Analysis of Hydraulic Turbine using MecaFlux Heliciel

Suppose that we have a stream of water with no head available then for getting power out of it we can just only use the kinetic energy of water.

$$P = \frac{1}{2}\rho A v^3$$

P = Power Available
ρ = Density of Water
A = Area of Discharge
v = Velocity of Water

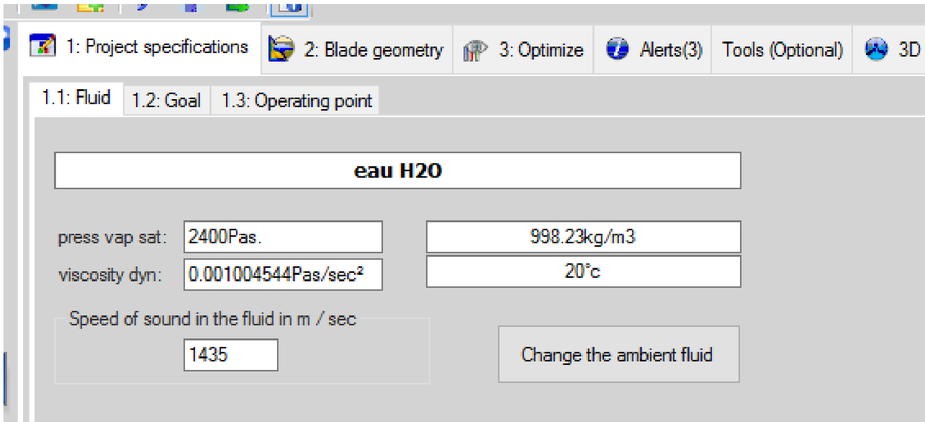
Suppose we have the stream speed of 4m/s and the depth of stream is only 3m and constant i.e. there is no variation in the depth of stream.
Our purpose is to capture energy from the stream using Hydraulic Turbine with Hydro-Kinetic Propeller.
Now we want to design and analyze the hydraulic turbine according to the given restrictions…….
I started surfing on the internet for this specific case. I read many research articles. I came to know about different software designed for Hydro-kinetic type of Hydraulic Turbine like Turbem, HARP etc. If software is free then it's not capable of drawing 3D model. On the other hand, software in which 3D model can be drawn are not free. Then I found a very much friendly software MecaFlux Heliciel and a great news for me on the website of this software company that I can use it freely if I do a partnership contract with company that I will do work on this and write an article or make a video tutorial.
I really appreciate this thought that students who could not pay for the software still they can use it freely. It's freedom for all.
Then I started to work on it
I found that it can do multiple analysis, calculate forces, draw velocity diagrams and estimate power output and shaft power.

1. Project Specifications

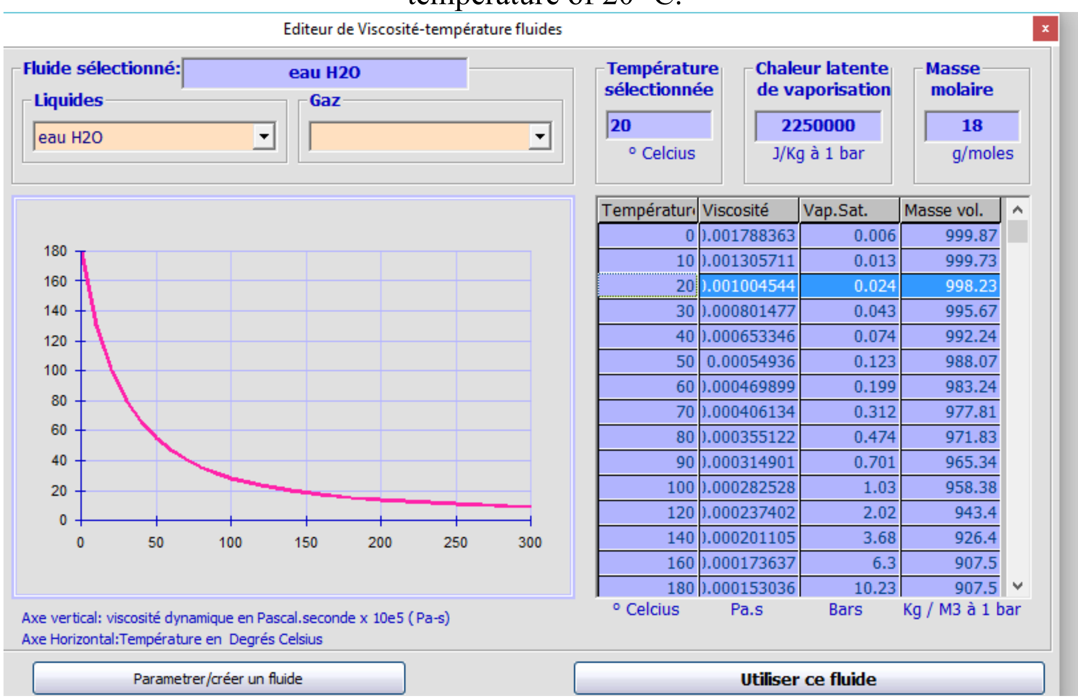
In MecaFlux Heliciel Software, Project Specifications were inserted by selecting type of fluid, temperature of fluid, purpose of installation and velocity of the fluid stream.

1.1 Type of Fluid

Water was selected among the list of Liquids.
One can change the ambient fluid by clicking on the tab on the bottom right side in the figure. This software can also deal with gases too such as air is the fluid in wind turbine.

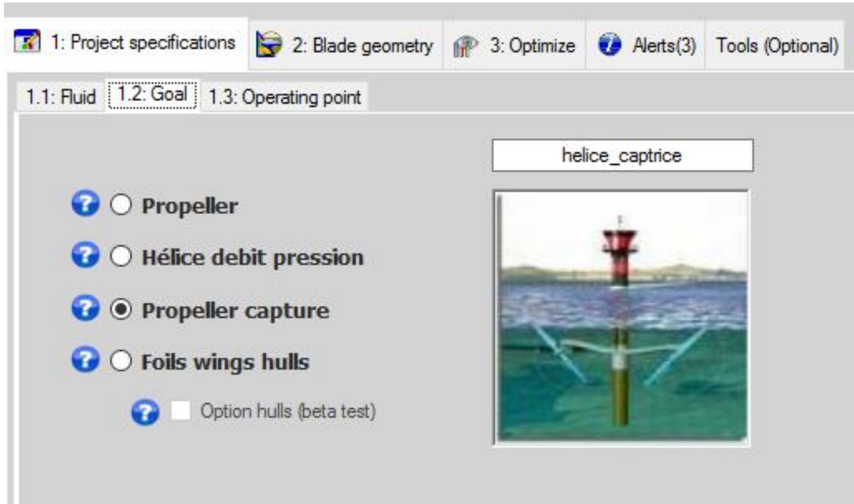


By clicking on the change the ambient fluid tab, a new window appears where we can select the type of fluid and ambient temperature of the fluid as shown in below figure that water has been selected with temperature of 20 ^{0}C.



1.2 Purpose/Goal

As our goal is to capture energy from the fluid stream so third option from the list was selected.

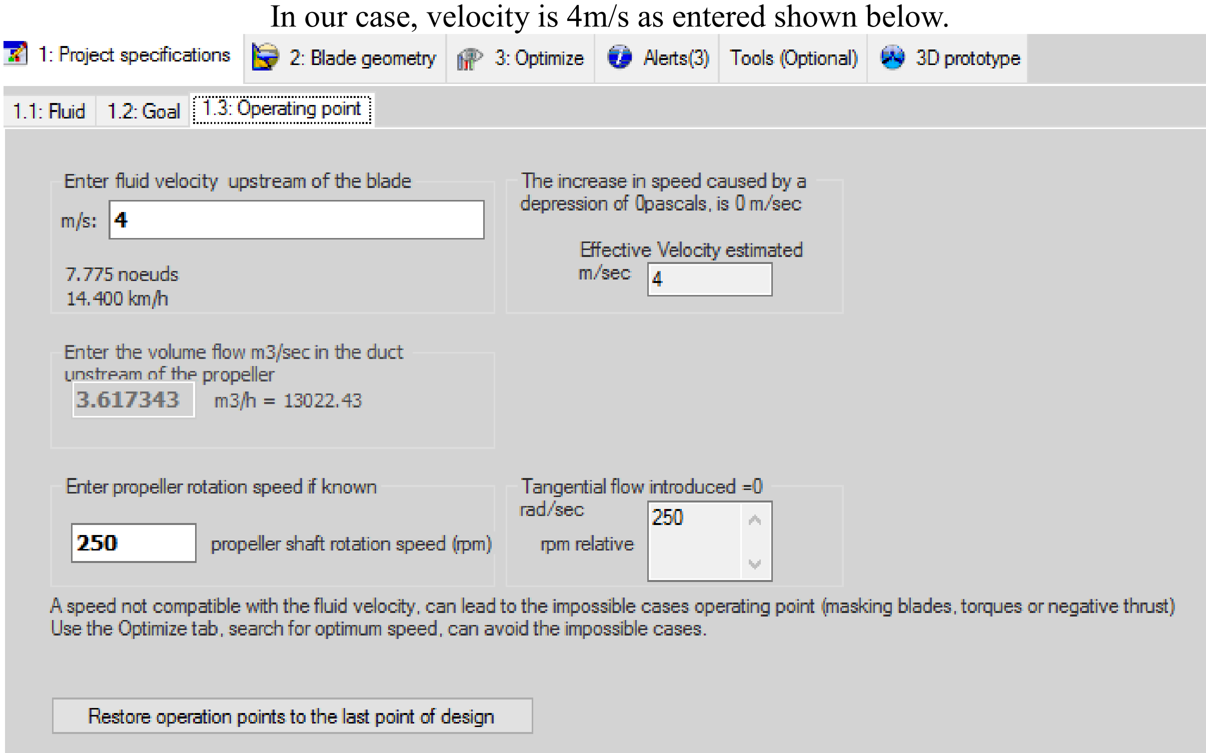


1.3 Operating Conditions

The velocity of the fluid stream can be measured by velocimeter or can be obtained from the nearby gauge station.

And also the propeller rotation can be entered if known but it's not necessary as Heliciel is capable of optimizing the propeller speed of rotation and also the no. of blades.

In our case, velocity is 4m/s as entered shown below.



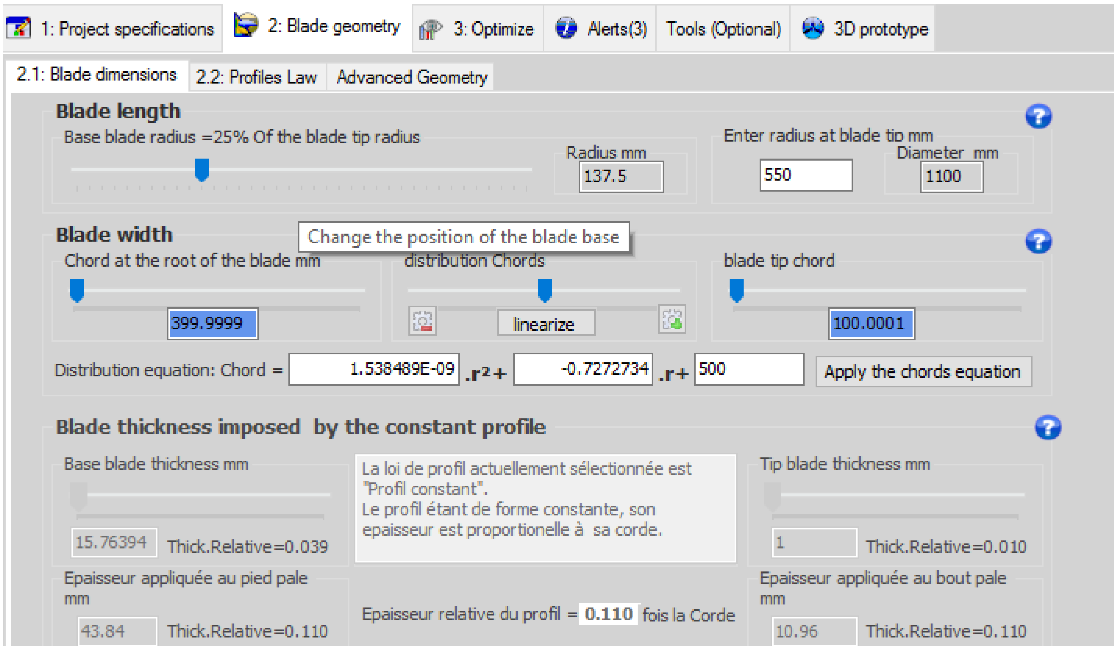
2. Blade Design

In blade designing procedure parameters like blade base radius, blade tip radius, chord at the root & tip of blade, blade profile, chord distribution equation, blade materials, no. of blade elements per blade and no. of blades were involved.

2.1 Blade Length

First of all due to the unavailability of large depth of stream a small design of turbine is required.

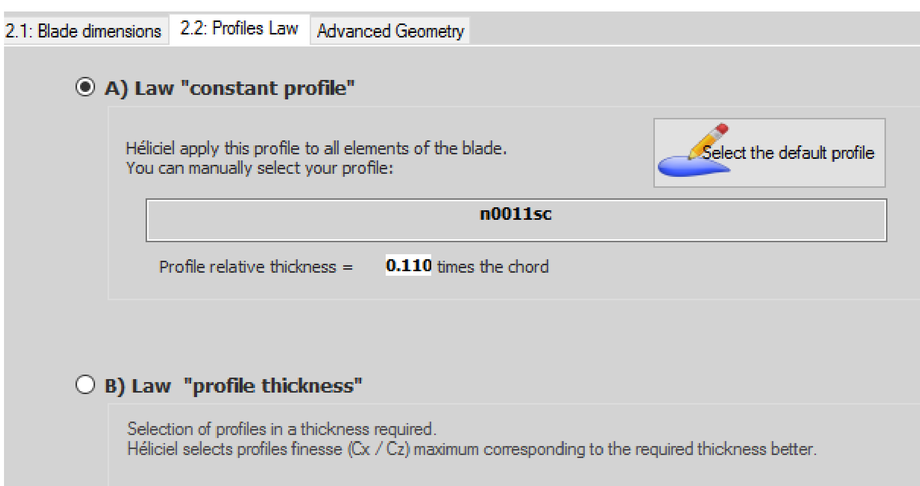
Blade radius at base can be adjusted and one can change it according to the requirement as rupture in element appears in 3D model sometimes. Similarly chord at the root and tip of blade can be adjusted.



2.2 Blade Profile

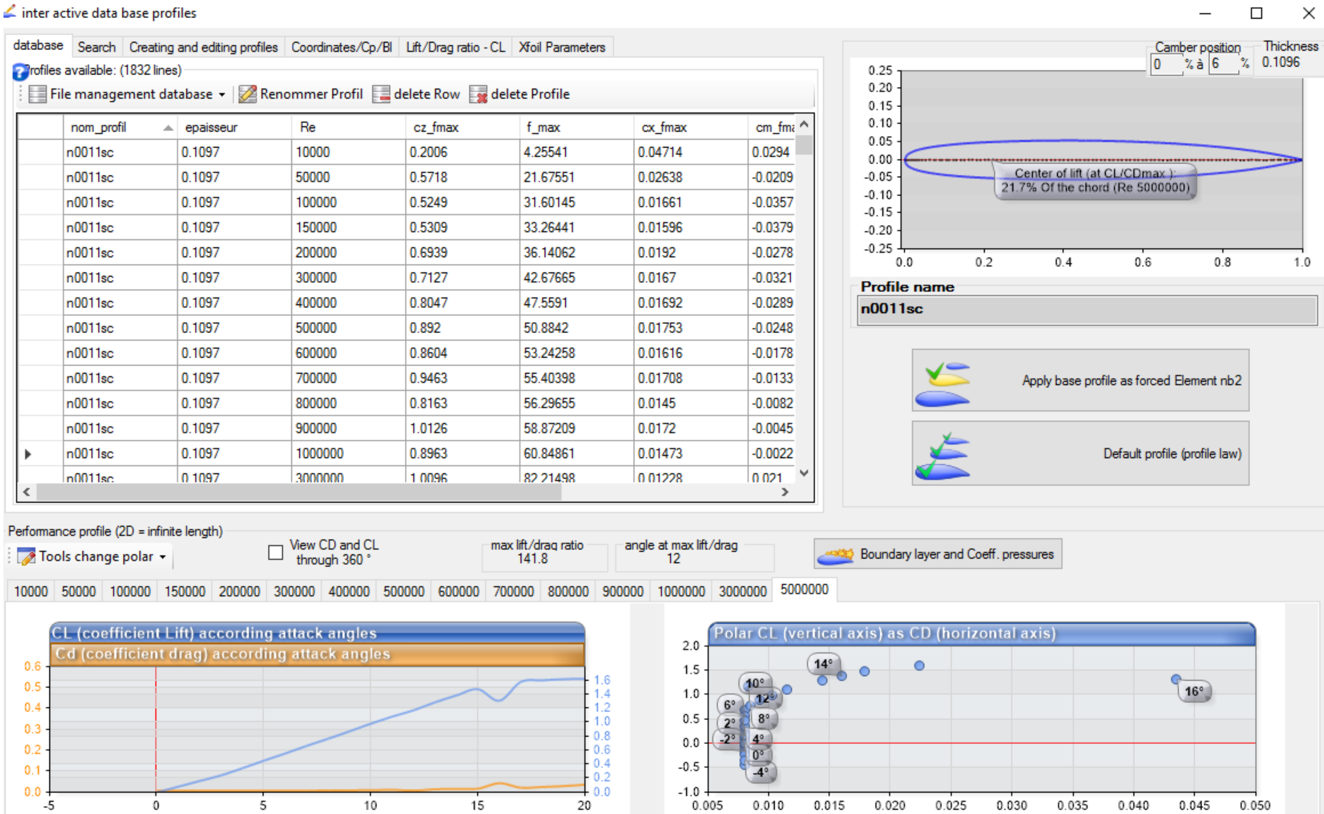
Blade profile has two options.

1. Constant Profile
2. Profile Thickness



In constant profile default profile is selected by clicking the tab on the right side. Heliciel has Interactive profiles database from which one can select with a larger variation in Renoyld's No. i.e., 10000 to 5000000.

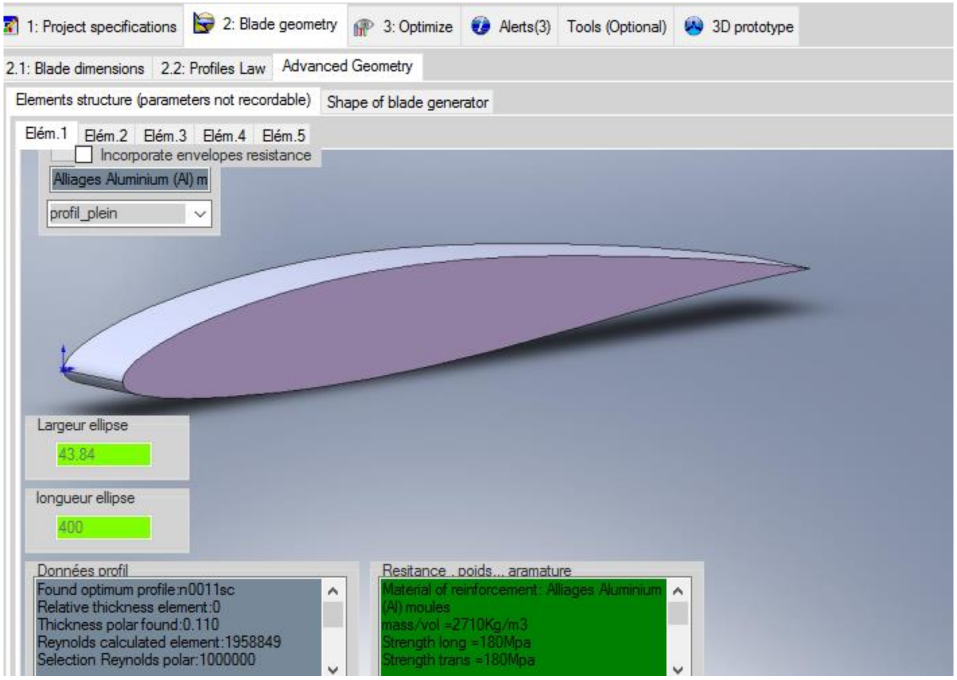
In our case n0011sc profile has been selected and Renoyld's no. is 5000000.



Also there are two options here wether we want to examine default profile for each element of blade or for specific element of the blade for example in the above figure it is shown that there is an option to select the profile for just blade element no. 2, not for the other elements of blade.

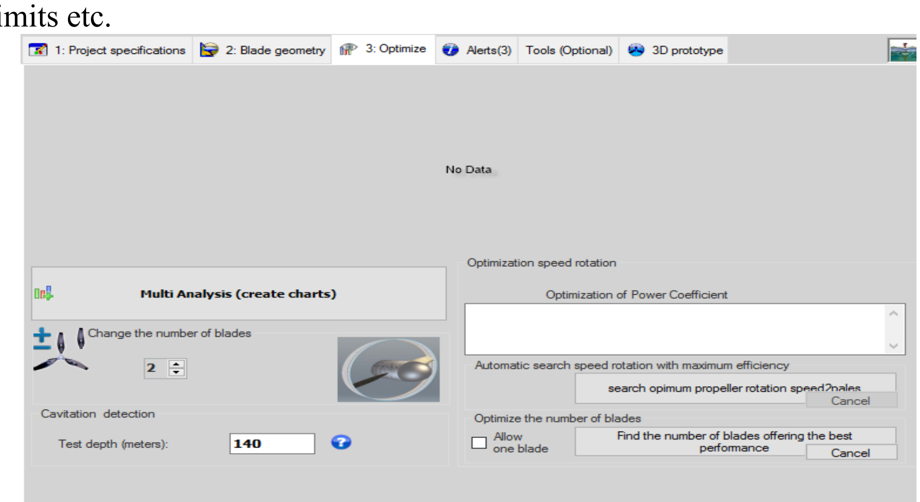
2.3 Blade Material

Blade has been divided into five elements in this case. Blade material can be chosen for all elements of blade or single element of blade just like blade profile. If strength of blade will not be appropriate the red colour will be shown instead of green colour which is shown in the figure.

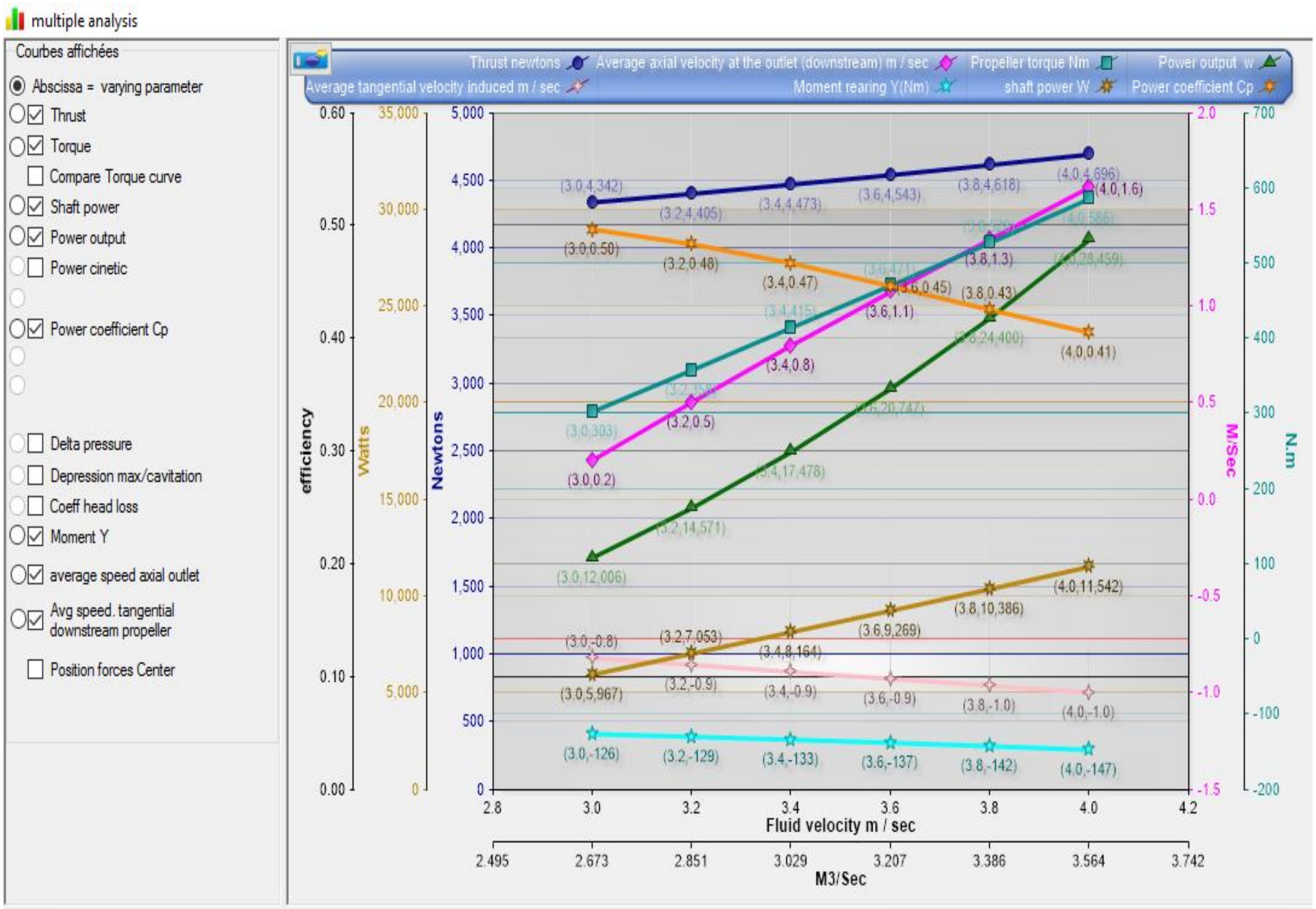


3. Optimizing the Design

In optimization, we can find the no. of blades offering best performance, optimum propeller speed and also one can analyze the design by changing no. of blades. Heliciel can also create multi-analysis charts offering various parameters vs fluid speed like thrust, moment, power output, power available according to Betz' Limit, Velocities at exit, Head loss coefficient and cavitation limits etc.



After this multiple analysis the different parameters as described earlier are plotted graphically according to fluid speed as shown below.



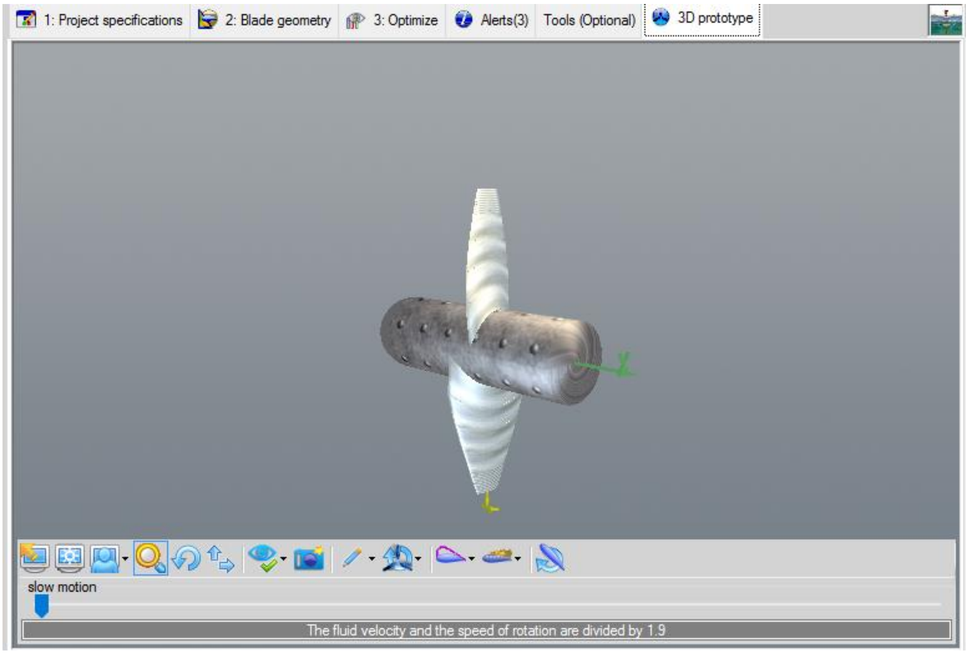
And also the values of different parameters at different velocity points can be viewed in the tabular form in the below section as shown.

Save   Enter a torque curve compared

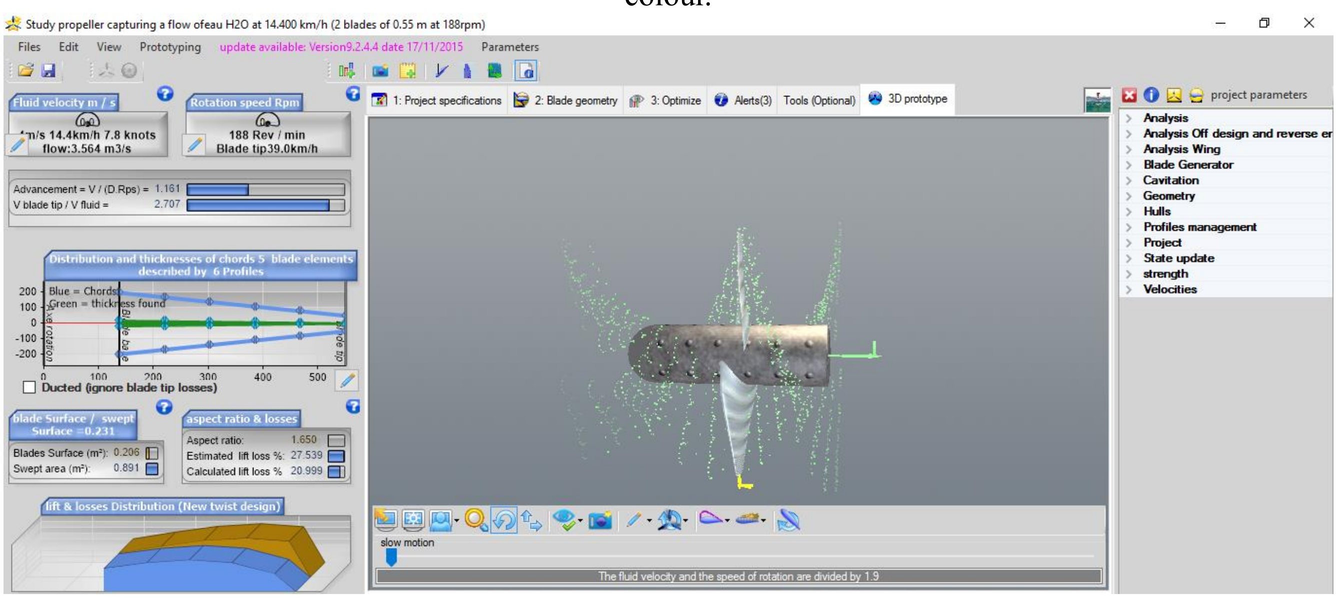
V(m/sec)	n(Rpm)	n(Rps)	λ=ω.R/V	Cp	Ct	Torque(Nm)	Thrust(N)	P shaft(W)	P.cin.(W)	delta P(pas)	V.tan.Downstr	V.ax.Downstre	Moment Y(Nm)	head loss coef
3	188	3.1333	3.609	0.4970	-0.3026	303.0788	4341.686	5966.808	12006.35	-4873.173	-0.8169	0.2051	-125.6626	1.0170
3.2	188	3.1333	3.384	0.4840	-0.3070	358.2275	4405.144	7052.537	14571.26	-4944.4	-0.8531	0.5054	-129.2149	0.9070
3.4	188	3.1333	3.185	0.4671	-0.3117	414.6832	4473.09	8163.998	17477.68	-5020.663	-0.8898	0.7989	-133.1277	0.8158
3.6	188	3.1333	3.008	0.4467	-0.3166	470.793	4543.02	9268.651	20746.97	-5099.154	-0.9250	1.0757	-137.2736	0.7390
3.8	188	3.1333	2.849	0.4257	-0.3218	527.5633	4617.6	10386.3	24400.46	-5182.864	-0.9606	1.3472	-141.7728	0.6742
4	188	3.1333	2.707	0.4056	-0.3273	586.2611	4695.818	11541.91	28459.49	-5270.656	-0.9967	1.6164	-146.5628	0.6188

4. 3D Model

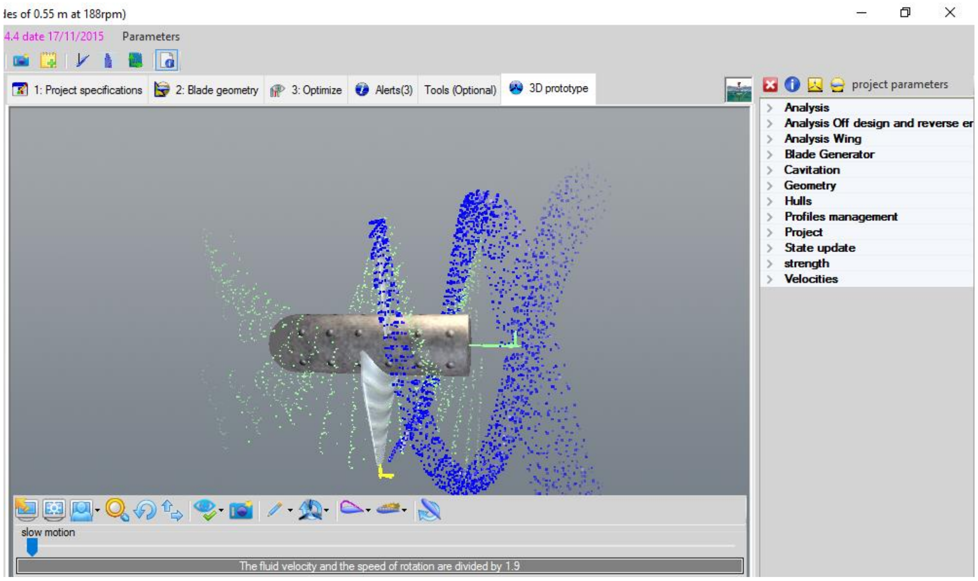
A 3D prototype can be viewed and one can also play with it using commands given in the bottom bar.



For example in the figure below it has been shown the path particles in the fluid stream with green colour.

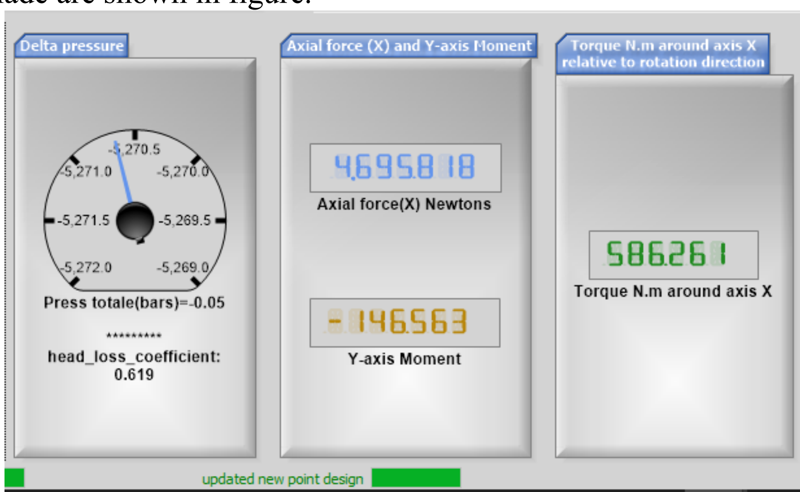


And also blade tip losses can be viewed as shown in blue color.

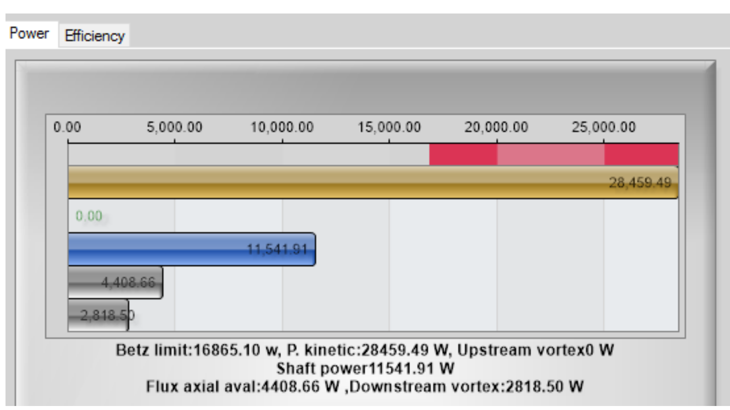


5. Heliciel Results

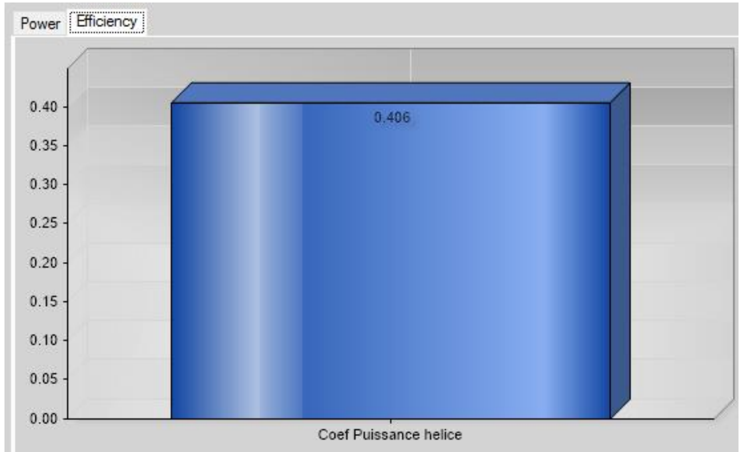
The Delta Pressure & Head Loss Coefficient , Axial Force & Y-axis Moment, Torque around x-axis for single blade are shown in figure.



The comparison among Betz Limit, Power available and Shaft Power output is shown in the form of bar graph.

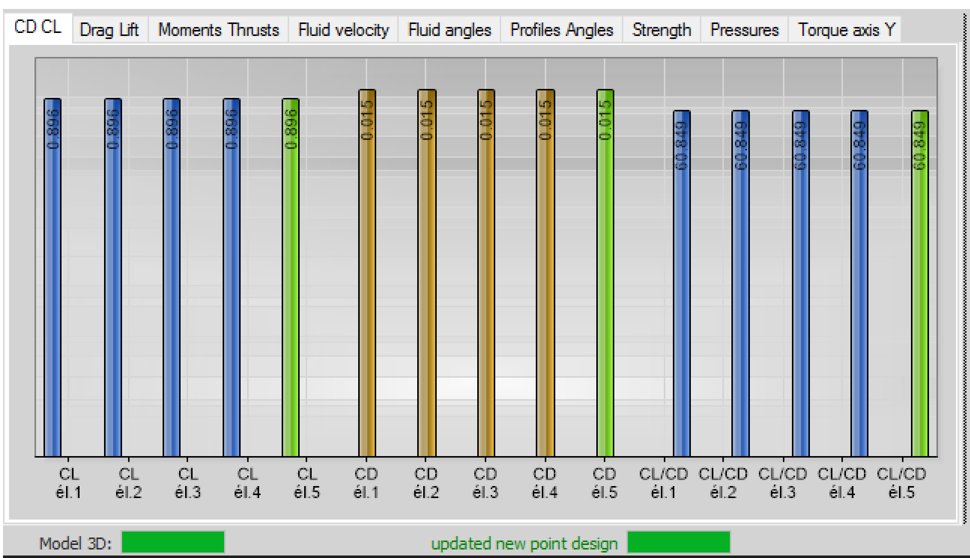


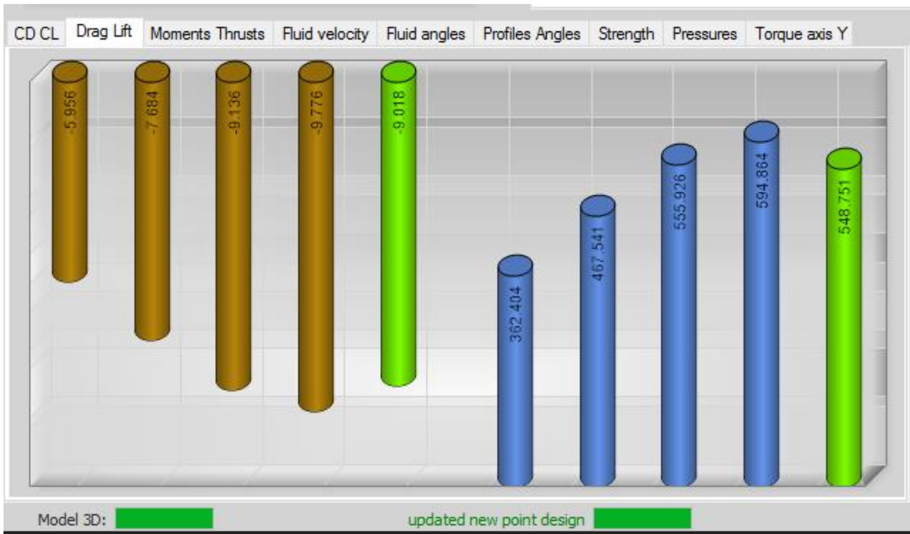
Efficiency is the ratio of shaft power to kinetic which is available power and it is 0.406.



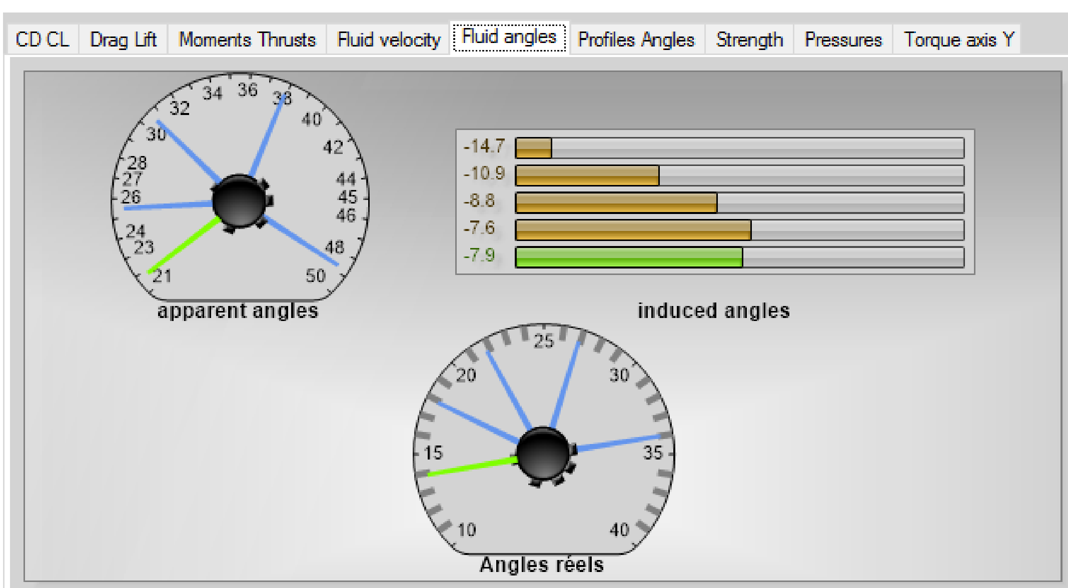
6. Heliciel Calculations per Element of Blade

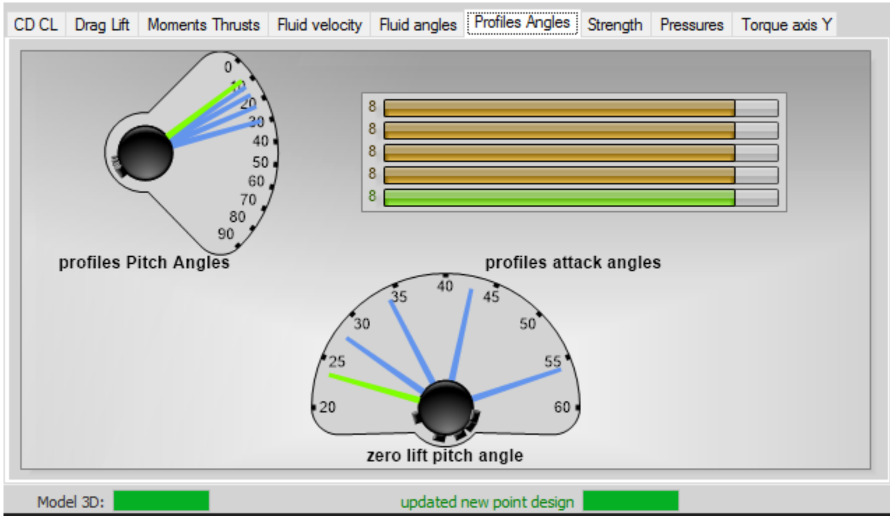
Heliciel calculates various parameters for individual element of single blade like Lift Coefficient, Drag Coefficient, Lift & Drag Forces, Moment & Thrust, Fluid velocities and angles, blade angles, Strength and Torque about axis Y. These are represented in bar graphs as shown.

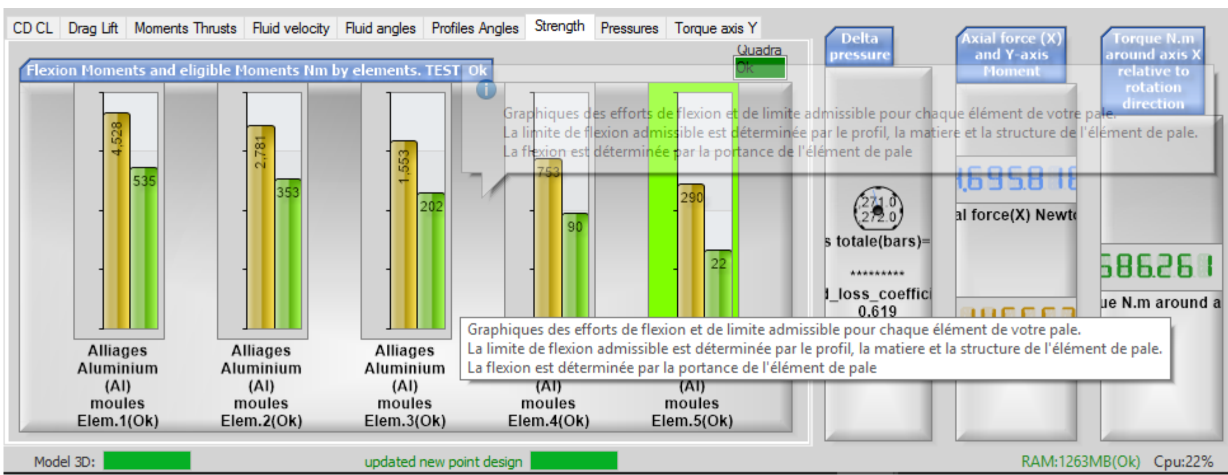


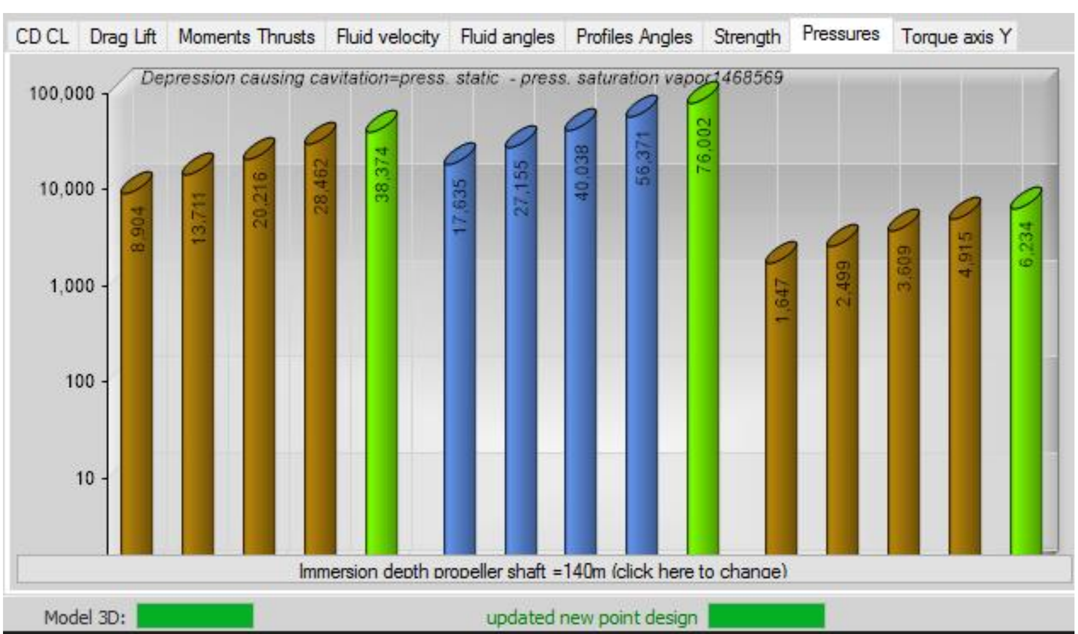

CD CL
Drag Lift
Moments Thrusts
Fluid velocity
Fluid angles
Profiles Angles
Strength
Pressures
Torque axis Y
-5.956
-7.684
-9.136
-9.776
-9.018
362.404
467.541
555.926
594.864
548.751
Model 3D:
updated new point design

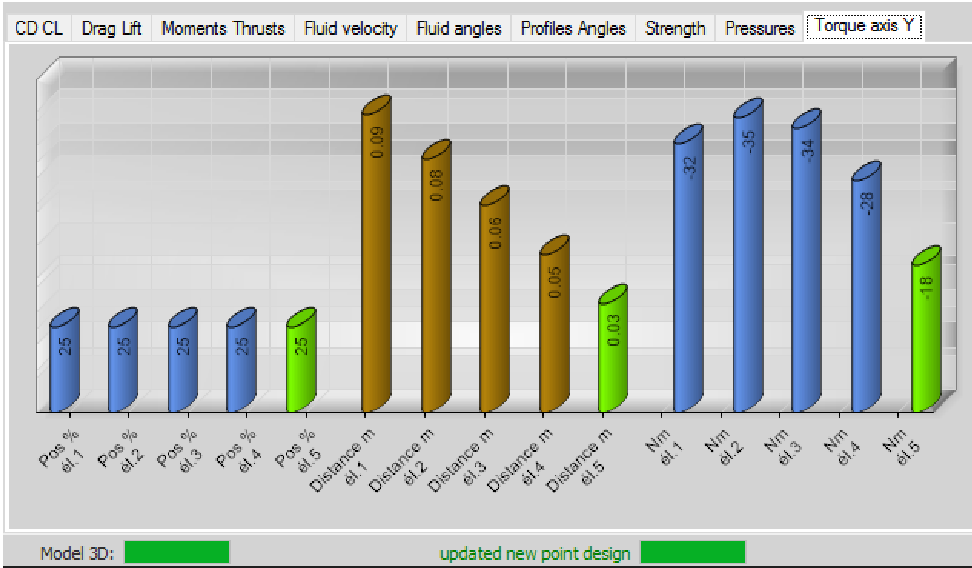

CD CL
Drag Lift
Moments Thrusts
Fluid velocity
Fluid angles
Profiles Angles
Strength
Pressures
Torque axis Y
35
54
68
74
62
303.858
420.324
519.658
569.146
534.922
Model 3D:
updated new point design


CD CL
Drag Lift
Moments Thrusts
Fluid velocity
Fluid angles
Profiles Angles
Strength
Pressures
Torque axis Y
-14.7
-10.9
-8.8
-7.6
-7.9
apparent angles
induced angles
Angles réels


CD CL
Drag Lift
Moments Thrusts
Fluid velocity
Fluid angles
Profiles Angles
Strength
Pressures
Torque axis Y
profiles Pitch Angles
profiles attack angles
zero lift pitch angle
Model 3D:
updated new point design

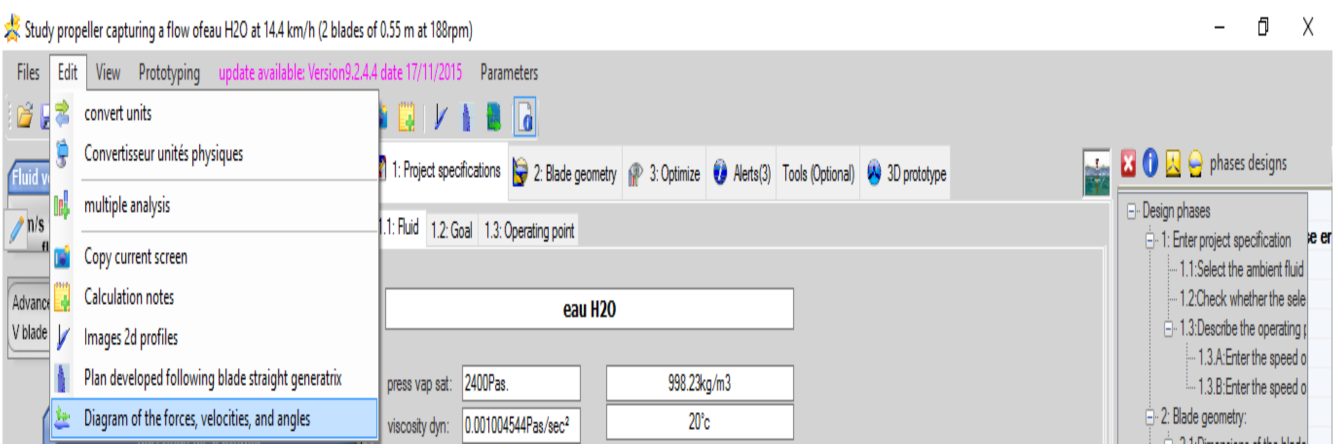

CD CL
Drag Lift
Moments Thrusts
Fluid velocity
Fluid angles
Profiles Angles
Strength
Pressures
Torque axis Y
Flexion Moments and eligible Moments Nm by elements. TEST Ok
Delta pressure
Axial force (X) and Y-axis Moment
Torque N.m around axis X relative to rotation direction
Graphiques des efforts de flexion et de limite admissible pour chaque élément de votre pale.
La limite de flexion admissible est déterminée par le profil, la matiere et la structure de l'élément de pale.
La flexion est déterminée par la portance de l'élément de pale
Alliages Aluminium (Al) moules Elem.1(Ok)
Alliages Aluminium (Al) moules Elem.2(Ok)
Alliages Aluminium (Al) moules Elem.3(Ok)
moules Elem.4(Ok)
moules Elem.5(Ok)
Model 3D:
updated new point design
RAM:1263MB(Ok) Cpu:22%


CD CL
Drag Lift
Moments Thrusts
Fluid velocity
Fluid angles
Profiles Angles
Strength
Pressures
Torque axis Y
Depression causing cavitation=press. static - press. saturation vapor 1468569
100,000
10,000
1,000
100
10
8,904
13,711
20,216
28,462
38,374
17,635
27,155
40,038
56,371
76,002
1,647
2,499
3,609
4,915
6,234
Immersion depth propeller shaft =140m (click here to change)
Model 3D:
updated new point design

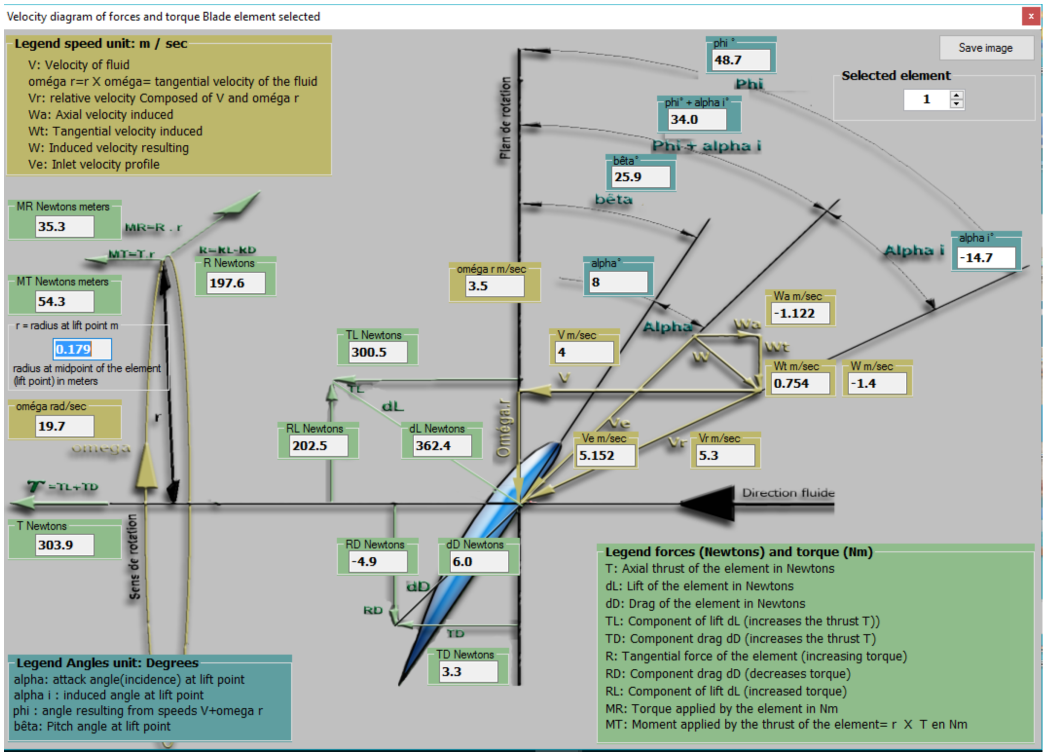


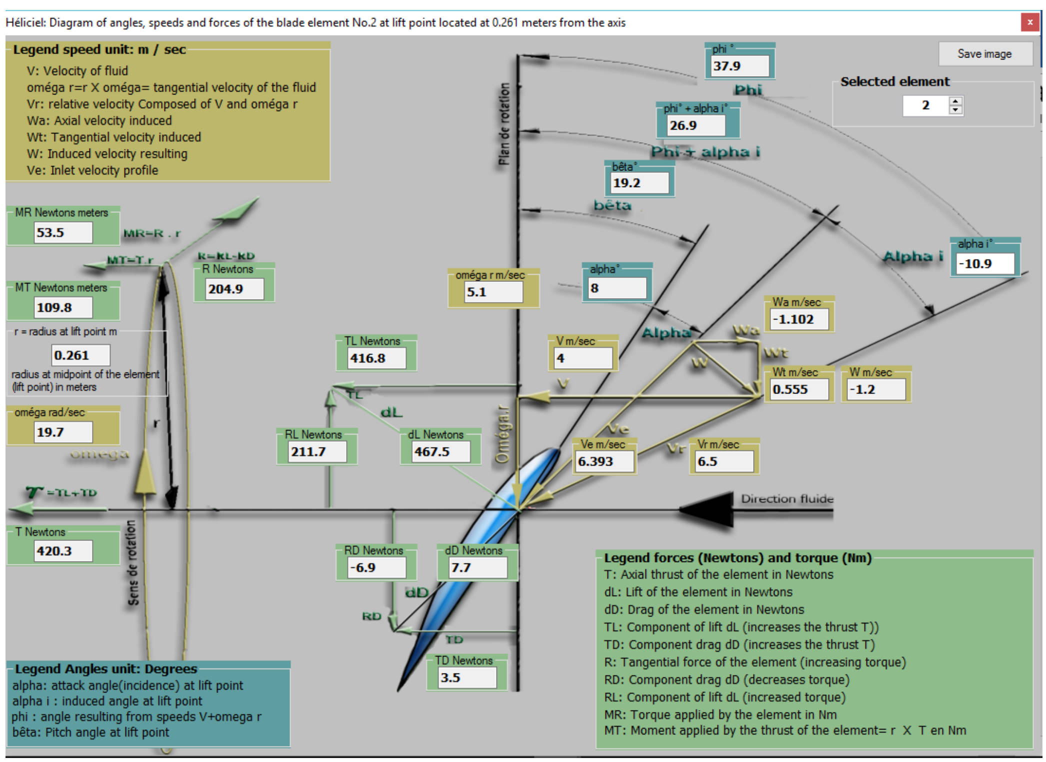
6.1 Force, Velocity and Angle Diagrams for Each Element

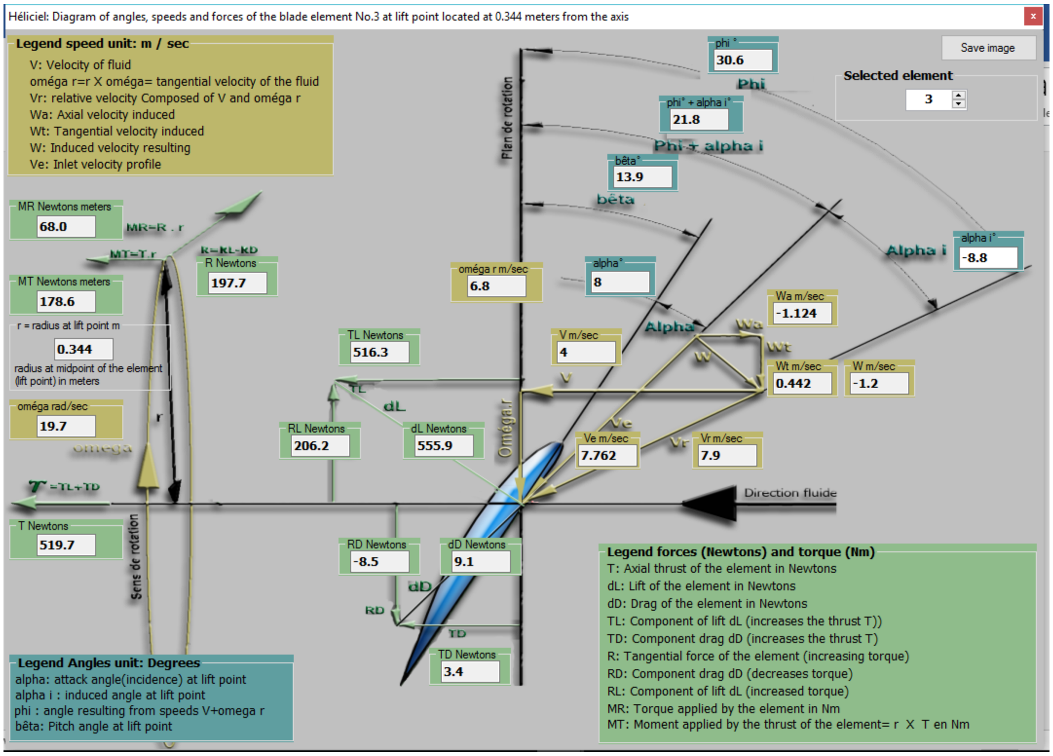
Heliciel is also capable of drawing velocity diagrams with full detailed knowledge of symbols and values of physical quantities. These diagrams are self-explanatory for the students of fluid mechanics. Go to Edit and select diagram of Forces, Velocities and angles.

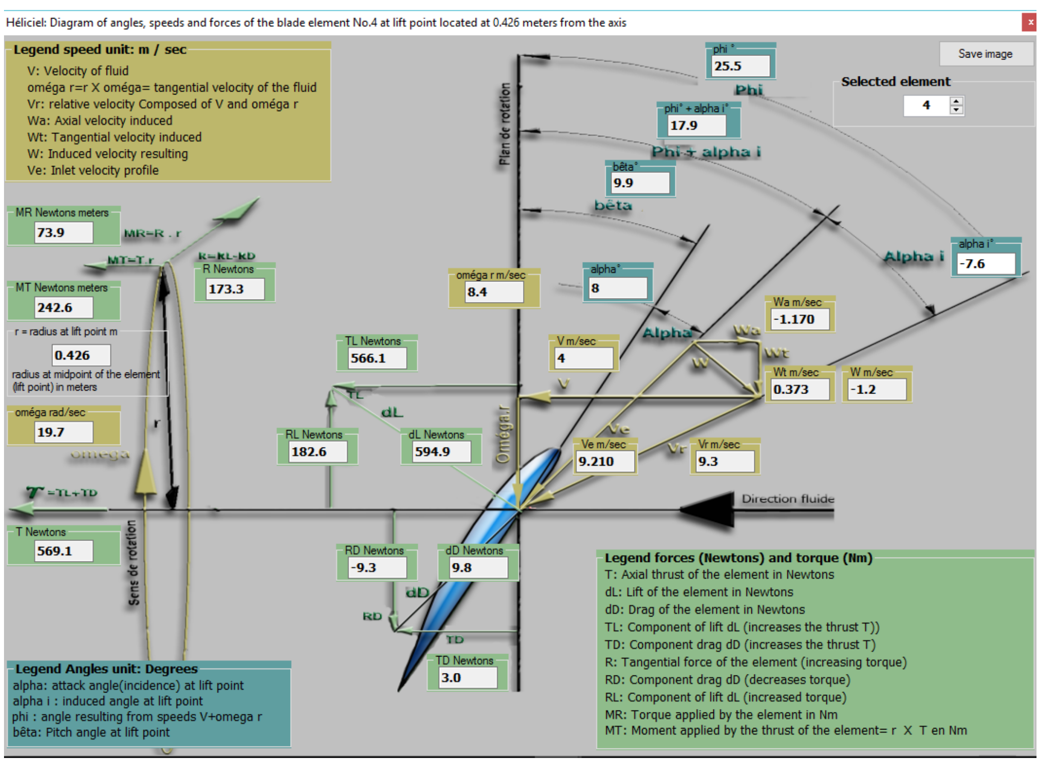


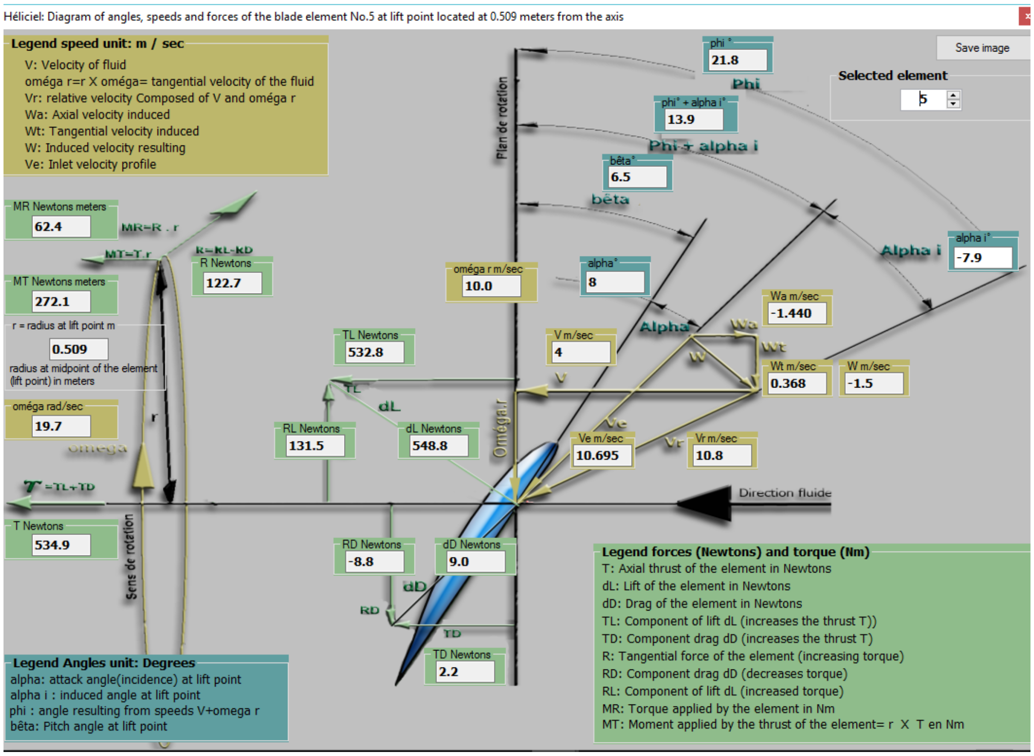
These Diagrams are shown For Element 1, Element 2, Element 3, Element 4 and Element 5 respectively.






Héliciel: Diagram of angles, speeds and forces of the blade element No.3 at lift point located at 0.344 meters from the axis
Legend speed unit: m / sec
V: Velocity of fluid
oméga r=r X oméga= tangential velocity of the fluid
Vr: relative velocity Composed of V and oméga r
Wa: Axial velocity induced
Wt: Tangential velocity induced
W: Induced velocity resulting
Ve: Inlet velocity profile
phi° 30.6
Save image
Selected element 3
phi° + alpha i° 21.8
bêta° 13.9
MR Newtons meters 68.0
MR=R . r
MT=T.r
R=RL-RD
R Newtons 197.7
MT Newtons meters 178.6
r = radius at lift point m 0.344
radius at midpoint of the element (lift point) in meters
oméga r m/sec 6.8
alpha° 8
alpha i° -8.8
Wa m/sec -1.124
TL Newtons 516.3
V m/sec 4
Wt m/sec 0.442
W m/sec -1.2
oméga rad/sec 19.7
RL Newtons 206.2
dL Newtons 555.9
Ve m/sec 7.762
Vr m/sec 7.9
Direction fluide
T Newtons 519.7
Sens de rotation
Plan de rotation
RD Newtons -8.5
dD Newtons 9.1
TD Newtons 3.4
Legend Angles unit: Degrees
alpha: attack angle(incidence) at lift point
alpha i : induced angle at lift point
phi : angle resulting from speeds V+omega r
bêta: Pitch angle at lift point
Legend forces (Newtons) and torque (Nm)
T: Axial thrust of the element in Newtons
dL: Lift of the element in Newtons
dD: Drag of the element in Newtons
TL: Component of lift dL (increases the thrust T))
TD: Component drag dD (increases the thrust T)
R: Tangential force of the element (increasing torque)
RD: Component drag dD (decreases torque)
RL: Component of lift dL (increased torque)
MR: Torque applied by the element in Nm
MT: Moment applied by the thrust of the element= r X T en Nm

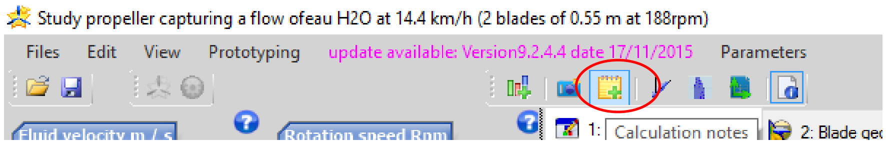

Héliciel: Diagram of angles, speeds and forces of the blade element No.4 at lift point located at 0.426 meters from the axis
Legend speed unit: m / sec
V: Velocity of fluid
oméga r=r X oméga= tangential velocity of the fluid
Vr: relative velocity Composed of V and oméga r
Wa: Axial velocity induced
Wt: Tangential velocity induced
W: Induced velocity resulting
Ve: Inlet velocity profile
phi° 25.5
Save image
Selected element 4
phi° + alpha i° 17.9
bêta° 9.9
MR Newtons meters 73.9
MR=R . r
MT=T.r
R=RL-RD
R Newtons 173.3
MT Newtons meters 242.6
r = radius at lift point m 0.426
radius at midpoint of the element (lift point) in meters
oméga r m/sec 8.4
alpha° 8
alpha i° -7.6
Wa m/sec -1.170
TL Newtons 566.1
V m/sec 4
Wt m/sec 0.373
W m/sec -1.2
oméga rad/sec 19.7
RL Newtons 182.6
dL Newtons 594.9
Ve m/sec 9.210
Vr m/sec 9.3
Direction fluide
T Newtons 569.1
Sens de rotation
Plan de rotation
RD Newtons -9.3
dD Newtons 9.8
TD Newtons 3.0
Legend Angles unit: Degrees
alpha: attack angle(incidence) at lift point
alpha i : induced angle at lift point
phi : angle resulting from speeds V+omega r
bêta: Pitch angle at lift point
Legend forces (Newtons) and torque (Nm)
T: Axial thrust of the element in Newtons
dL: Lift of the element in Newtons
dD: Drag of the element in Newtons
TL: Component of lift dL (increases the thrust T))
TD: Component drag dD (increases the thrust T)
R: Tangential force of the element (increasing torque)
RD: Component drag dD (decreases torque)
RL: Component of lift dL (increased torque)
MR: Torque applied by the element in Nm
MT: Moment applied by the thrust of the element= r X T en Nm



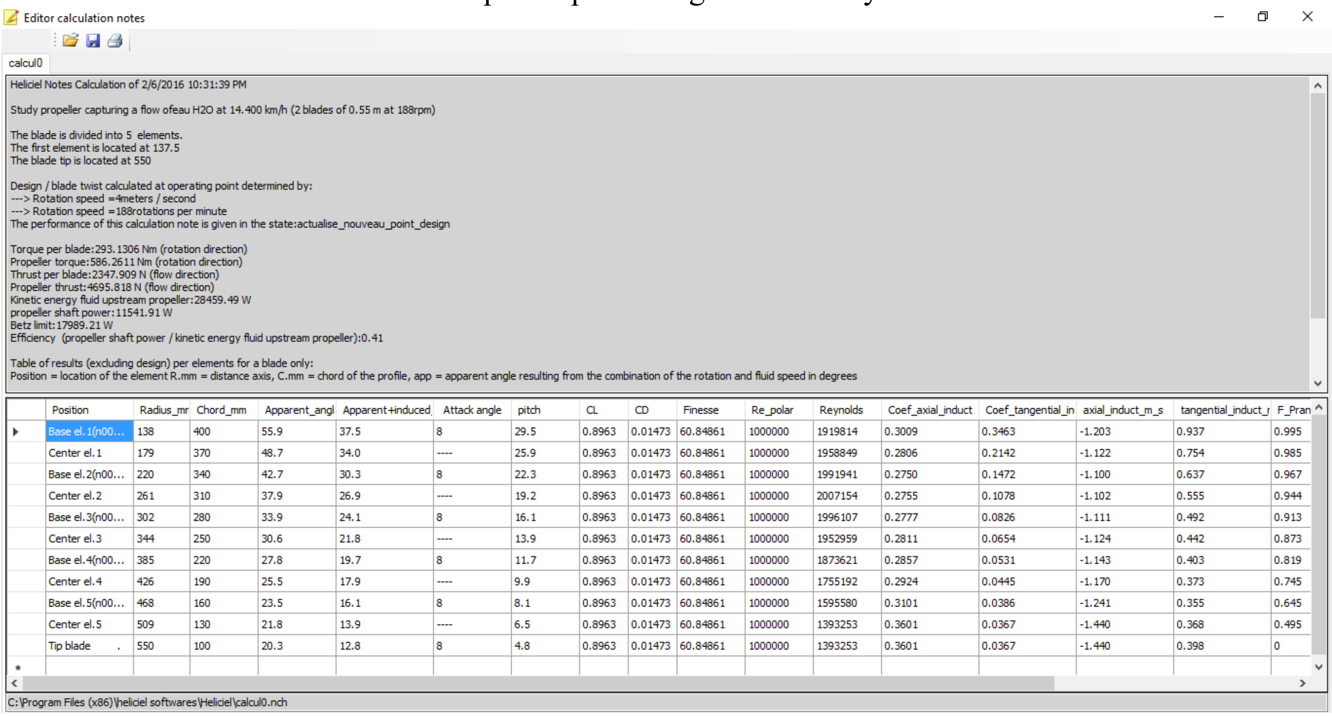
Héliciel: Diagram of angles, speeds and forces of the blade element No.5 at lift point located at 0.509 meters from the axis
Legend speed unit: m / sec
V: Velocity of fluid
oméga r=r X oméga= tangential velocity of the fluid
Vr: relative velocity Composed of V and oméga r
Wa: Axial velocity induced
Wt: Tangential velocity induced
W: Induced velocity resulting
Ve: Inlet velocity profile
Save image
Selected element
5
phi °
21.8
Phi
phi° + alpha i°
13.9
Phi + alpha i
bêta°
6.5
bêta
Plan de rotation
alpha i°
-7.9
Alpha i
MR Newtons meters
62.4
MR=R . r
MT=T.r
R=RL-RD
R Newtons
122.7
MT Newtons meters
272.1
r = radius at lift point m
0.509
radius at midpoint of the element (lift point) in meters
oméga r m/sec
10.0
alpha°
8
Alpha
Wa m/sec
-1.440
Wa
Wt
W
TL Newtons
532.8
V m/sec
4
V
Wt m/sec
0.368
W m/sec
-1.5
TL
dL
oméga rad/sec
19.7
r
RL Newtons
131.5
dL Newtons
548.8
Ve
Ve m/sec
10.695
Vr
Vr m/sec
10.8
Oméga.r
T=TL+TD
Direction fluide
T Newtons
534.9
Sens de rotation
RD Newtons
-8.8
dD Newtons
9.0
dD
RD
TD
TD Newtons
2.2
Legend forces (Newtons) and torque (Nm)
T: Axial thrust of the element in Newtons
dL: Lift of the element in Newtons
dD: Drag of the element in Newtons
TL: Component of lift dL (increases the thrust T))
TD: Component drag dD (increases the thrust T)
R: Tangential force of the element (increasing torque)
RD: Component drag dD (decreases torque)
RL: Component of lift dL (increased torque)
MR: Torque applied by the element in Nm
MT: Moment applied by the thrust of the element= r X T en Nm
Legend Angles unit: Degrees
alpha: attack angle(incidence) at lift point
alpha i : induced angle at lift point
phi : angle resulting from speeds V+omega r
bêta: Pitch angle at lift point

Results & Calculation Notes Summary

For the summary of calcultaions performed for the 5 individual elements of blade, click an icon higlighted mentioning Calculation notes.



A new window will apear representing the summary of all calculations.



Editor calculation notes

calcul0

Heliciel Notes Calculation of 2/6/2016 10:31:39 PM

Study propeller capturing a flow ofeau H2O at 14.400 km/h (2 blades of 0.55 m at 188rpm)

The blade is divided into 5 elements.
The first element is located at 137.5
The blade tip is located at 550

Design / blade twist calculated at operating point determined by:
---> Rotation speed =4meters / second
---> Rotation speed =188rotations per minute
The performance of this calculation note is given in the state:actualise_nouveau_point_design

Torque per blade:293.1306 Nm (rotation direction)
Propeller torque:586.2611 Nm (rotation direction)
Thrust per blade:2347.909 N (flow direction)
Propeller thrust:4695.818 N (flow direction)
Kinetic energy fluid upstream propeller:28459.49 W
propeller shaft power:11541.91 W
Betz limit:17989.21 W
Efficiency (propeller shaft power / kinetic energy fluid upstream propeller):0.41

Table of results (excluding design) per elements for a blade only:
Position = location of the element R.mm = distance axis, C.mm = chord of the profile, app = apparent angle resulting from the combination of the rotation and fluid speed in degrees

Position	Radius_mr	Chord_mm	Apparent_angl	Apparent+induced	Attack angle	pitch	CL	CD	Finesse	Re_polar	Reynolds	Coef_axial_induct	Coef_tangential_in	axial_induct_m_s	tangential_induct_r	F_Pran
Base el.1(n00...	138	400	55.9	37.5	8	29.5	0.8963	0.01473	60.84861	1000000	1919814	0.3009	0.3463	-1.203	0.937	0.995
Center el.1	179	370	48.7	34.0	----	25.9	0.8963	0.01473	60.84861	1000000	1958849	0.2806	0.2142	-1.122	0.754	0.985
Base el.2(n00...	220	340	42.7	30.3	8	22.3	0.8963	0.01473	60.84861	1000000	1991941	0.2750	0.1472	-1.100	0.637	0.967
Center el.2	261	310	37.9	26.9	----	19.2	0.8963	0.01473	60.84861	1000000	2007154	0.2755	0.1078	-1.102	0.555	0.944
Base el.3(n00...	302	280	33.9	24.1	8	16.1	0.8963	0.01473	60.84861	1000000	1996107	0.2777	0.0826	-1.111	0.492	0.913
Center el.3	344	250	30.6	21.8	----	13.9	0.8963	0.01473	60.84861	1000000	1952959	0.2811	0.0654	-1.124	0.442	0.873
Base el.4(n00...	385	220	27.8	19.7	8	11.7	0.8963	0.01473	60.84861	1000000	1873621	0.2857	0.0531	-1.143	0.403	0.819
Center el.4	426	190	25.5	17.9	----	9.9	0.8963	0.01473	60.84861	1000000	1755192	0.2924	0.0445	-1.170	0.373	0.745
Base el.5(n00...	468	160	23.5	16.1	8	8.1	0.8963	0.01473	60.84861	1000000	1595580	0.3101	0.0386	-1.241	0.355	0.645
Center el.5	509	130	21.8	13.9	----	6.5	0.8963	0.01473	60.84861	1000000	1393253	0.3601	0.0367	-1.440	0.368	0.495
Tip blade .	550	100	20.3	12.8	8	4.8	0.8963	0.01473	60.84861	1000000	1393253	0.3601	0.0367	-1.440	0.398	0

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