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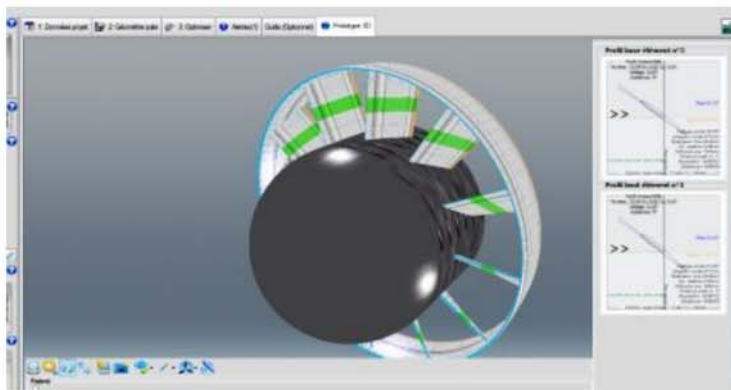
Tutorial example small hydropower plant design 2/3

geometry of the stator guide vanes and turbine kaplan:

Chapter Summary hydroelectric turbines::

- [kaplan hydraulic turbine energy capture 1/3](#) :Components Overview
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axial guide vanes



Here we will design the guide vanes for converting a part of the load height, in rotation of the flow upstream of the turbine. This will change the turbine inlet angles and the actual speed detected by the blades. This rotation upstream of the turbine also compensates the rotation (tangential induction) caused by the reaction torque of the turbine.

- [Effects of the tangential speed upstream](#)
- [Angle of the fins of the distributor and flow diversion](#)
- [guide vanes design and evaluation of pressure drop](#)

Effects of tangential Speed introduced upstream of the turbine :

stator or guide vanes upstream of the turbine produces a tangential velocity (vortex), of direction opposite to the tangential velocity induced by the turbine.. The tangential velocity induced by the turbine will be recovered. Increased velocity through the turbine can be achieved without changing the flow rate so as to utilize the energy of high load, by converting it into tangential speed. Adjusting the angle of the vanes of the distributor will adjust the tangential velocity..

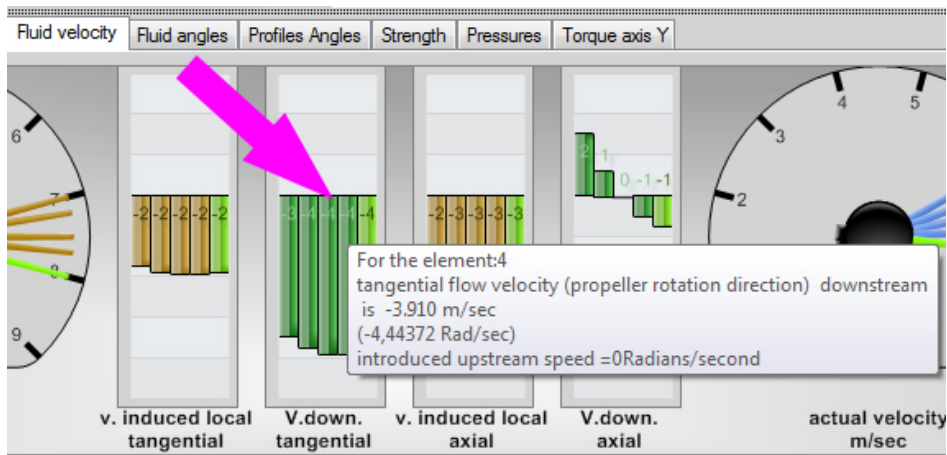
Let us take our turbine designed in [turbine design Tutorial 1/3](#) ,updated to operating point and design speed of 53.2 rpm. In the results of HELICIEL software, select the tab "fluid velocities". On the graph downstream tangential speeds, let your cursor at the element producing the most tangential velocity (element4), to show the tooltip with the value in radians / second:

Modeling turbine kaplan in heliciel

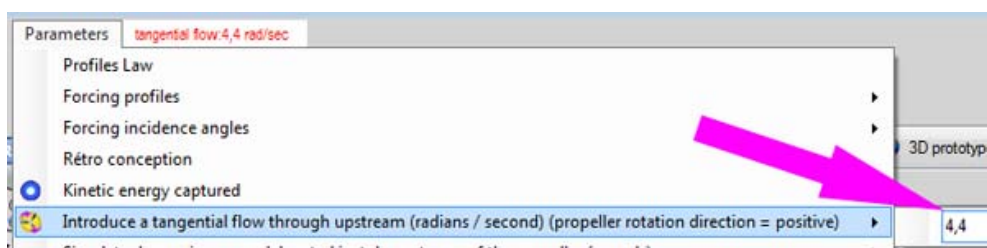


guide vanes draft tube turbine





In our example, the induced tangential velocity downstream of the turbine is around **4.4 rad/sec** at the element level 4. **So we need to introduce a tangential velocity of 4.4 rad / sec with our stator guide vanes.** For this, use the parameter menu / introduce a tangential velocity, and enter 4.4 rad / sec:



Relaunch the search for optimum rotation speed (**Tab3:Optimize**), search speed for optimum rotation and updating the propeller in its best configuration:

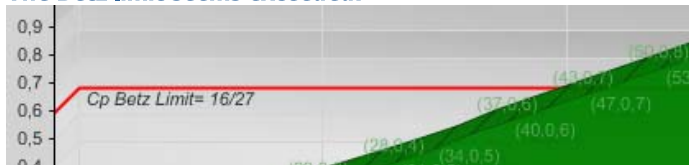


Several important points should be noted in this configuration above:

- **Area calculations without converging:** Certain conditions of speed and impact, generate negative axial velocities in some elements, which would result in a return of fluid back and turbulence, degrading conditions of flow around profiles. Heliciel considered these areas results too uncertain, null, in terms of performance for elements disturbed. In the graph, this results in a discontinuity in performance depending on the rotational speed:



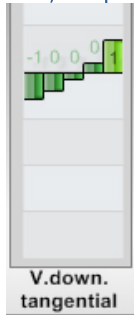
- **The Betz limit seems exceeded!**



but **this is an illusion** due to the fact that it is based only on the axial flow, without integrating the contribution of the tangential flow. The tangential flow introduced

upstream **Parameters tangential flow: 4,4 rad/sec** gives us additional power, we could increase the power by increasing the tangential flow, but this will result in an increase in the pressure drop in the distributor / stator which should increase the angle of deflection of the stream.

- **We can also estimate the tangential velocity downstream of the turbine**, the average tangential velocities should be as close as possible to zero, to represent an adjustment of the flow and cancellation downstream losses..



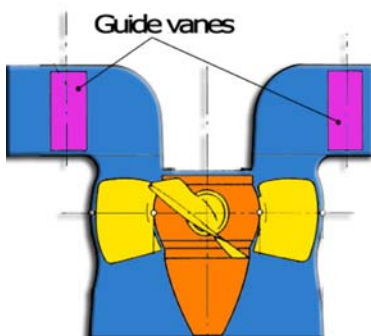
if the tangential speed, introduced into the propeller is greater than the tangential velocity produced by the propeller, the flow will have a non-zero tangential velocity downstream. Which is a lost energy.

Angle of the blades of the distributor and flow diversion:

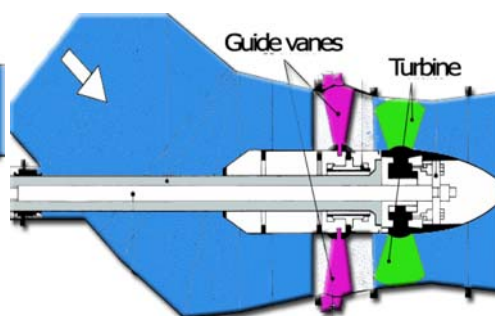
We can estimate the angle of the vanes of the stator guide vanes, using the axial velocity and the tangential velocity to produce.

- **tangential velocity:** The tangential velocity(m/sec) to produce is calculated using the velocity in radian second:
 - tangential velocity (m/sec) = angular velocity (rad/sec) x radius tip blade(m) So for our example:
 - tangential velocity(m/sec) = 4.4(rad/sec) x 1(m) = **4.4m/sec**

guide vanes kaplan:



guide vanes bulb:



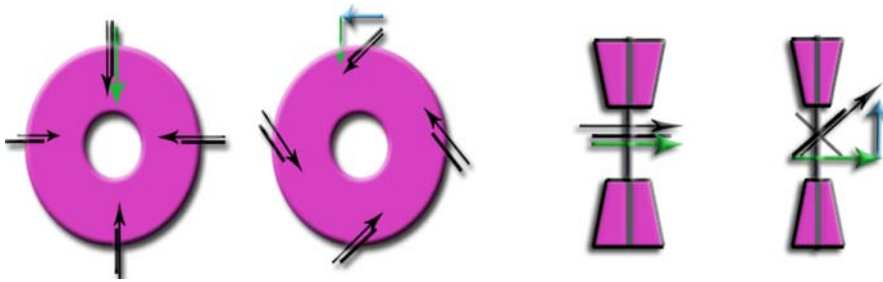
The axial velocity is given by the speed / throughput section. In our example we will assume that the pass section of the guide vanes is equal to the section swept by the turbine blades (2.01m² for our example), but this is not always the case, as it can be useful to have a low speed in the guide vanes to minimize losses, and deflection angles of fins.

- **axial velocity** = $(Q_v / \text{section}) = (12 / 2.01) = 5.97 \text{ m/sec}$
- **Angle of the vanes:**
 1. For a guide vanes in crown Kaplan (with volute):
 - tangent (Angle ailettes) = axial velocity / tangential velocity
 - $\Rightarrow \text{blades angle} = \text{Atan}(\text{axial velocity} / \text{tangential velocity})$
 - $\Rightarrow \text{blades angle} = \text{Atan}(5.97 / 3) = 63^\circ$
 2. For a guide vanes ring bulb type:
 - tangent (blades angle) = tangential velocity / axial velocity

■ \Rightarrow blades angle = $\text{Atan}(\text{tangential velocity} / \text{axial velocity})$

■ \Rightarrow blades angle = $\text{Atan}(3 / 5.97) = 26^\circ$

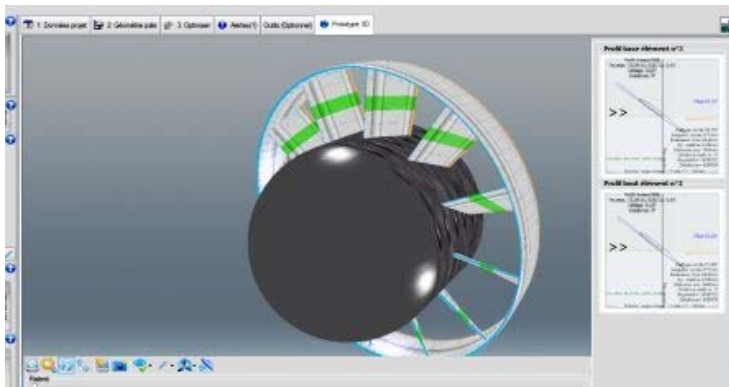
Q_v = flow rate through the turbine m^3/sec , section m^2 velocity m/sec



Guide vanes design and evaluation of pressure loss:

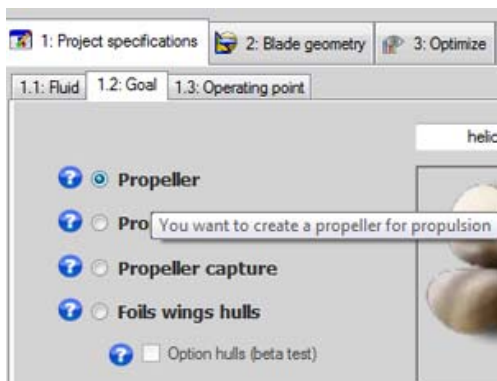
The losses in the guide vanes are related to the angle of deflection experienced by the fluid. For vanes guides rings, bulbs types, the angle of deflection is directly that of the blade. In the Kaplan-type systems, the volute gives to fluid a tangential trajectory. The angle of deflection of the fluid will, also equal to the angle of the blades. A low angle of blades produces minimal pressure loss. Volute allows to generate significant tangential velocities without inducing high losses by diverting the fluid in the grid blades. Note that a stator bulb type will have a low deflection angle if the axial speed is greater than the tangential speed. A guide vanes Kaplan type, due to the volute has a low angle of deflection for high tangential velocity. This predisposes the guide vanes with volute, to power plants, whose load height (transformed into tangential velocity) is high and systems bulbs for high throughput, and low drop. The volute will be sized to maintain a constant speed around the guide vanes. This section will therefore decline to consider the volume of fluid drained into the upstream portions:

• Design of a ring-type guide vanes or a stator:

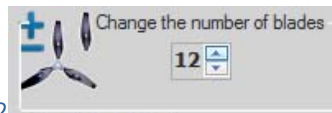


A **ring-type guide vanes is a propeller does not rotate (stator)**. We will use Heliciel to calculate the delta pressure between the upstream and downstream of a propeller with a speed of almost zero rotation, and a number of blade, corresponding to the number of blades in our guide vanes. The propeller should generate a tangential velocity downstream of about $4.4 \text{ rad} / \text{sec}$. We can even, if we wish, export the 3D igs file stator blades, to a CAD to realize them.

- After having successfully saved our turbine (File menu / Register), we will **transform it into stator ring type**:
 - **CAUTION! : 1.2Objectif tab, check propeller propulsive**

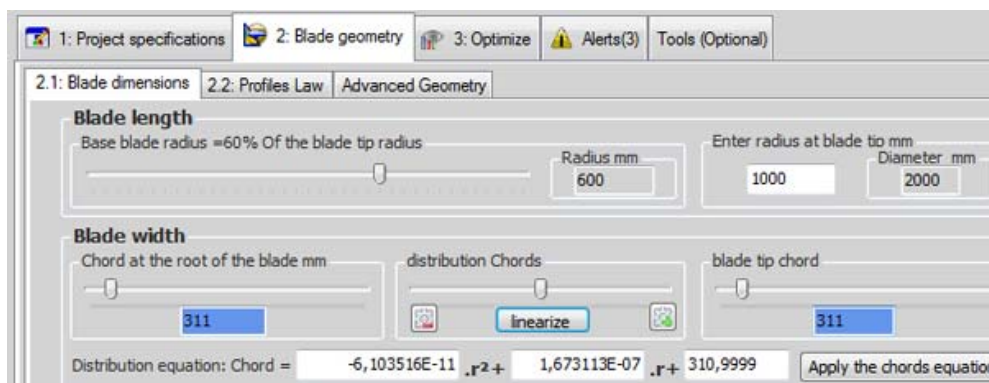


- **Tab 3. optimize** / number of blade:

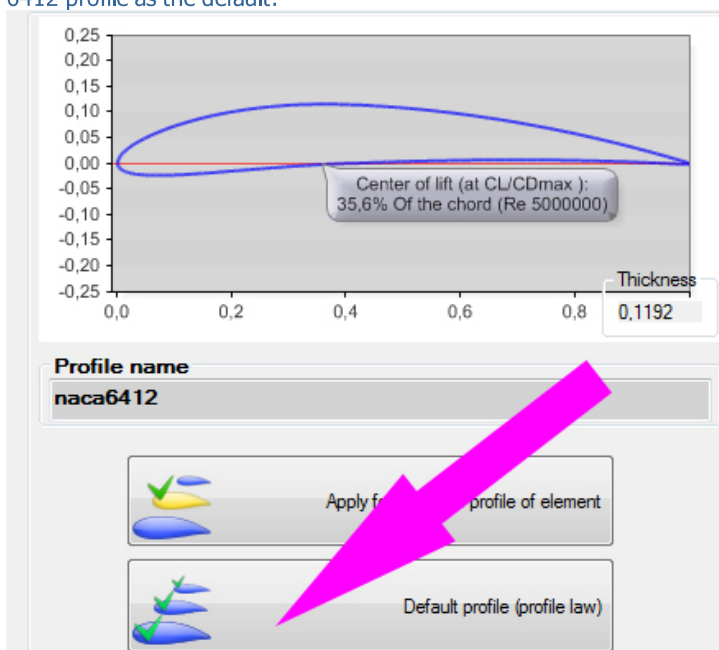


change number of blades from 4 to 12

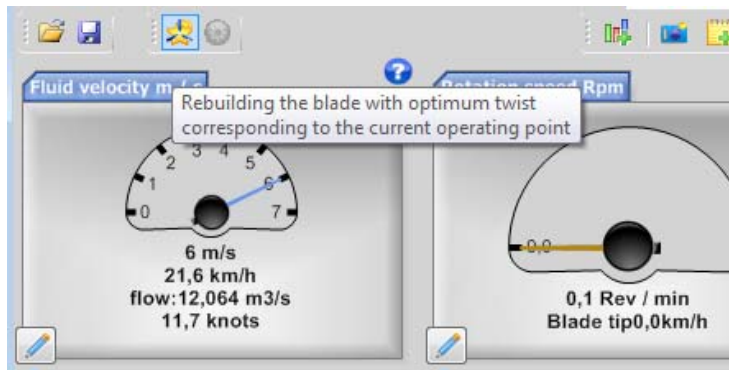
- Geometry is enhanced by decreasing the widths of cords foot and the blade tip, so as to minimize friction and pressure losses. We set the chord at blade root to **311 mm** and the same to the tip chord (**remember to the linearized distribution chord**). We will keep the tip radius, and blade root **1000 and 600 mm**.



- We will select a different profile, more curved, generating more lift for our stator, **the naca 6412**. To do this, use the database and apply the naca 6412 profile as the default:



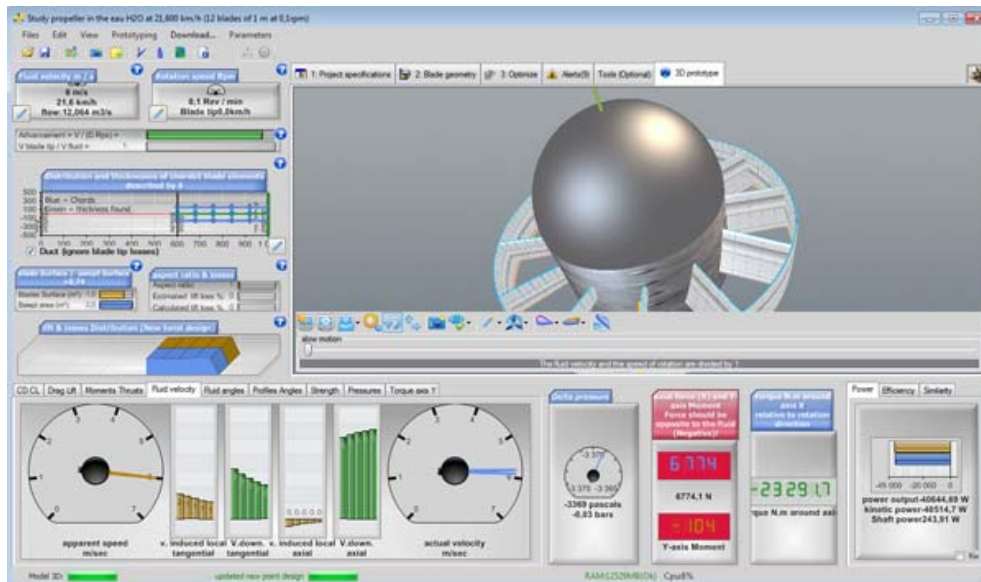
- We **keep the speed of 6 m / sec** and as we have not touched the foot radius and blade tip, The throughput section is the same as the turbine, and the flow rate is always **12 m3/sec**.
- Combined with a rotational speed (**tab 1.3 operating point**) set to **0.1 rpm** to simulate a zero rotational (a zero rotational velocity causes errors in the equations)



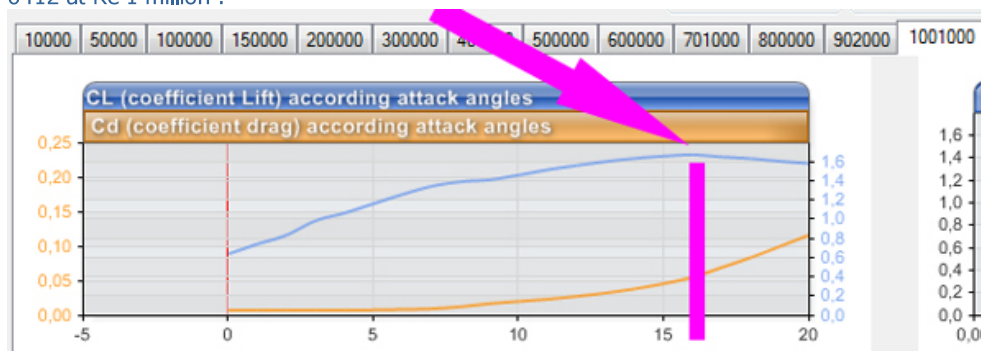
- In the parameters menu, **we remove the tangential flow by setting it to 0**



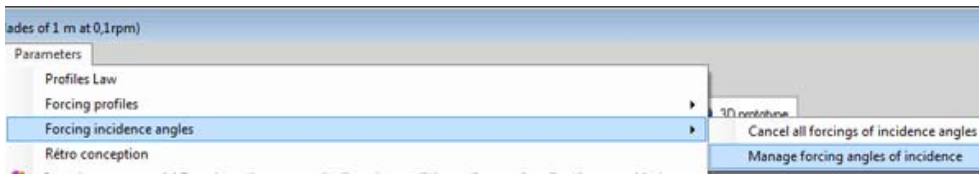
Here the parameters of our stator are input, it remains to start rebuilding :
Our 3D model of stator ring is created :



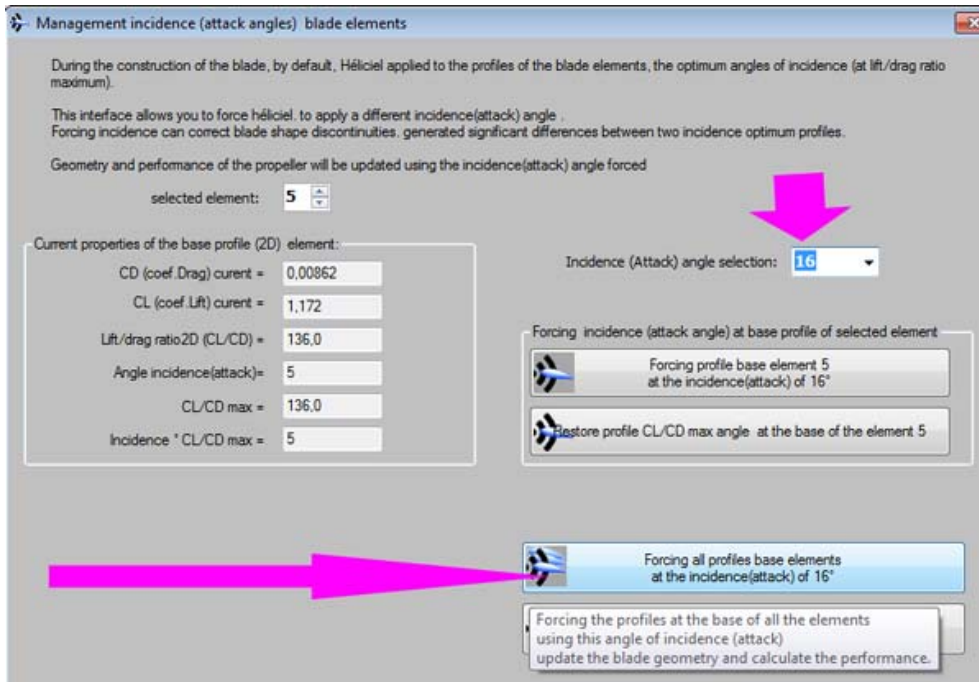
Some alarms inform us that our propeller propulsion does not produce thrust, but this is normal for a stator with a near-zero rotation. What interest us, is to **produce a tangential velocity downstream about 4.4 rad sec**. For this we will force the attack angles of profiles, to angles providing lift max, because it is this attack angle that generates the most tangential induction. The profile evolves to a Reynolds about 1 million in this project (see profiles pictures in 3D prototype tab, after selection of an element). So we are going to read the curve CL (lift coefficient) in the database for naca 6412 at Re 1 million :



and deduce that the **angle of attack, generating most Cz (lift)** thus the more tangential force, is 16 degrees to the naca 6412 at Re 1 million. So we **force angle of attack** to 16 degrees using the "parameter menu / manage forcin angle incidences:

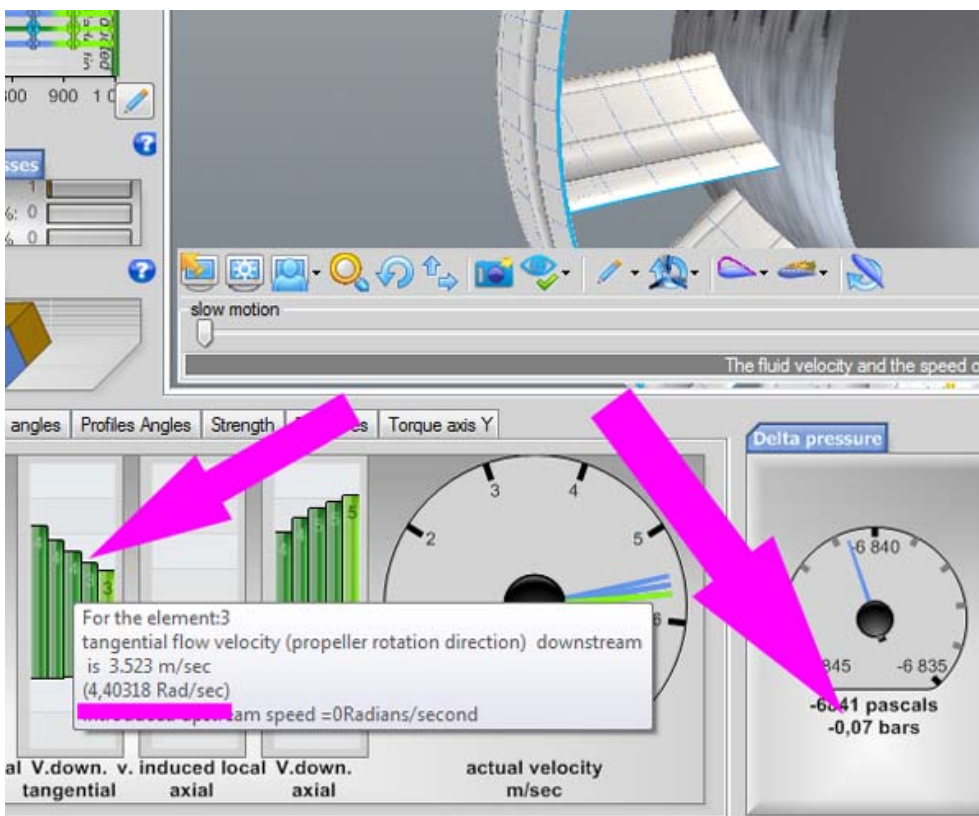


and apply the incidence of 16 degrees at all profiles:



Our stator is rebuilt with profiles whose incidence is forced to 16 degrees. **2 Results hold our attention:**

1. The **tangential speed** at the outlet of stator
2. and the **pressure loss** when the fluid passes through the stator:



The **tangential velocity** produced is about **4 rad/sec** and the pressure loss is **0.07 bars about 0.7 meters**. We finished the calculation of our stator guide vanes ring type,

Summary: We have seen how the sator or guide vanes, allows us to transform a portion of the load height into kinetic energy by rotating the

flow upstream of the propeller. This rotation generates an increase in speed through the blades and blade angles of attack more favorable to transform torque force. A tangential velocity upstream properly adjusted must balance the tangential velocity produced by the turbine. This balance is verified by the absence of rotation of the flow downstream of the propeller. The designer of the stator, or guide vanes, will find a compromise between pressure loss caused by the deflection angle, and the axial and tangential velocity ratio to produce. The choice of the passage section of the distributor allows the designer to control the ratio between the axial velocity and the tangential velocity, Thus the deviation angle to create, for a maximum rotation of the upstream flow..

Another factor increasing the power of the propeller: the diffuser or vacuum draft tube.

next: [Tutorial hydroelectric turbine design 3/3](#) :Choice sections, design draft tube

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