

# **Static Aeroelastics of the Wind Turbine Rotor Blade**

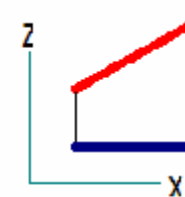
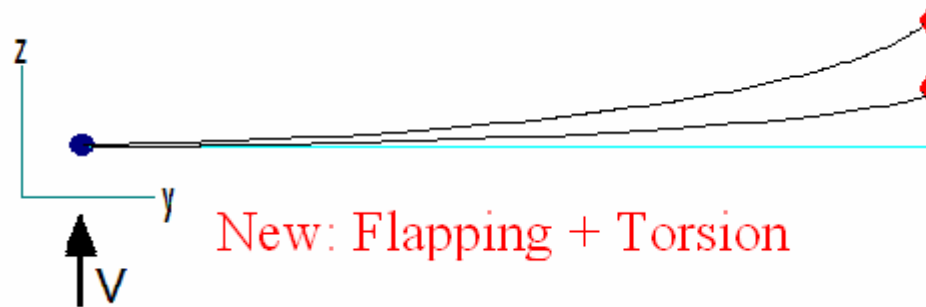
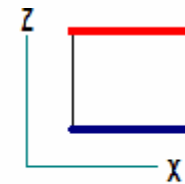
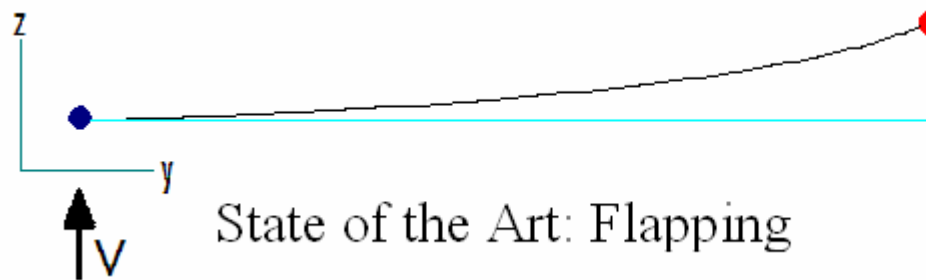
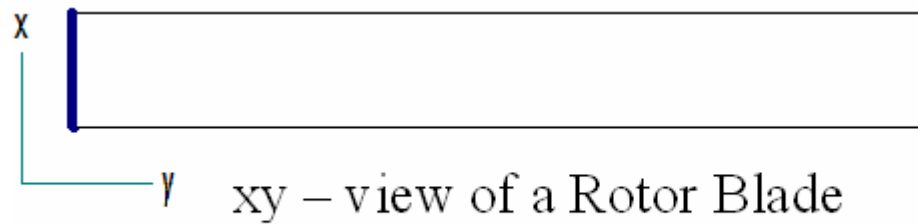
Writer

Dr.-Ing. Armin F. Khadjavi

# Aim and Content

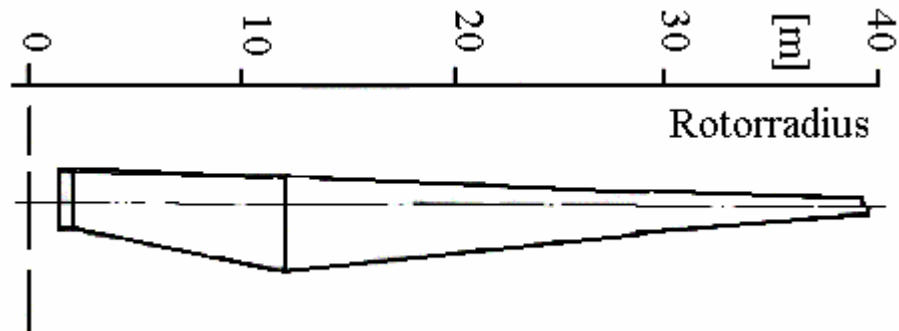
- Evaluation of Contribution of Static Torsional Effects to a Wind Turbine Rotor Blade on the Aerodynamic Power Generation
- Modelling
- Aerodynamics
- Structure
- Boundary Conditions, Loads, Calculation
- Results

# Static Torsional Effects to a Wind Turbine Rotor Blade

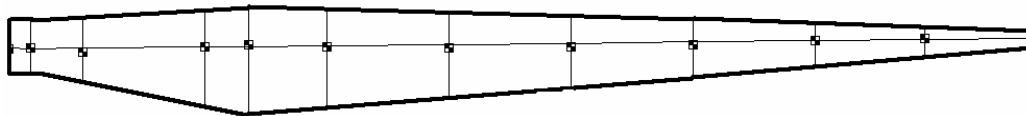


# Modelling

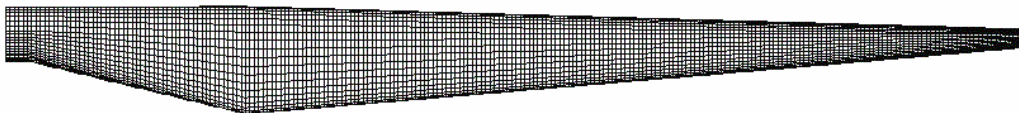
T100 concepted based on AEOLUS II



Aeolus II

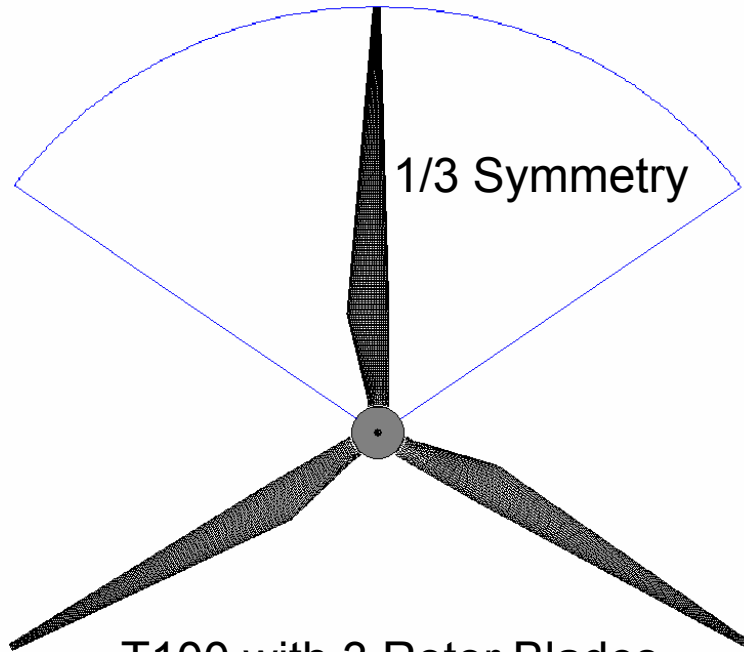


T100  
Beam model



T100 Shell model

# Aerodynamics



T100 with 3 Rotor Blades

Common Features Beam Model and Shell Model :

1 Chord Length,

2 Twist,

3 Losses related to Hub and Blade Tip,

4 Velocity Distribution,

5 Diagram for the local Reynolds-numbers,

6 Distribution of the Angle of Attack.

## Tip Speed Ratio

Tip Speed Ratio is the ratio out of Circumferential Speed at the Rotor Blade Tip and the Free Wind Speed,  $\lambda = u / v_w$ .

Tip Speed Ratios for the Beam Modell are:

At  $v_w = 15$  m/s,  $n = 0,4$  Hz,  $\lambda = 8,4$

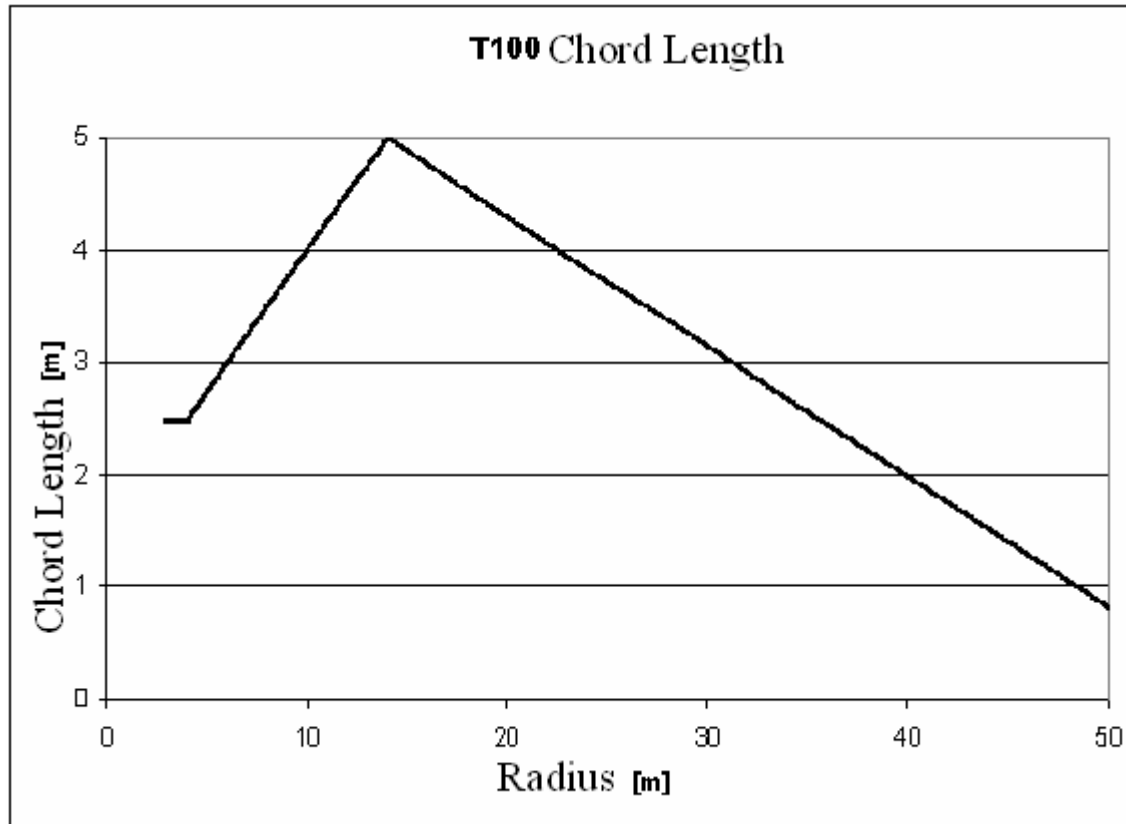
At  $v_w = 15$  m/s,  $n = 0,45$  Hz,  $\lambda = 9,4$

At  $v_w = 15$  m/s,  $n = 0,5$  Hz,  $\lambda = 10,5$

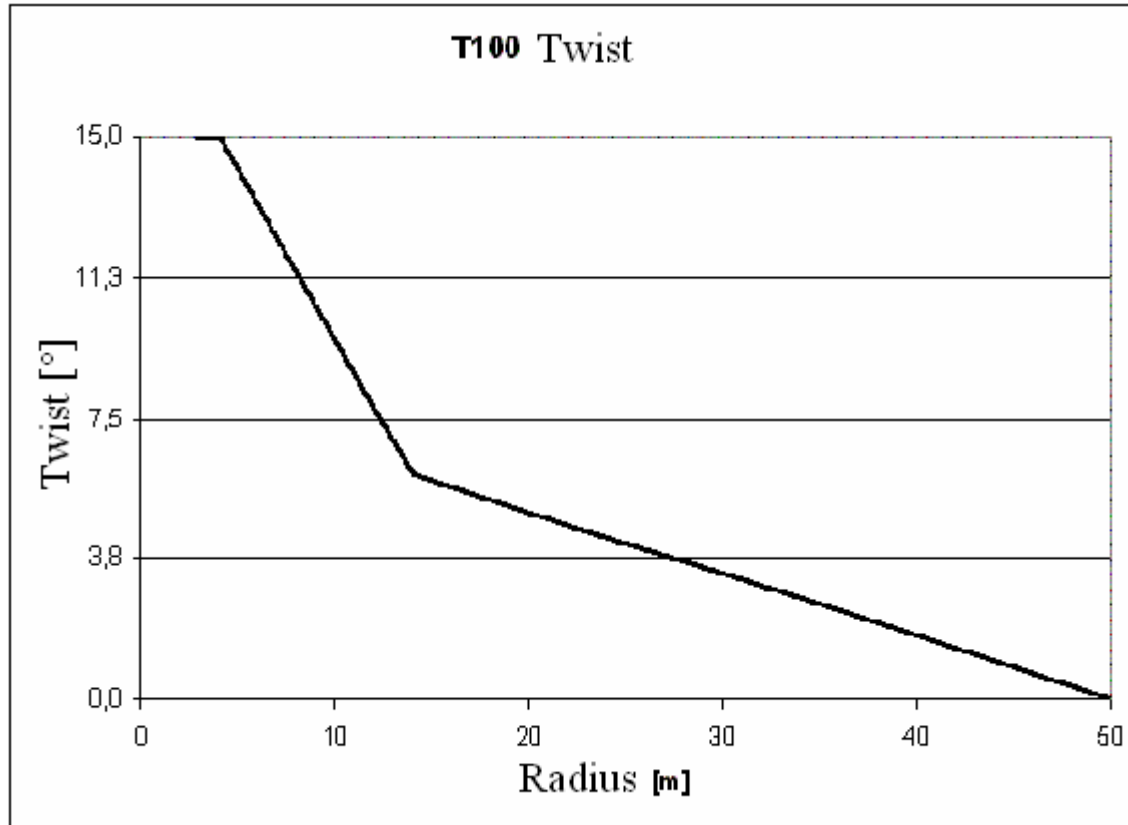
Tip Speed Ratios for the Shell Modell are :

At  $v_w = 15$  m/s,  $n = 0,45$  Hz,  $\lambda = 9,4$

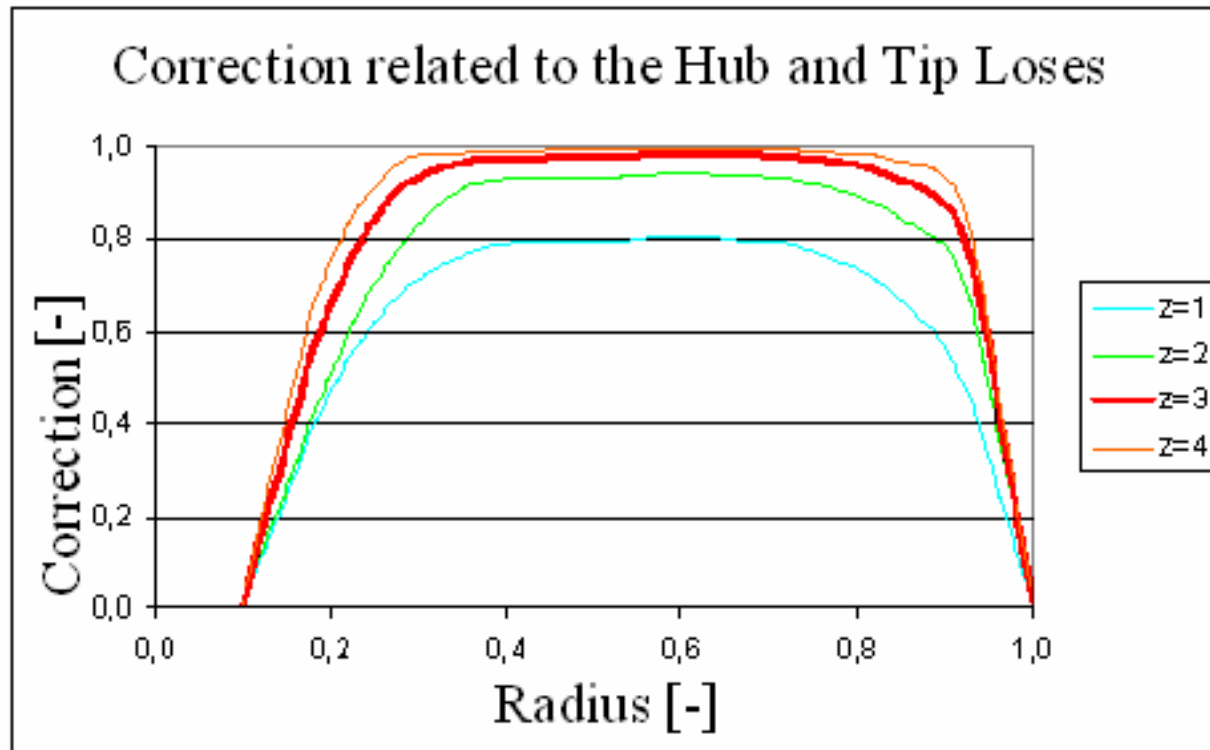
# Chord Length



# Twist



## Correction related to the Hub and Tip Loses



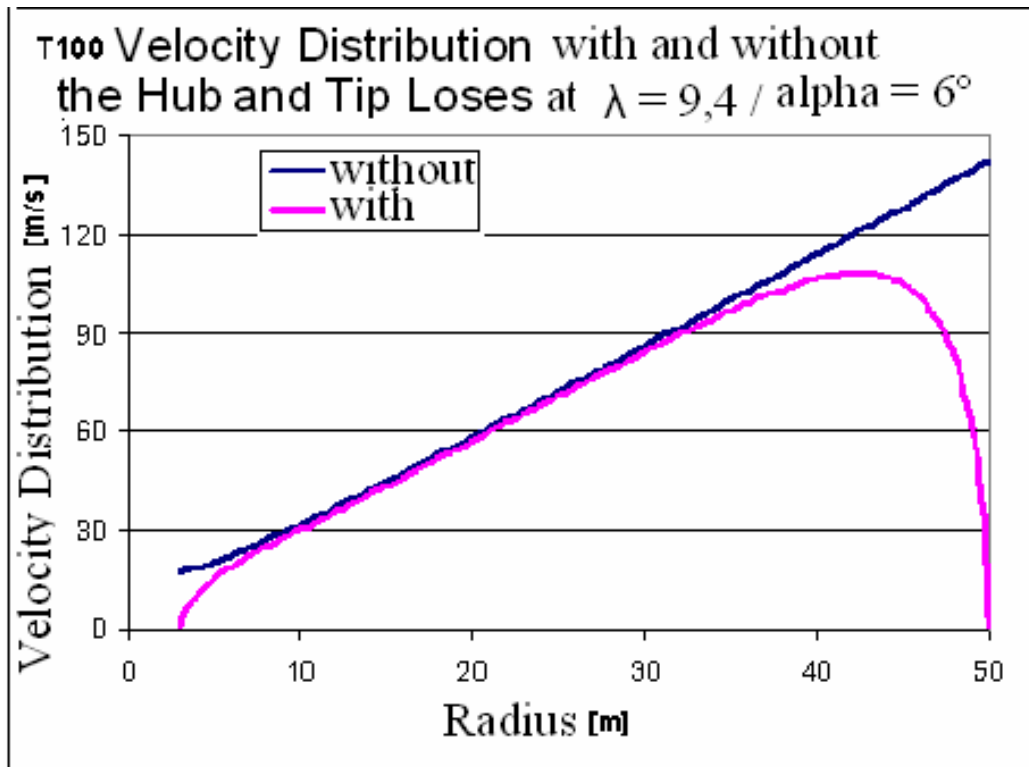
$$F = F_S \cdot F_N$$

Hub and Tip Loses [-]

$$F_S = \frac{2}{\pi} \arccos e^{-[z/(2 \sin \delta)](1-r/R_a)} \quad \text{Tip Loses} \quad [-]$$

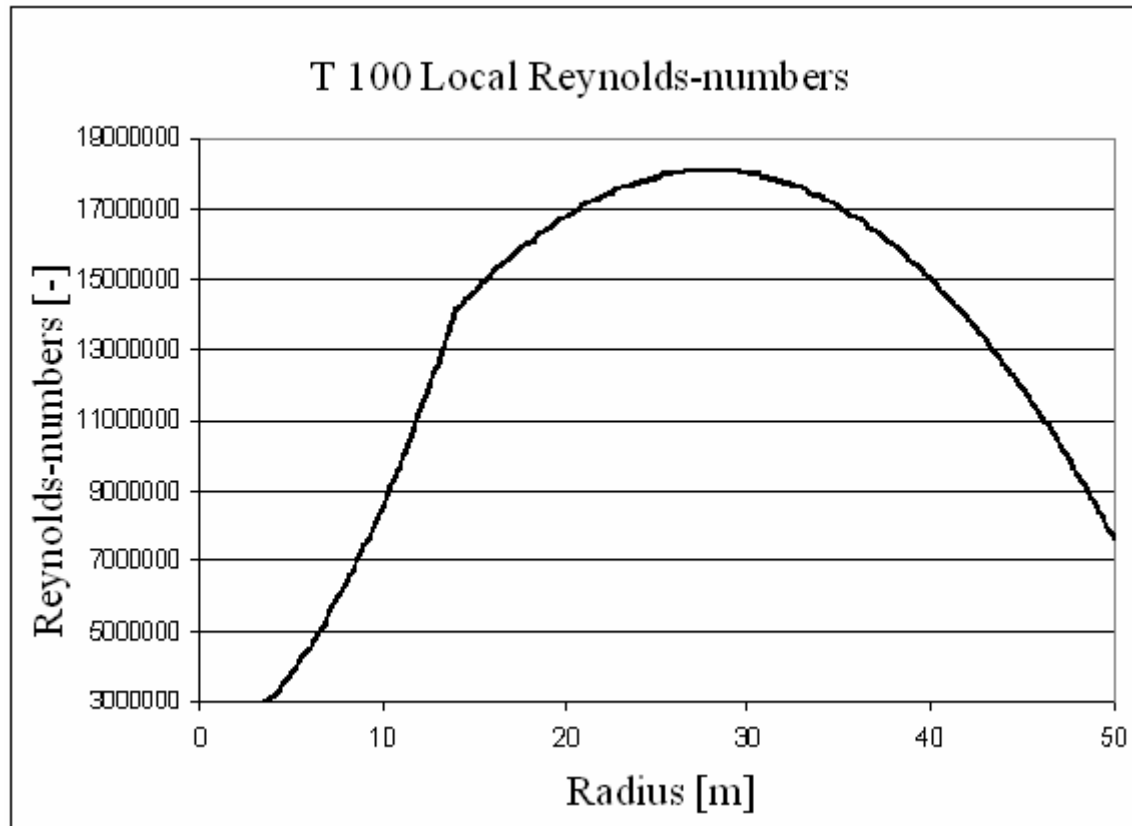
$$F_N = \frac{2}{\pi} \arccos e^{-[z/(2 \sin \delta)](r/R_i-1)} \quad \text{Hub Loses} \quad [-]$$

## Velocity Distribution



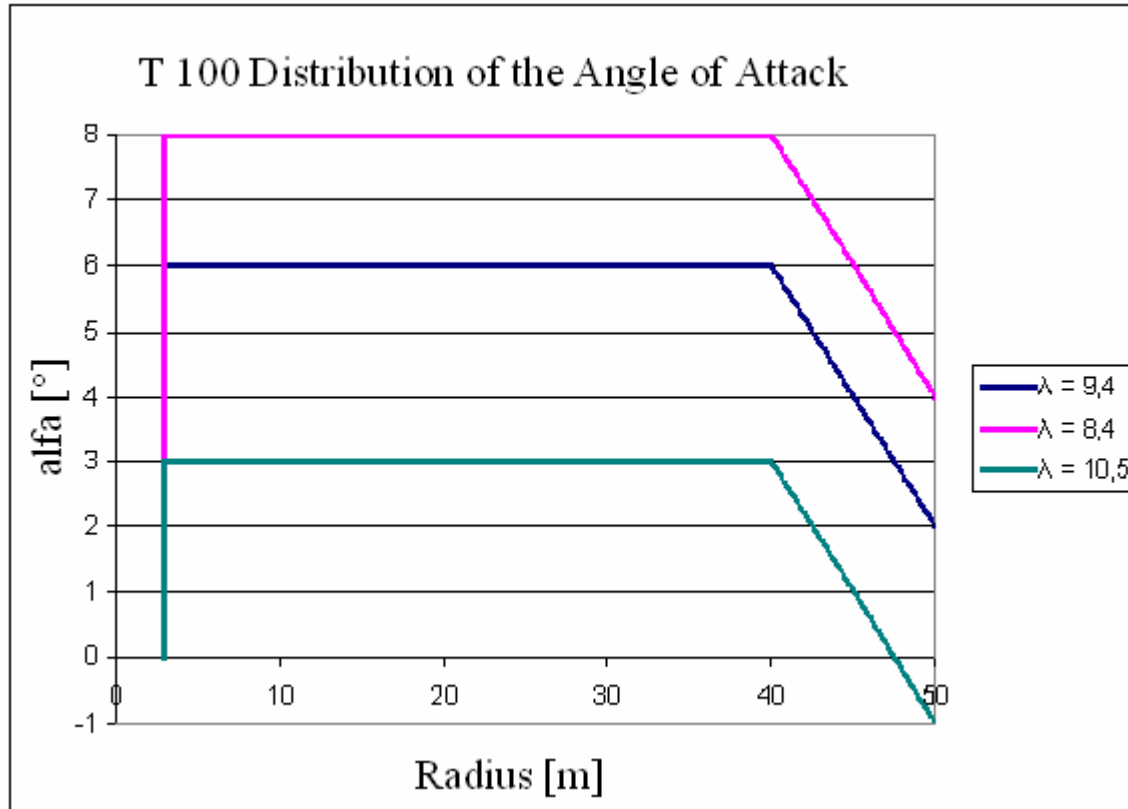
At the Design Tip Speed Ratio  $\lambda = 9,4$

## Diagram for the local Reynolds-numbers



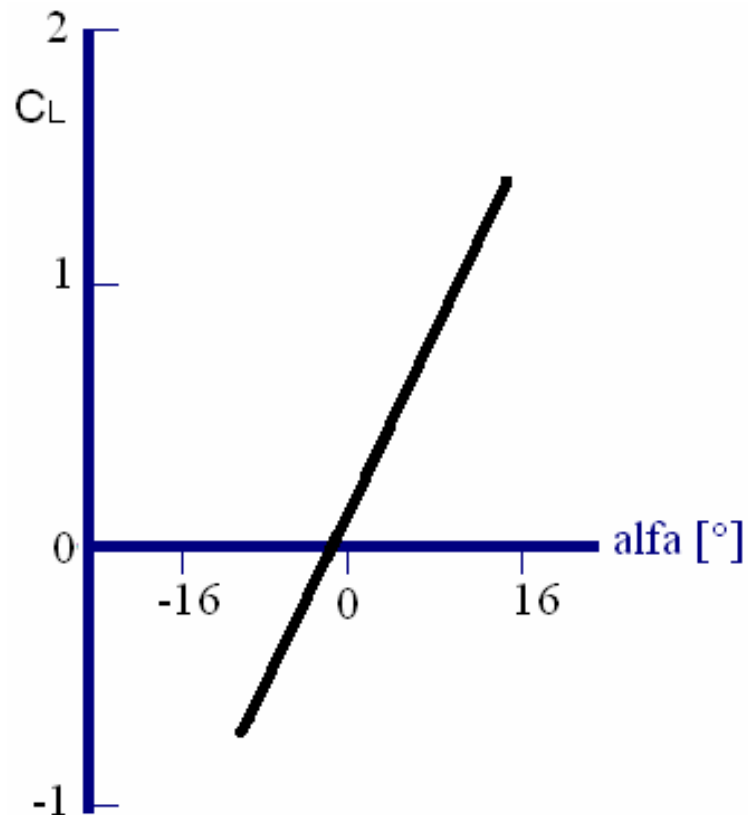
At the Design Tip Speed Ratio  $\lambda = 9,4$

## Distribution of the Angle of Attack



At Tip Speed Ratios  $\lambda = 8,4 / 9,4 / 10,5$

## Aerodynamics of the Beam Model



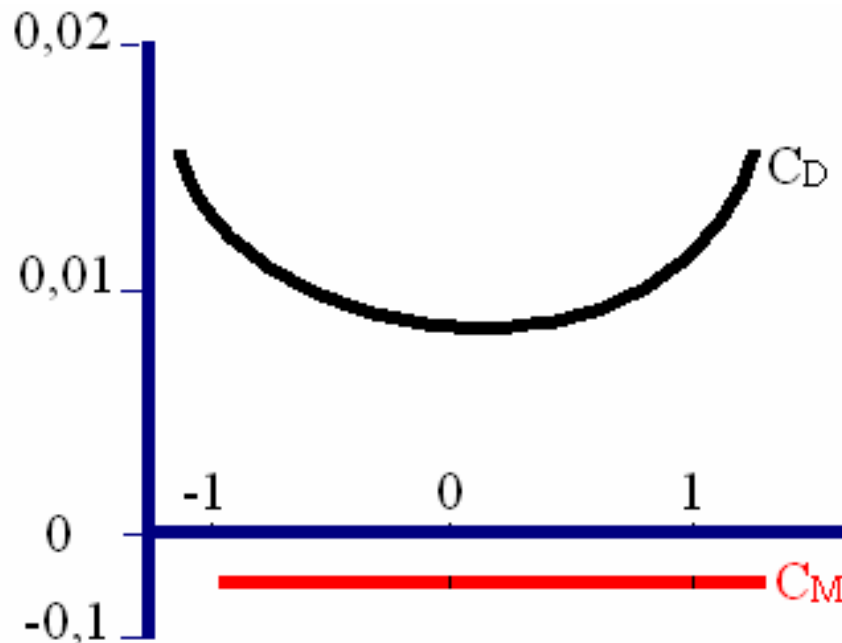
The aerodynamic loads for the 1/3-symmetrical aerodynamic Model:

$$A = C_L A_F q \text{ [N]} \quad \text{Lift}$$

$$q = (\rho/2) v^2 \text{ [N/m}^2\text{]} \quad \text{Stagnation Pressure}$$

Lift Data for naca2410

# Aerodynamics of the Beam Model

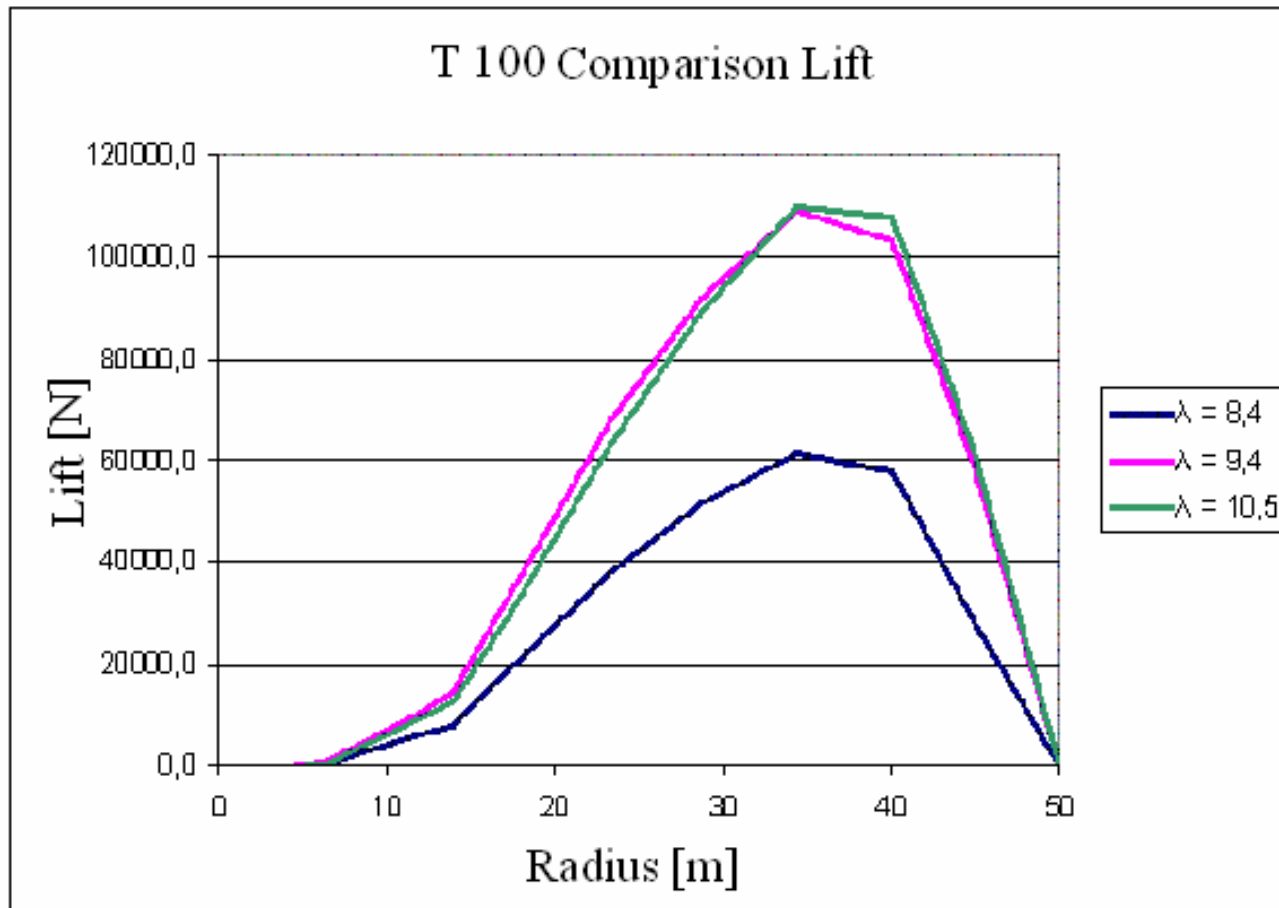


$$W = C_d A F q \quad [\text{N}] \text{ Drag}$$

$$M = C_m A F q c \quad [\text{N}] \text{ Pitching Moment}$$

Drag and Pitching Moment for  
naca2410

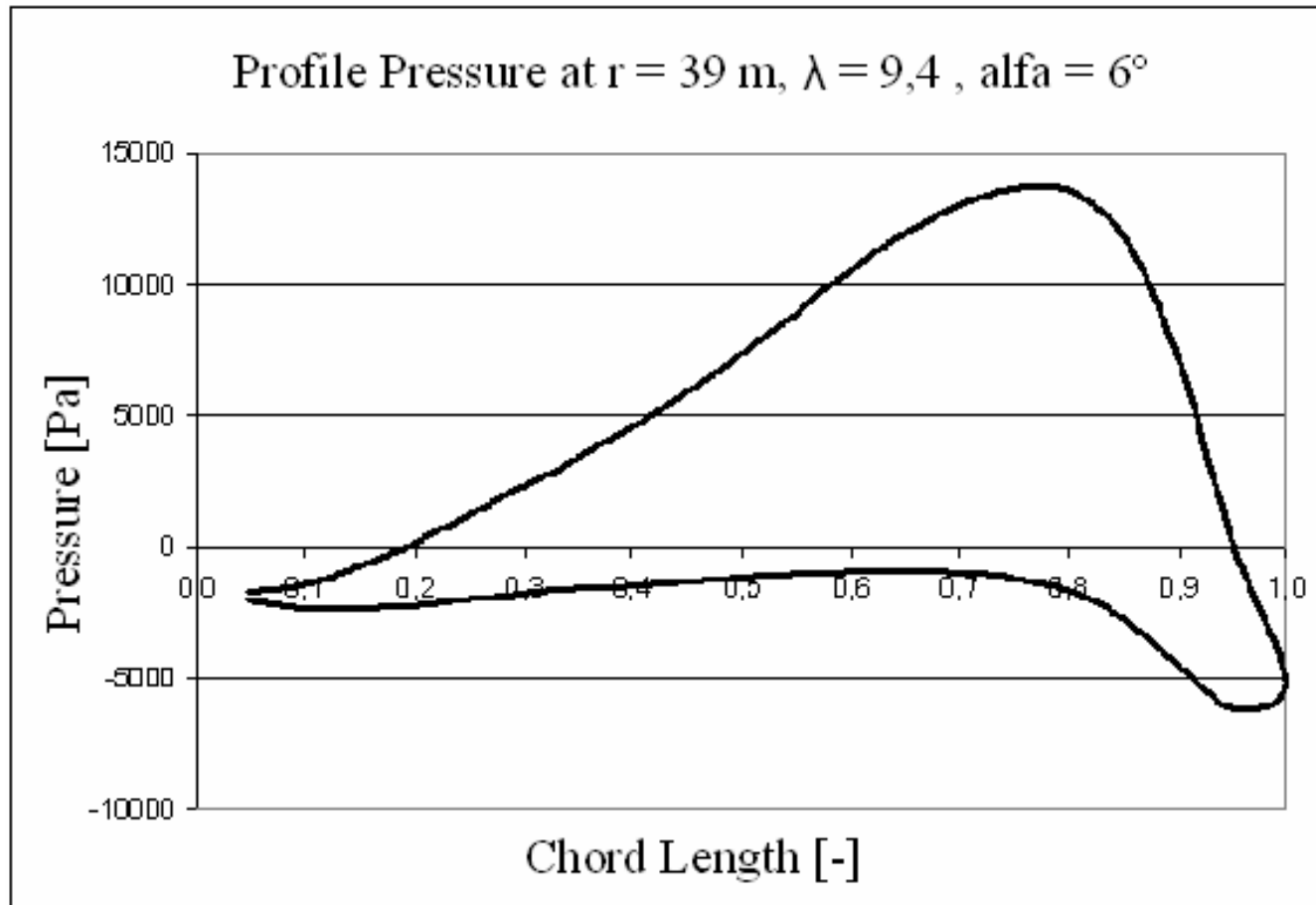
## Lift Distribution of the Beam Model



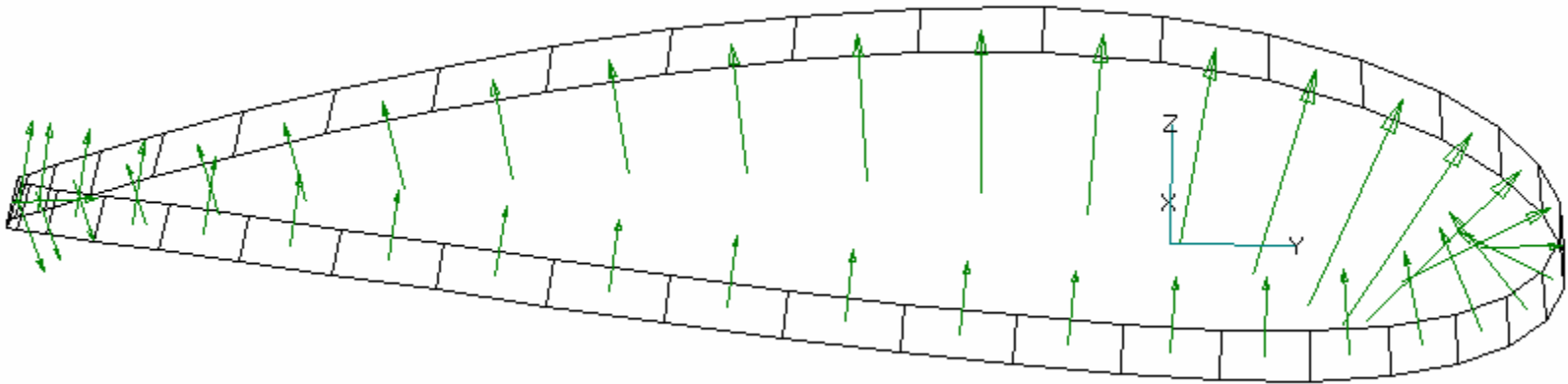
Comparison of the radial Lift Distribution at  $\lambda = 8,4 / 9,4 / 10,5$

# Aerodynamics of the Shell Model

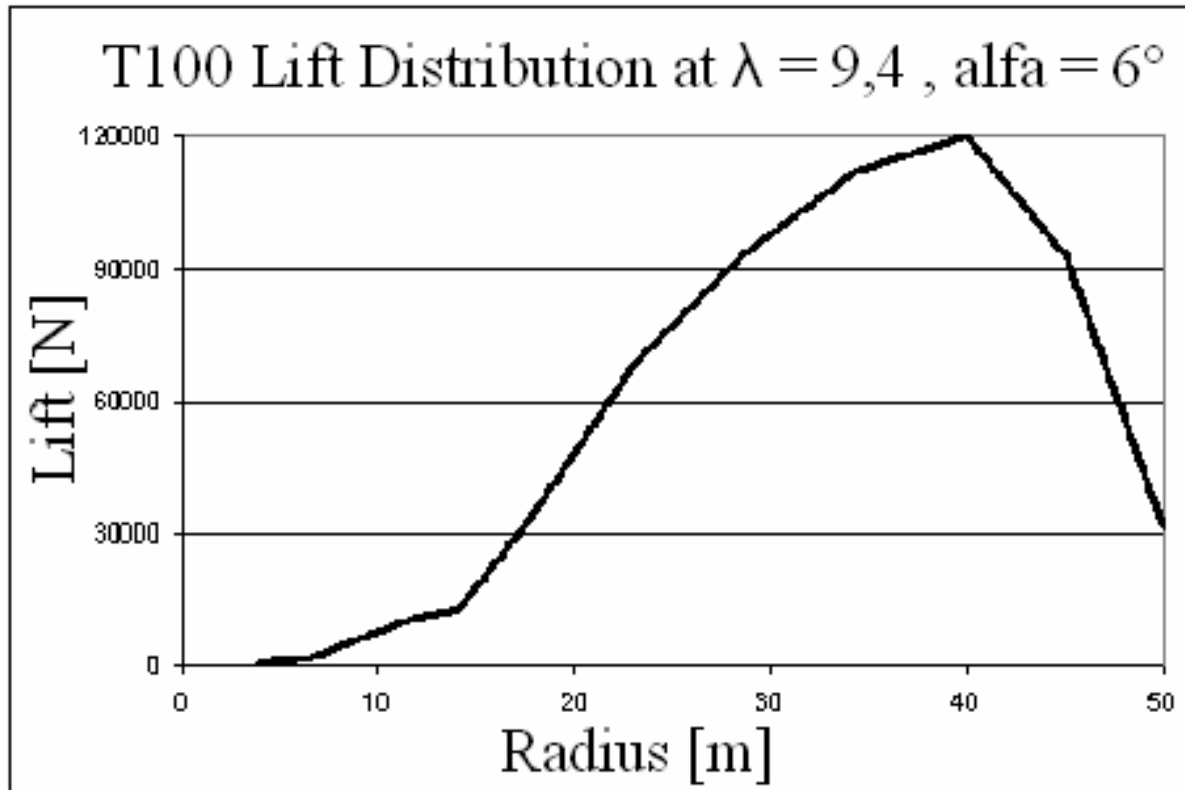
Pressure Distribution based on Panel Method and Potential Flow



## Interpolation of the Pressure Distribution using the Pressure Distribution of the adjacent Profiles

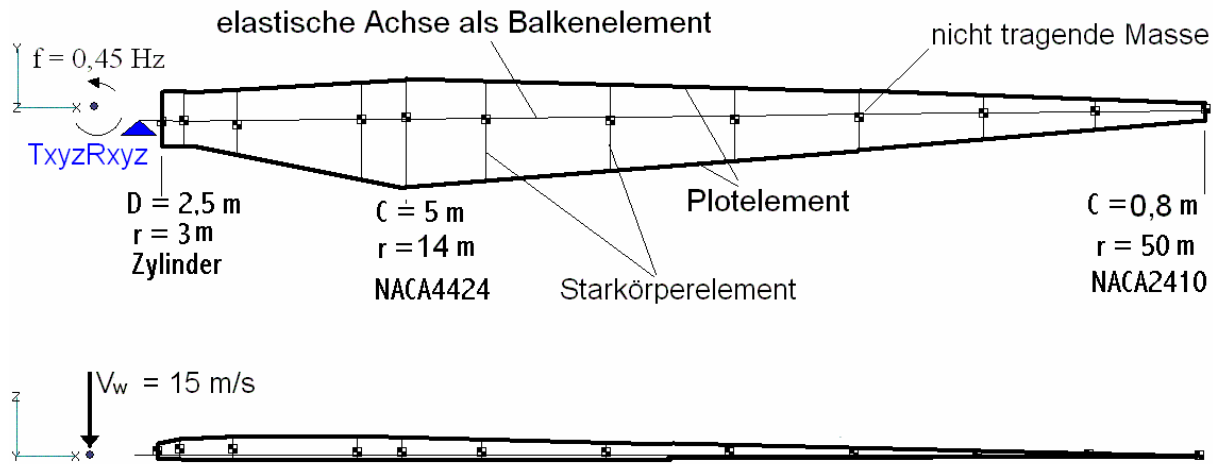


## Lift Distribution of the Shell Model



# Structure

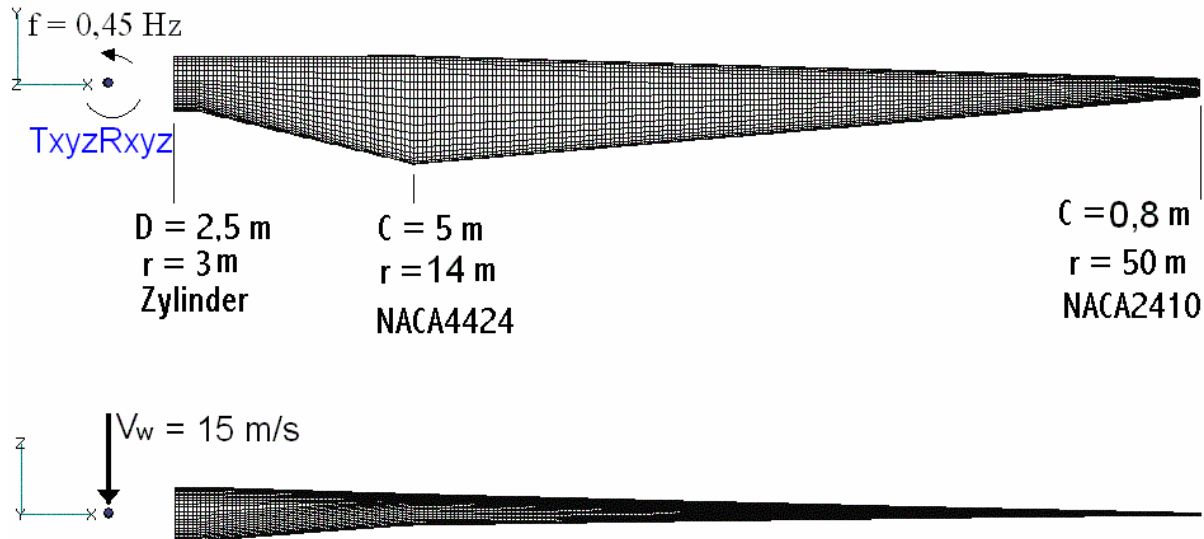
Beam Model: 62 nodes, 58 bars, masses, rigid bodies and plotel elements.



Mass: 8311 kg.

Center of Gravity:  $X = 14,1 \text{ m}$ ,  $Y = -0,6 \text{ m}$ ,  $Z = 0,04 \text{ m}$ .

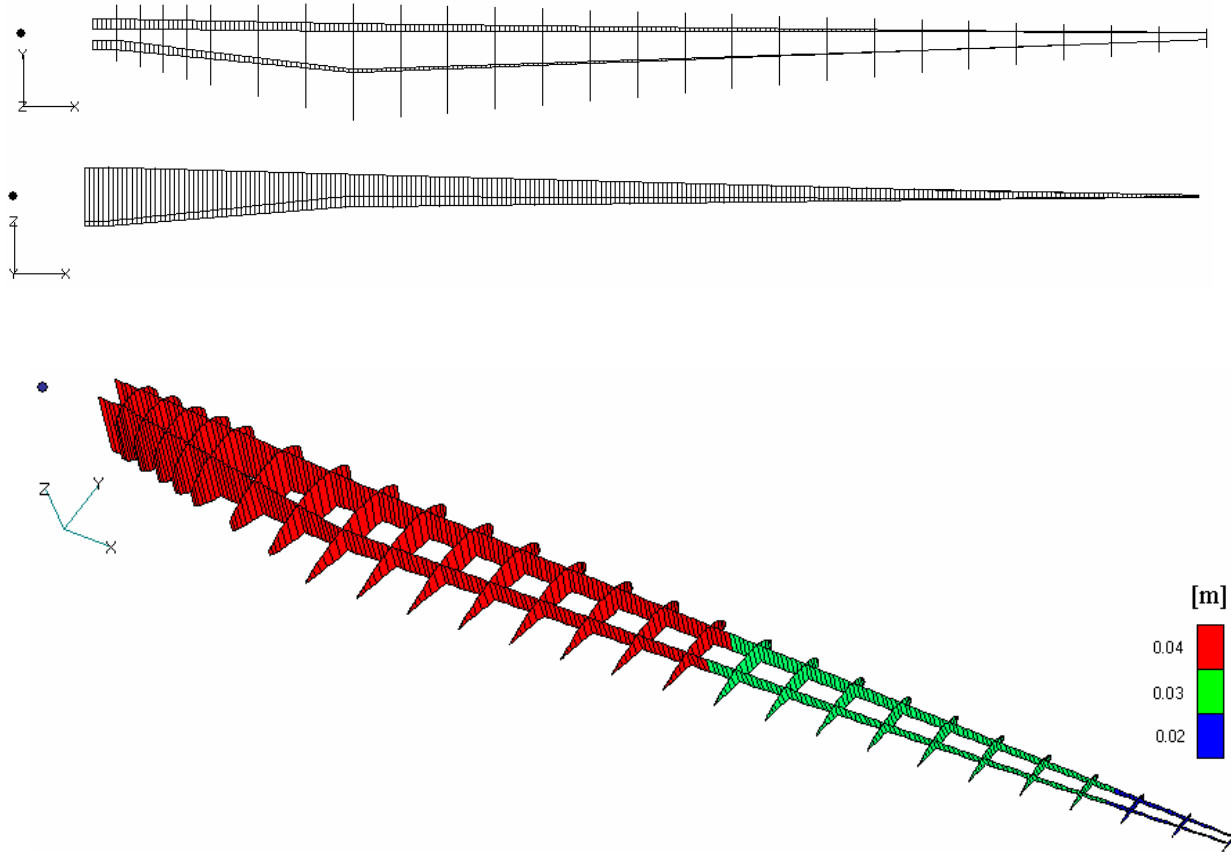
Shell Model: 9677 nodes, 31487 linear shell elements for the skin (composit), holms and ribs (isotrop).



Mass: 10106 kg.

Center of Gravity:  $X = 20,43 \text{ m}$ ,  $Y = -0,63 \text{ m}$ ,  $Z = 0,18 \text{ m}$ .

# Holms und Ribs of the Shell Model



# Boundary Condition, Loads, Calculation



Boundary Condition:  $T_{xyz}R_{xyz}$

Loads: aerodynamic Loads, Gravity, Centrifugal Loads

Computation: Modal Analysis and linear, static Computation with the Convergence Criterium  $\rightarrow$  Angle Deformation  $< 0,4^\circ$

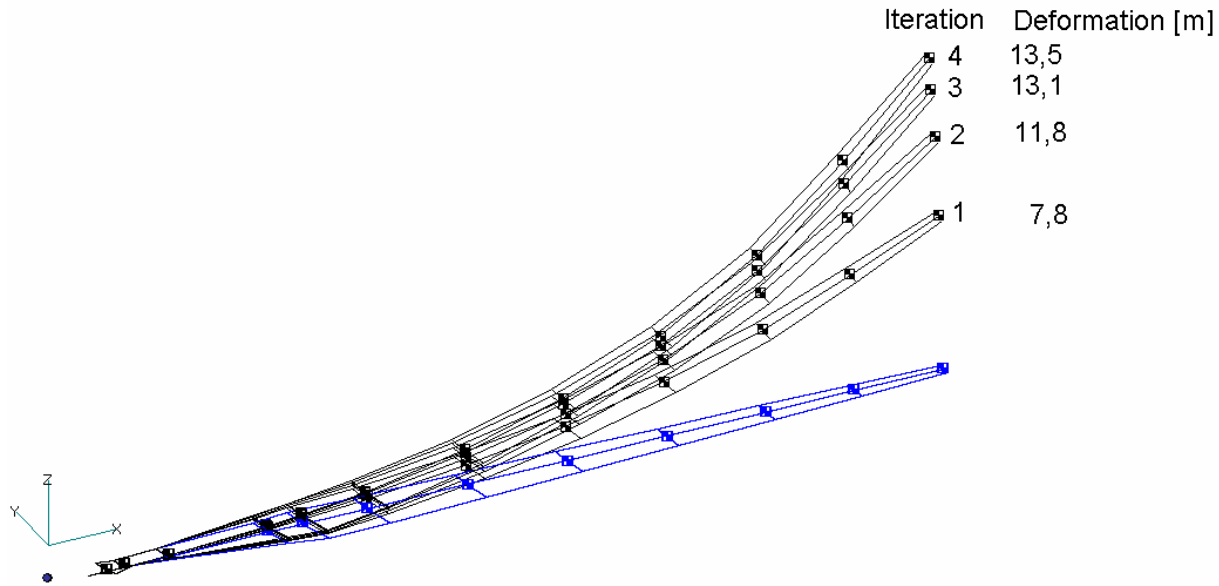
# Results

The first vibration mode of the Beam Model T100 is Flapping at 1,68 Hz.



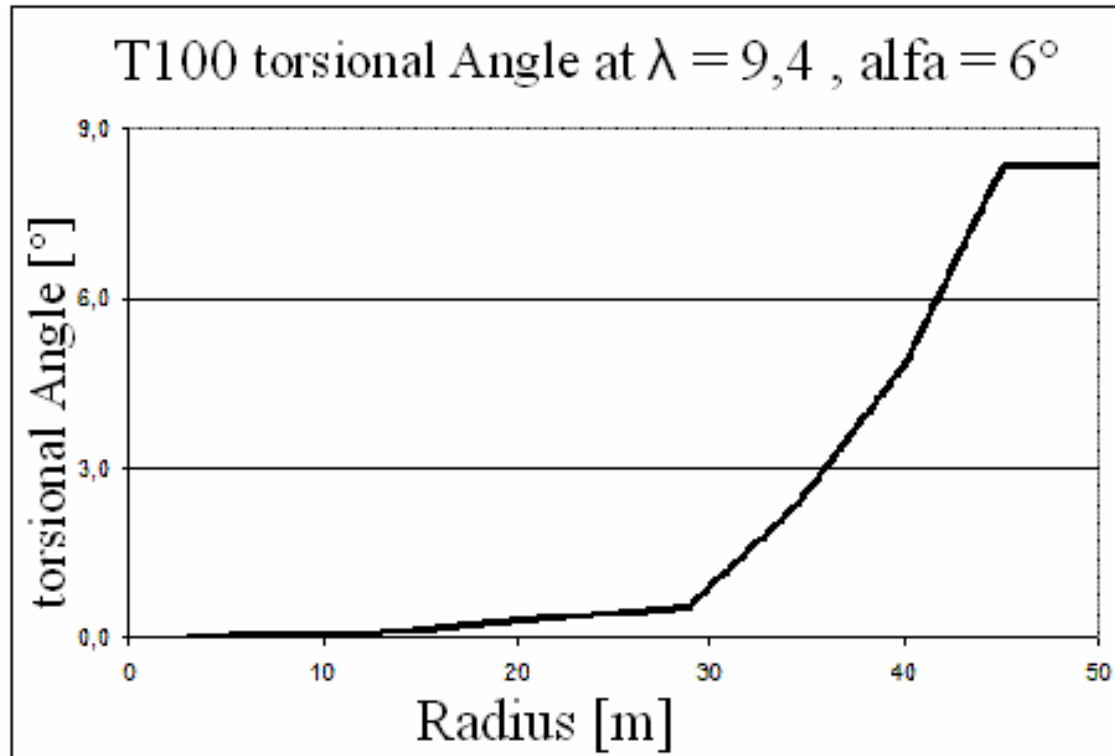
The first vibration mode of the Shell Model T100 is Flapping at 1,02 Hz.

# Results Beam Model



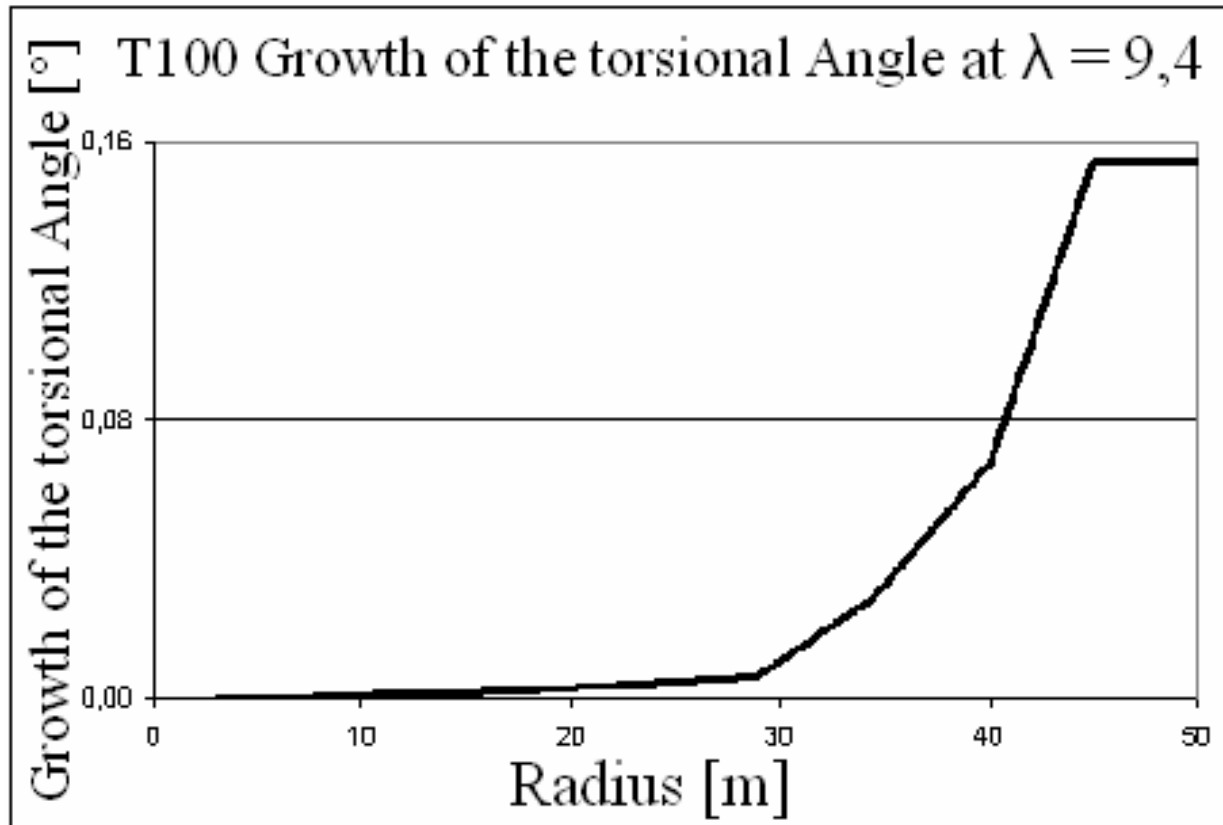
Deformations of the Beam Model T100 bei  $\lambda = 9,4$

# Results Beam Model



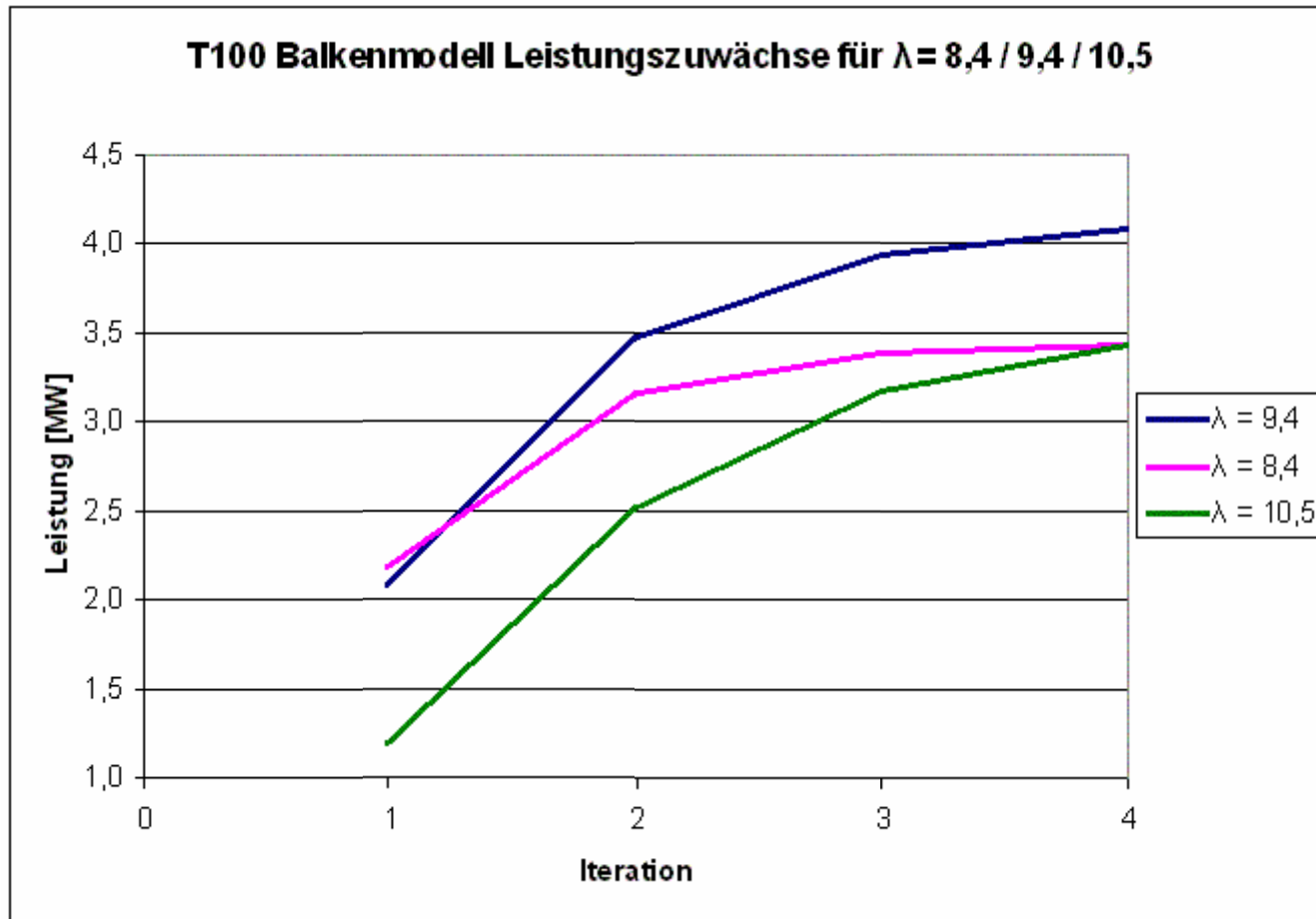
Distribution of the torsional Angle at  $\lambda = 9,4$

## Results Beam Model



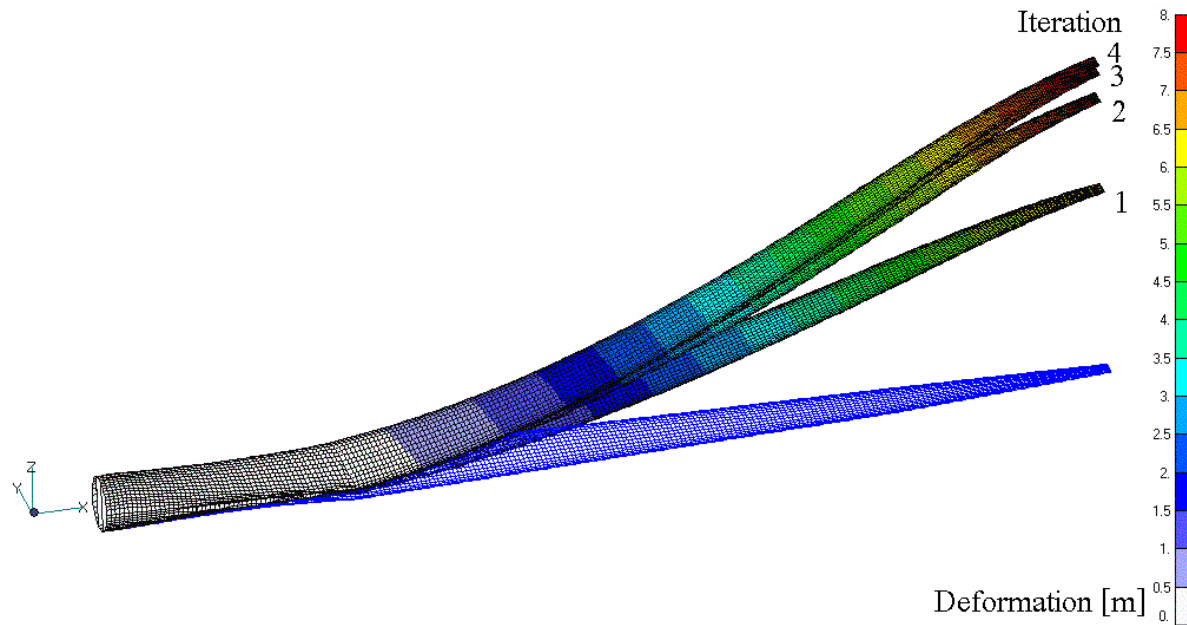
Growth of the torsional Angle at  $\lambda = 9,4$  from 3rd to 4th iteration

# Results Beam Model



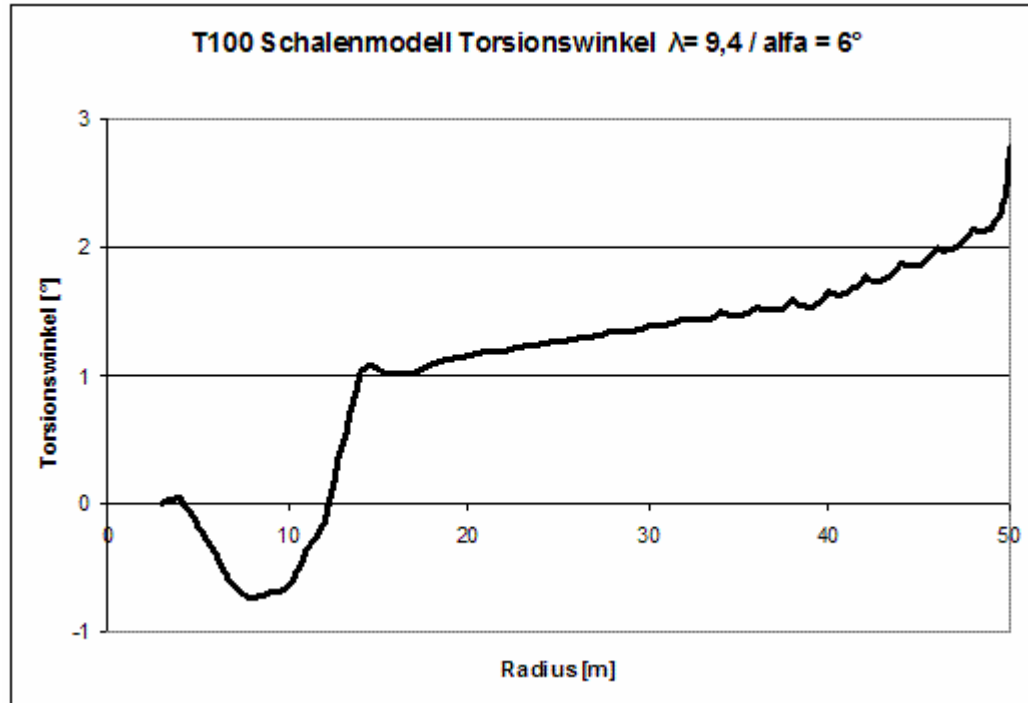
T100 Growth of the power at  $\lambda = 8,4 / 9,4 / 10,5$

# Results Shell Model



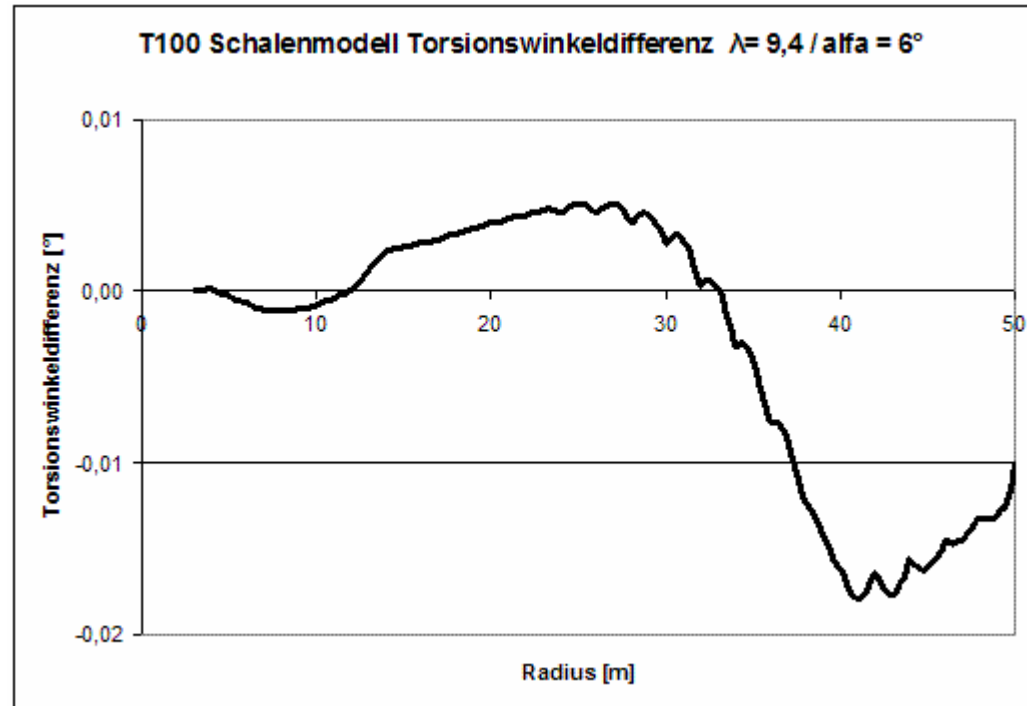
Deformations of the Shell Model T100 bei  $\lambda = 9,4$

# Results Shell Model



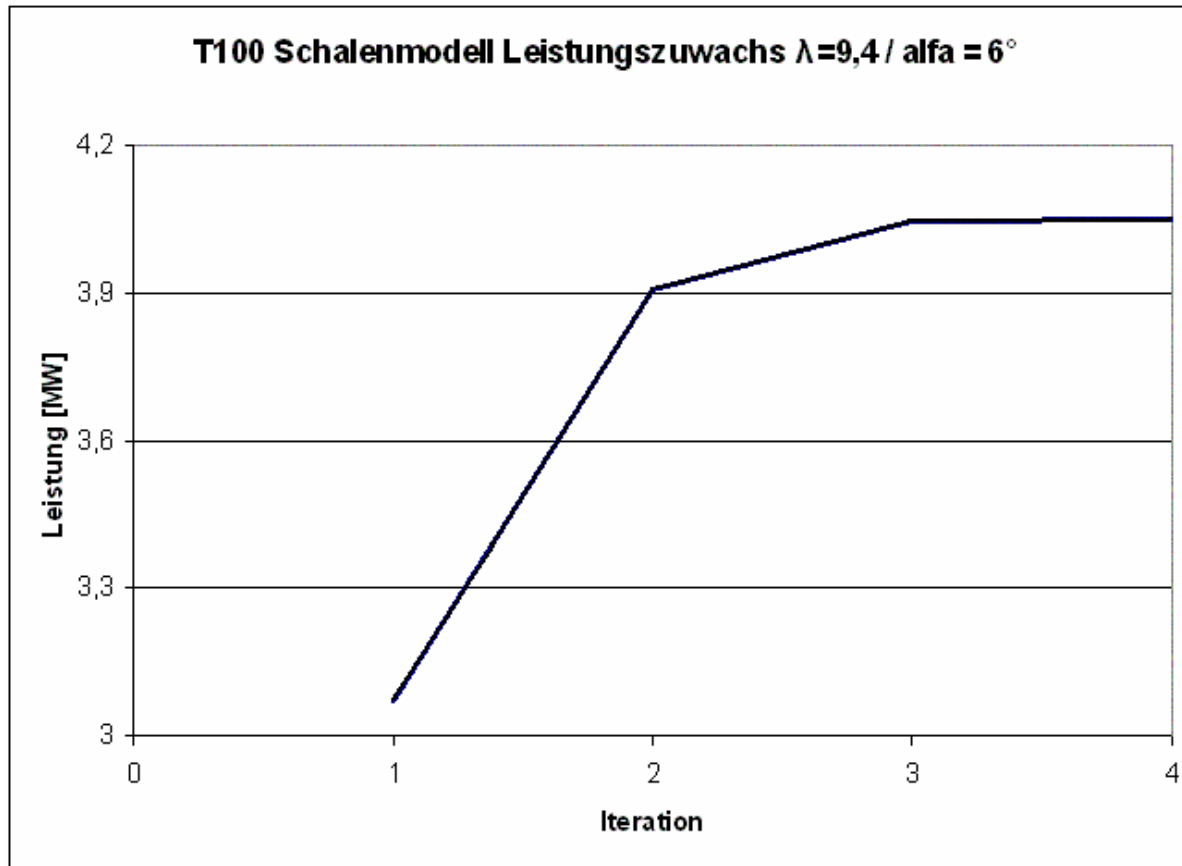
Distribution of the torsional Angle at  $\lambda = 9,4$

# Results Shell Model



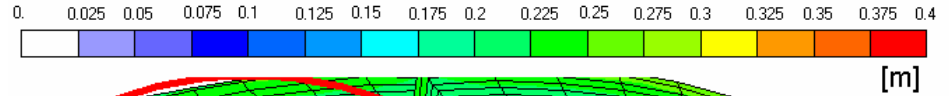
Growth of the torsional Angle at  $\lambda = 9,4$  from 3rd to 4th iteration

# Results Shell Model

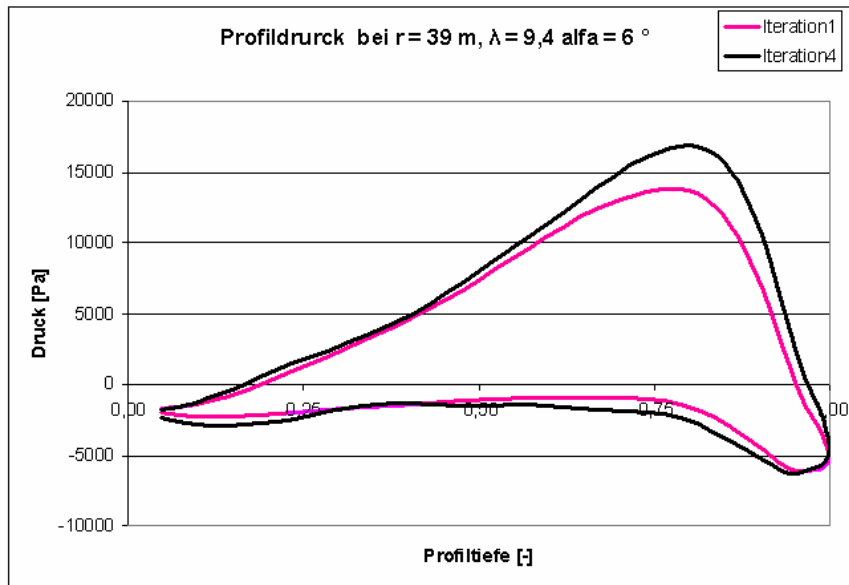
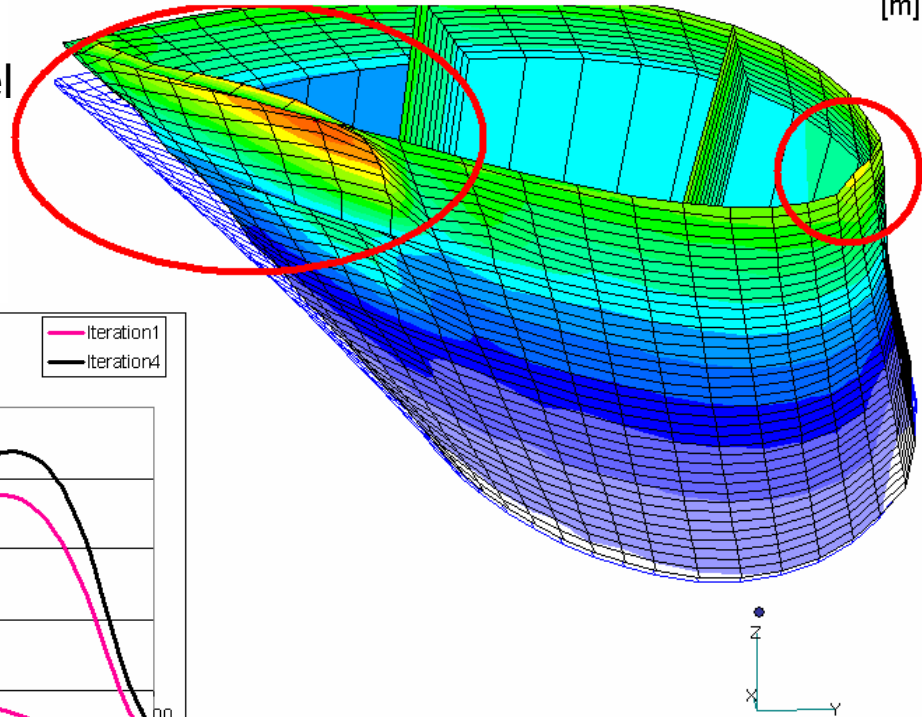


T100 Growth of the power, shell model at  $\lambda = 9,4$

# Results Shell Model



Deformations on the shell model related to the pressure load



# Summary

Comparison between a torsionally elastic and a torsionally rigid model indicates differences and in this paper it ends to a higher Power Balance for the elastic model.

Without the consideration of the torsional elasticity one will gain higher power balance at the upper region of the optimal Tip Speed Ratio than for the design Tip Speed Ratio.

It is to be recommended to use this computation method for the real wind turbine blades and to compare the results with the experimental data.