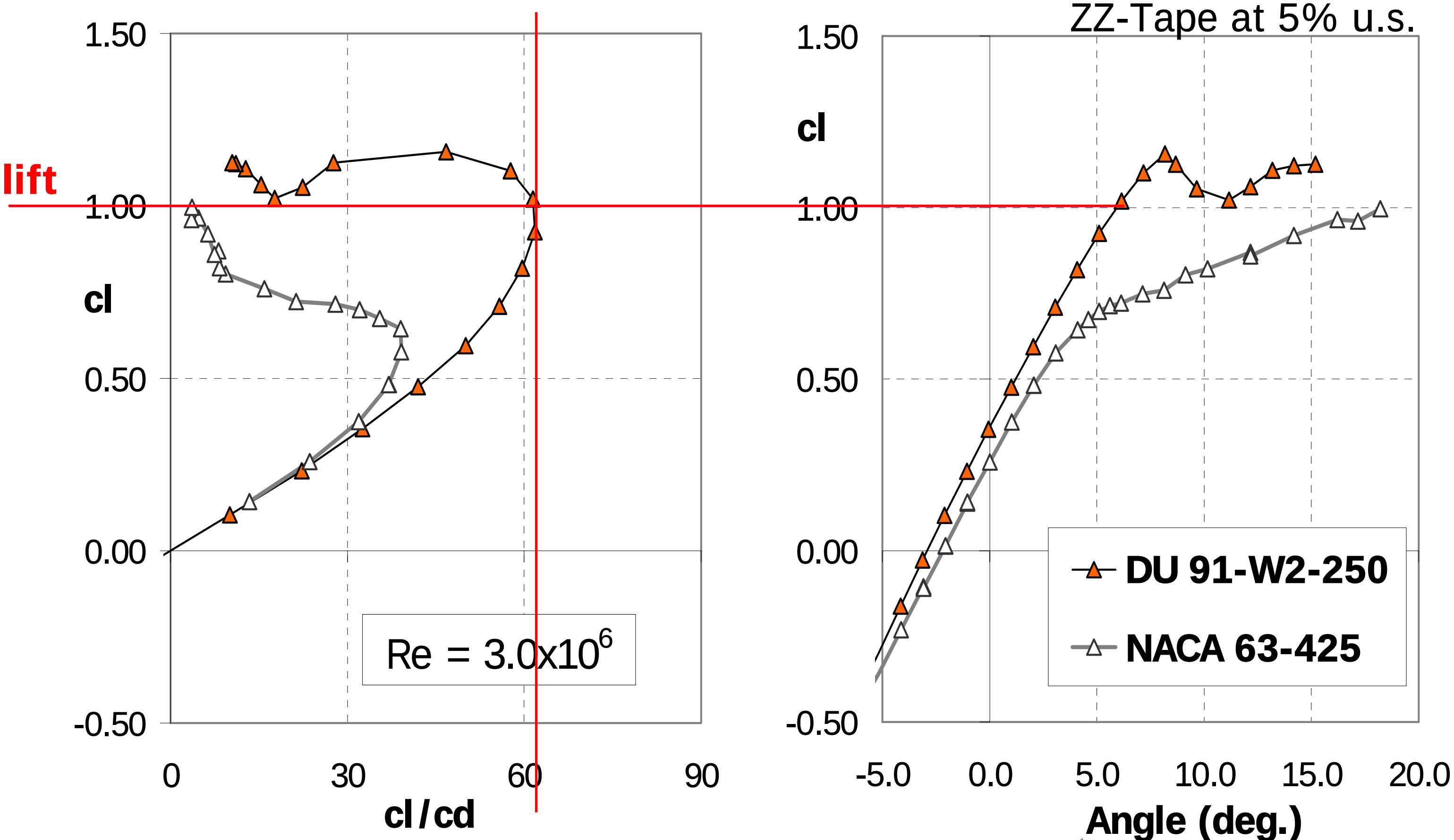
Measurements at LST-TU Delft: Clean





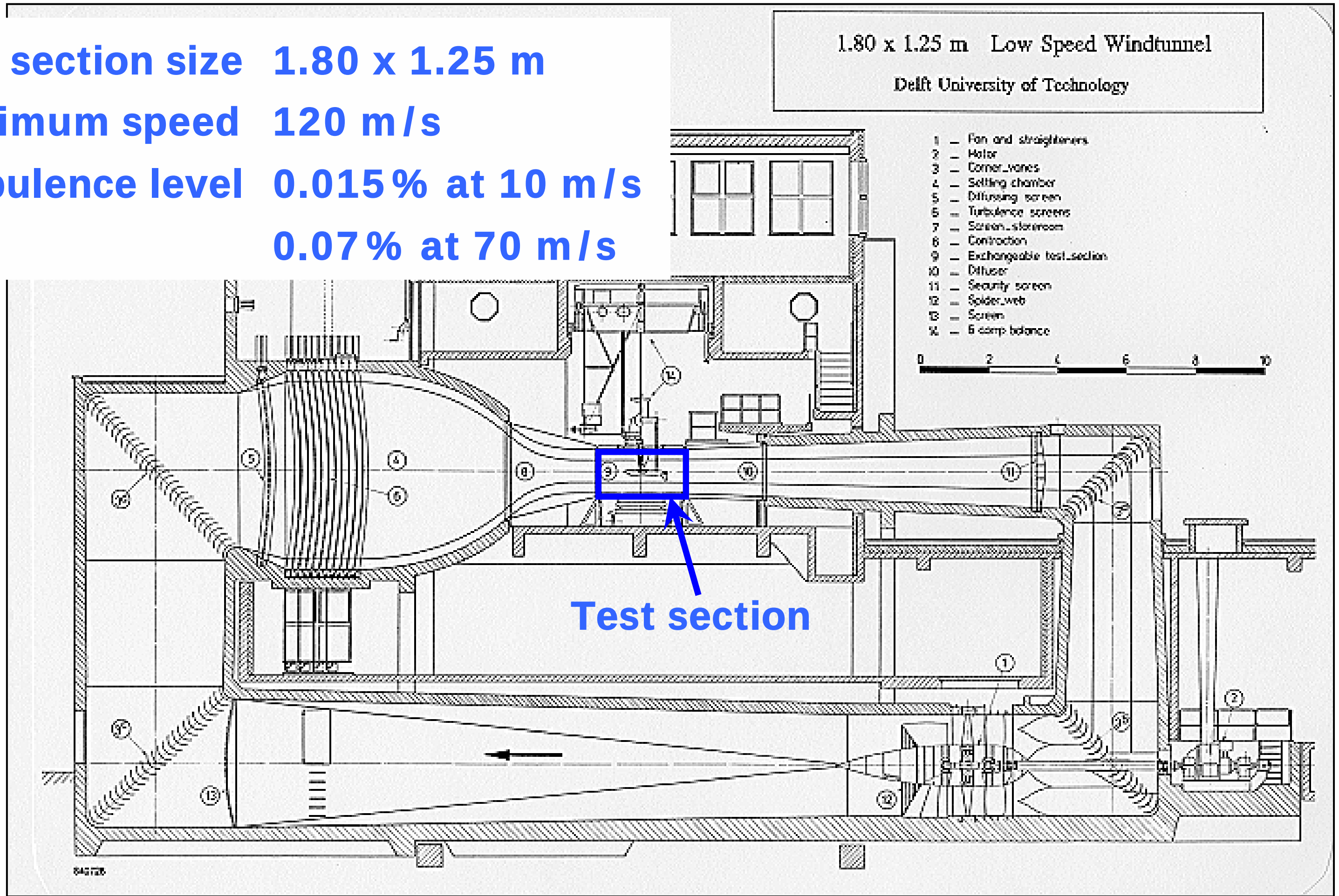
Airfoil design
(2d performance)

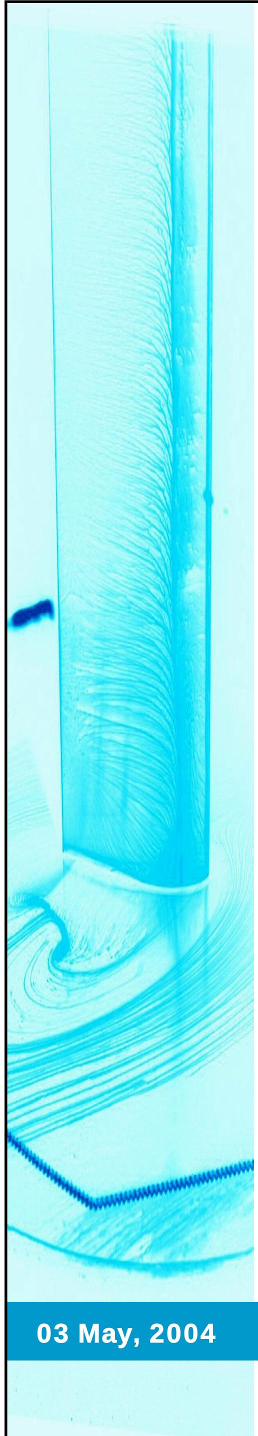
Measurements at LST-TU Delft: Roughness simulated



Airfoil testing
(Low speed low turbulence tunnel)

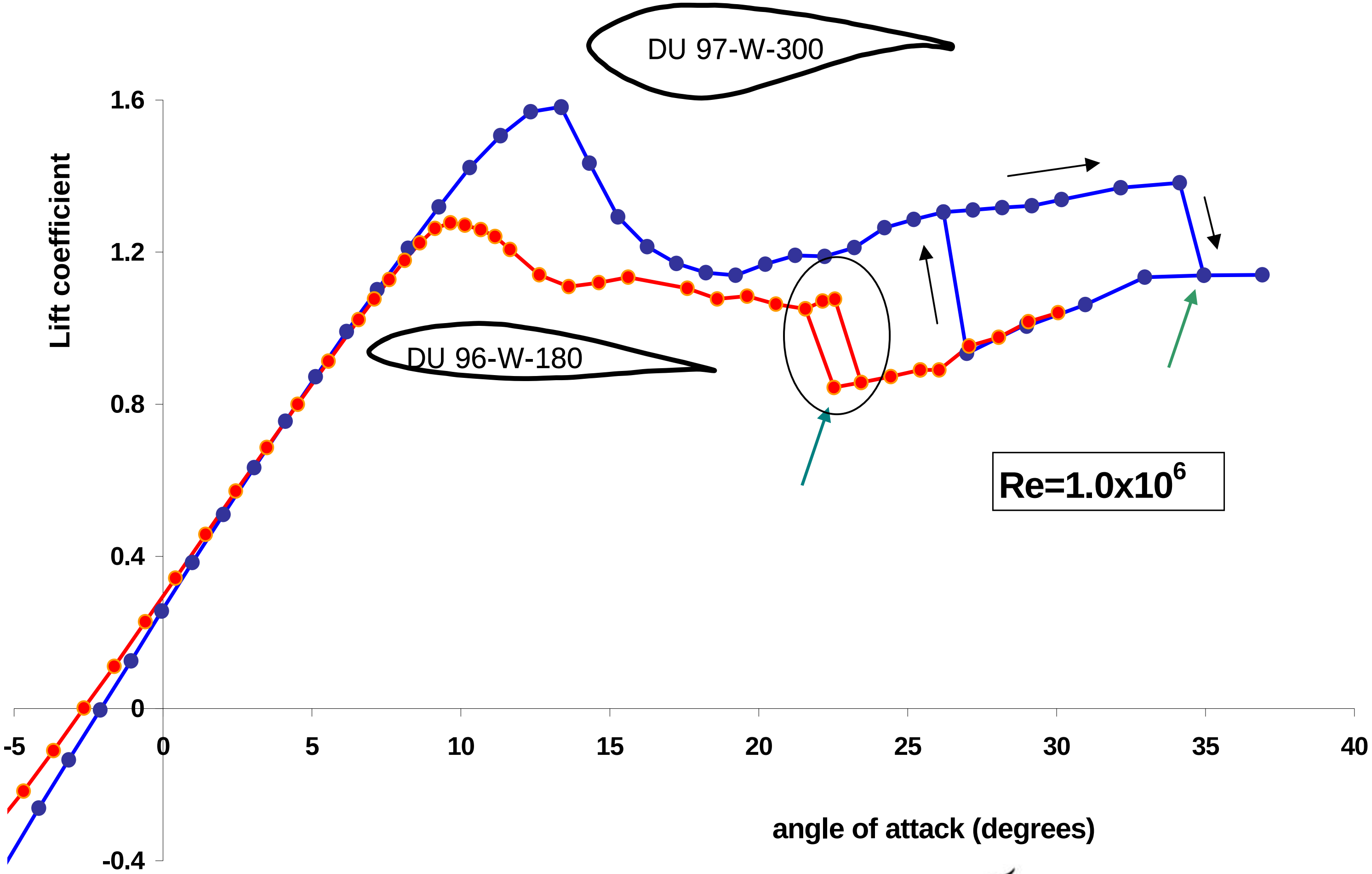
Test section size	1.80 x 1.25 m
Maximum speed	120 m/s
Turbulence level	0.015% at 10 m/s
	0.07% at 70 m/s



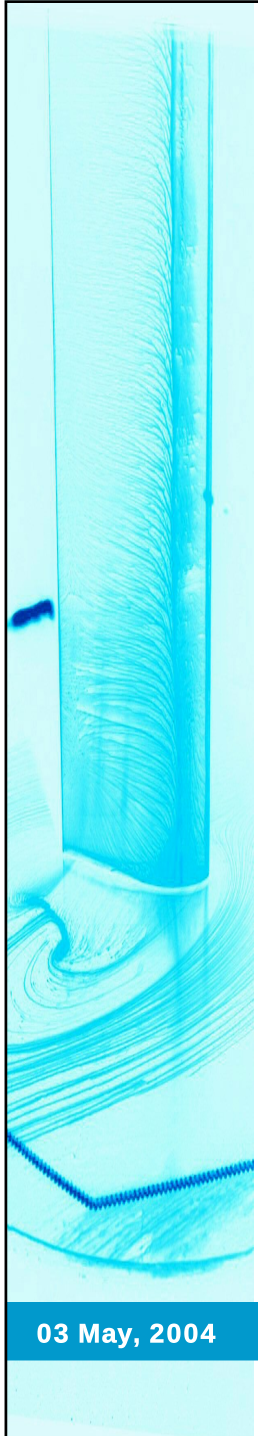


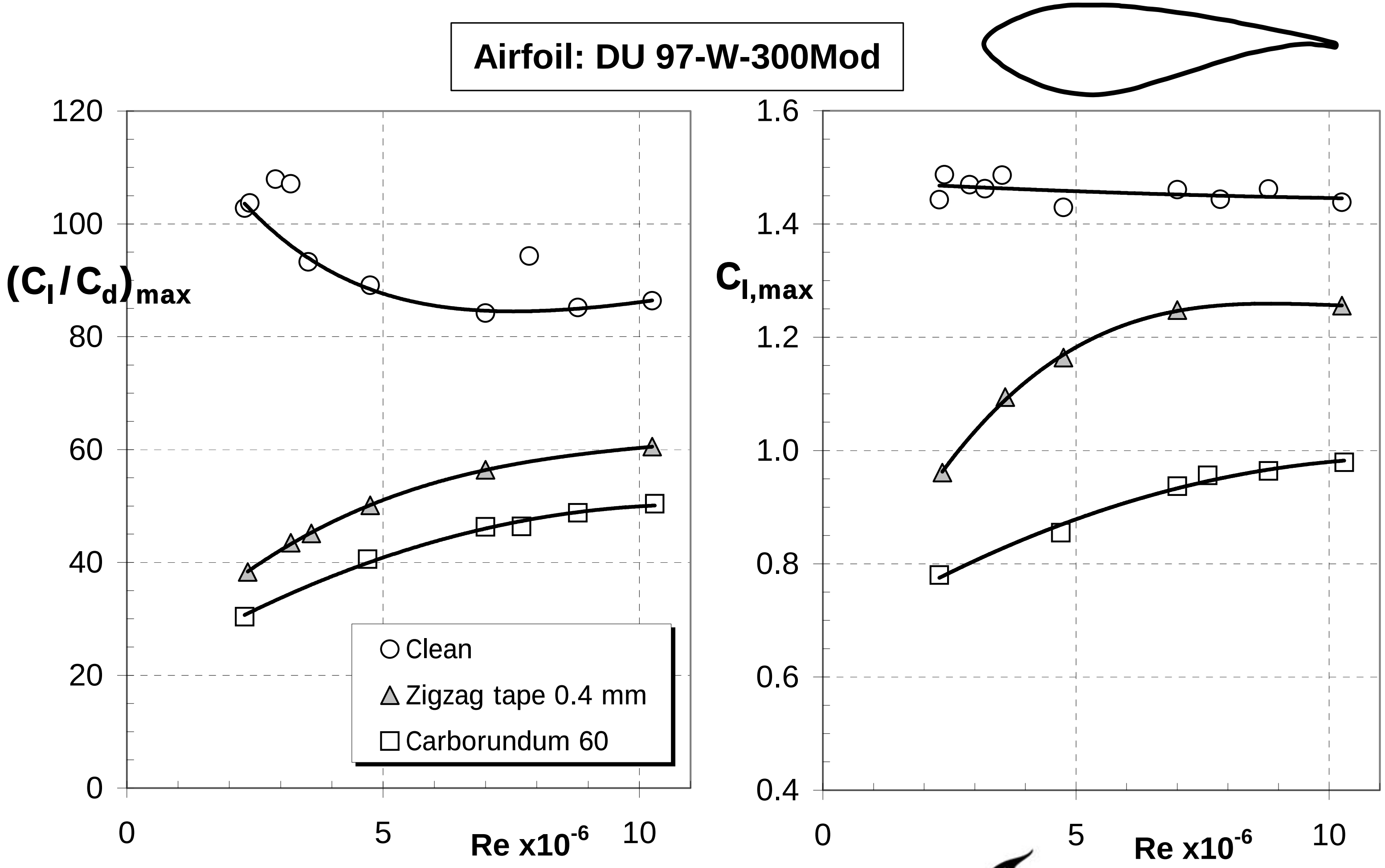
Airfoil testing

(effect of leading edge thickness)

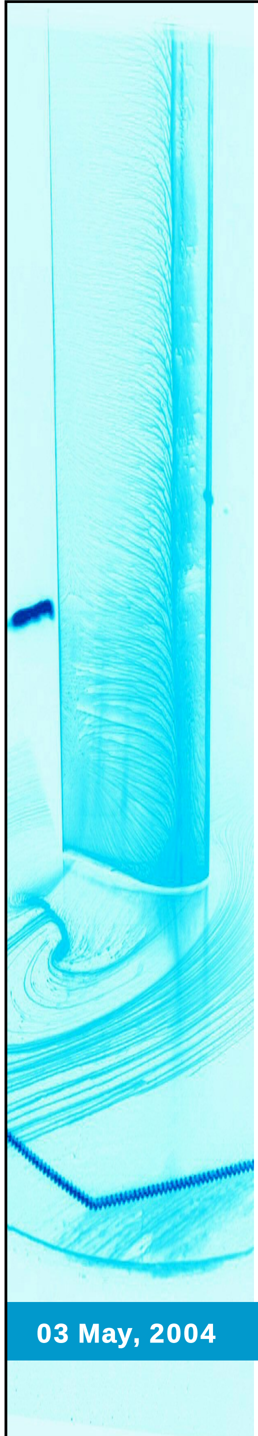


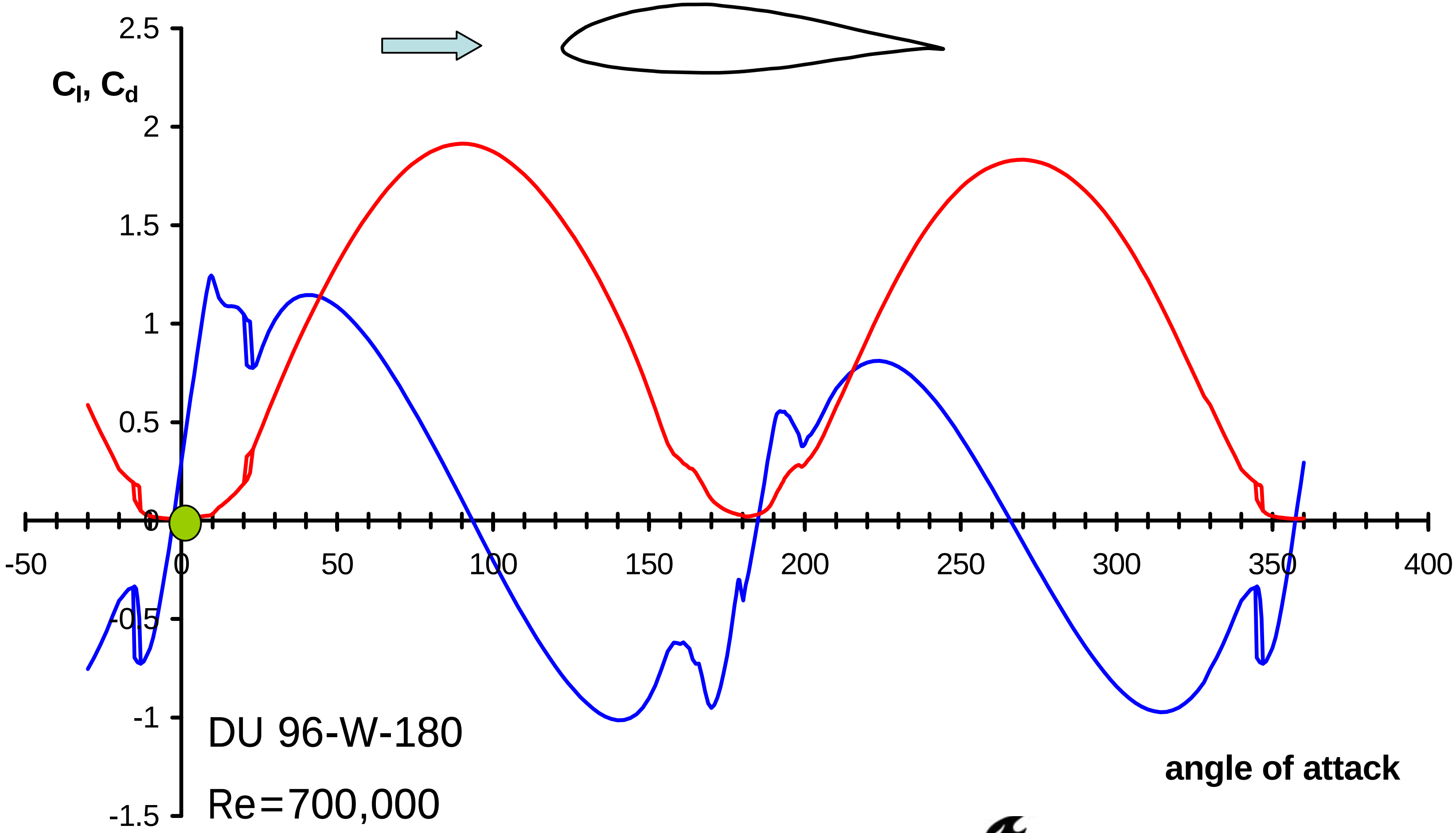
Airfoil testing
(effect of high Reynolds numbers)



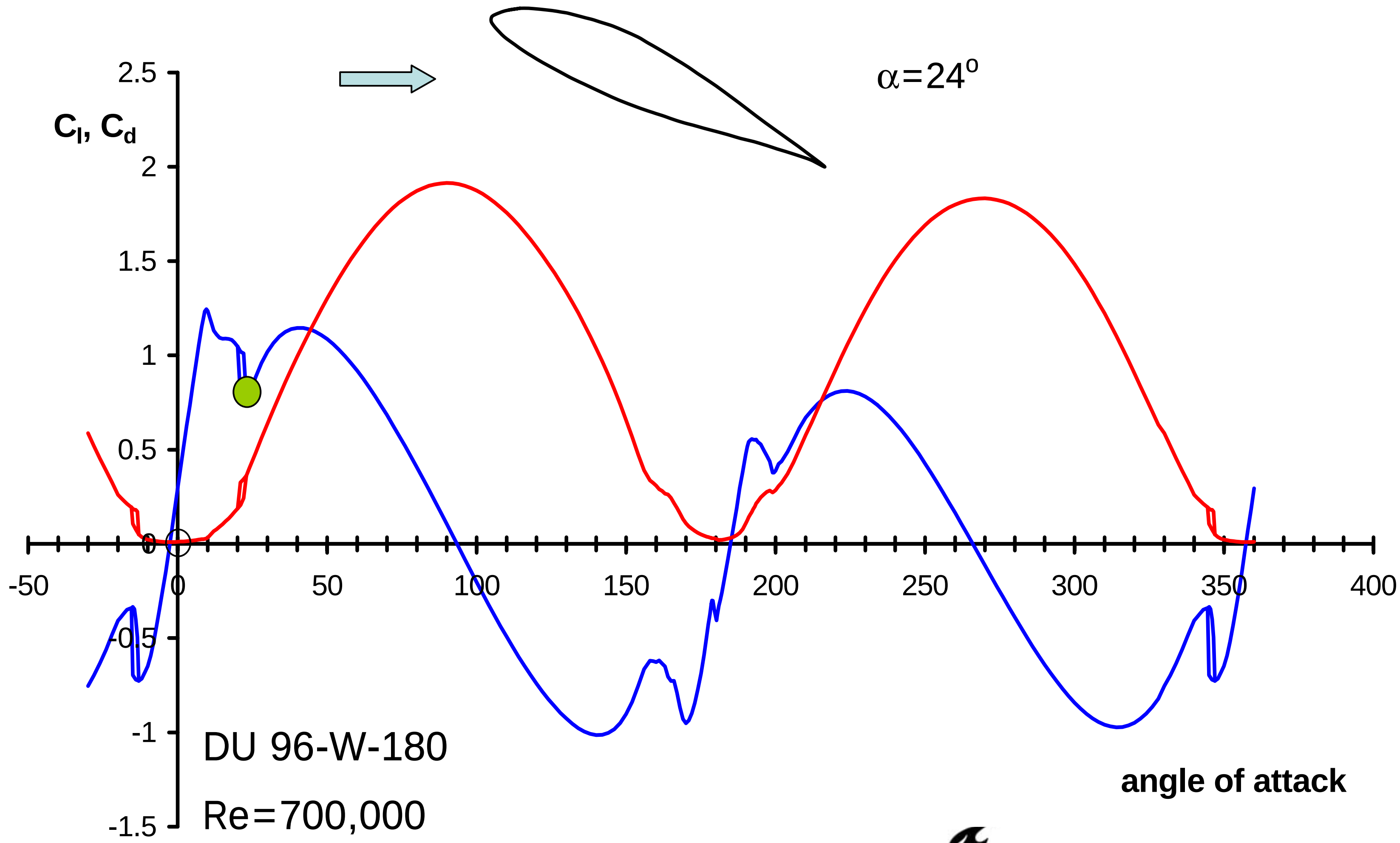


Airfoil testing
(360 degrees)

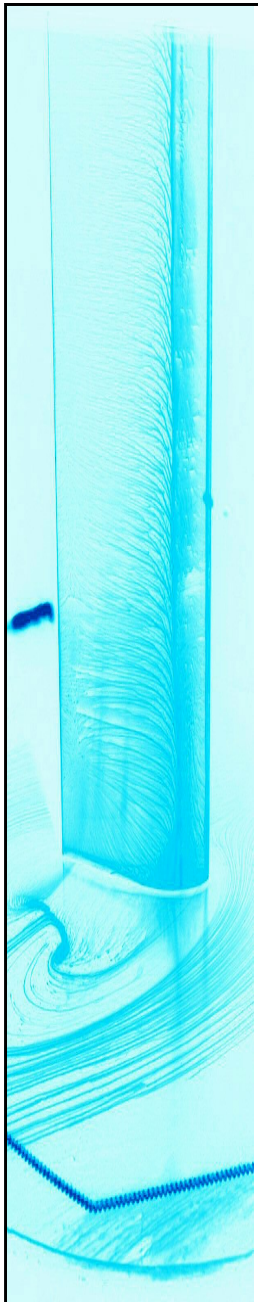


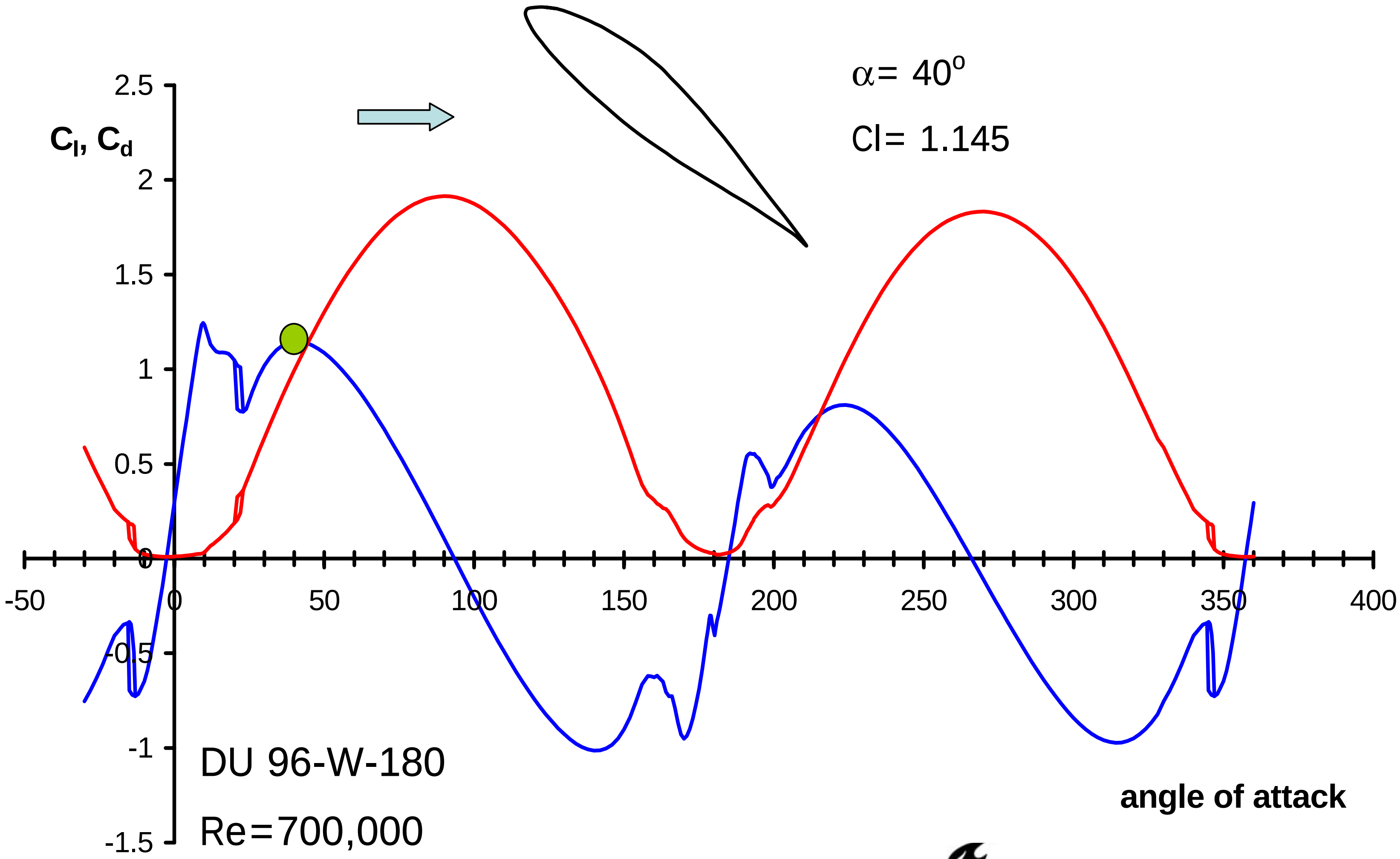


Airfoil testing
(360 degrees)



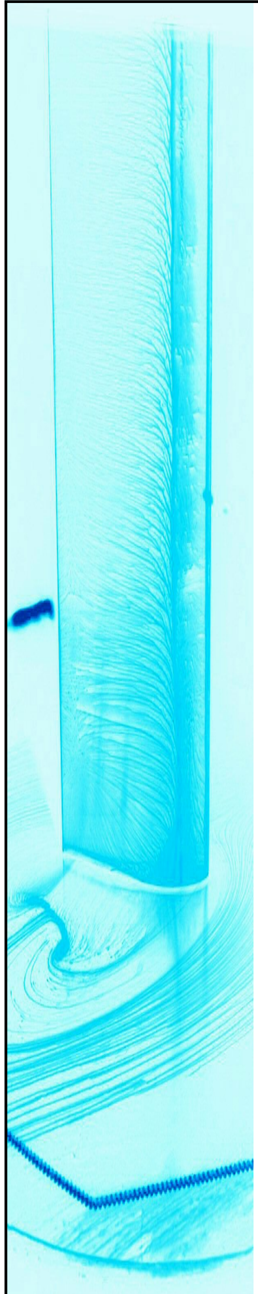
Airfoil testing
(360 degrees)

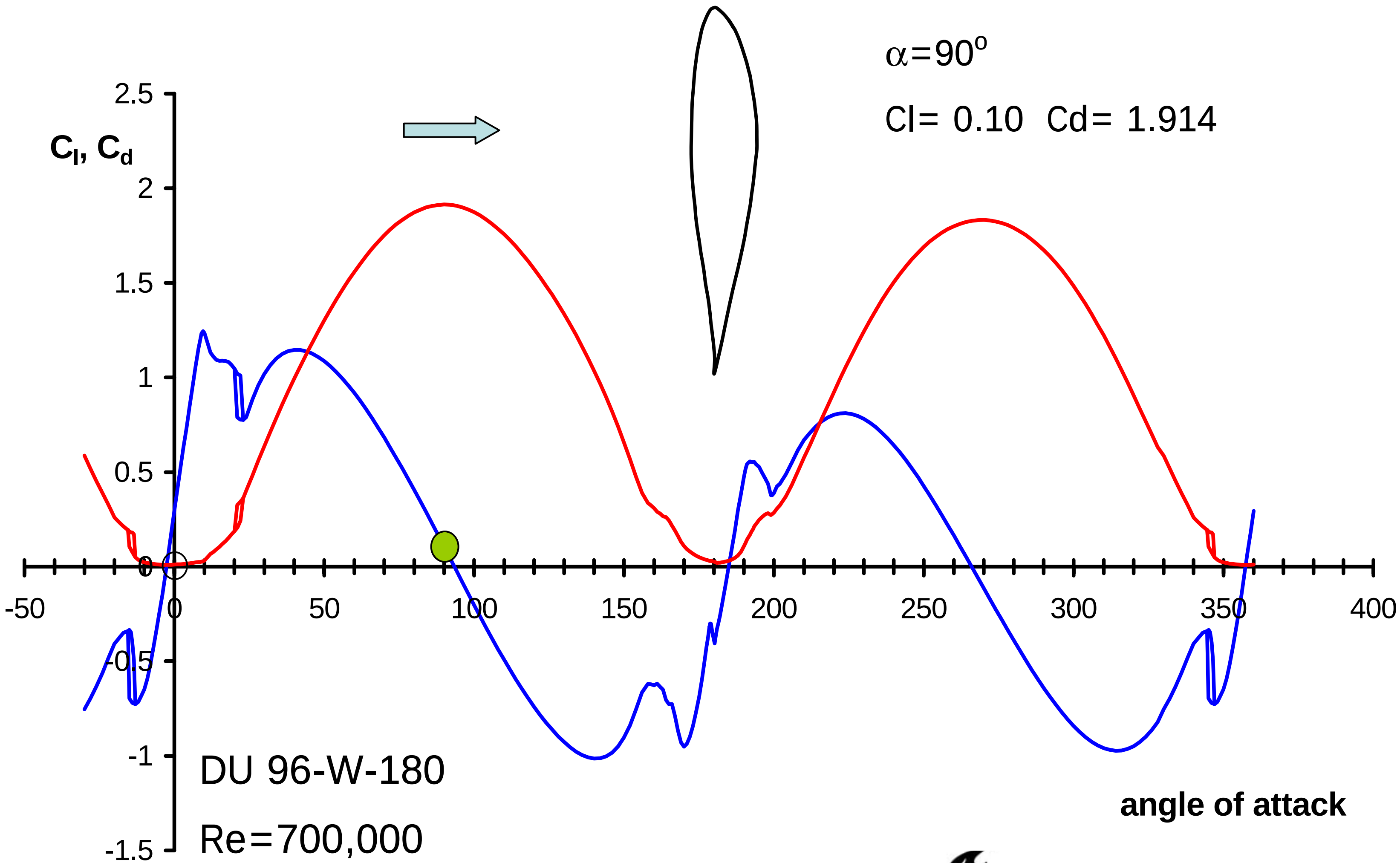


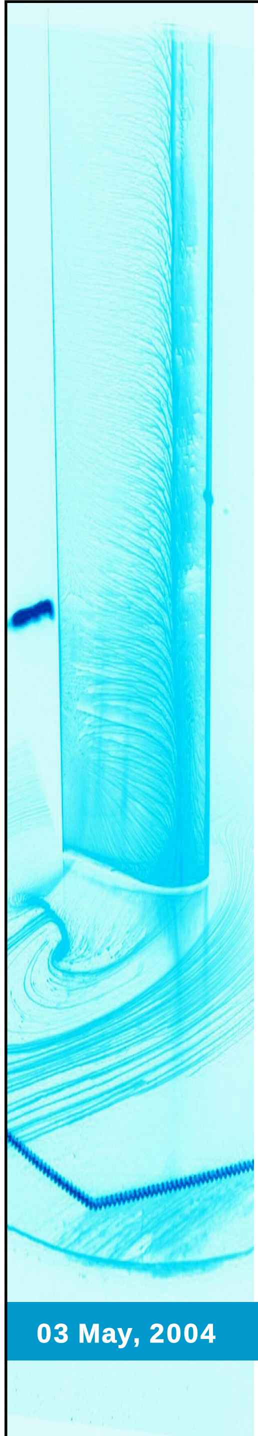


Airfoil testing

(360 degrees)

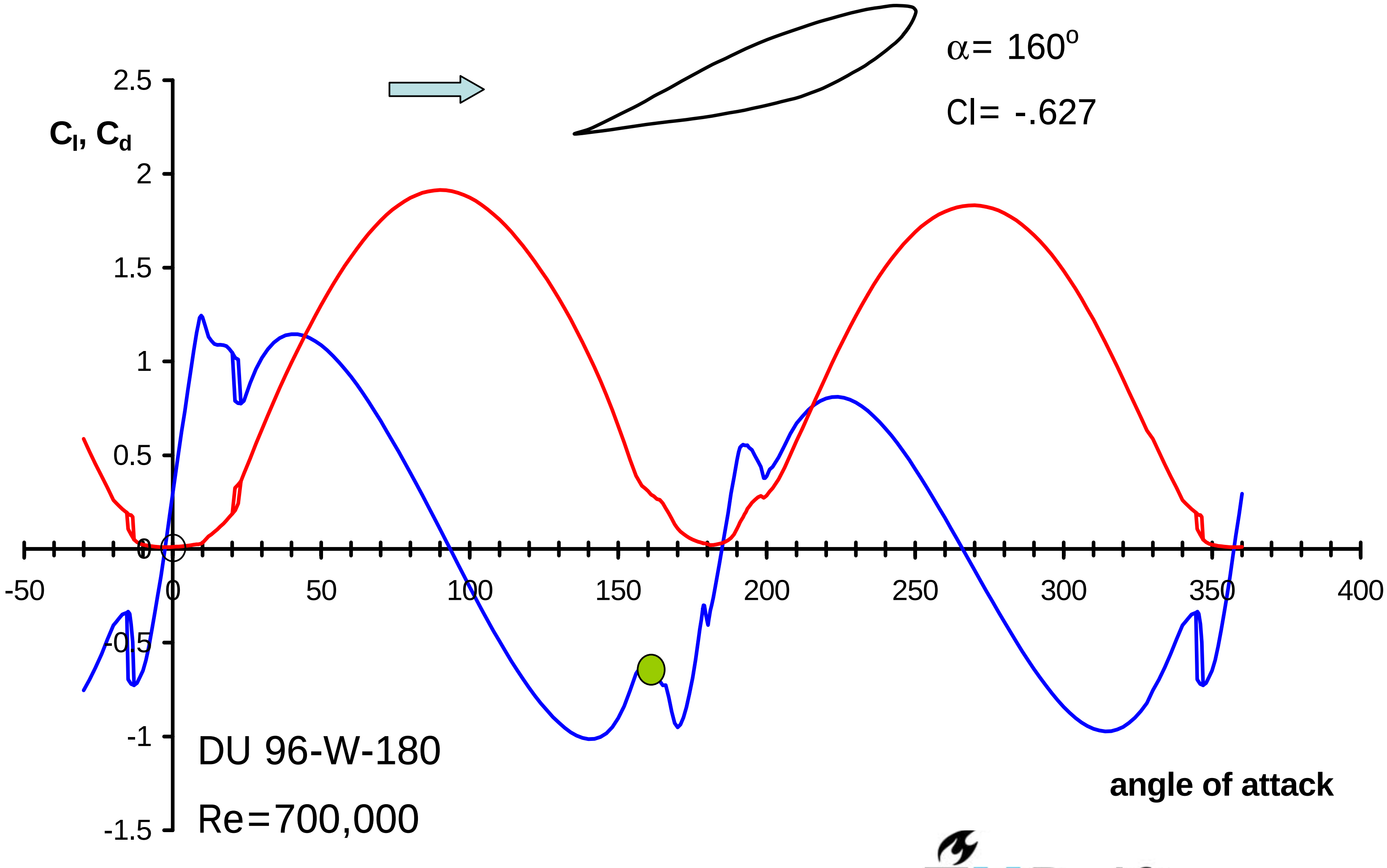




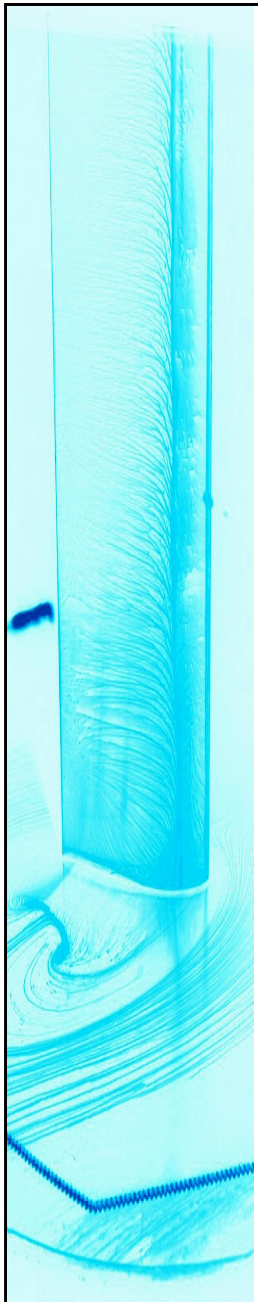


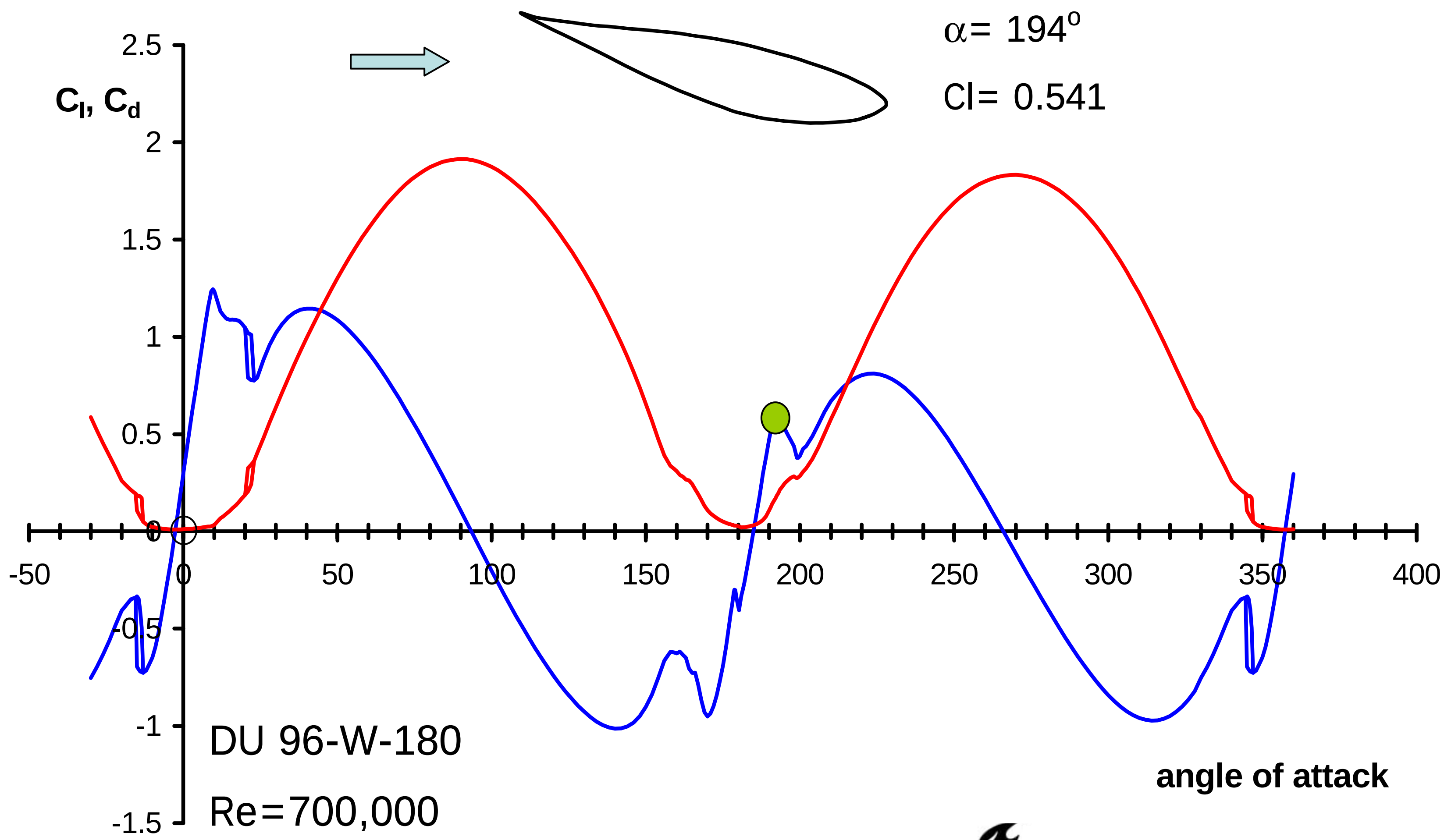
Airfoil testing

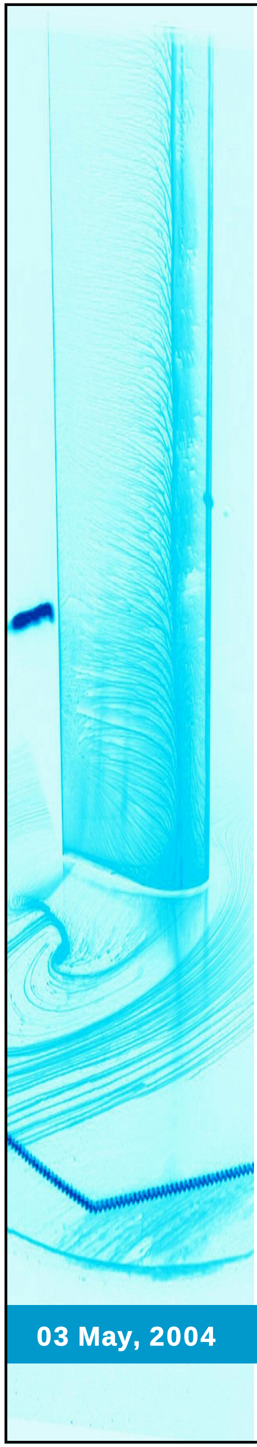
(360 degrees)



Airfoil testing
(360 degrees)

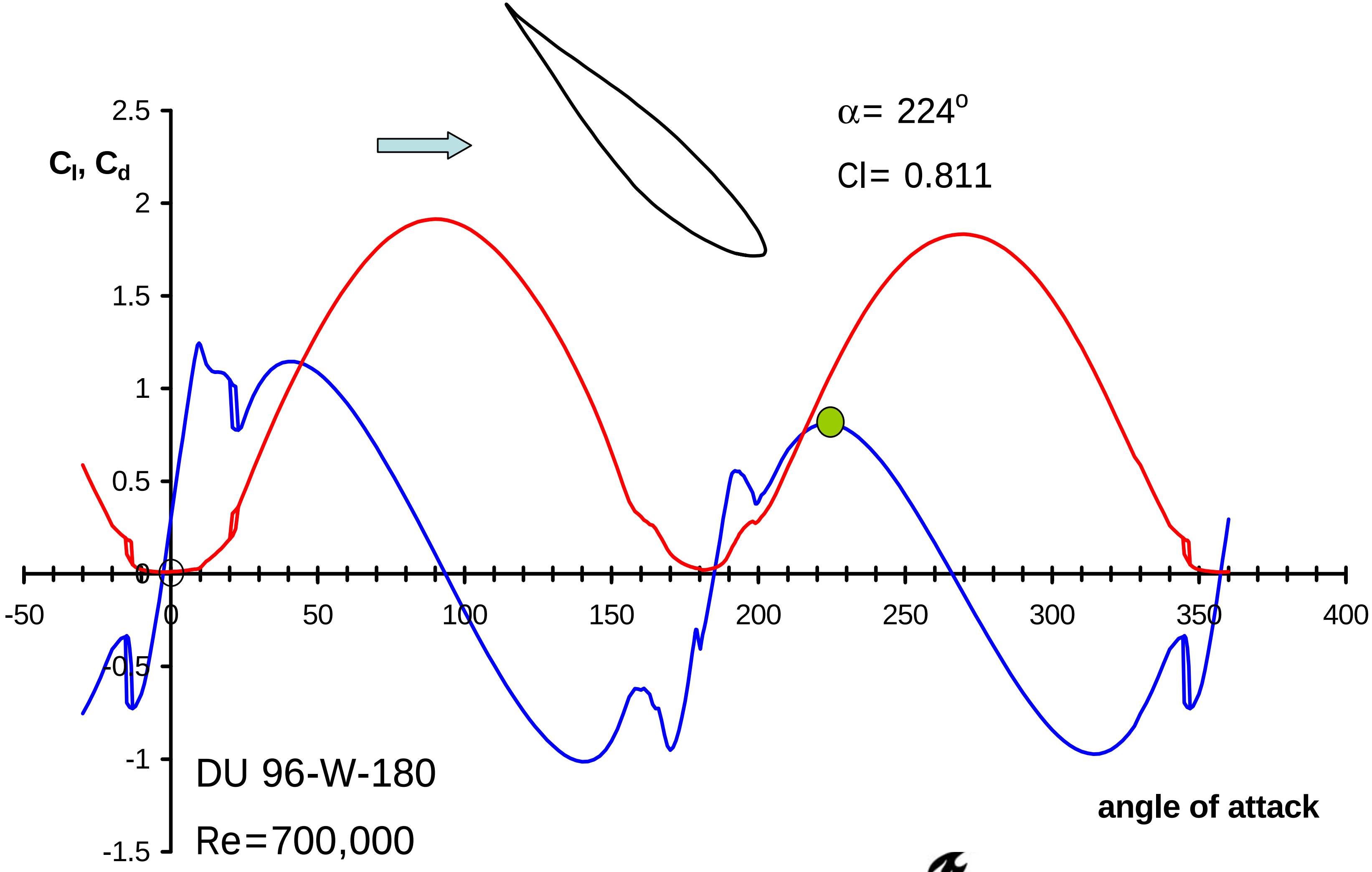






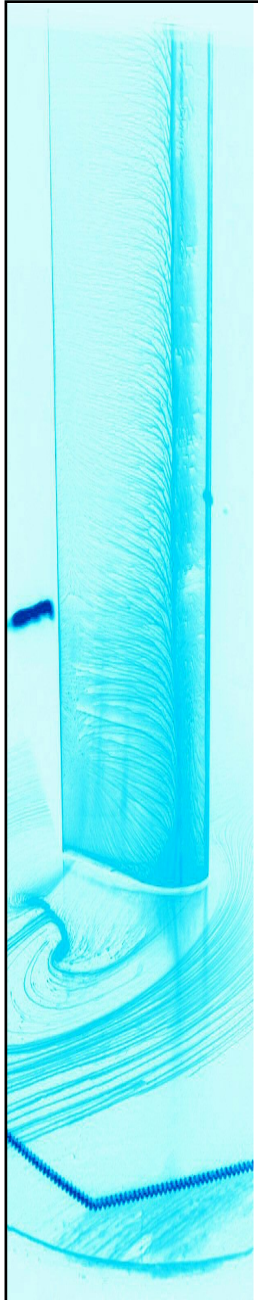
Airfoil testing

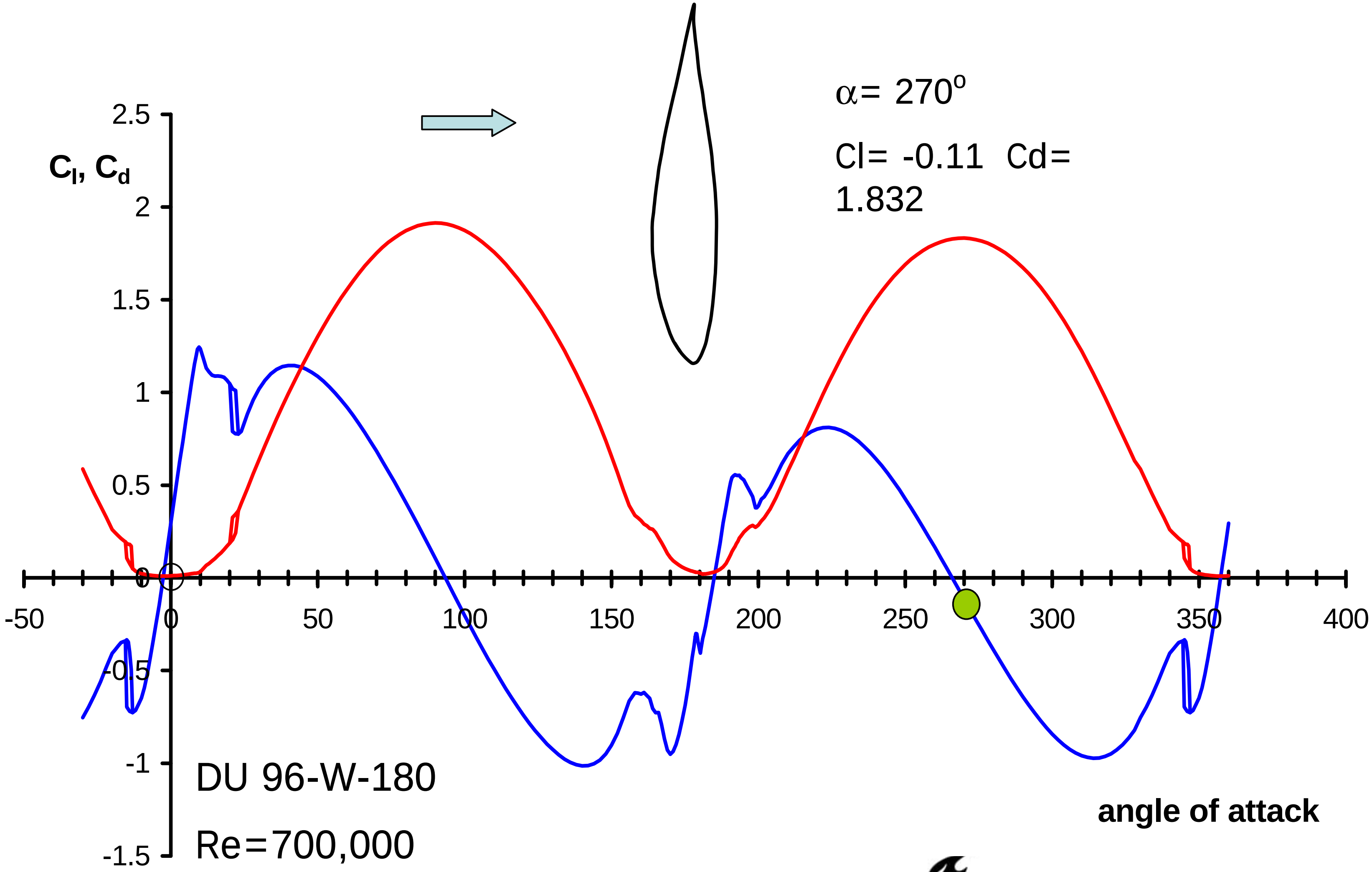
(360 degrees)



Airfoil testing

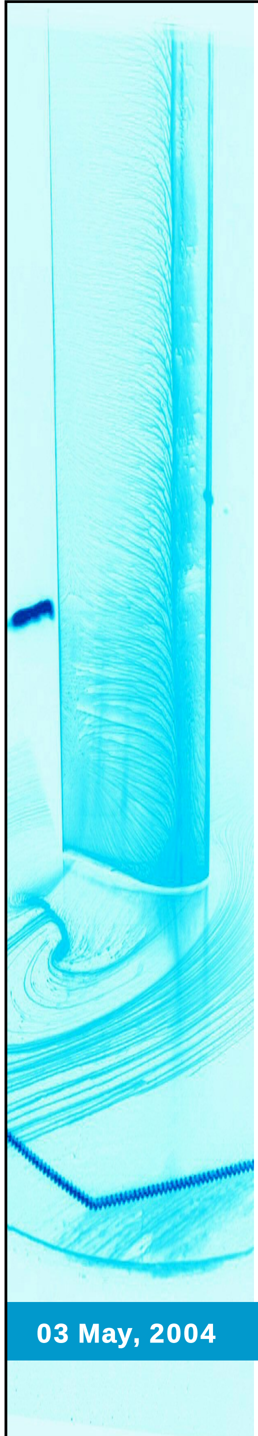
(360 degrees)

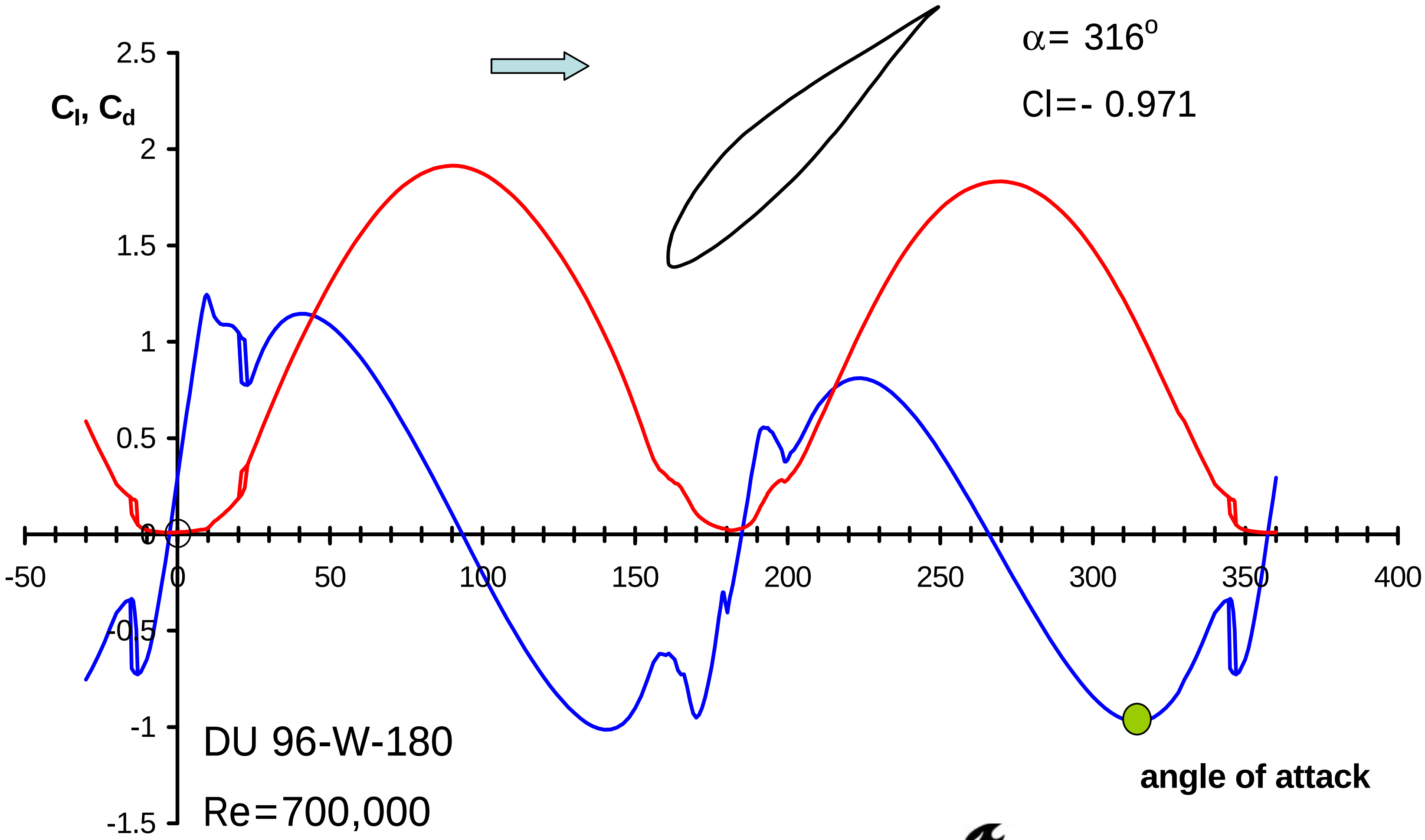


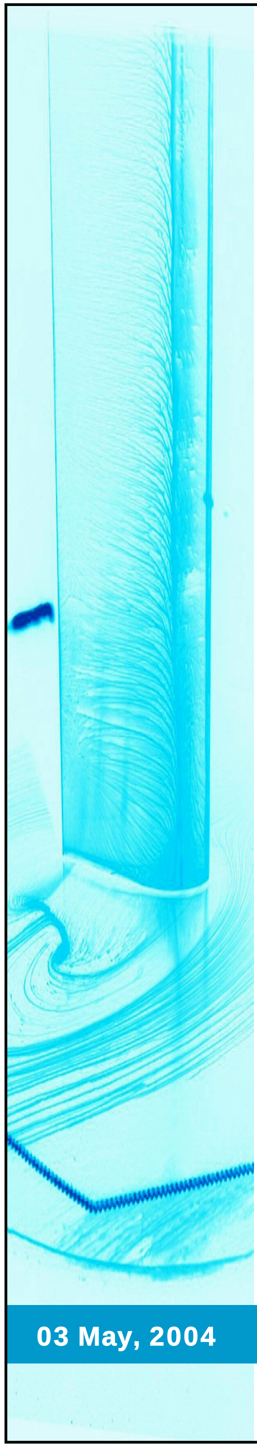


Airfoil testing

(360 degrees)



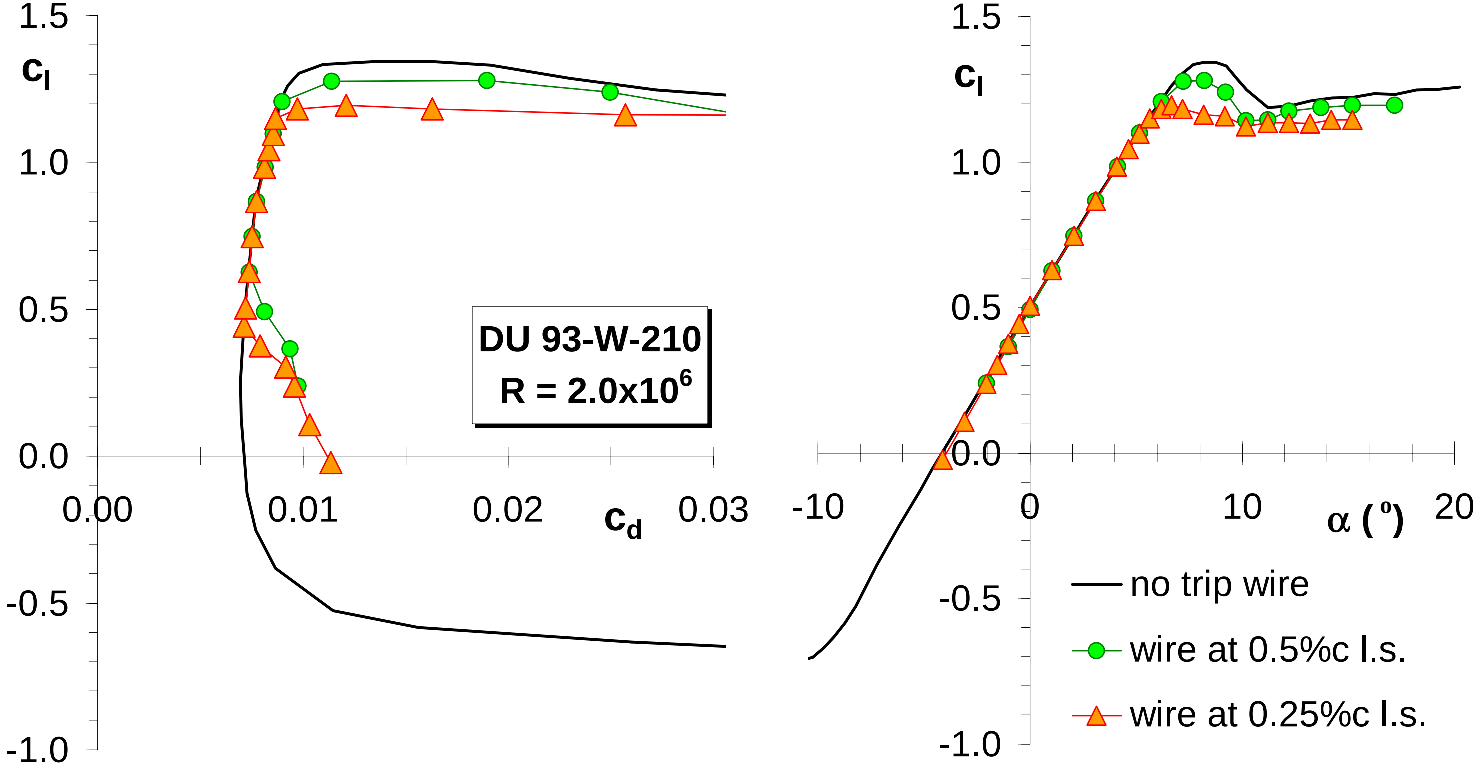


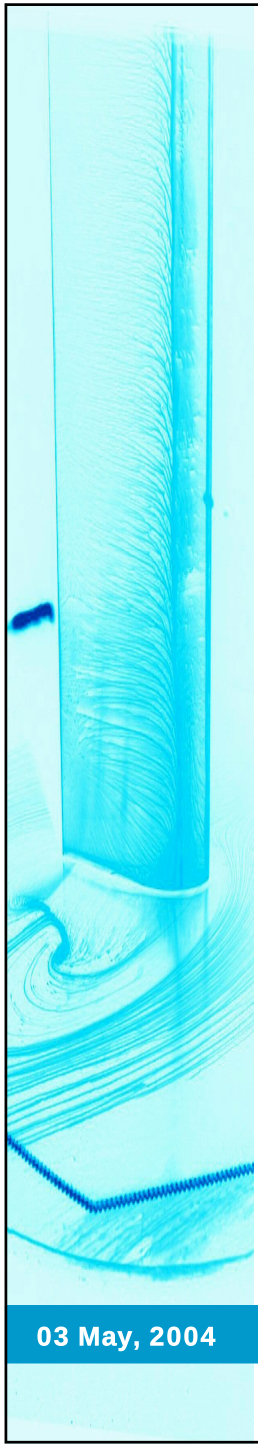


Airfoil testing

(aerodynamic devices)

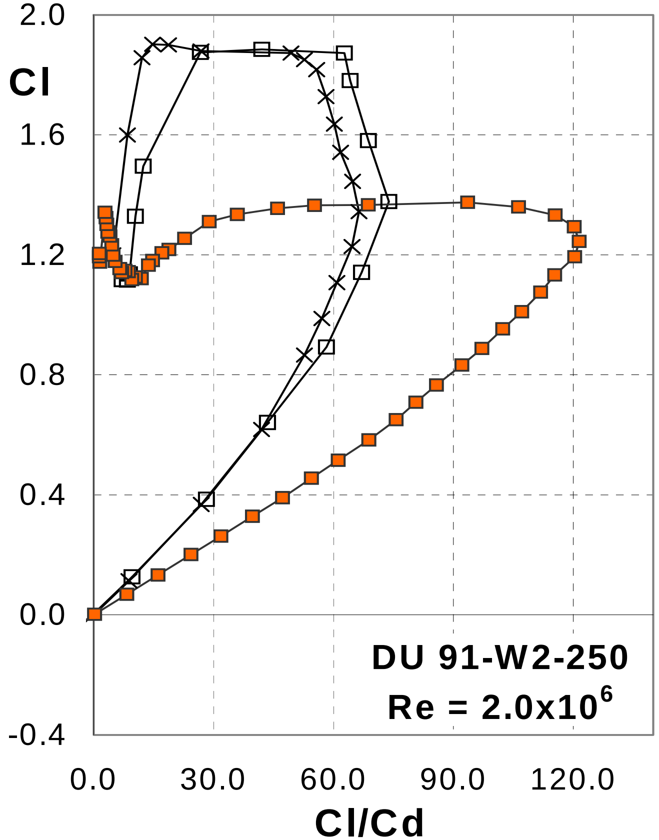
- Stall strips

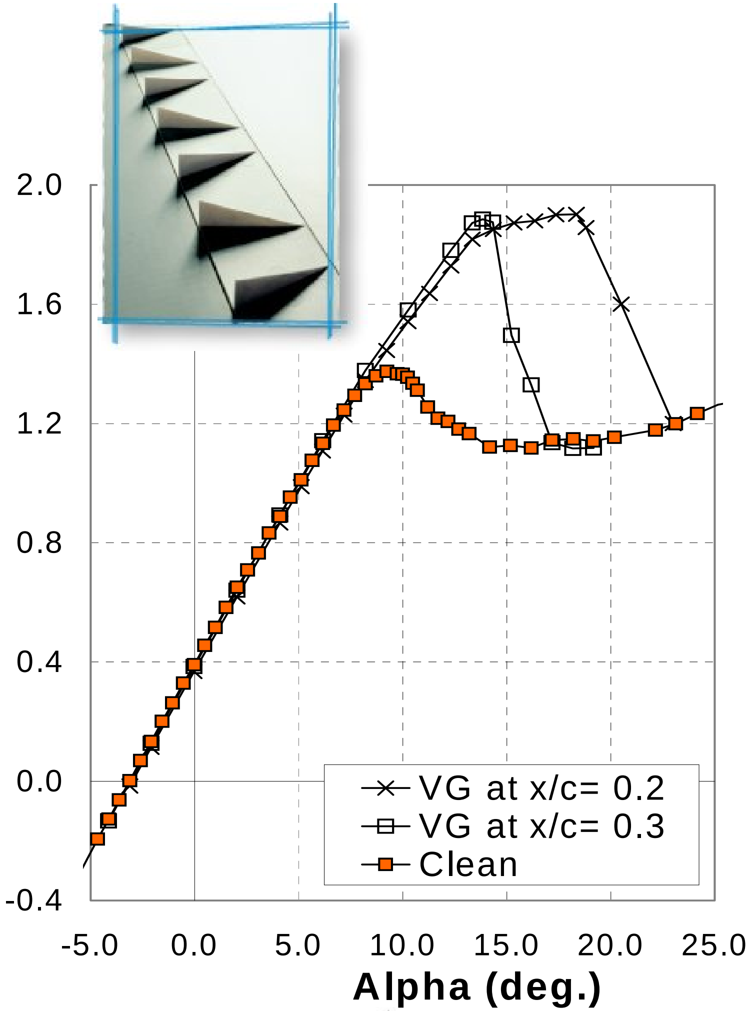


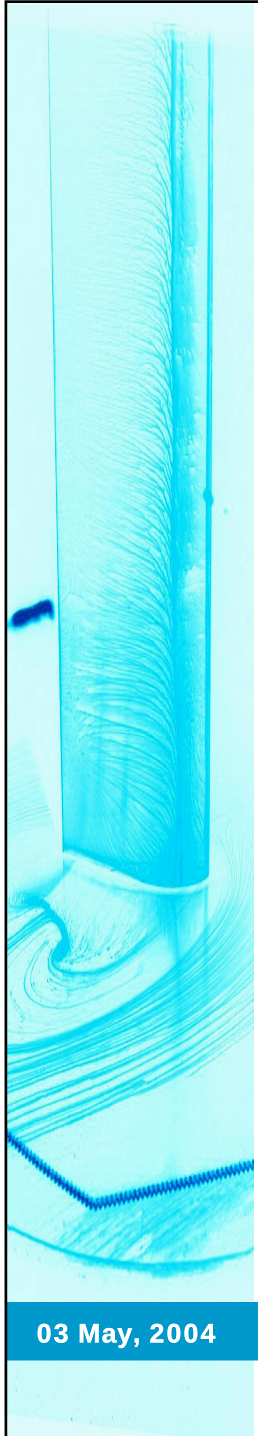


Airfoil testing
(aerodynamic devices)

- Vortex generators







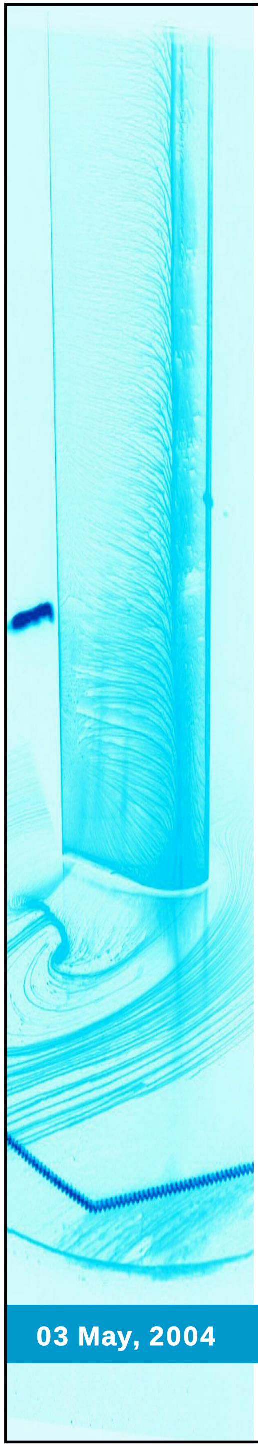
Effect on wind turbine performance

(2d stationary performance)

Calculated optimal element performance at mid-span for TSR= 7.5

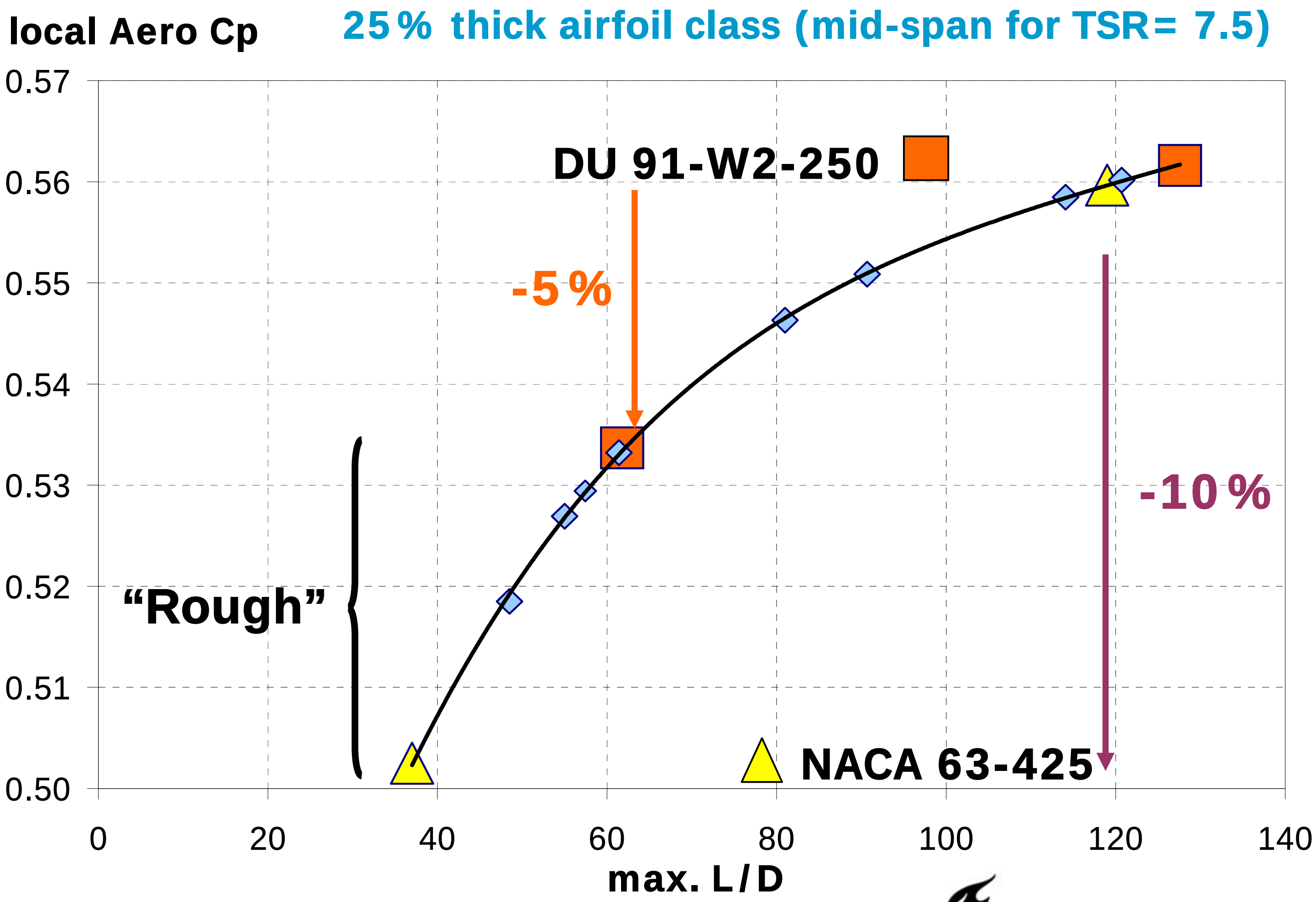
Clean	c/R	L/D-max	"Static load" Cl_max*c	Cp_elem	Loading	Cp
AH 93-W-257	0.106	122	0.149	.56	4%	-0.06%
DU 91-W2-250	**0.105**	**125**	**0.143**	**.561**	**0 %**	**0 %**
NACA 63-425	0.119	119	0.152	.56	6%	-0.24%
ZZ-tape 5 % u.s.						
DU 91-W2-250	0.135	60	.155	.532	8%	-5.1%
NACA 63-425	0.212	39	.212	.503	48%	-10.2%

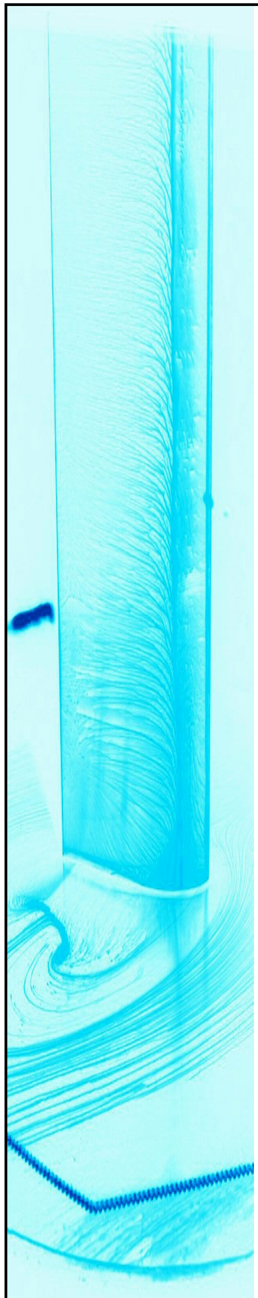
* "Static load" reference based on 1 year gust for fixed pitch blades



Effect on wind turbine performance

(2d stationary performance)





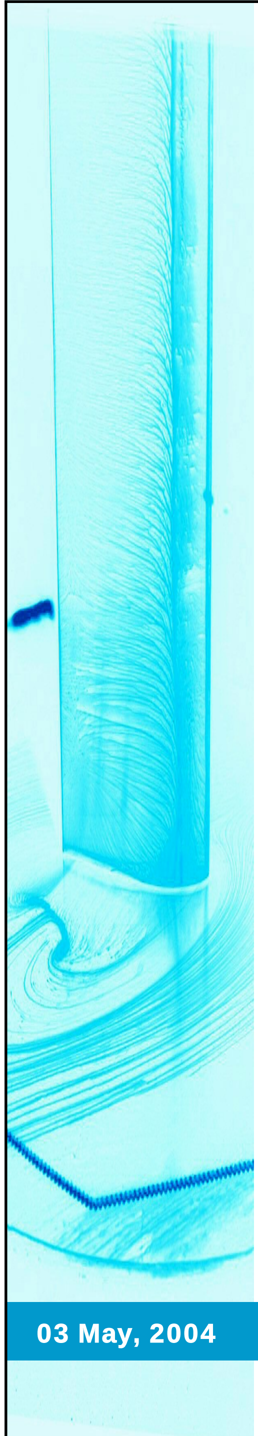
Overview of HAWT airfoils

General aviation airfoils

- NACA 63-4xx and NACA 63-6xx series
- NACA 64-4xx

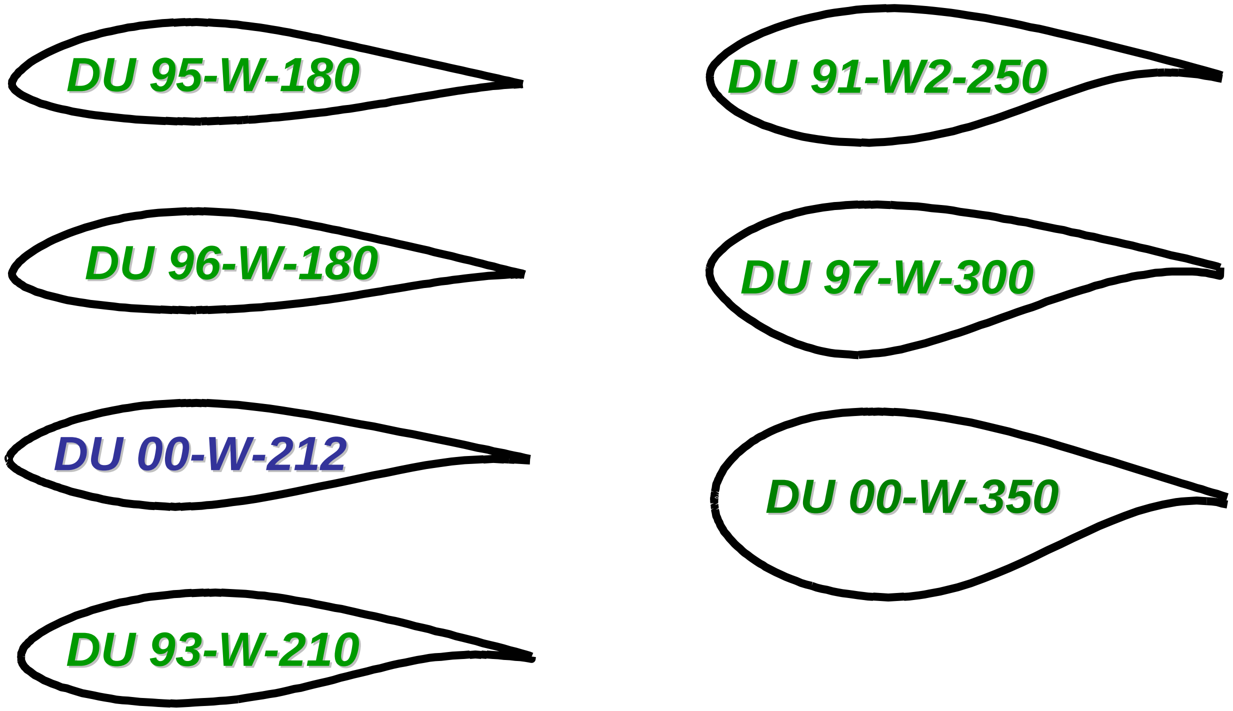
Dedicated airfoils

- S8xx series (NREL, USA)
- FFA W-xxx (FOI, Sweden)
- Risø-A1-xxx (also B, P-series, Risø, Denmark)
- DU xx-W-xxx (Delft, Netherlands)

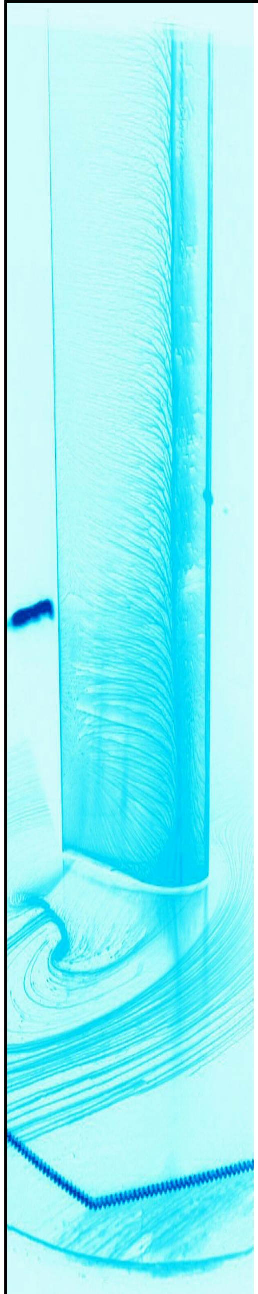


Overview of HAWT airfoils

- Overview of DU-airfoils and users



GE-Wind, REpower, Dewind, Suzlon, Gamesa, LM Glasfiber, NOI Rotortechnik, Fuhrlander, Pfleiderer, EUROS, NEG Micon, Umoe blades, Ecotecnia ....



Next steps:

<u>Extending to all operational situations :</u>

- Measurements => "high" Reynolds number
  => chart unsteady behavior of DU airfoils

<u>New airfoil designs :</u>

- Very thick airfoils for lightweight blades
- Control of rpm only => Low TSR
  Low Cl-max, benign stall
  => High TSR
  Low drag
- Aero-elastic tailoring => Dynamic airfoil design
  (Probably low Cl-max)