CENER

CENTRO NACIONAL DE ENEGÍAS RENOVABLES

NATIONAL RENEWABLE ENERGY CENTER OF SPAIN

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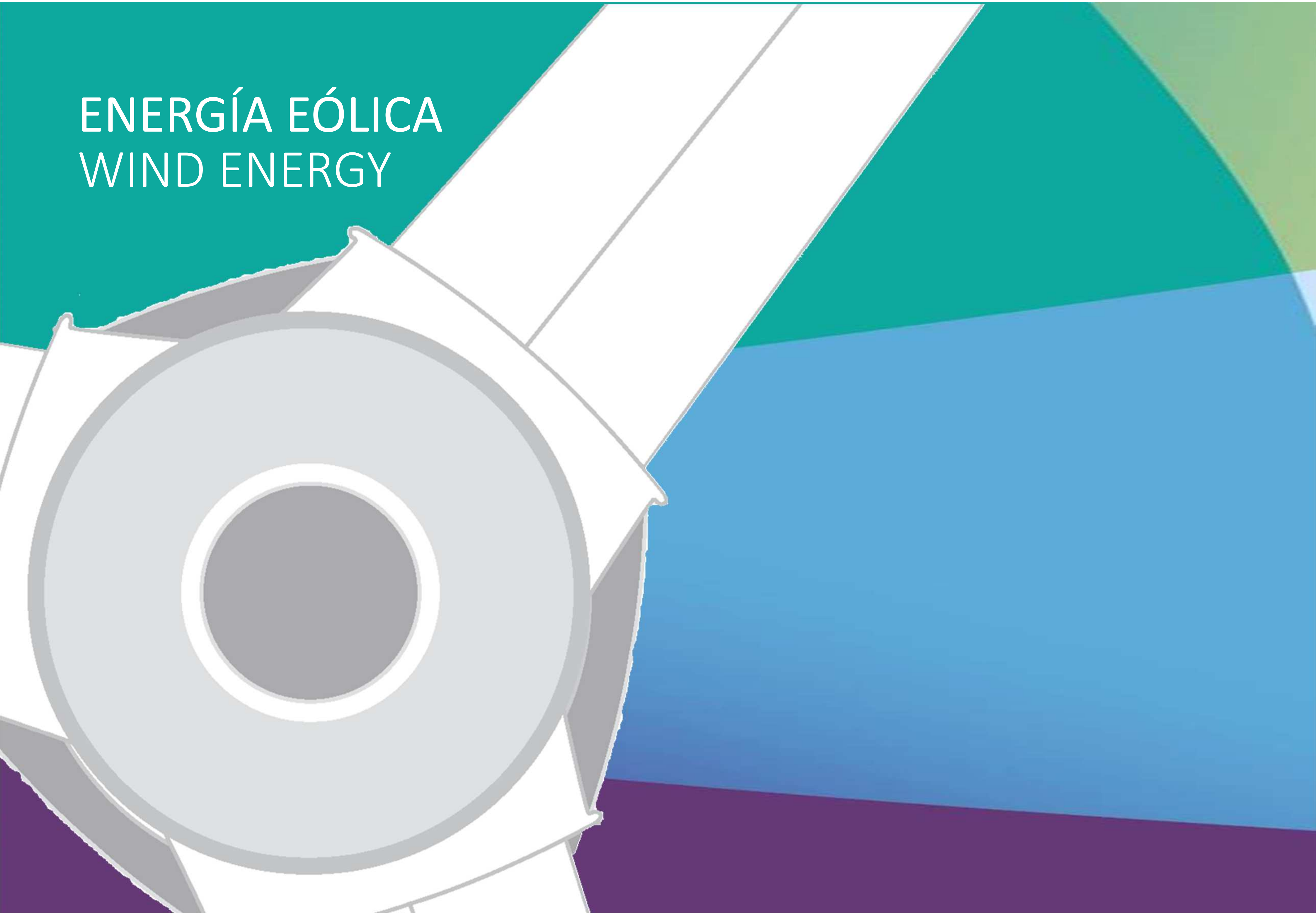
October 4, 2019

ENERGÍA EÓLICA
WIND ENERGY



BladeOASIS

CONTENT

- Introduction to BladeOASIS
- Running BladeOASIS
- Practical cases

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Blade Optimal **A**ero-**S**tructural **I**ntegrated **S**olutions

Blade Oasis

MDAO Tool for wind turbine blades

Simultaneous optimization of blade **geometry and structure**.

Can be used also for isolated aerodynamic or structural optimizations or analysis.

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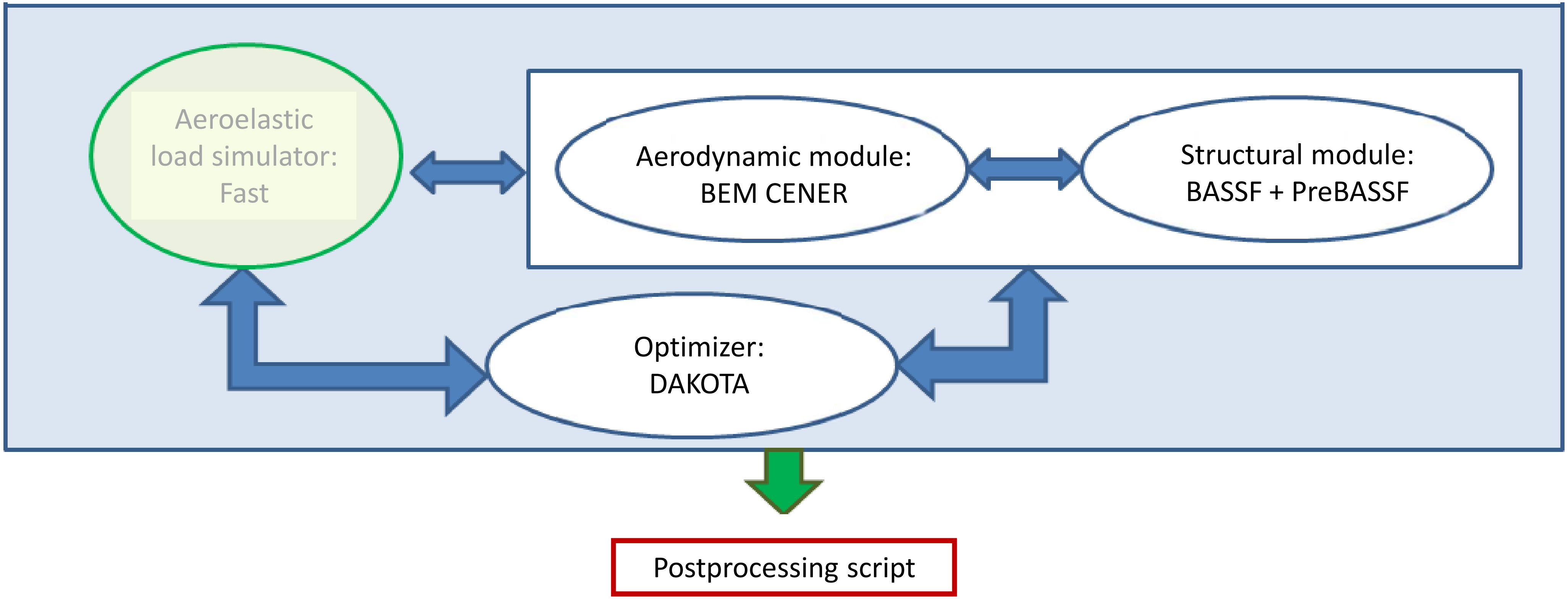
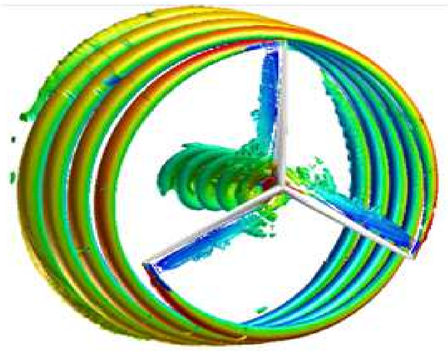
INTRODUCTION TO BLADEOASIS

Software Structure

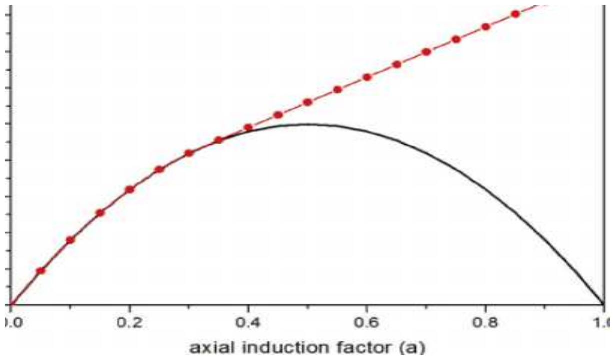


INTRODUCTION TO BLADEOASIS
Aerodynamic module

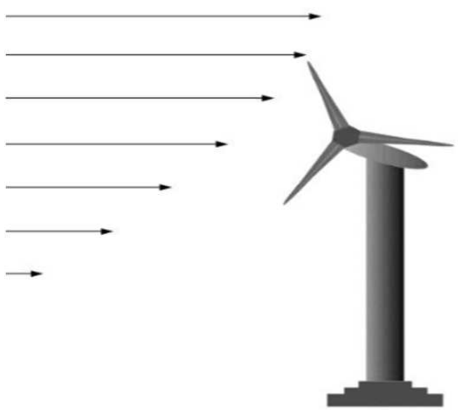
Aerodynamic Module – BEM CENER:



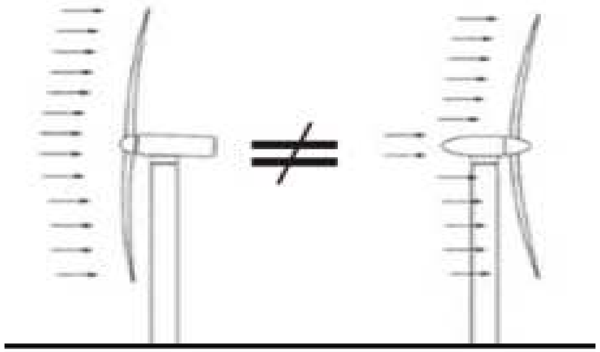
Tip and Root losses



Correction for high *CT*

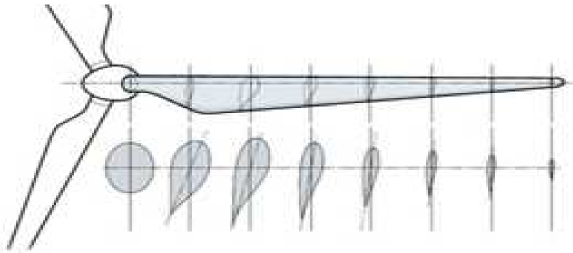


Wind shear



Tower shadow models:

Upwind and downwind



Automatic airfoil data

interpolation depending on t/c

Tilt

Precone

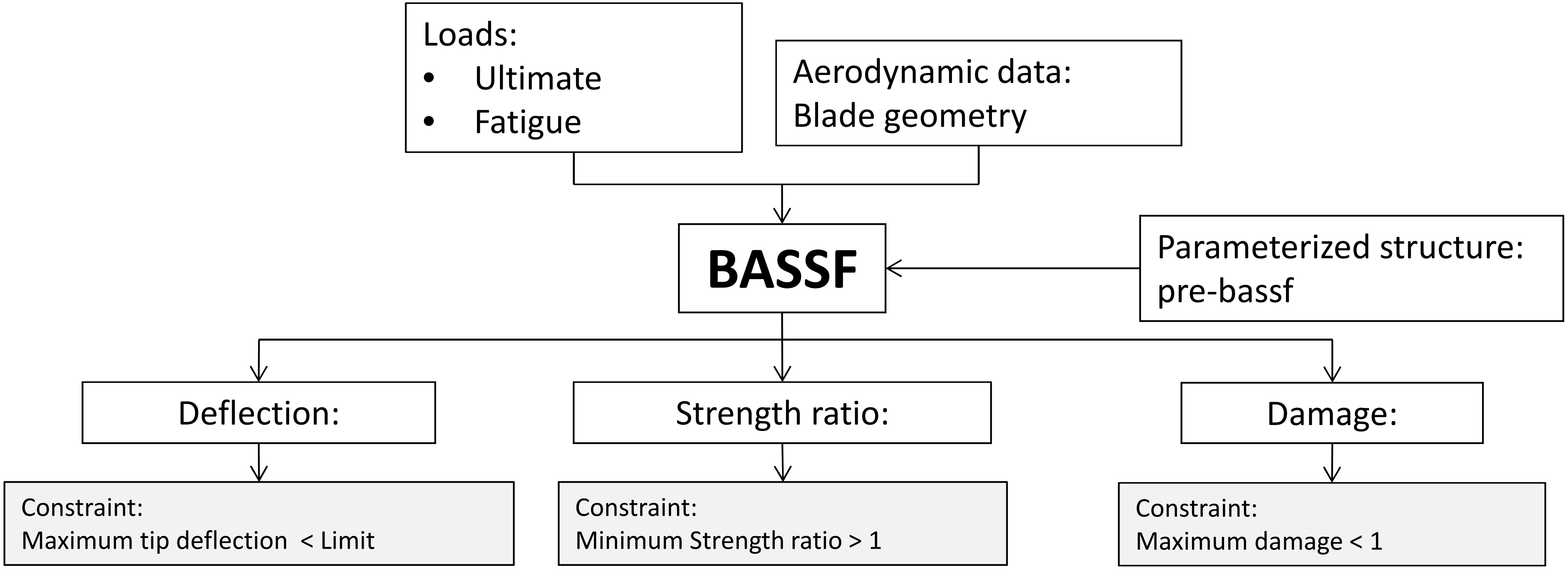
Prebend

Presweep

Yaw

INTRODUCTION TO BLADEOASIS
Structural module

- BASSF (Blade Analysis Stress Strain Failure): Analytical tool for the preliminary design of blades
- Based in 3 main theories:
  - Mechanical properties extraction:
    - ✓ Classical Laminate Theory (CLT)
  - Strength analysis:
    - ✓ Euler-Bernoulli Beam Theory (EBT): Axial strain
    - ✓ Thin-walled multi-cell beam theory (TMBT): Shear strain
- BASFF architecture:



INTRODUCTION TO BLADEOASIS
Capabilities

- Variables that define **blade geometry**
- Variables that define **blade structure**
- Variables that describe the **wind turbine**

= **Design Variables**

Optimizers from Dakota → **Genetic** algorithm (Coliny_ea)

Fitness functions:

Aerodynamic optimization:

- **Maximize AEP** or match an AEP
- Maximize CP o match a CP
- Minimize CT o match a CT
- Combination of max CP and min CT

Structural optimization:

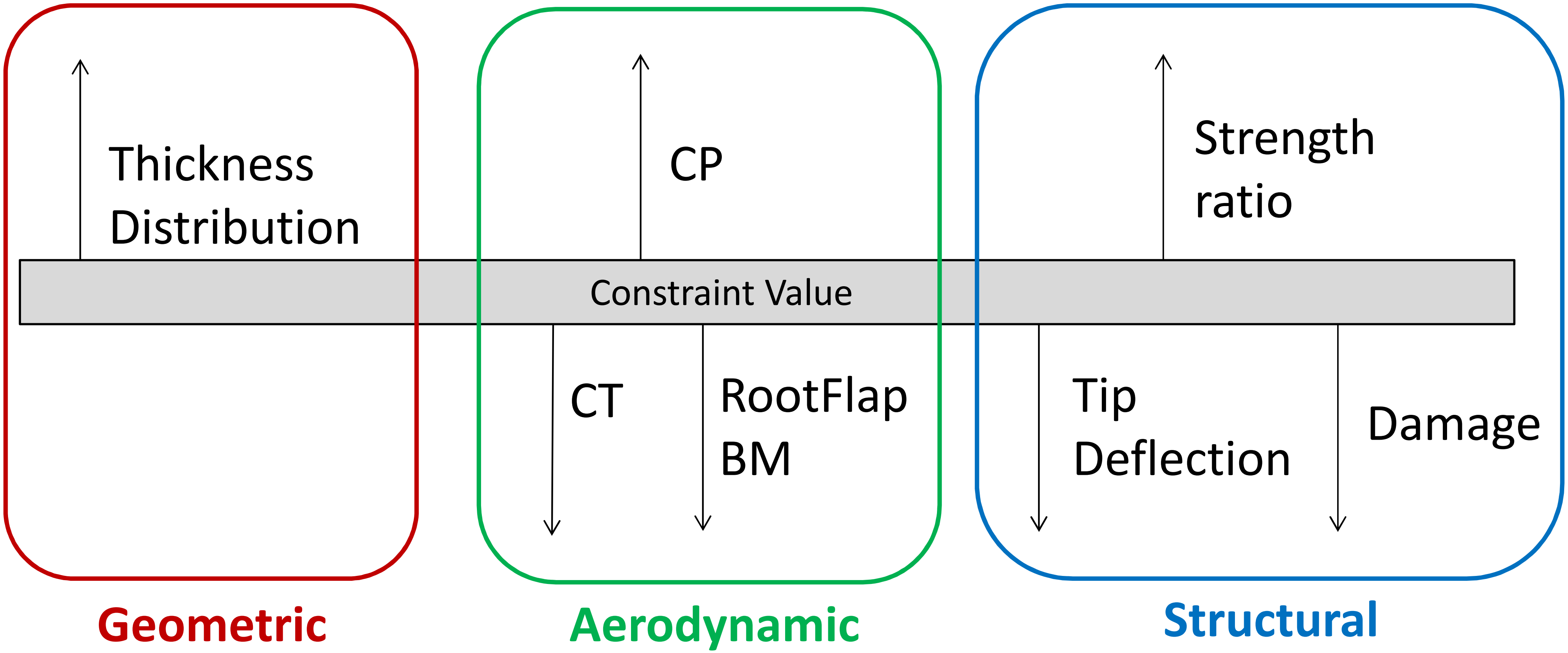
- **Minimize** or match **BladeMass**

Aero-Structural optimization:

- Combination of **max AEP & min BladeMass**
- Minimize **COE**

INTRODUCTION TO BLADEOASIS
Constraints

Available constraints:



BladeOASIS

CONTENT

RUNNING BLADEOASIS

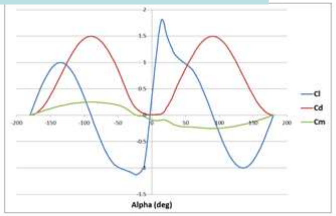
Inputs for the aerodynamic module

Airfoil data

- Cylinder_originalDTU.dat
- FFA_W3_241_originalDTU.dat
- FFA_W3_301_originalDTU.dat
- FFA_W3_360_originalDTU.dat
- FFA_W3_480_originalDTU.dat
- FFA_W3_600_originalDTU.dat

t/c of the airfoil
# of points

No need to have data in the whole [-180 ;180] deg range



24.1
105

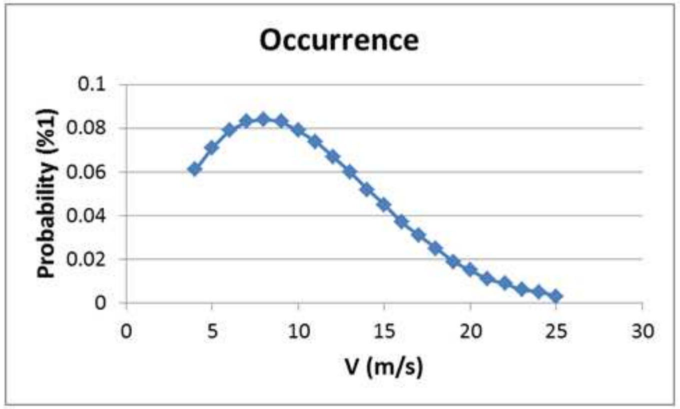
Alpha	Cl	Cd	Cm
-180	0.0000	0.0000	0.0000
-175	0.1736	0.0114	0.0218
-170	0.3420	0.0452	0.0434
-165	0.5000	0.1005	0.0647
-160	0.6428	0.1755	0.0855
-155	0.7660	0.2679	0.1057
-150	0.8660	0.3750	0.1250
[illegible]	0.9397	0.4935	0.1434
-140	0.9848	0.6197	0.1607
-135	1.0000	0.7500	0.1768
-130	0.9848	0.8803	0.1915
-125	0.9397	1.0065	0.2048
-120	[illegible]	1.1250	0.2165
-115	0.7660	1.2321	0.2266
-110	0.6428	1.3245	0.2349
-105	0.5000	1.3995	0.2415
-100	0.3420	[illegible]	0.2462
-95	0.1736	1.4886	0.2490
-90	0.0000	1.5000	0.2500
-85	-0.1736	1.4886	0.2490
-80	-0.3420	1.4548	0.2462
-75	-0.5000	1.3995	[illegible]
-70	-0.6428	1.3245	0.2349
-65	-0.7660	1.2321	0.2266
-60	-0.8660	1.1250	0.2165
-55	-0.9397	1.0065	0.2048
-50	-0.9848	0.8603	0.1915
-45	-1.0120	0.7120	0.1708
-40	-1.0376	0.5475	0.1416
-39	-1.0419	0.5165	0.1346
-38	-1.0462	0.4816	0.1276
-37	-1.0525	0.4487	0.1185
-36	-1.0568	0.4177	0.1095
-35	-1.0611	0.3848	0.1005
-34	-1.0654	0.3558	0.0894
-33	-1.0717	0.3289	0.0824
-32	-1.0765	0.3031	0.0678
-30	-1.0889	0.2560	0.0508
-28	-1.0993	0.2090	0.0337
-26	-1.1168	0.1756	0.0206
-24	-1.1282	0.1423	0.0075
-22	-1.1215	0.1183	-0.0008
-20	-1.1148	0.0943	-0.0091
-18	-1.0919	0.0765	-0.0123
-16	-1.0691	0.0587	-0.0156
-14	-1.0379	0.0454	-0.0156
-12	-1.0067	0.0321	-0.0155
-10	-0.8479	0.0230	-0.0318

Wind distribution

of lines = wind speeds

V (m/s) , Frequency

```
22
4,0.061
5,0.071
6,0.079
7,0.083
8,0.084
9,0.083
10,0.079
11,0.074
12,0.067
13,0.060
14,0.052
15,0.045
16,0.037
17,0.031
18,0.025
19,0.019
20,0.015
21,0.011
22,0.009
23,0.006
24,0.005
25,0.003
```



WT Configuration

```
89.166            -RTIP (m)
2.8               -RROOT (m)
4.15              -TOWERRBASE radius(m)
2.75              -TOWERRTOP radius(m)
5.38              -CROOT (m)
0.6               -CTIP (m)
119               -HUBHEIGHT (m)
3                 -NBLADES
1                 -TLOSS: 1= TIPLOSS & HUBLOSS
1                 -WINDDAT: 1= read WIND file
10.0              -Vdes (m/s)
0.2               -SHEAR_FACTOR
7.5               -TSR
9.6               -OMEGA MAX (rpm)
6.0               -OMEGA_MIN (rpm)
1                 -varPITCH
0.0               -PITCH (deg)
0                 -YAW (deg)
(tilt)            -TILT (deg)
2.5               -CONE (deg)
1.828D-5          -VISC (dynamic=rho*kinematic)
1                 -RANGE (1=detailed, 0=coarse)
4                 -TSR_MIN
12                -TSR_MAX
0                 -TWR (=1 calculate tower)
1                 -TWRSHADOW (=1 pot =2 def =3 bak)
"Tower_file.txt"        -TWRfile
7.1               -OverHang
0                 -DOWNW
0                 -LOSSES (valor de perdidas en porcentaje)
10000             -POWER RATED (kW)
1.245             -RHO (kg/m^3)
0.005             -CVA
36                -AZIMUT_DISC
115.63            -TOWER HEIGHT (m)
20                -LIFETIME (years)
54002.149390      -AEP REF (MWh)
50608.7253635     -MASS REF (kg)
0.443396          -CPref
0.756782          -CTref
2899.869          -RtFlapMomRef
```

Blade Configuration

l/L	chord	twist	t/c	prebend	presweep
0.0000	5.3800	14.5000	100.0000	0.0000	0
0.0023	5.3800	14.5000	99.9757	0.0007	0
0.0058	5.3800	14.5000	99.9392	0.0019	0
0.0087	{chord4}	{twist4}	{tc4}	0.0029	0
0.0116	{chord5}	{twist5}	{tc5}	0.0039	0
0.0342	{chord6}	{twist6}	{tc6}	0.0120	0
0.0662	{chord7}	{twist7}	{tc7}	0.025271403	0
0.0953	{chord8}	{twist8}	{tc8}	0.038891079	0
0.1343	{chord9}	{twist9}	{tc9}	0.060943767	0
0.1778	{chord10}	{twist10}	{tc10}	0.091045244	0
0.2011	{chord11}	{twist11}	{tc11}	0.109504287	0
0.2316	{chord12}	{twist12}	{tc12}	0.137428217	0
0.285517449	{chord13}	{twist13}	{tc13}	0.198156186	0
0.358983859	{chord14}	{twist14}	{tc14}	0.305291054	0
0.464048352	{chord15}	{twist15}	{tc15}	0.519610579	0
0.612173772	{chord16}	{twist16}	{tc16}	0.973077735	0
0.765602205	{chord17}	{twist17}	{tc17}	1.677887822	0
0.845240025	{chord18}	{twist18}	{tc18}	2.153996333	0
0.914074983	{chord19}	{twist19}	{tc19}	2.634672068	0
0.964754649	{chord20}	{twist20}	{tc20}	3.032167447	0
0.977873237	{chord21}	{twist21}	{tc21}	3.141443933	0
0.995113818	{chord22}	{twist22}	{tc22}	3.301786163	0

RUNNING BLADEOASIS
Inputs for the structural module

Blade geometry

Blade definition	
Blade name	INNWIND
Blade lenght [m]	86.37
Hub diameter [m]	5.6

Architecture Configuration						
Sec_number	Af_shape_file	Twist_aero [°]	Chord [m]	Le_loc [°/1 chord]	Span_loc [°/1 span]	tw_web [°]
1	estac_01_bassf.txt	14.50	5.380	0.500	0.000	0
2	estac_02_bassf.txt	14.50	5.380	0.500	0.002	0
3	estac_03_bassf.txt	14.50	5.380	0.500	0.006	0
4	estac_04_bassf.txt	15.44	5.440	0.500	0.009	0
5	estac_05_bassf.txt	15.43	5.500	0.500	0.012	0
6	estac_06_bassf.txt	15.31	5.992	0.500	0.034	0
7	estac_07_bassf.txt	14.98	6.752	0.500	0.066	0
8	estac_08_bassf.txt	14.56	7.414	0.494	0.095	0
9	estac_09_bassf.txt	13.82	8.092	0.466	0.134	0
10	estac_10_bassf.txt	12.84	8.346	0.427	0.178	0
11	estac_11_bassf.txt	12.26	8.231	0.410	0.201	0
12	estac_12_bassf.txt	11.46	7.918	0.392	0.232	0
....	....	....	....	....	....	....
21	estac_21_bassf.txt	-3.29	1.156	0.350	0.978	0
22	estac_22_bassf.txt	-3.76	0.512	0.350	0.995	0

Nweb	From section	To section	Position at initial section [°/1 chord]	Position at final section [°/1 chord]
1	6	20	0.44826	0.12664
2	6	20	0.56175	0.61659

Material information

				Elastic Properties			
Mat_ID	Material_Name	Ply thickness [mm]	Density [Kg/m3]	E_1 [MPa]	E_2 [MPa]	G_{12} [MPa]	ν_{12} [-]
1	SPARCAP	0.80	2003.7	51500	11500	3400	0.14
2	REFUERZO B.A.	0.80	1915.5	41630	14930	5047	0.241
3	REFUERZO B.S.	0.80	1915.5	41630	14930	5047	0.241
4	SHELL	0.70	1993.7	27000	27000	3900	0.104
5	RAIZ	0.75	1954.6	34315	20965	4474	0.173
6	LARGUEROS	0.70	1993.7	27000	27000	3900	0.104

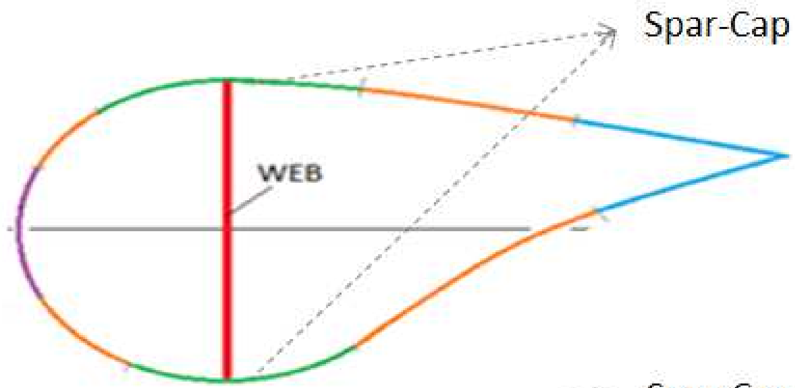
				Allowable Strains & Stresses									
Mat_ID	Material_Name	Ply thickness [mm]	Density [Kg/m3]	ε_{11}^{comp} [mm/mm]	ε_{22}^{comp} [mm/mm]	γ_{12} [mm/mm]	$\varepsilon_{11}^{tension}$ [mm/mm]	$\varepsilon_{22}^{tension}$ [mm/mm]	σ_{11}^{comp} [MPa]	σ_{22}^{comp} [MPa]	τ_{12} [Mpa]	$\sigma_{11}^{tension}$ [MPa]	$\sigma_{22}^{tension}$ [MPa]
1	SPARCAP	0.80	2003.7	1.35E-02	1.00E-02	2.50E-02	2.40E-02	4.91E-03	680.0	120.0	85.0	1260.0	54.0
2	REFUERZO B.A.	0.80	1915.5	1.50E-02	1.27E-02	1.12E-02	2.10E-02	4.94E-03	624.0	188.95	56.4	874.15	73.9
3	REFUERZO B.S.	0.80	1915.5	1.50E-02	1.27E-02	1.12E-02	2.10E-02	4.94E-03	624.0	188.95	56.4	874.15	73.9
4	SHELL	0.70	1993.7	1.63E-02	1.48E-02	1.44E-02	1.31E-02	1.54E-02	423	400	56	366	416
5	RAIZ	0.75	1954.6	1.56E-02	1.37E-02	1.28E-02	1.70E-02	1.02E-02	524	294	56	620	245
6	LARGUEROS	0.70	1993.7	1.63E-02	1.48E-02	1.44E-02	1.31E-02	1.54E-02	423	400	56	366	416

RUNNING BLADEOASIS

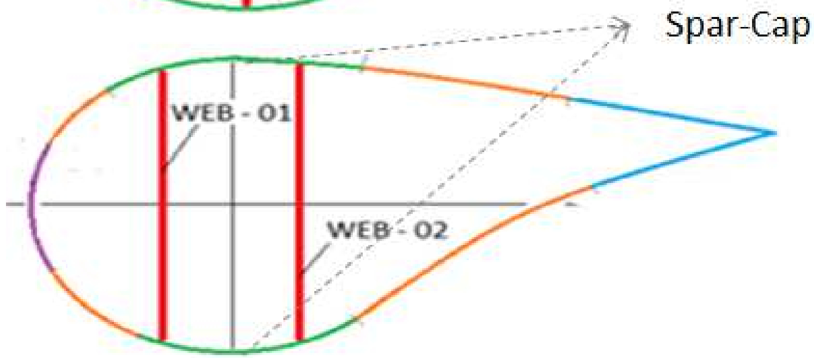
Inputs for the structural module

Internal Arquitecture

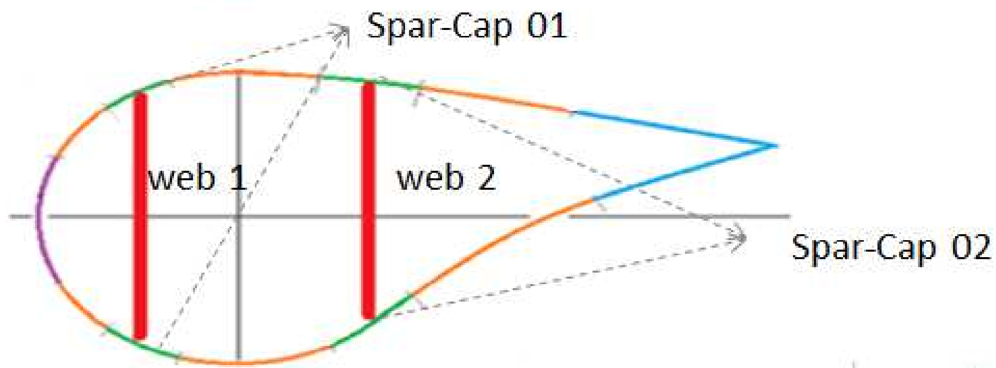
- 1 spar-cap and 1 web



- 1 spar-cap and 2 webs



- 2 spar-caps and 2 webs



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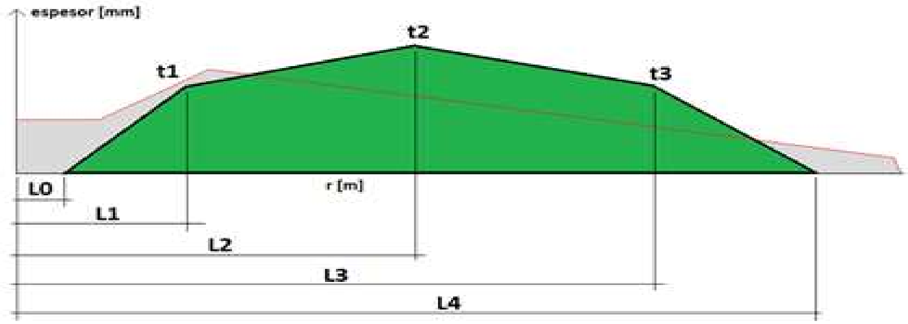
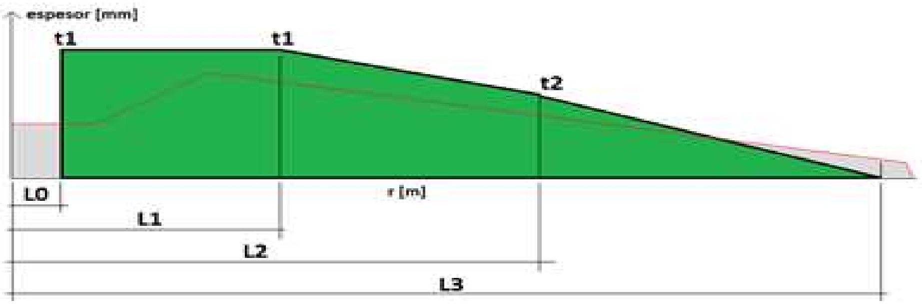
RUNNING BLADEOASIS
Inputs for the structural module

Parametric lay-up

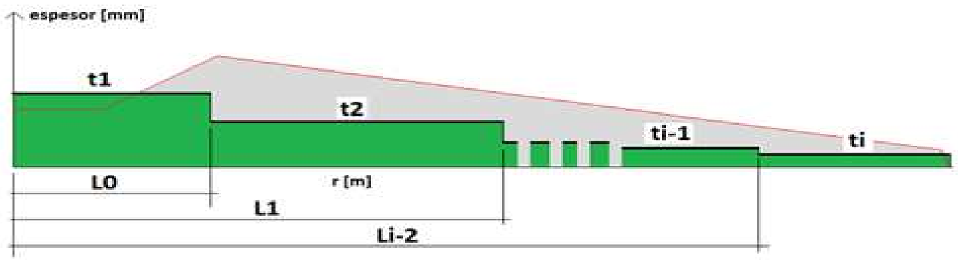
Spar-cap



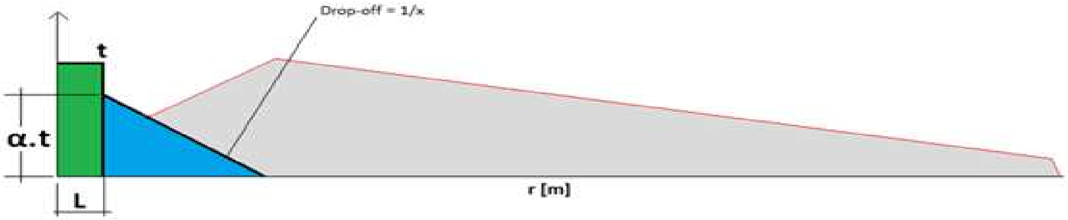
TE Reinforcement



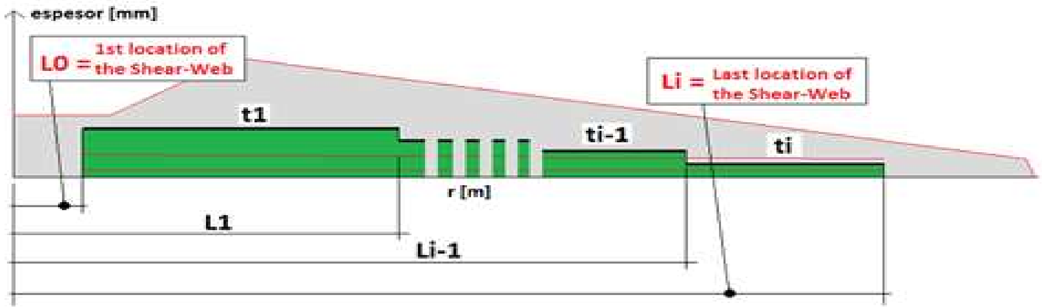
Shell



Root



Webs

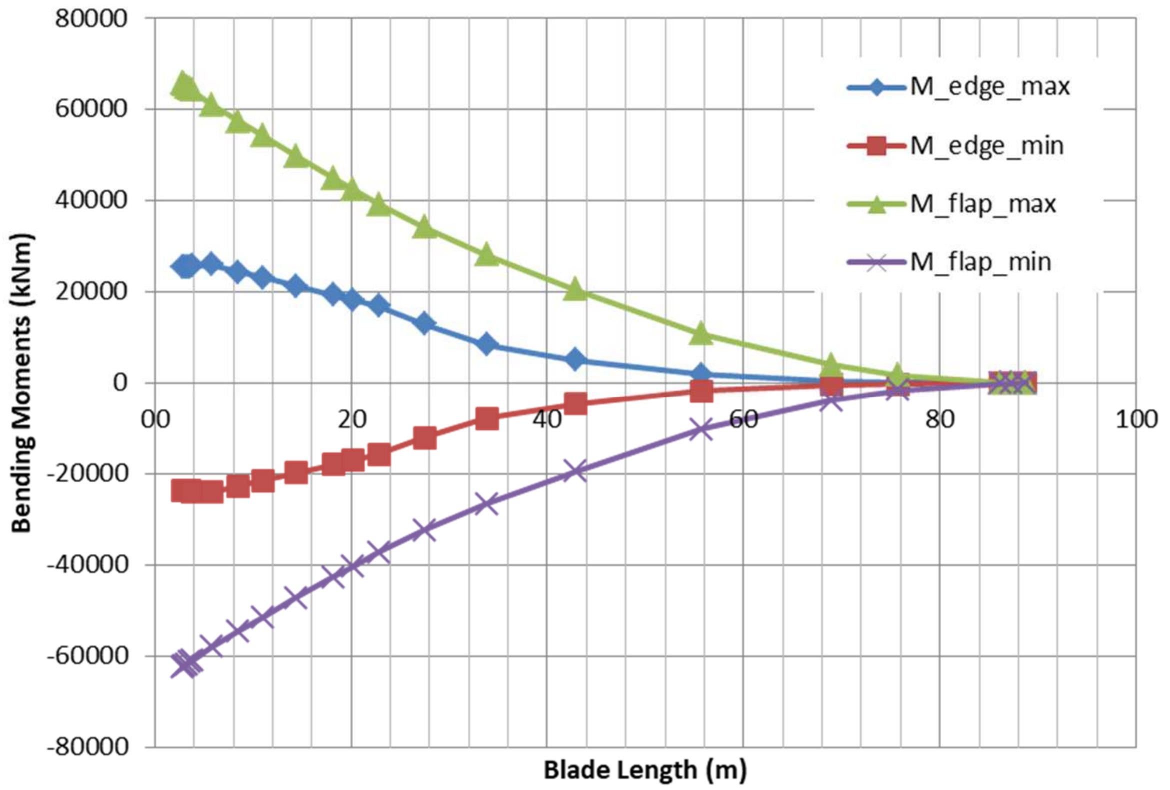


RUNNING BLADEOASIS

Inputs for the structural module

Loads (Extreme – Fatigue)

L (m)	M_edge_max (kNm)	M_edge_min (kNm)	M_flap_max (kNm)	M_flap_min (kNm)
0.0	25459	-23677	65745	-62458
0.2	25489	-23705	65441	-62169
0.5	25535	-23748	64984	-61735
0.8	25576	-23786	64578	-61349
1.0	25617	-23824	64172	-60963
3.0	25934	-24119	61006	-57956
5.7	24373	-22667	57431	-54559
8.2	23097	-21480	54149	-51442
11.6	21326	-19833	49786	-47297
15.4	19369	-18014	44976	-42727
17.4	18314	-17032	42505	-40380
20.0	16839	-15660	39226	-37264
24.7	12935	-12029	34152	-32444
31.0	8362	-7777	28092	-26687
40.1	4995	-4646	20490	-19465
52.9	1866	-1736	10771	-10232
66.1	457	-425	4011	-3811
73.0	207	-192	1755	-1667
83.3	13	-12	71	-68
84.5	6	-5	31	-30
85.9	1	-1	3	-3



RUNNING BLADEOASIS
Design Variables & Optimization

Design variables

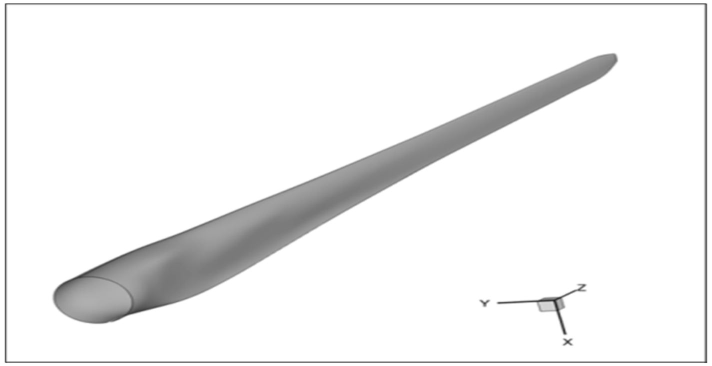
```
variables,
continuous_design = 18
lower_bounds     10.29          8.41          5.54          1.17          -2.00          -3.00          -3.50
upper_bounds     19.29          17.41         14.54         10.17         5.56           3.83           2.50
descriptors      'twist8'       'twist10'     'twist13'     'twist15'     'twist17'      'twist19'      'twist22'
```

Parameters for the optimization

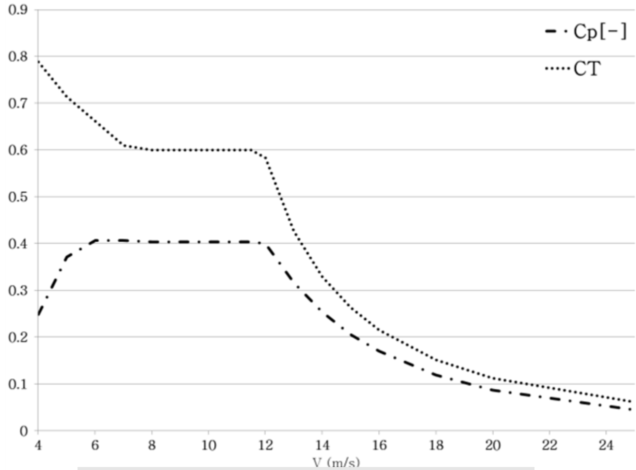
```
method,
        coliny_ea
          max_iterations = 1000
          max_function_evaluations = 1000
          seed = 11011011
          population_size = 50
          fitness_type merit_function
          mutation_type offset_normal
          mutation_rate 0.15
          crossover_type two_point
          crossover_rate 0.8
          replacement_type chc = 15
          debug output
```

RUNNING BLADEOASIS
Aerodynamic outputs

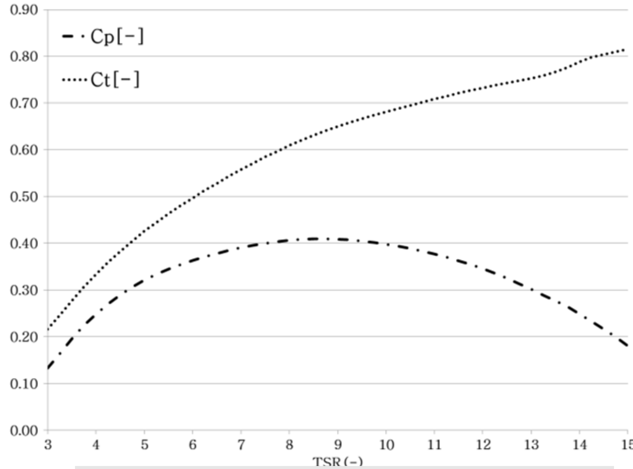
Outputs:



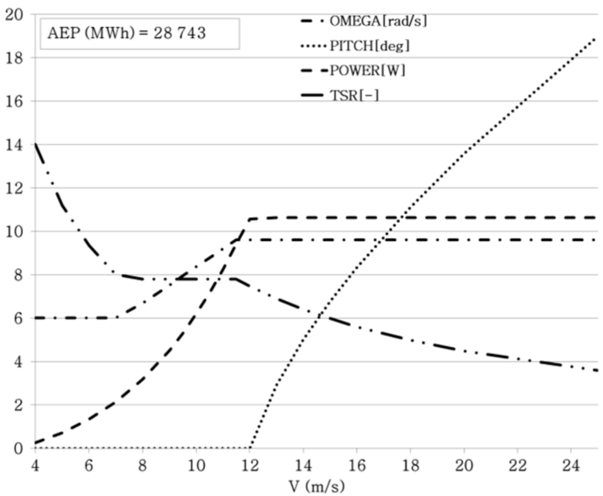
Blade geometry



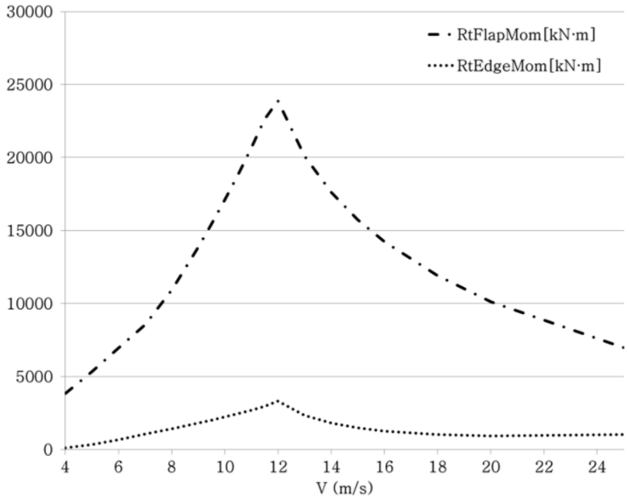
CP & CT vs Wind speed



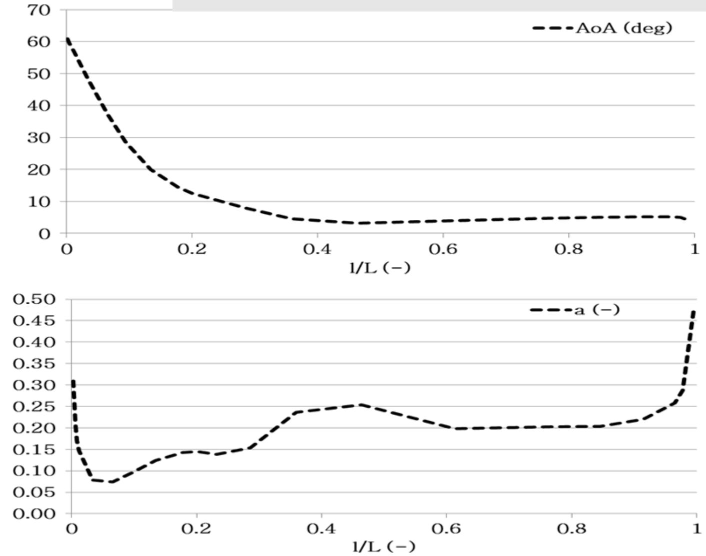
CP & CT vs Tip Speed Ratio



Ꞷ, Pitch, Power, TSR vs Wind speed (AEP)



Moments at blade root



Angle of Attack and "a" vs spanwise

RUNNING BLADEOASIS
Structural Outputs

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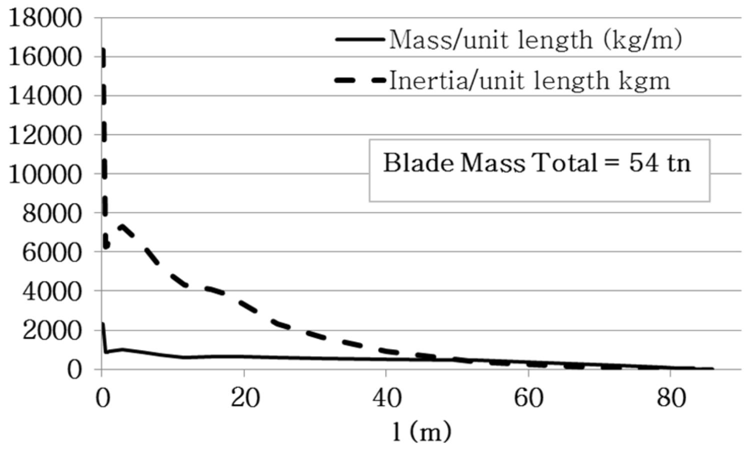
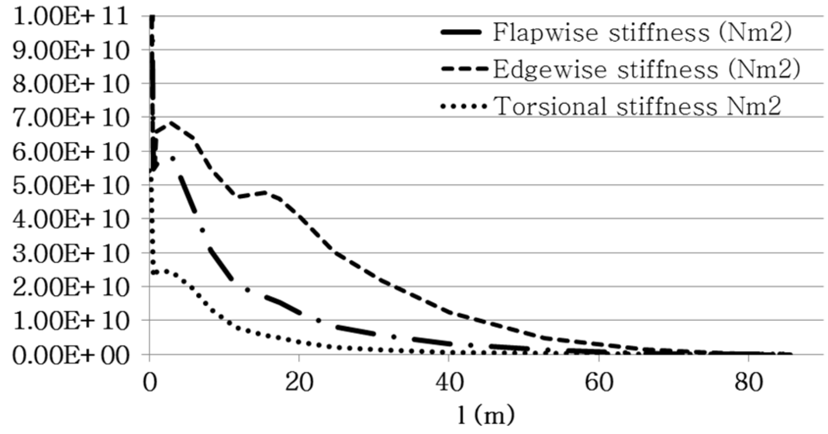
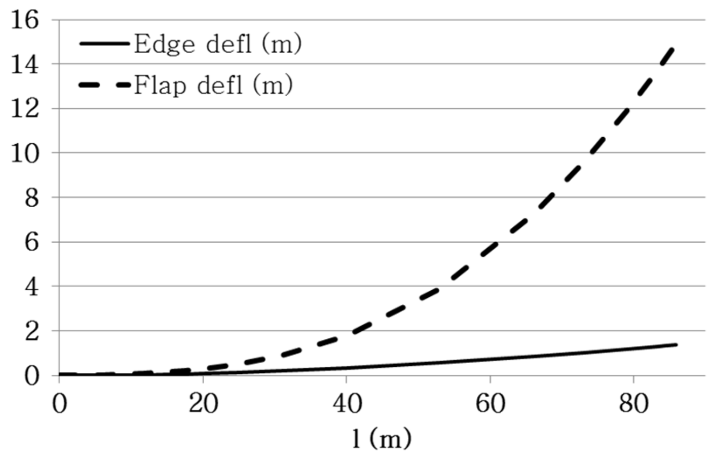
Outputs:



Distribution of mass



Stiffness distribution



Blade deflection

yers_params.txt

```
#====== sparcaps
matID=1
orientacion=0
posicion=[-0.5972806476*899.6544146]
anchura=[899.6544146]
L0=[0.4]
L1=[18]
L2=[31]
L3=[54]
L4=[83]
t1=[0.8196427865*80.0]
t2=[80.0]
t3=[0.9989862418*80.0]

#====== rba
matID=1
orientacion=0
anchura=[500 500]
L0=[1 1]
L1=[25.89 25.89]
L2=[60 60]
L3=[75 75]
t1=[16 16]
t2=[16 16]

#====== rbs
matID=1
orientacion=0
offsetTE=[-50 -50]
anchura=[-800 -800]
L0=[1 1]
L1=[25.89 25.89]
L2=[60 60]
L3=[75 75]
t1=[10.27918899 10.27918899]
t2=[0.15*10.27918899 0.15*10.27918899]
```

```
#====== shell
matID=3
orientacion=0
t=[4.0 0.8390298888*4.0 0.8390298888*1.0*4.0 0.8390298888*1.0*0.7105253022*4.0]
L=[21.575 45 80]

#====== raiz
L=0.5
t=64.4
alpha=0.3
matID=4
orientacion=0
dropoff=500.0

#====== webs
nWebs=2
#====== web
matID=2
orientacion=45
alpha=0.03
t=[8.536872933 1.0*8.536872933 1.0*1.0*8.536872933]
L=[25.89 66.1]
#====== web
matID=2
orientacion=45
alpha=0.03
t=[8.536872933 1.0*8.536872933 1.0*1.0*8.536872933]
L=[25.89 66.1]
```

Parametric lay-up

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BladeOASIS

CONTENT

- Introduction to BladeOASIS
- Running BladeOASIS
- Practical cases

PRACTICAL CASES

C1- Blade aerodynamic and structural optimization in two steps:

Step 1: Aerodynamic optimization

↓

Step 2: Structural optimization

C2- Blade aero-structural integrated optimization (MDAO)

Aero-Structural optimization

PRACTICAL CASES

C1.Step1 – Aerodynamic Optim.

Starting point: DTU 10MW with some changes on the blade

- Reduced chord
- Less aggressive twist
- thicker blades

(same blade than in IEA Task 37, WP3)

DTU 10MW reference wind turbine – overall parameters:

- 3 Bladed Upwind
- Rated power: 10MW
- Blade length: 86.366m
- Hub height: 127m
- Airfoil family: FFA
- Vdesign = 8m/s
- rpm range: 6-9.6 rpm
- Tilt = 5 deg
- Cone = 2.5 deg

PRACTICAL CASES

C1.Step1 – Aerodynamic Optim.

Optimizer: Genetic (coliny_ea of Dakota)

Fitness function: **Maximize AEP**

Design variables:

- **chord**
- **t/c**
- **twist**

Constraints:

- Min Tabs
- Max CT
- Max Root flapwise bending moment

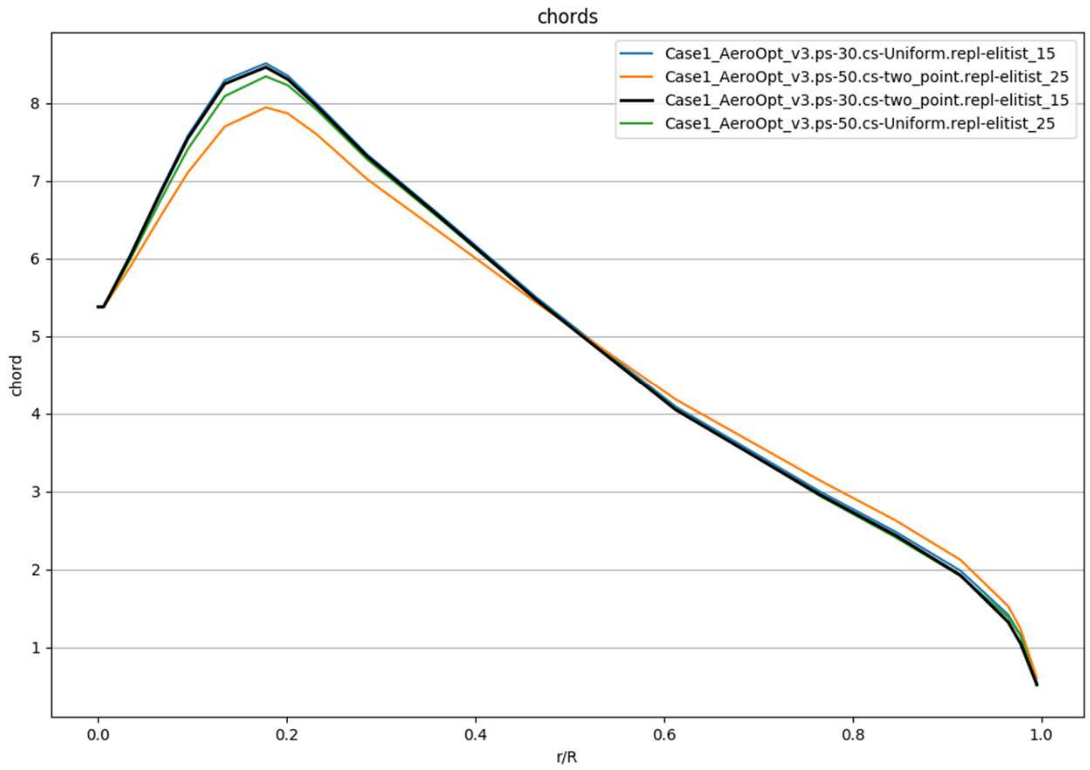
PRACTICAL CASES

C1.Step1 – Aerodynamic Optim.

Parameters for the optimization:

- Population sizes: 30 and 50
- Two crossover types
- One replacement type
- 10 000 evaluations per case

The result will be the best evaluation among the four parameter combinations.



PRACTICAL CASES
C1.Step1 – Aerodynamic Optim.

Running the optimization:

It can be run in local or in CENER's cluster

Time in local: around 30 hours.

Time in cluster: around 2 hours.

Postprocessing the optimization:

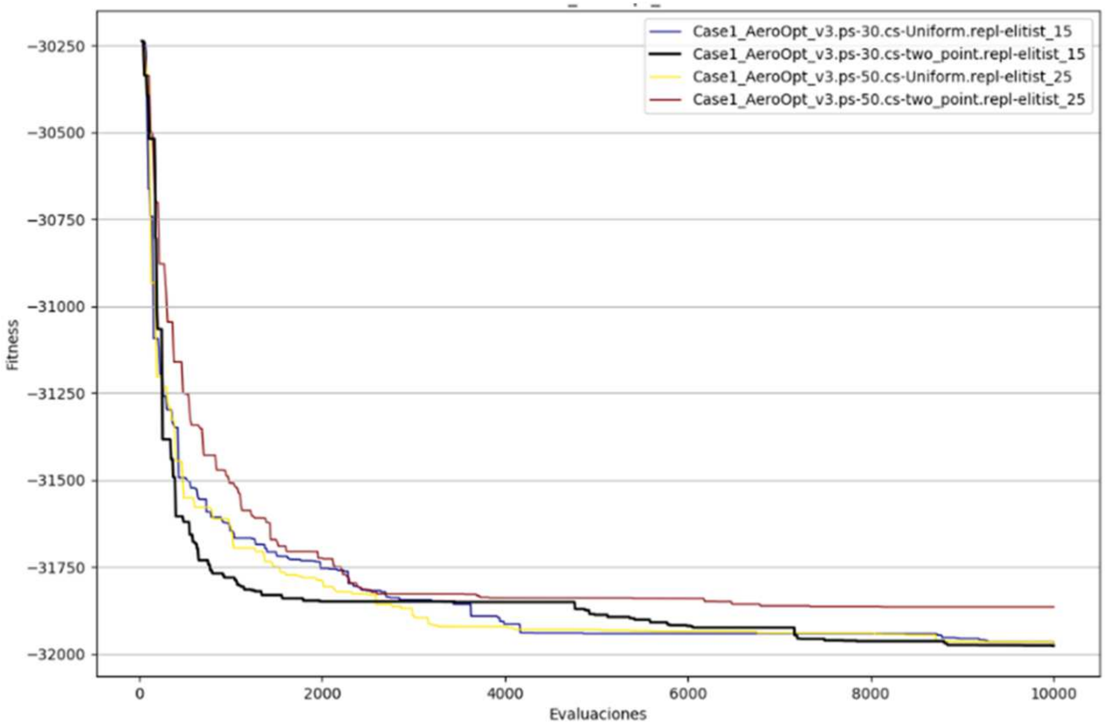
Several postprocessing scripts:

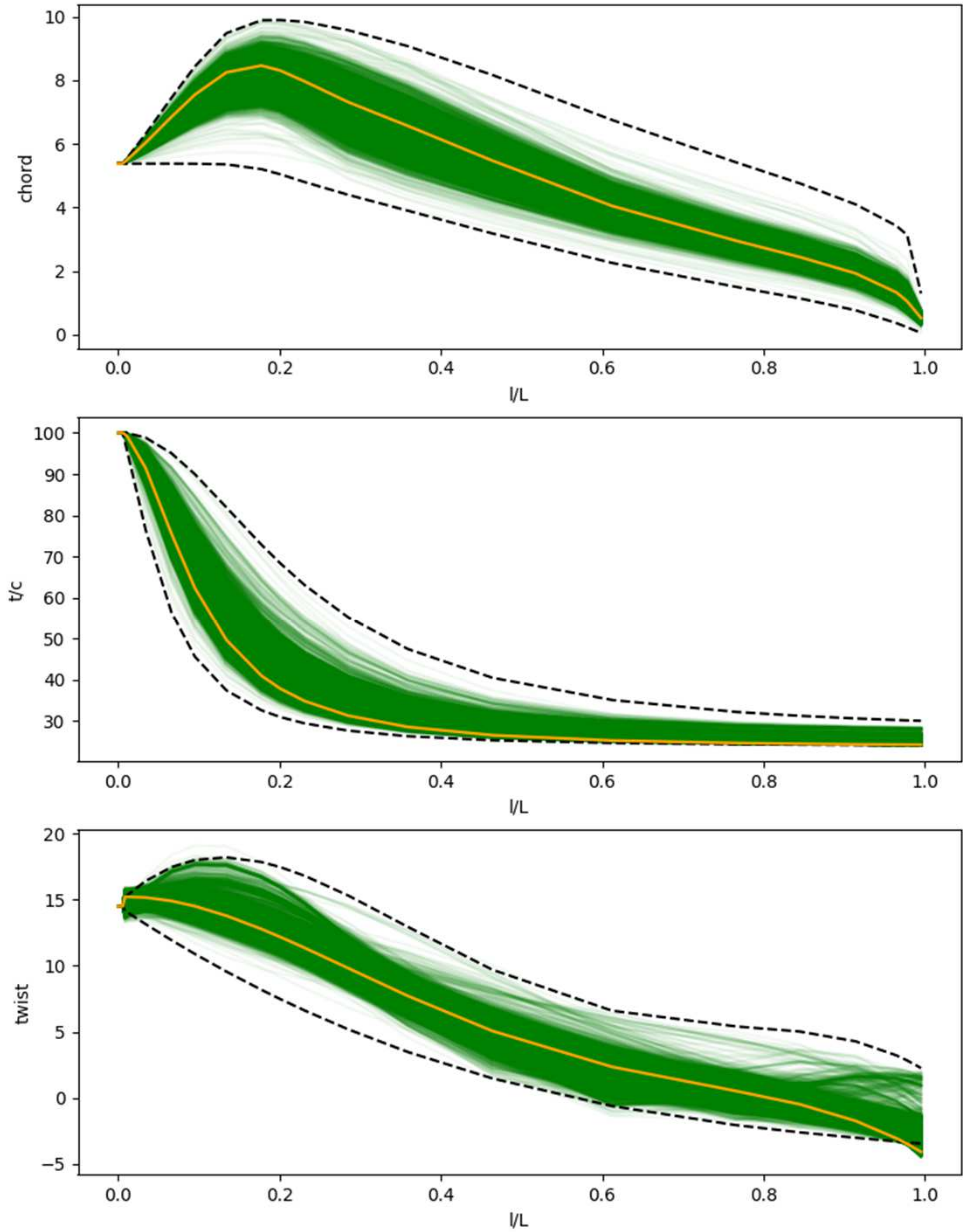
- To find the best solution among all iterations.
- To obtain results of the best solution.
- To generate some graphs.

PRACTICAL CASES

C1.Step1 – Aerodynamic Optim.

Results: Evolution of fitness function and design variables





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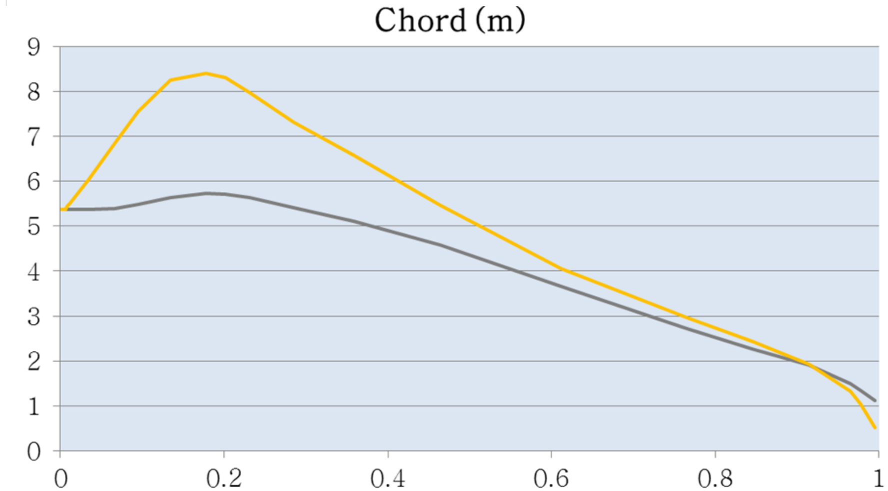
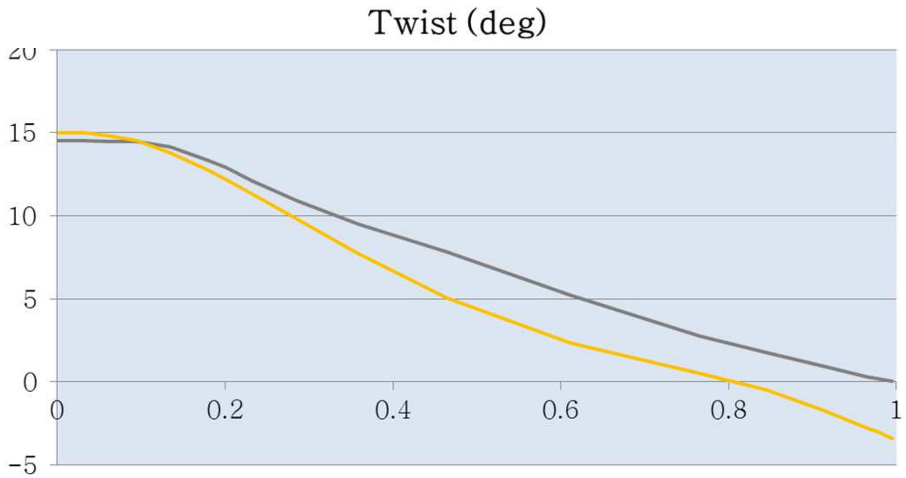
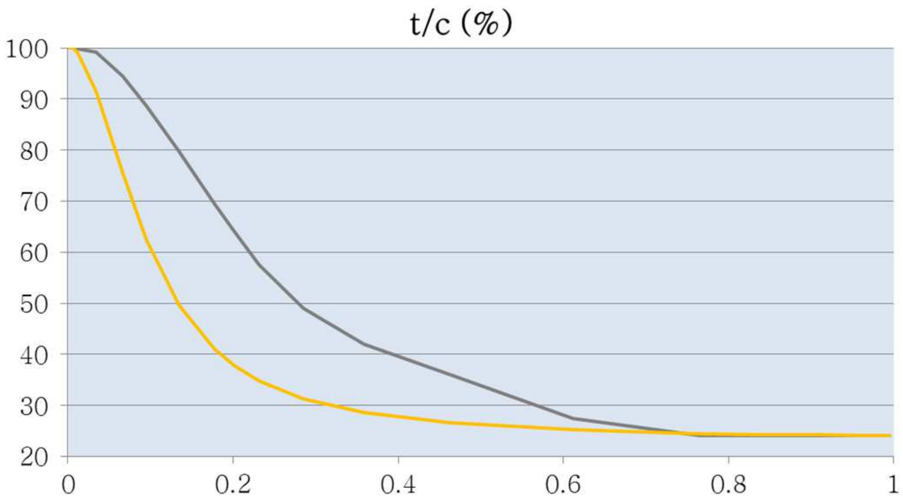
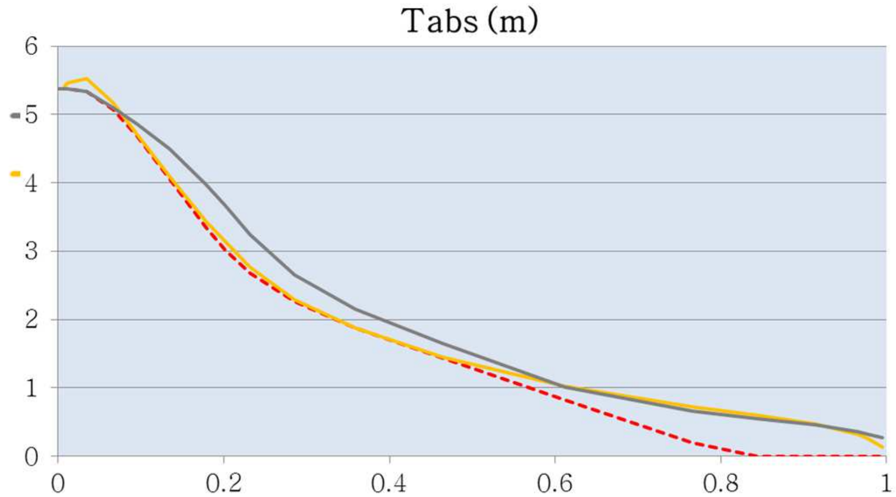
PRACTICAL CASES
C1.Step1 – Aerodynamic Optim.

Results: Blade geometry









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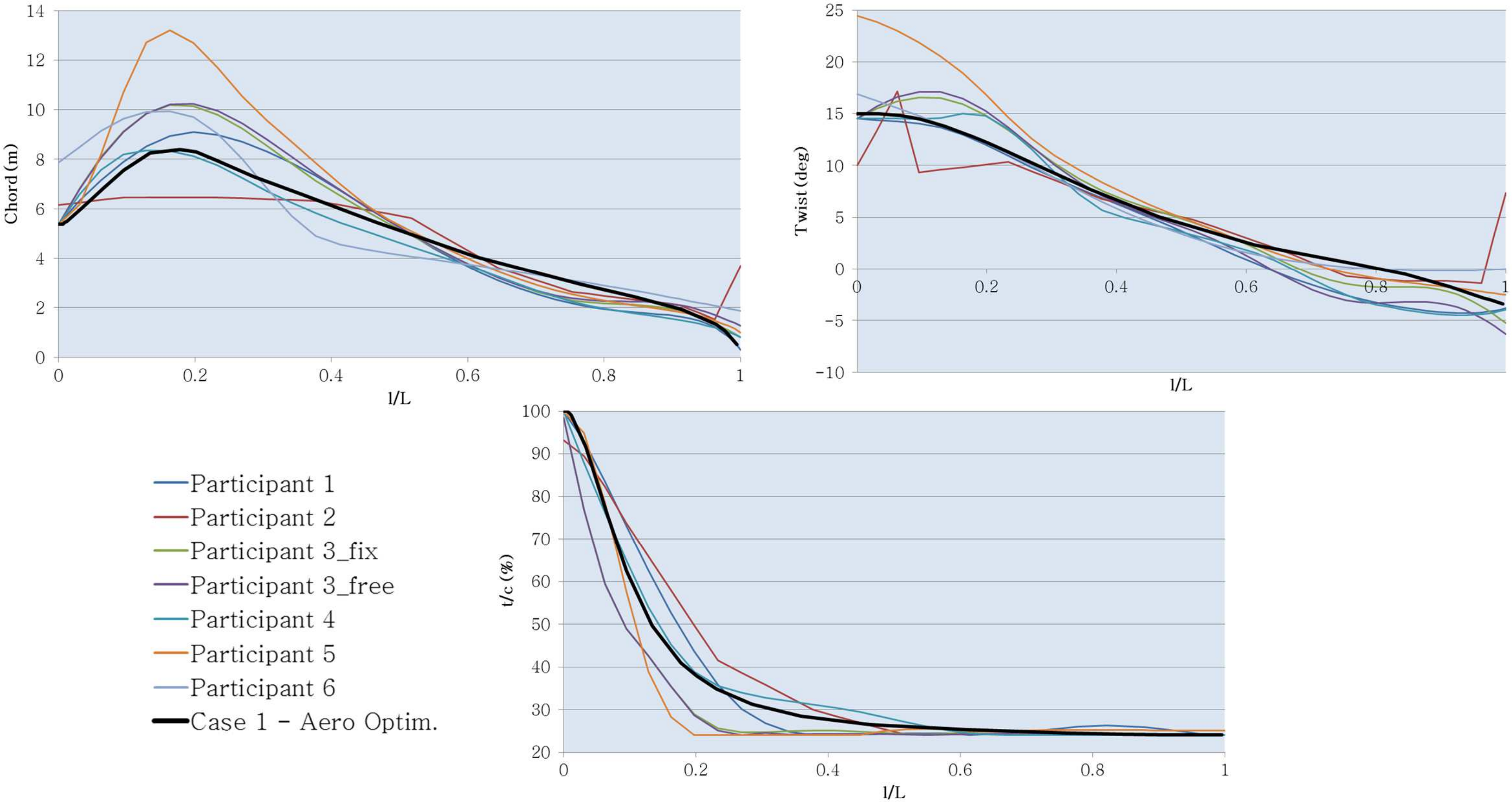
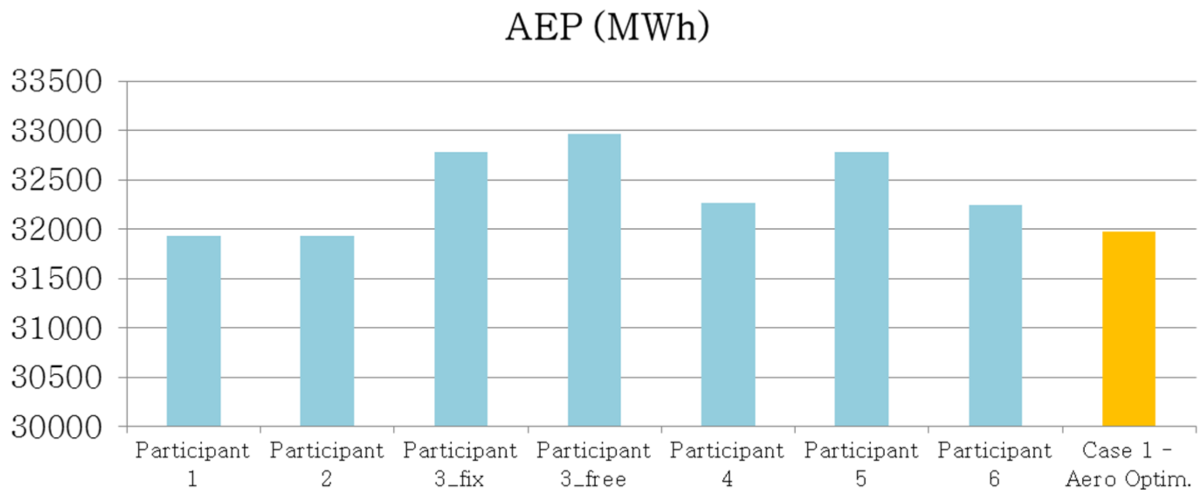
PRACTICAL CASES
C1 – Isolated optimizations

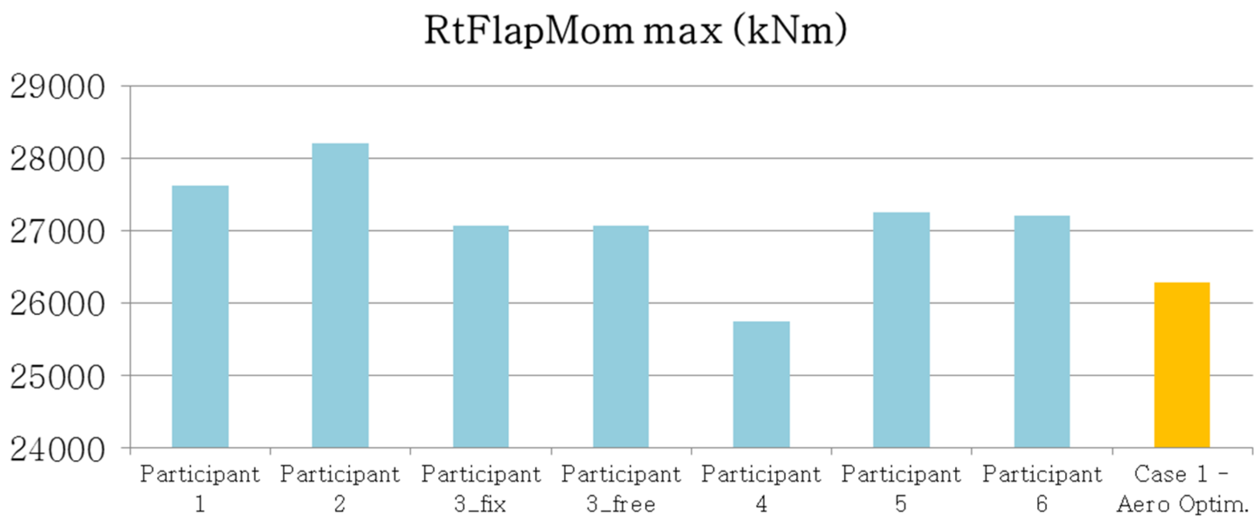
Results: Compared to IEA Task 37 results



PRACTICAL CASES
C1 – Isolated optimizations

Results: Compared to IEA Task 37 results





PRACTICAL CASES

C1.Step2 – Structural Optim.

Blade geometry:

Optimal Aerodynamic from Step 1.

Optimizer: Genetic (coliny_ea of Dakota)

Fitness function: **Minimize Blade Mass**

Design variables:

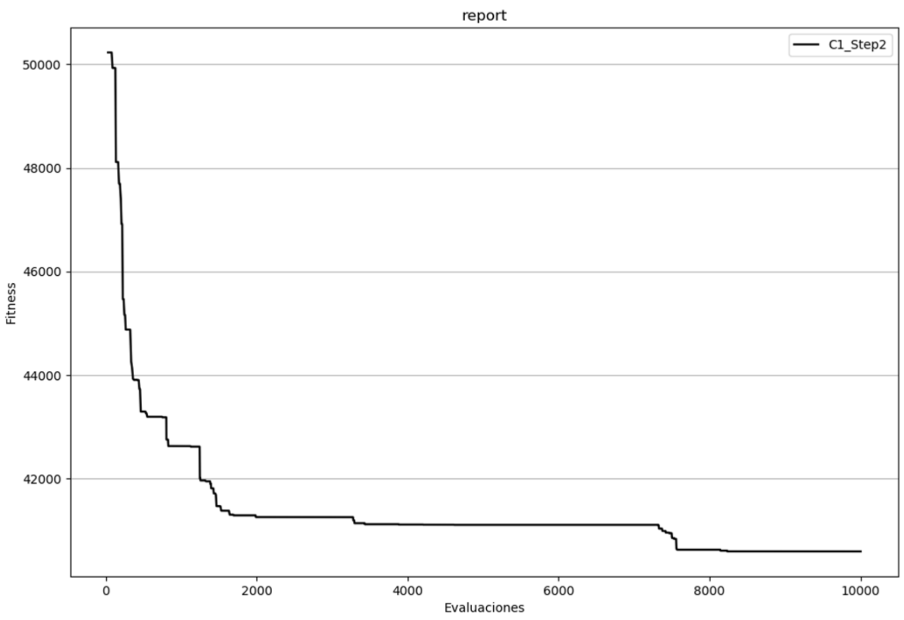
- **Sparcap** (1): width, position and thicknesses.
- **TE reinforcement**: thicknesses
- **Root**: alpha and dropoff.
- **Shell**: thicknesses
- **Webs** (2): thicknesses

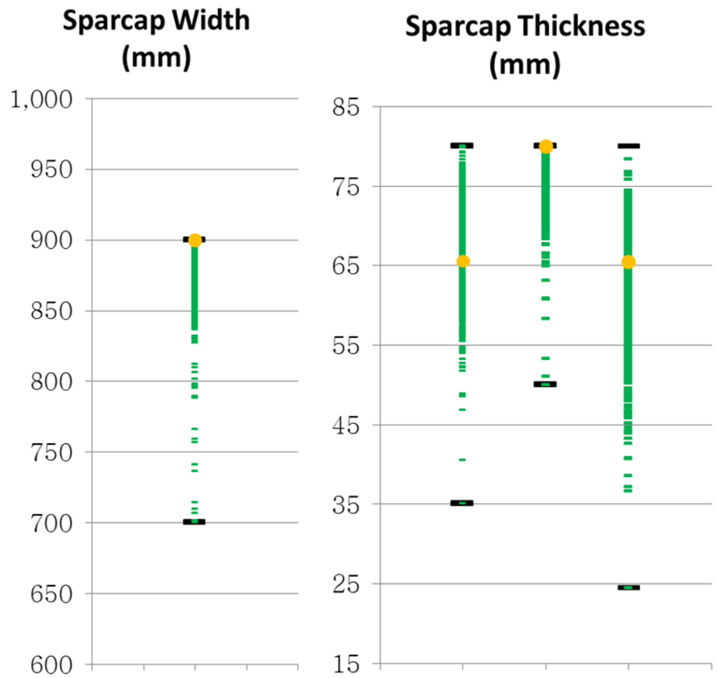
Constraints:

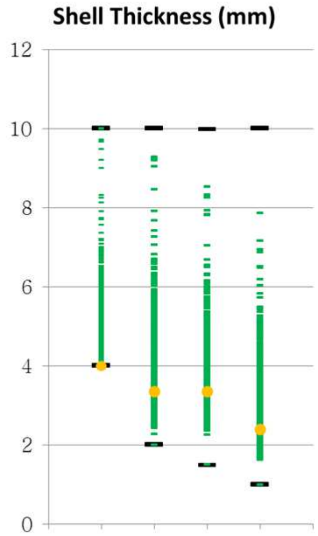
- Strength analysis based on extreme loads: max strain criteria.
- Maximum tip deflection: tip to tower minimum clearance.

PRACTICAL CASES
C1.Step2 – Structural Optim.

Results: Evolution of fitness function and design variables



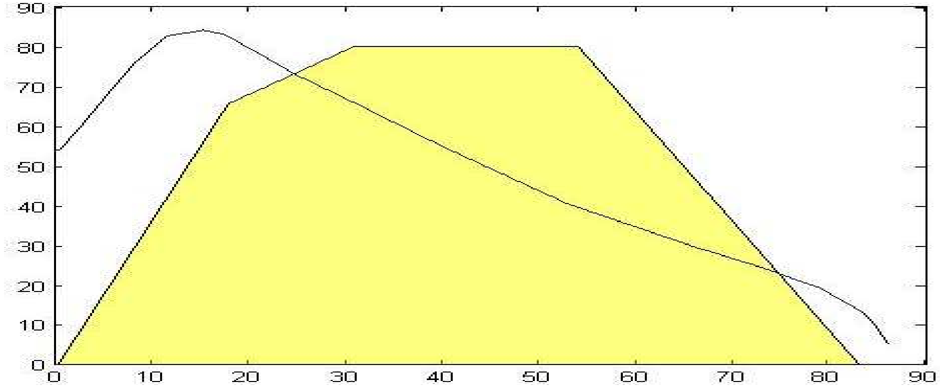




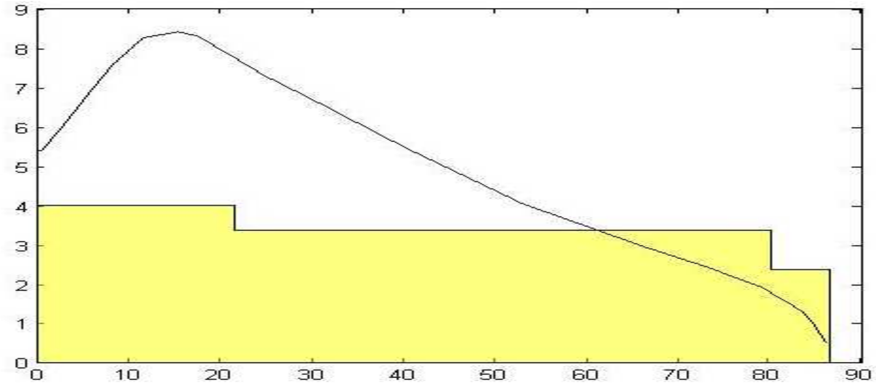
PRACTICAL CASES
C1.Step2 – Structural Optim.

Results: Blade Structure

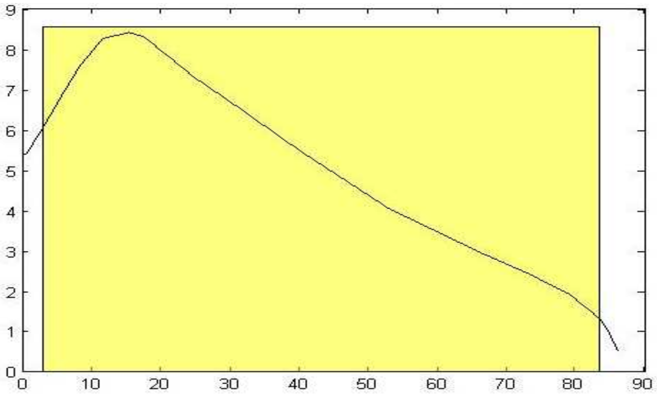
Sparcap



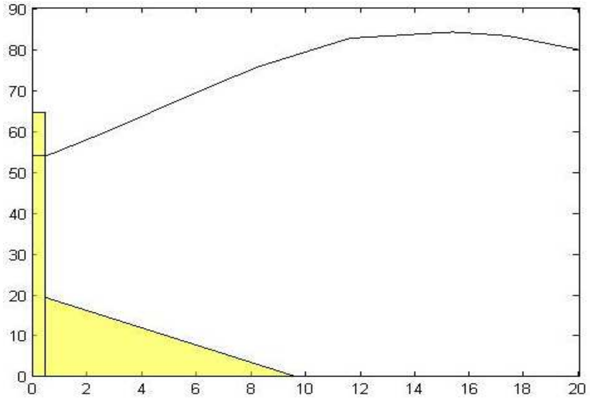
Shell



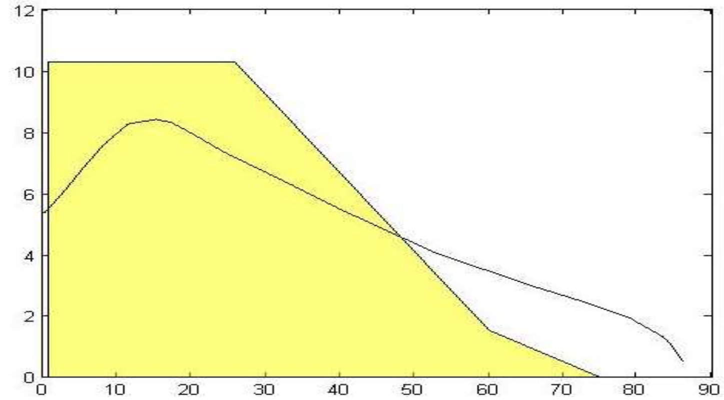
Webs



Root



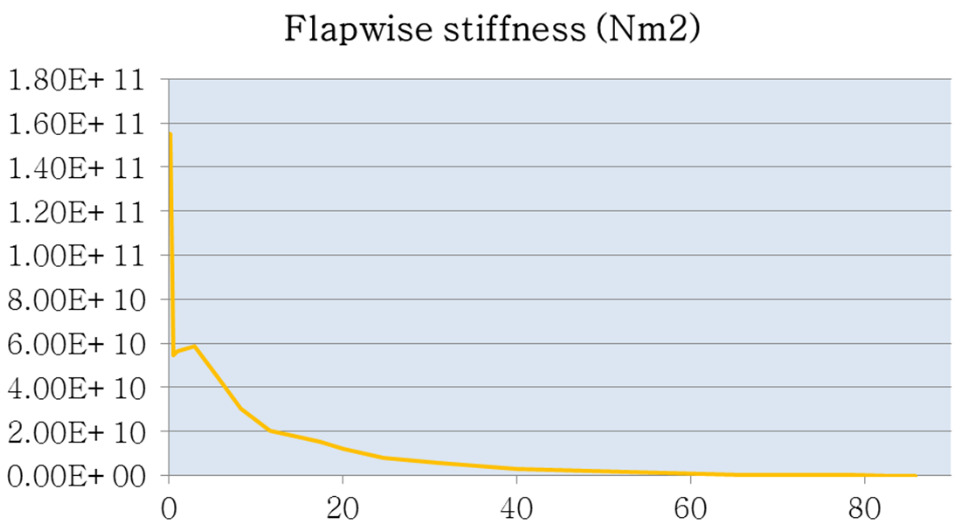
TE reinforcement

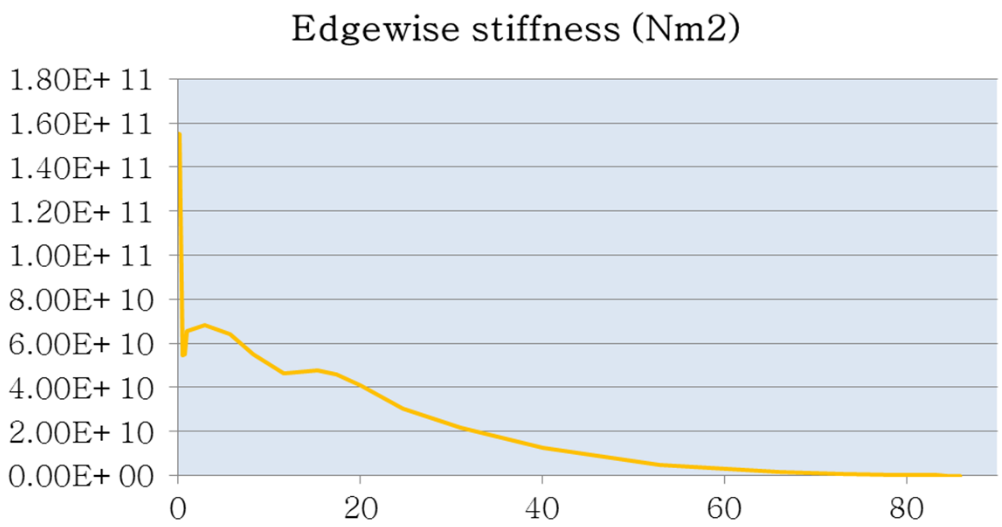


PRACTICAL CASES
C1.Step2 – Structural Optim.

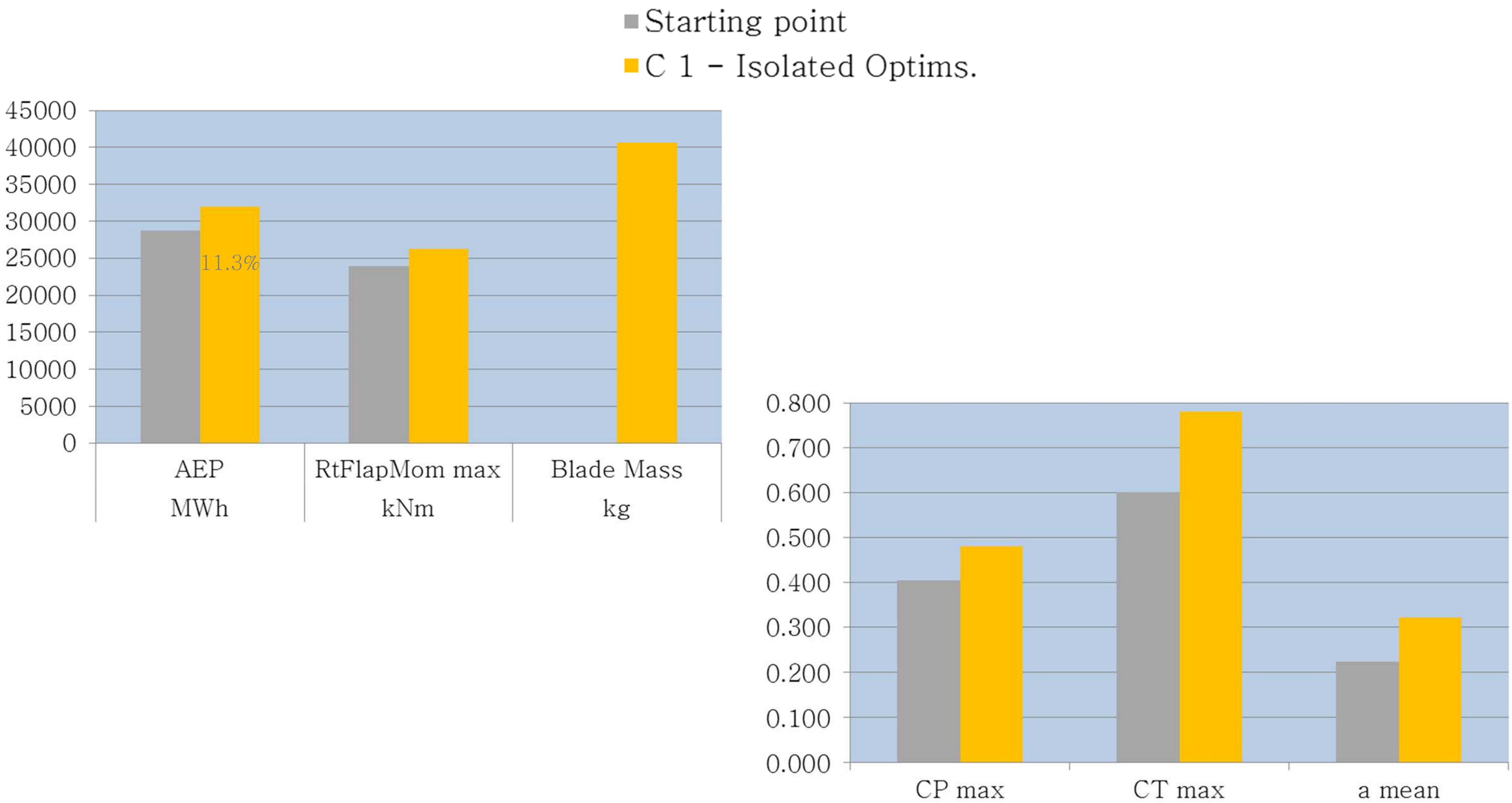
Results: Blade Structure

Blade Mass Total = 40.6 tn





Results: Performance and loads



AERO-STRUCTURAL OPTIMIZATION

Fitness function: **max AEP and min BladeMass**

Design variables:

- chord distribution
- t/c distribution
- twist distribution

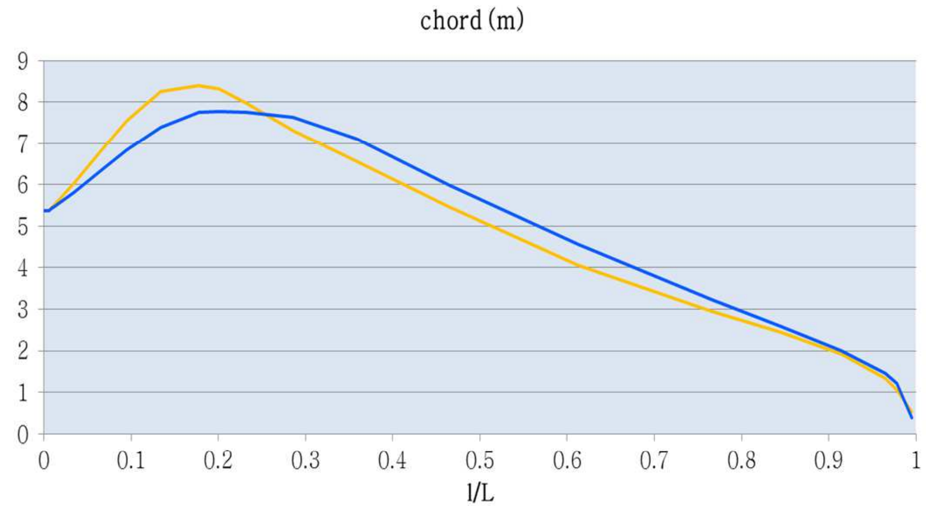
- Sparcap: width, position and thicknesses
- TE reinforcement: thicknesses
- Root: alpha and dropoff
- Shell: thicknesses
- Webs: thicknesses

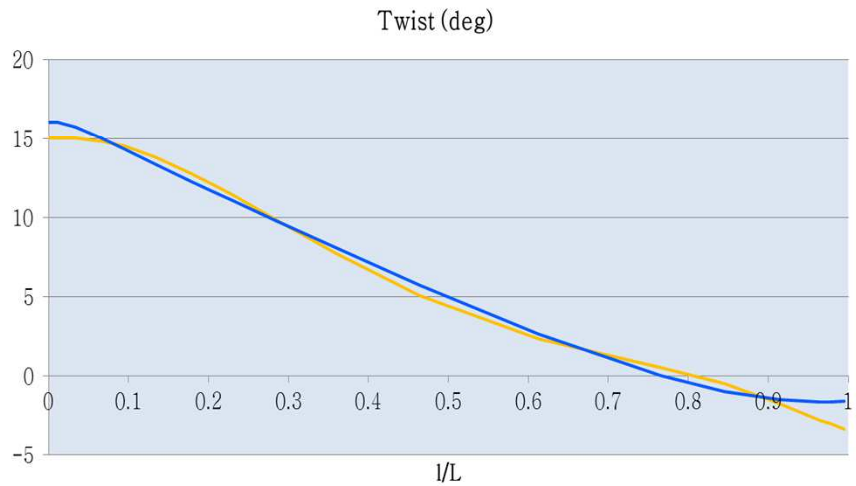
Constraints:

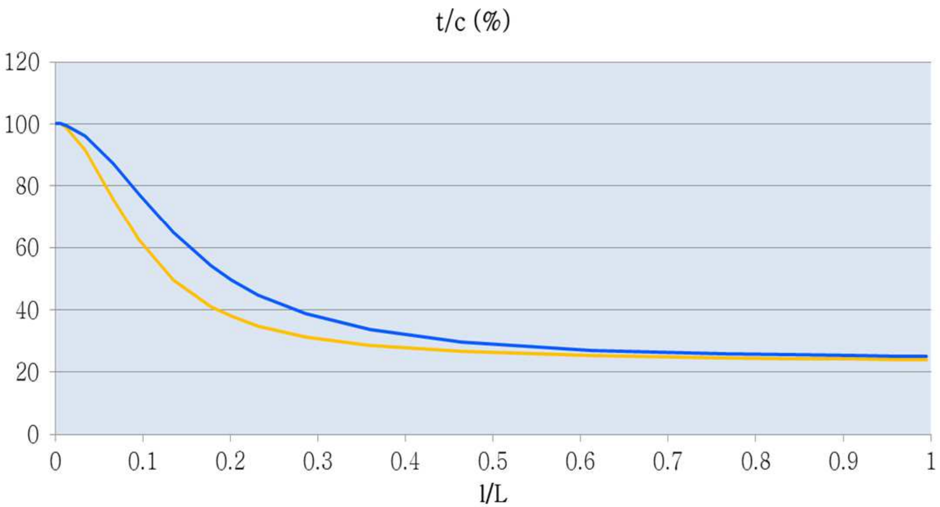
- CT max
- Root Flapwise BM (aerodynamic) max
- T min

- Strength analysis based on extreme loads.
- - Maximum tip deflection

Results: Blade geometry







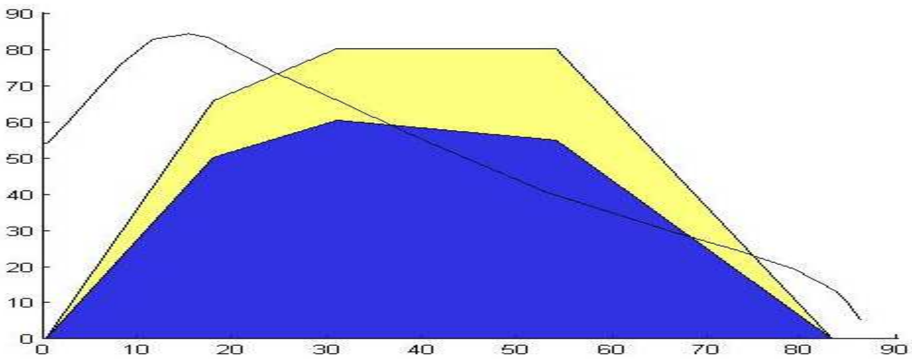
C1 – Isolated Optims
C2 – MDAO

PRACTICAL CASES
Case 1 vs Case 2

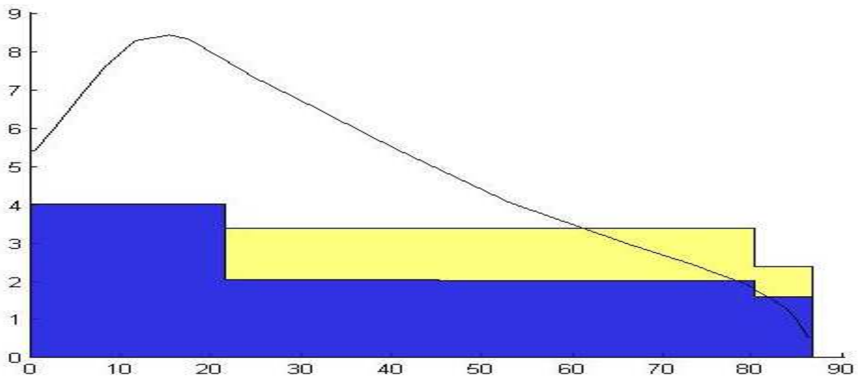
Results: Blade Structure

—C1 - Isolated Optims
—C2 - MDAO

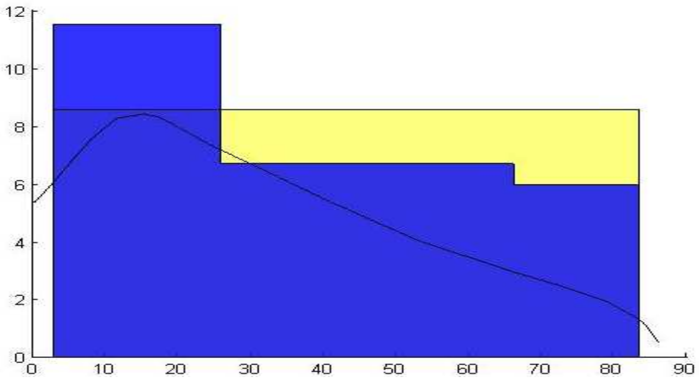
Sparcap



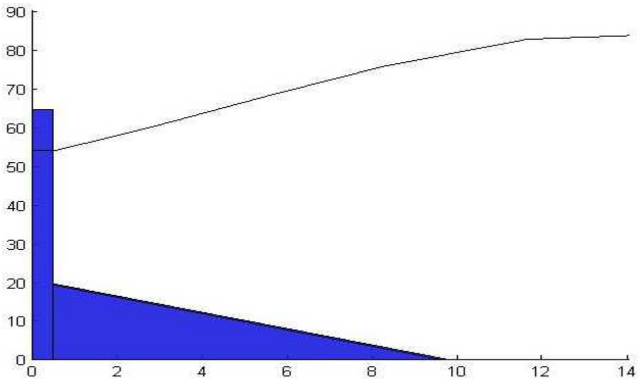
Shell



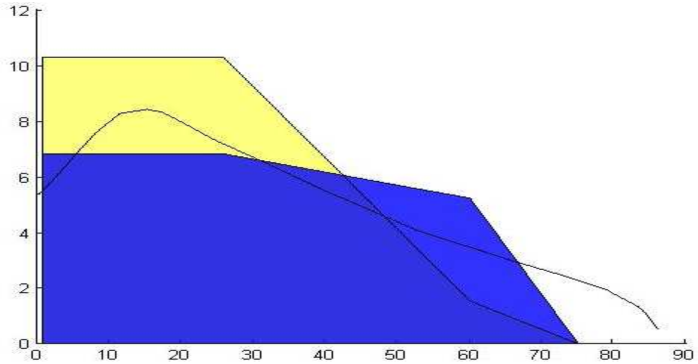
Webs



Root



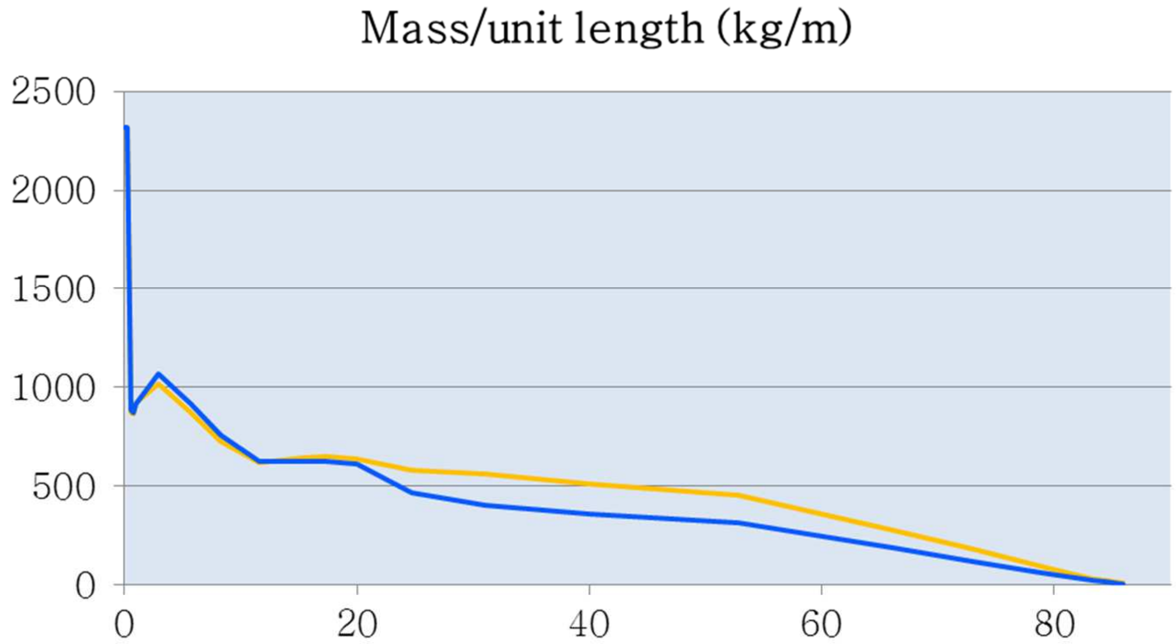
TE reinforcement

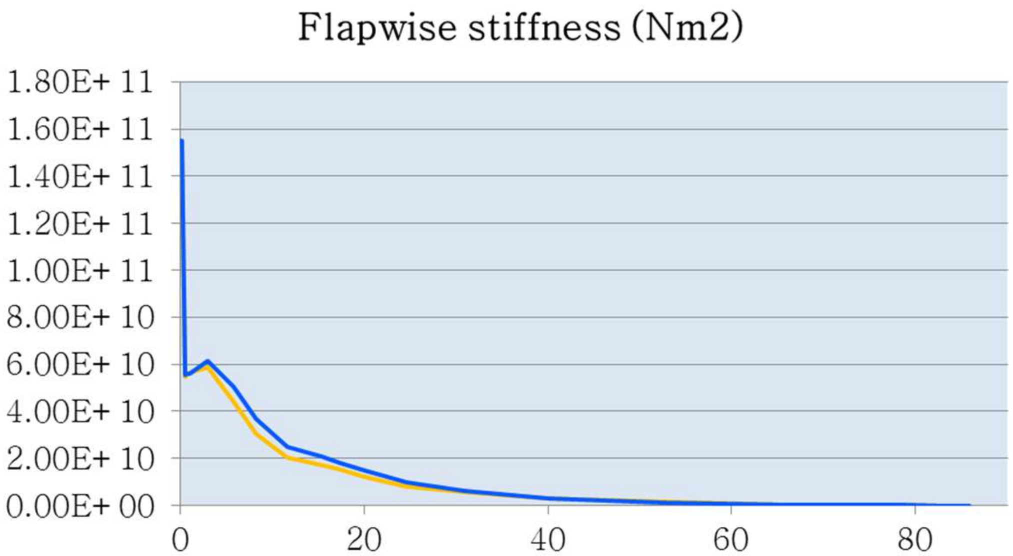


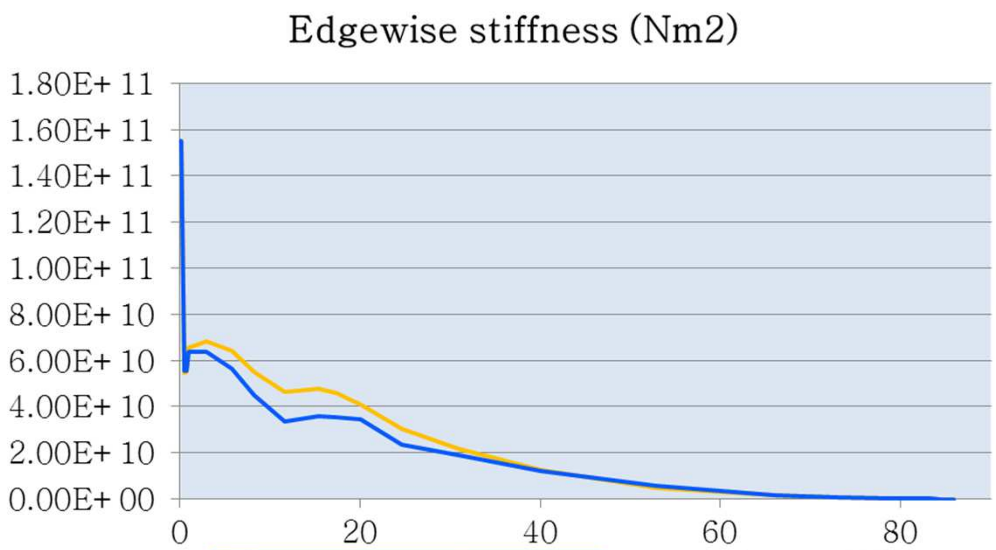
PRACTICAL CASES
Case 1 vs Case 2

Results: Blade Structure

C1 Structural Optim.
C2 MDAO

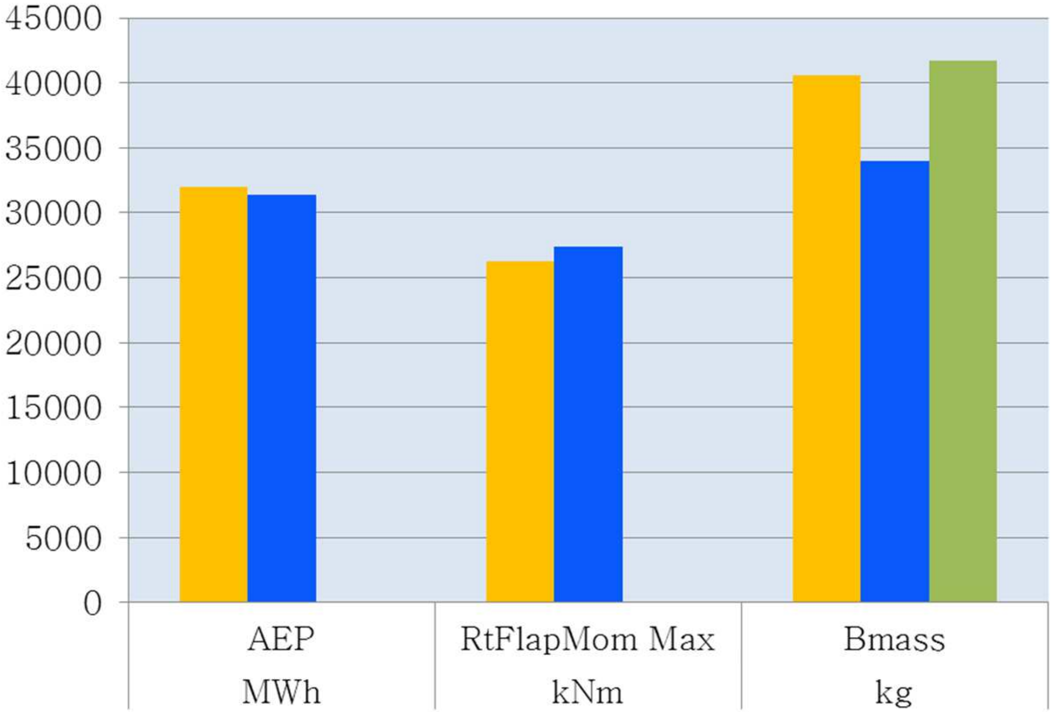


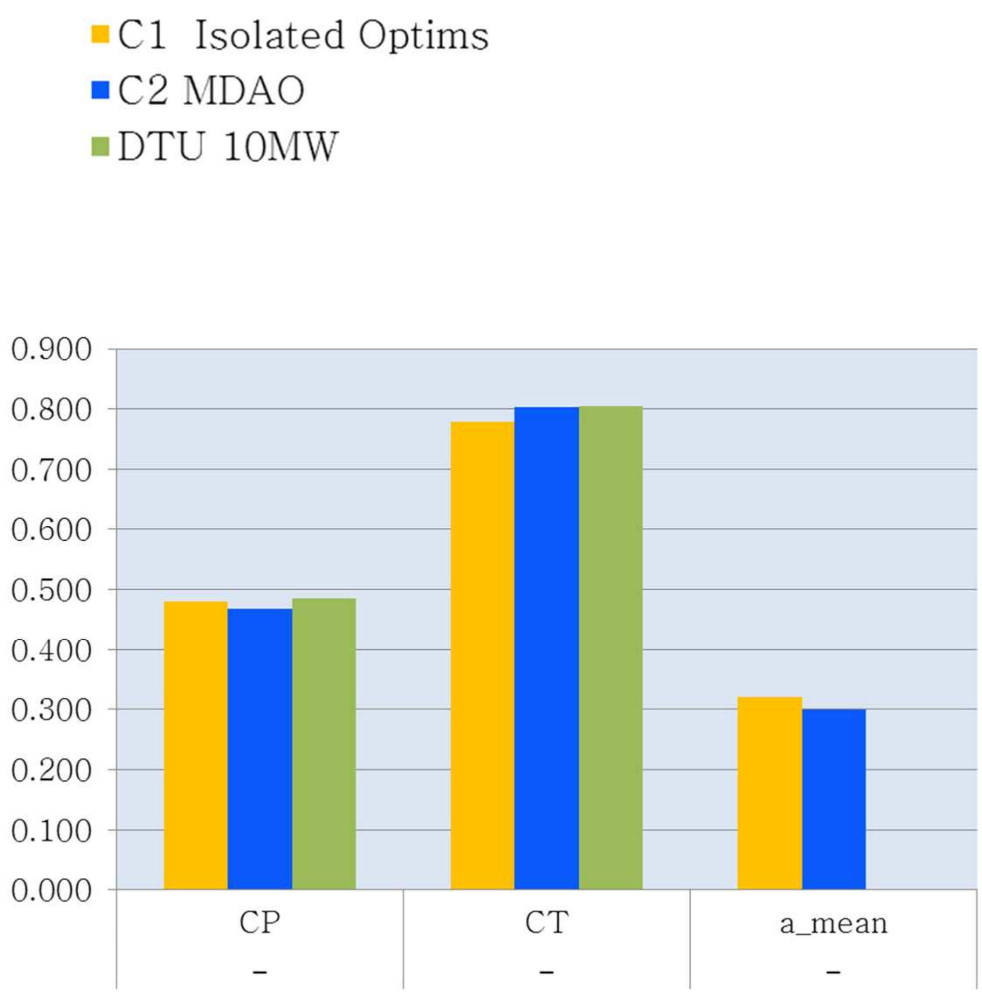




PRACTICAL CASES
Case 1 vs Case 2

Results: Performance and loads





BLADEOASIS OPTIMIZATION CONCLUSIONS

- BladeOASIS' results are coherent and in line with other codes'.
- Case 1 Step 1 - Aerodynamic optimization: the highest AEP.
- Case 1 Step 2 - Structural optimization: mass reduction conditioned by optimal geometry.

  Lowest Blade Mass FOR THE GIVEN GEOMETRY.
- Case 2 – Aero-Structural optimization: best combination of both improvements:

  Lower increase in AEP

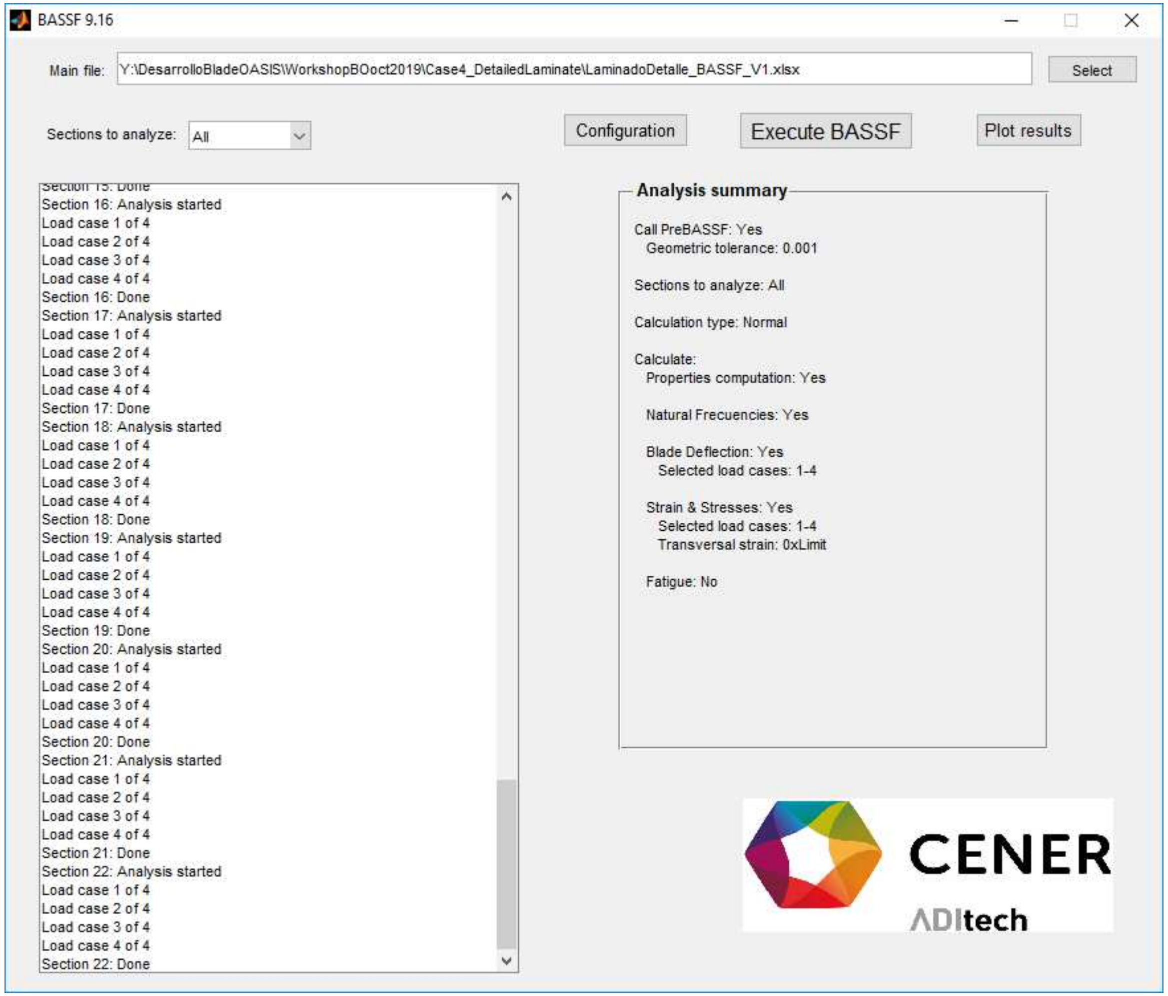
  BUT

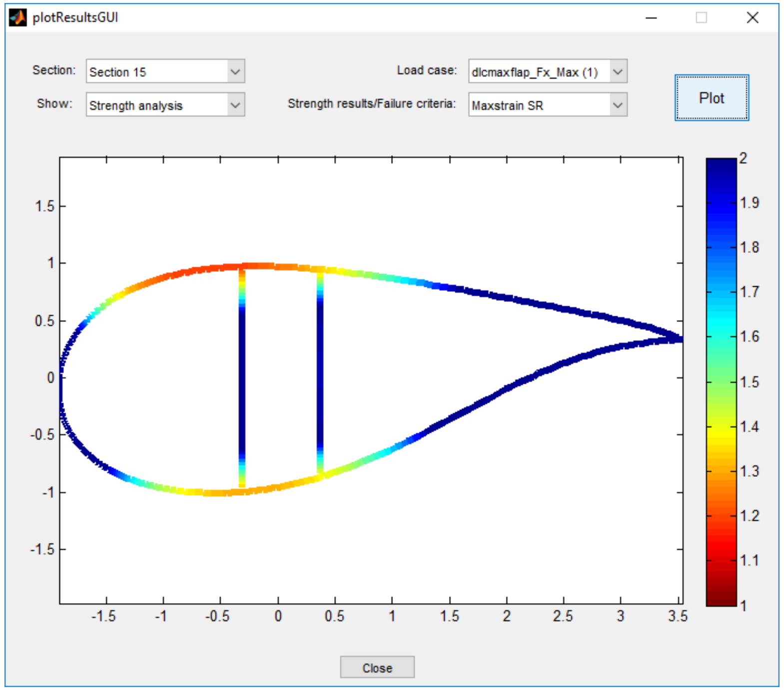
  Reduction in Blade Mass.

MDAO WORKS!

PRACTICAL CASES

C3- From a parametric lay-up to a detailed design (using BASSF)





PRACTICAL CASES

C3- From a parametric lay-up to a detailed design (using BASSF)

#====== Spar-Cap
Material ID=1
Orientation=0
Location=[-362.15]
Width=[782.37]
L0=[0.4]
L1=[18]
L2=[31]
L3=[54]
L4=[83]
t1=[50.02]
t2=[60.23]
t3=[54.73]

Section ID (-)	L (m)	Thickness (mm)
S1	0.00	0
S2	0.20	0
S3	0.50	1
S4	0.75	2
S5	1.00	2
S6	2.95	8
S7	5.72	16
S8	8.23	23
S9	11.60	33
S10	15.36	44
S11	17.37	50
S12	20.00	52
S13	24.66	55
S14	31.00	60
S15	40.08	58
S16	52.87	55
S17	66.12	31
S18	73.00	19
S19	78.94	8
S20	83.32	0
S21	84.45	0
S22	85.94	0

#====== TE Reinforcement
Material ID=1
Orientation=0
Offset TE=[-50 -50]
Width=[-800 -800]
L0=[1 1]
L1=[25.89 25.89]
L2=[60 60]
L3=[75 75]
t1=[6.81 6.81]
t2=[5.22 5.22]

Section ID (-)	L (m)	Thickness (mm)
S1	0.00	0
S2	0.20	0
S3	0.50	0
S4	0.75	0
S5	1.00	7
S6	2.95	7
S7	5.72	7
S8	8.23	7
S9	11.60	7
S10	15.36	7
S11	17.37	7
S12	20.00	7
S13	24.66	7
S14	31.00	7
S15	40.08	6
S16	52.87	6
S17	66.12	5
S18	73.00	2
S19	78.94	0
S20	83.32	0
S21	84.45	0
S22	85.94	0

#====== Shell
Material ID=3
Orientation=0
t=[4.0 2.04 2.02 1.60]
L=[21.575 45 80]

Section ID (-)	L (m)	Thickness (mm)
S1	0.00	8
S2	0.20	8
S3	0.50	8
S4	0.75	8
S5	1.00	8
S6	2.95	8
S7	5.72	8
S8	8.23	8
S9	11.60	8
S10	15.36	8
S11	17.37	8
S12	20.00	8
S13	24.66	4
S14	31.00	4
S15	40.08	4
S16	52.87	4
S17	66.12	4
S18	73.00	4
S19	78.94	4
S20	83.32	4
S21	84.45	4
S22	85.94	4

#====== Root
Material ID=4
L=0.5
t=64.4
Alpha=0.305
Orientacion=0
Drop-off=500.0

Section ID (-)	L (m)	Thickness (mm)
S1	0.00	64
S2	0.20	64
S3	0.50	40
S4	0.75	25
S5	1.00	20
S6	2.95	15
S7	5.72	10
S8	8.23	5
S9	11.60	0
S10	15.36	0
S11	17.37	0
S12	20.00	0
S13	24.66	0
S14	31.00	0
S15	40.08	0
S16	52.87	0
S17	66.12	0
S18	73.00	0
S19	78.94	0
S20	83.32	0
S21	84.45	0
S22	85.94	0

#====== Web
Material ID=2
Orientation=45
Alpha=0.03
t=[11.48 6.69 5.95]
L=[25.89 66.1]

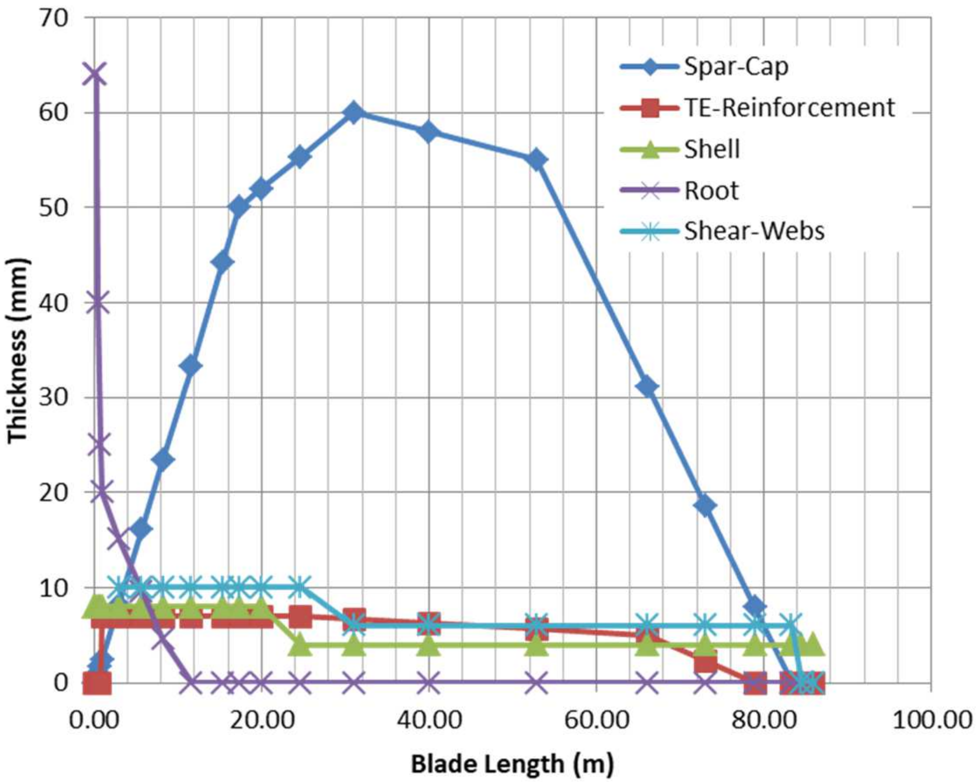
Section ID (-)	L (m)	Thickness (mm)
S1	0.00	
S2	0.20	
S3	0.50	
S4	0.75	
S5	1.00	
S6	2.95	10
S7	5.72	10
S8	8.23	10
S9	11.60	10
S10	15.36	10
S11	17.37	10
S12	20.00	10
S13	24.66	10
S14	31.00	6
S15	40.08	6
S16	52.87	6
S17	66.12	6
S18	73.00	6
S19	78.94	6
S20	83.32	6
S21	84.45	0
S22	85.94	0

PRACTICAL CASES
Definition of the ply-book

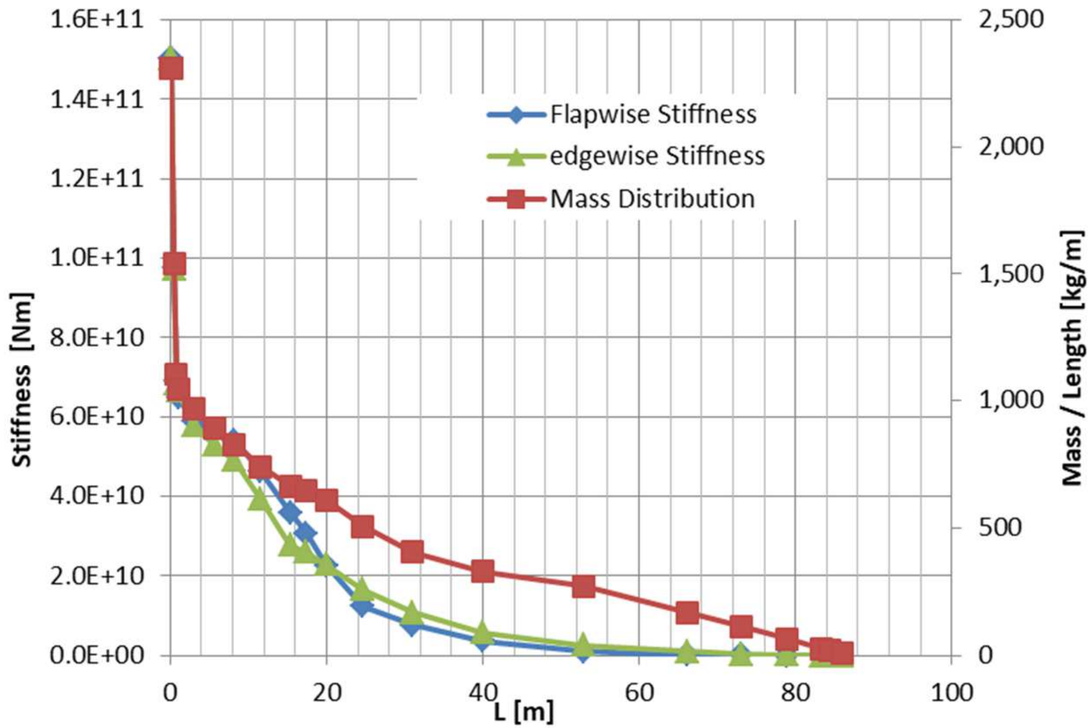
PRACTICAL CASES

C3- From a parametric lay-up to a detailed design (using BASSF)

Blade name	INNWIND - CENER
Hub diameter (m)	5.6
Blade length (m)	86.37
Blade mass (kg)	33958
Centre of Gravity (m)	25.68
First Flapwise Frequency (Hz)	0.776
First Edgewise Frequency (Hz)	0.906
Maximum Deflection Flapwise (m)	15.56
Maximum Deflection Edgewise (m)	2.24



Thickness distribution of the lay-up



Mass and Stiffness distribution

CENER

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Thank you for your attention.