



# ***TOMY Joseph Praful***

8<sup>th</sup> EMship cycle: September 2017 – February 2019

## **Master Thesis**

# **Blade Element Momentum Theory numerical model of a tidal turbine in a realistic time-dependent environment**

**Supervisors:** **Prof. Herve le Sourne**, Insitut Catholique Arts et Metiers, Nantes

**Mr. Stephane Paboeuf**, Bureau Veritas Marine & Offshore, Nantes

**Reviewer:** **Prof. Nikolai Kornev**, University of Rostock, Germany

**Hamburg, February 2019**

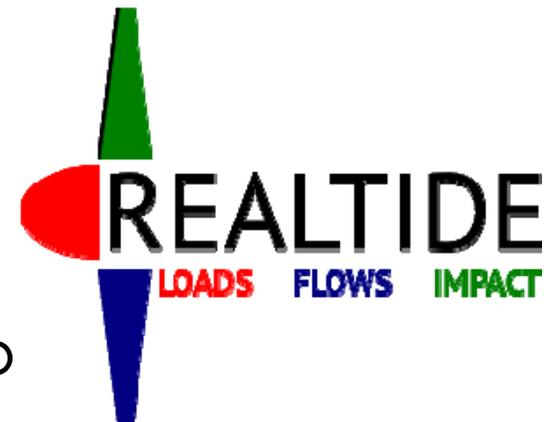


# I About the Project

- ❑ Internship at Bureau Veritas Marine & Offshore, Nantes
- ❑ Project undertaken as part of RealTide project (WP3, Task 3.1)
- ❑ Objective of WP3, Task 3.1 : to develop a tide-to-wire model using Blade Element Momentum Theory (BEMT)
- ❑ Work undertaken in this master thesis: Develop a Python tool using BEMT that can predict the forces generated by a tidal turbine in realistic flow conditions
- ❑ Validation with experimental and CFD results
- ❑ Capability for future integration with electrical module and CFD



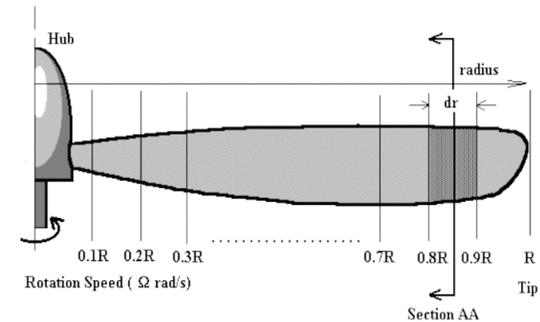
BUREAU  
VERITAS



# BEMT: An overview

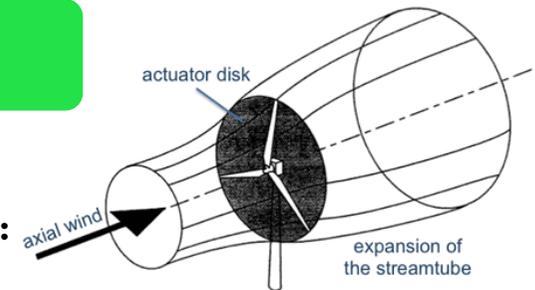
## Blade Element Theory

- Blade  $\rightarrow$  individual blade elements (BE)
- Forces on BE: lift and drag experienced during the flow
- Total Force =  $\Sigma$  forces in BEs



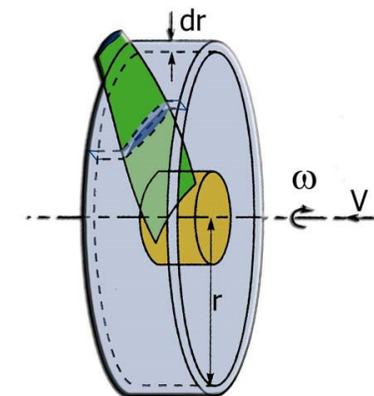
## Actuator Disk Momentum Theory

- Based on Newton's Second Law of Motion
- Change in velocity of fluid represented in terms of induction factors: Axial Induction Factor (a) and Tangential Induction Factor (b)



## Blade Element Momentum Theory

- Combines Blade Element theory and Actuator Disk Momentum theory
- Each blade element considered as an actuator disk; independent of other blade elements
- a & b expressed in terms of the lift and drag coefficients of the BE



# | BEMT: SWOT Analysis

## STRENGTHS

- Relatively easy implementation within a computer code
- Faster computations when compared to tank testing and CFD
- Reusability

## WEAKNESSES

- Simplified theory with many assumptions and idealized conditions
- Dynamic effects such as dynamic stall, dynamic inflow are not inherently considered

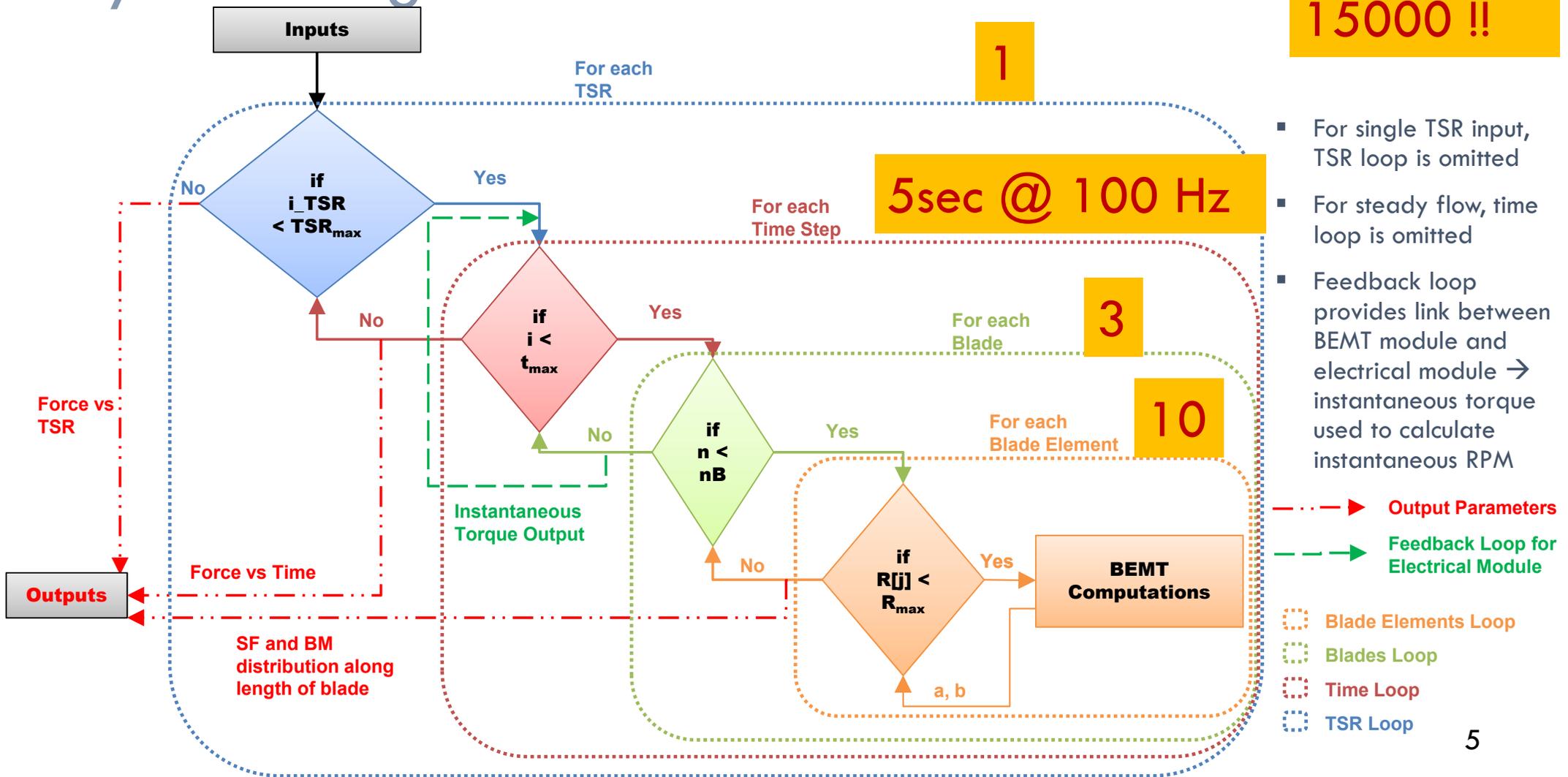
## OPPORTUNITIES

- At preliminary design stage
- Scope for optimization algorithms
- Empirical models as BEMT improvements

## THREATS

- Accuracy
- Computational Speed
- Large number of computations
- Numerical analysis with dynamic effects

# Python Program Architecture

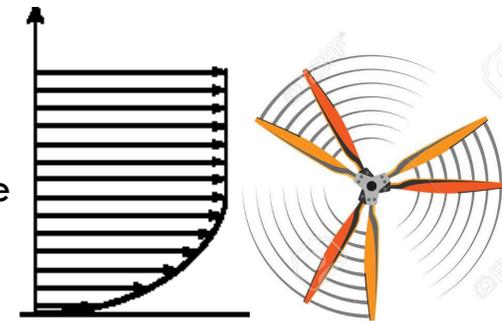
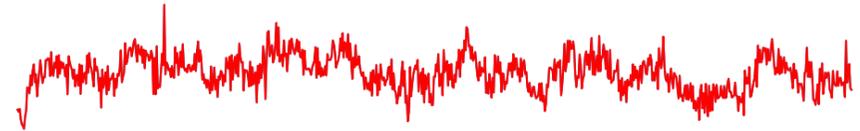


15000 !!

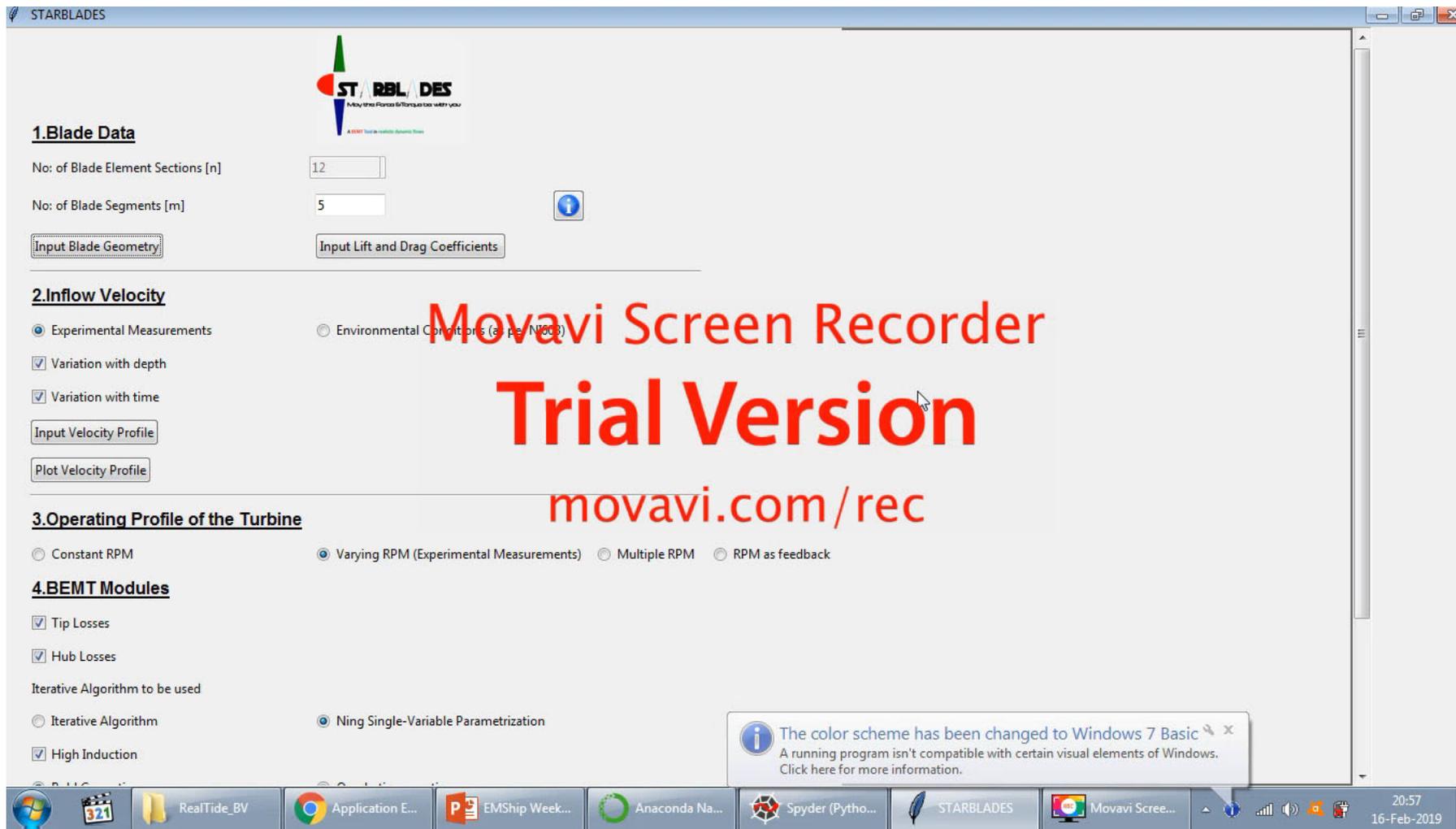
- For single TSR input, TSR loop is omitted
- For steady flow, time loop is omitted
- Feedback loop provides link between BEMT module and electrical module → instantaneous torque used to calculate instantaneous RPM

# Inflow Conditions

- In the simplest scenario, the inflow is a constant steady stream velocity
- Variation with time (dynamic inflow):
  - The velocity in a time-dependent environment is not constant
  - Can be due to waves, tidal flow, or ocean currents
  - Turbulence in the flow
- Variation with depth:
  - Each blade element would experience a different inflow velocity
  - In a time dependent environment, the local inflow velocity would also depend on the instantaneous location of the blade element (due to rotation)
- Computational complexity:
  - Instantaneous position of the blade element to be determined based on the rotational speed
  - Instantaneous velocity depends on instantaneous position and the time



# User Interface – 1) Blade Geometry



# User Interface – 2) Lift and Drag Coefficients

The screenshot displays the STARBLADES software interface. At the top left, the title bar reads "STARBLADES". The main window features the STARBLADES logo and the tagline "A New Tool in turbomachinery design". The interface is organized into several sections:

- 1. Blade Data:** Includes input fields for "No: of Blade Element Sections [n]" (set to 21) and "No: of Blade Segments [m]" (set to 5). There are buttons for "Input Blade Geometry" and "Input Lift and Drag Coefficients".
- 2. Inflow Velocity:** Offers radio buttons for "Experimental Measurements" (selected) and "Environmental Conditions (e.g. per NREL)". Checkboxes for "Variation with depth" and "Variation with time" are checked. Buttons for "Input Velocity Profile" and "Plot Velocity Profile" are present.
- 3. Operating Profile of the Turbine:** Features radio buttons for "Constant RPM", "Varying RPM (Experimental Measurements)" (selected), "Multiple RPM", and "RPM as feedback".
- 4. BEMT Modules:** Includes checkboxes for "Tip Losses" and "Hub Losses". A section for "Iterative Algorithm to be used" has radio buttons for "Iterative Algorithm" and "Ning Single-Variable Parametrization" (selected). A "High Induction" checkbox is also checked.

A large red watermark is overlaid on the center of the screen, reading "Movavi Screen Recorder Trial Version" and "movavi.com/rec". A Windows system message box is visible in the bottom right corner, stating: "The color scheme has been changed to Windows 7 Basic. A running program isn't compatible with certain visual elements of Windows. Click here for more information."

The Windows taskbar at the bottom shows several open applications: RealTide\_BV, Application E..., EMShip Week..., Anaconda Na..., Spyder (Pytho..., STARBLADES, and Movavi Scee... The system tray on the right indicates the time is 20:59 on 16-Feb-2019.

# User Interface – 3) Velocity Input

**STARBLADES**

**1. Blade Data**

No: of Blade Element Sections [n]

No: of Blade Segments [m]  

**2. Inflow Velocity**

Experimental Measurements  Environmental Conditions (e.g. ps-N8003)

Start Time (secs)  Current Velocity due to Tides  m/s

Stop Time (secs)  Current Velocity due to Waves  m/s

Current Velocity due to Wind  m/s

Variation with depth

Variation with time

**3. Operating Profile of the Turbine**

Constant RPM  Varying RPM (Experimental Measurements)  Multiple RPM  RPM as feedback

**4. BEMT Modules**

Tip Losses

Hub Losses

Iterative Algorithm to be used

**Windows 7 Notification:** The color scheme has been changed to Windows 7 Basic. A running program isn't compatible with certain visual elements of Windows. Click here for more information.

**Taskbar:** RealTide\_BV, Application E..., EMShip Week..., Anaconda Na..., Spyder (Pytho..., STARBLADES, Movavi Sree..., 21:03 16-Feb-2019

# User Interface – 4) BEMT Modules

**STARBLADES**  
**2. Inflow Velocity**

Experimental Measurements     Environmental Conditions (as per NREL5003)

Start Time (secs)     Current Velocity due to Tides  m/s  
Stop Time (secs)     Current Velocity due to Waves  m/s  
Current Velocity due to Wind  m/s

Variation with depth  
 Variation with time

---

**3. Operating Profile of the Turbine**

Constant RPM     Varying RPM (Experimental Measurements)     Multiple RPM     RPM as feedback

RPM =

**4. BEMT Modules**

Tip Losses  
 Hub Losses

Iterative Algorithm to be used

Iterative Algorithm     Ning Single-Variable Parametrization

High Induction     Quadratic correction

Buhl Correction

Dynamic Wake   

Dynamic Stall  
 Rotational Augmentation

**Movavi Screen Recorder**  
**Trial Version**  
[movavi.com/rec](http://movavi.com/rec)

**Windows 7 Basic**  
The color scheme has been changed to Windows 7 Basic. A running program isn't compatible with certain visual elements of Windows. Click here for more information.

Taskbar: screen re..., Applicati..., EMShip ..., Anacond..., Spyder (...), STARBL..., Blade Ge..., Lift and ..., Movavi ...  
System tray: 22:04, 16-Feb-2019

# User Interface – 5) Postprocessing

The screenshot displays the Spyder Python IDE interface. A 'Postprocessing' dialog box is open, showing options for X and Y axes, a chart title 'Sabella D10 Validation Case for V=2.75m/s', and a 'No. of Experimental Results' set to 0. The code editor shows Python code for calculating performance coefficients and processing results. The console window displays the execution output, including completion times for blades and TSR calculations. A help window is also visible, providing usage instructions for the IDE.

**Postprocessing Dialog:**

- X-axis: Time, TSR, Length
- Y-axis: Forces, Root Bending Moment, Shear Force, Bending Moment, Elemental Axial Forces, Elemental Tangential F, Operating Conditions
- Chart Title: Sabella D10 Validation Case for V=2.75m/s
- No. of Experimental Results: 0
- Output Options: PLOT

**Code Editor:**

```
330 GlobDyn['CT'] = GlobDyn['Thrust']/((0.5*rho*np.pi*R**2*V**2))
331 GlobDyn['CQ'] = GlobDyn['Torque']/((0.5*rho*np.pi*R**3*Vmean**2))
332 GlobDyn['CP'] = GlobDyn['Power']/((0.5*rho*np.pi*R**2*Vmean**3))
333 Results['TSR=%0.2f'%inp.tsr.TSR[i_TSR]]['Dynamic'] = Dy
334 Results['TSR=%0.2f'%inp.tsr.TSR[i_TSR]]['Dynamic']['GlobalForces'] = GlobDyn
335
336 printemps("TSR%0.0f computed"%i_TSR)
337 # end of TSR Loop
338
339 param_list = ['Thrust','Torque','Power','CT','CQ','CP']
340 PerfCoeffs = pd.DataFrame(columns=param_list,index=range(len_TSR))
341 PerfCoeffs = inp.tsr[['TSR','RPM_A']].join(PerfCoeffs)
342 for i_TSR in range(len_TSR):
343     for k in param_list:
344         PerfCoeffs[k][i_TSR] = Results['TSR=%0.2f'%inp.tsr.TSR[i_TSR]]['Static']['GlobalForces']
345 Results['PerfCoeffs'] = PerfCoeffs
346 timelist = time.timer
347 printemps("Computation complete")
348
349 ###
350
351 print("Entering Postprocessor....")
352 postprocess(len_TSR,Results.vel_profile.Vmean)
```

**Console Output:**

```
Blade2 complete = 11.97 seconds
Blade3 complete = 12.14 seconds
Blade4 complete = 12.34 seconds
Blade5 complete = 12.51 seconds
Time 0.000 complete = 12.51 seconds
TSR10 computed = 12.51 seconds
J:/EMShip/RealTide_BV/Codes/RUN_Scripts/main.py:344: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame
See the caveats in the documentation: http://pandas.pydata.org/pandas-docs/stable/indexing.html#indexing-view-versus-copy
PerfCoeffs[k][i_TSR] = Results['TSR=%0.2f'%inp.tsr.TSR[i_TSR]]['Static']
['GlobalForces'][k].mean()
```

**Help Window:**

**Usage**

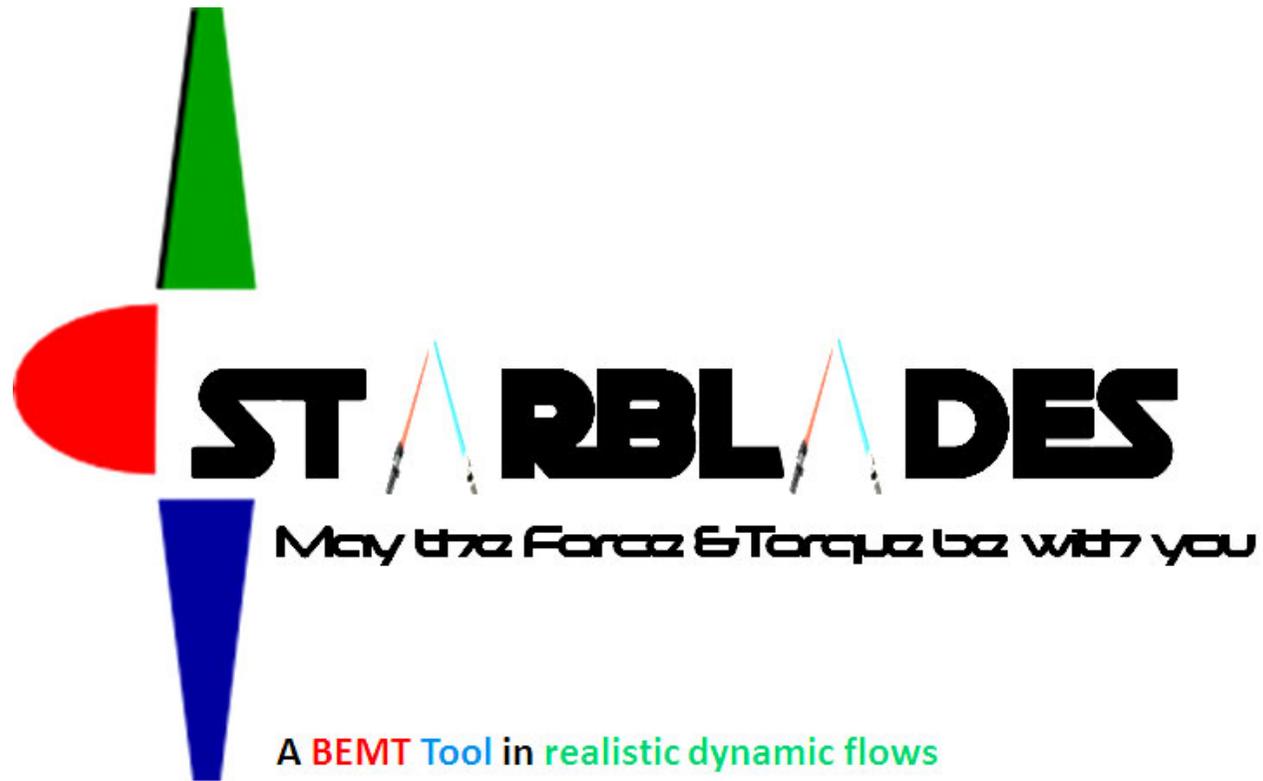
Here you can get help of any object by pressing **Ctrl+I** in front of it, either on the Editor or the Console.

Help can also be shown automatically after writing a left parenthesis next to an object. You can activate this behavior in **Preferences > Help**.

New to Spyder? Read our [tutorial](#)

Movavi Screen Recorder  
Trial Version  
movavi.com/rec

# | Logo and Motto



# Summary

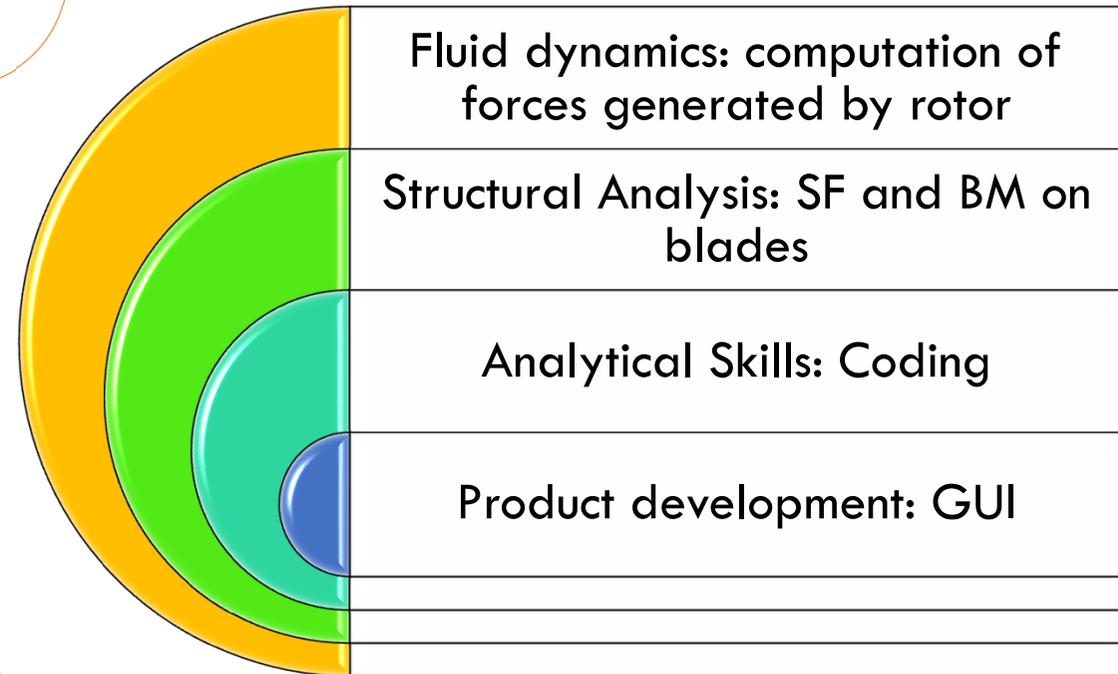
Python code developed for computation of forces on a tidal turbine

Realistic Scenario: Time variation and depth-wise variation in velocity profile considered

BEMT improvements added as modules

Preliminary User interface developed

## Knowledge Application



# | Future Work

- Integration with electrical module
  - Improve computational speed
  - Validation with sea test results
  - Additional BEMT improvements
  - Convergence study
  - User interface improvement
  - Design optimization tools
- ✓ Tool will be used and further developed by BV for Structural Analysis of turbine blades
  - ✓ Tool will be used as part of RealTide project and be coupled with electrical module, turbulence simulator model and CFD

THANK YOU...

