The 22nd Offshore Symposium

Redefining Offshore Development: Technologies and Solutions

Feb 2, 2017 | Houston, USA

"RANS/Lifting Line Model Interaction Method for the Design of Ducted Propellers and Tidal Turbines"

Weikang DU*, Spyros A. Kinnas*, Robin Martins Mendes, Thomas Le Quere****

*Ocean Engineering Group, The University of Texas at Austin

**Ecole Navale, France

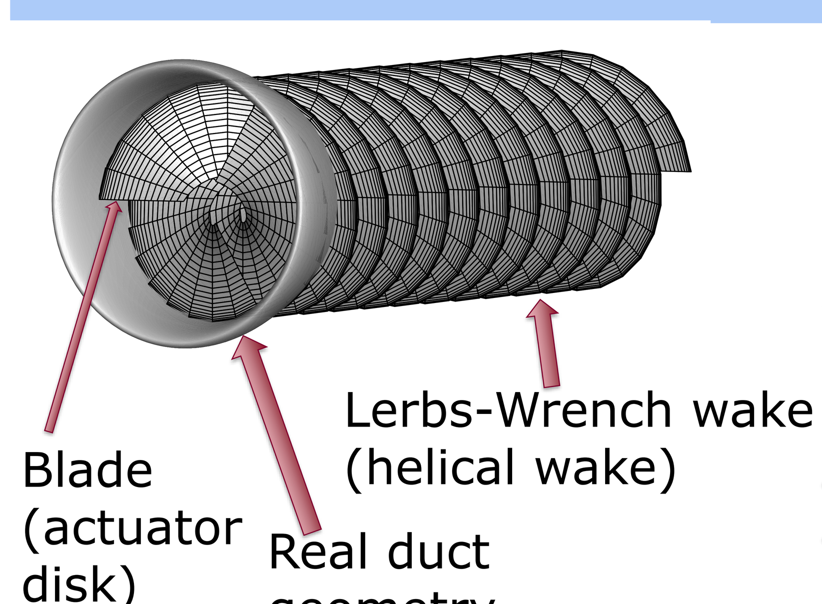
Introduction

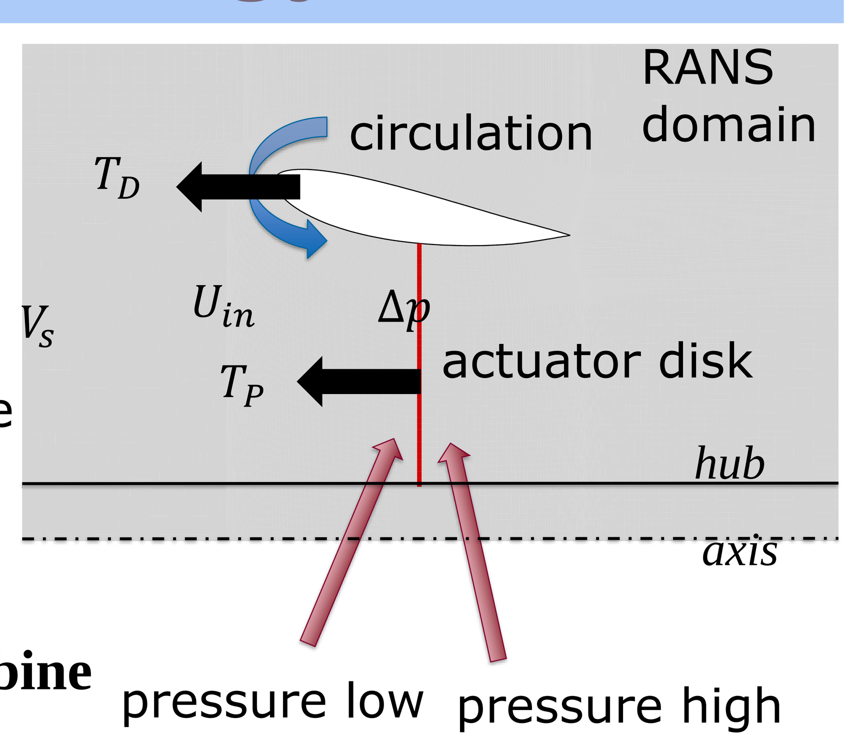
- **Propeller and turbine design tools developed at UT's OEG:**
  - **LLOPT: lifting line theory based optimization**
  - **LLOPT-BASE: circulation database searching method**
  - **CAVOPT-BASE: database-searching method for the design of propeller (coupled with VLM method)**
  - **CAVOPT-3D: nonlinear optimization method for propeller design (coupled with VLM method)**
- **Wake alignment procedure:**
  - **Lerbs-Wrench formulas: assuming a constant pitch along the x-direction (LLOPT-LW)**
  - **Simplified Wake Alignment (LLOPT-SWA)**
  - **Full wake alignment (LLOPT-FWA)**
- **However, the duct geometry is not taken into consideration in those methods**

Objectives

In this paper, a RANS/lifting line model interaction method is proposed to consider the duct geometry in the design of propellers and tidal turbines.

Methodology

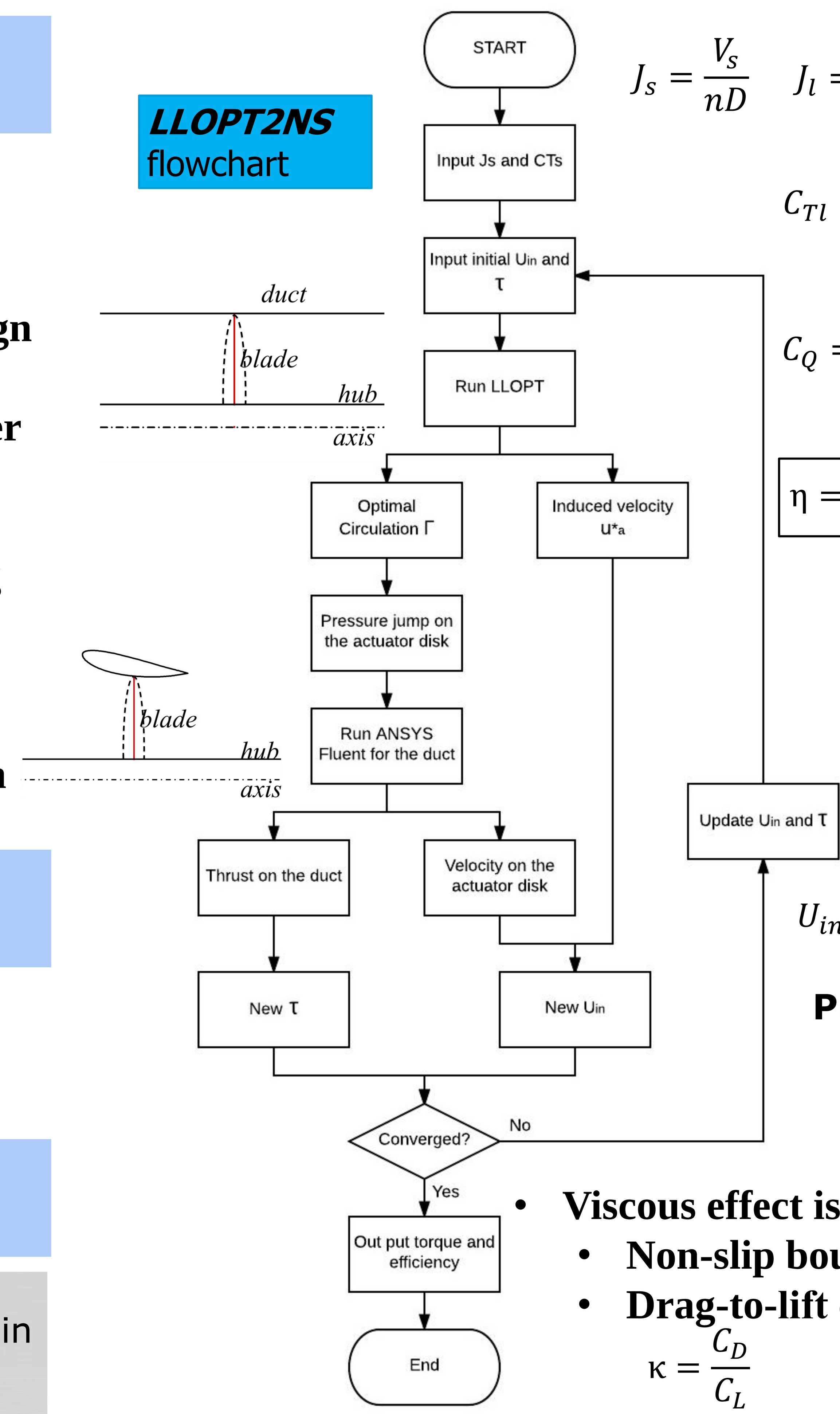




In this method, the propeller/turbine blade is solved in the lifting line model, and the duct is solved in the axisymmetric RANS solver. The blade is represented as an actuator disk with a pressure jump profile. T_P: thrust on the propeller, T_D: thrust on the duct.

$$\tau = \frac{T_P}{T_P + T_D} = \frac{T_P}{T_T}$$

LLOPT2NS flowchart



$$J_s = \frac{V_s}{nD} \quad J_i = \frac{U_{in}}{nD} \quad C_{Ts} = \frac{T_T}{\frac{1}{2}\rho\pi V_s^2 R^2}$$

$$C_{Ti} = \frac{T_P}{\frac{1}{2}\rho\pi U_{in}^2 R^2} = \tau C_{Ts}\frac{V_s^2}{U_{in}^2}$$

$$C_Q = \frac{Q}{\frac{1}{2}\rho\pi V_s^2 R^3}$$

$$\eta = \frac{T_T V_s}{Q\omega} = \frac{J_s C_{Ts}}{\pi C_Q}$$

$$\tau = \frac{T_T - T_D}{T_T}$$

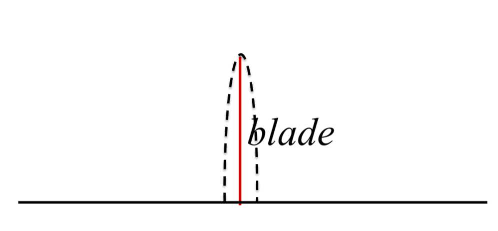
$$U_{in} = U_{RANS} - u_a^*$$

Previous iteration

- **Viscous effect is included in two parts:**
  - **Non-slip boundary condition on duct**
  - **Drag-to-lift coefficient κ**

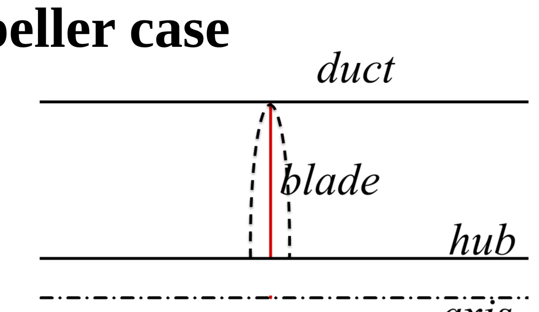
$$\kappa = \frac{C_D}{C_L}$$

- **Turbine case:**
  - **Only U_{in} is updated** $U_{in} = U_{RANS} + u_a^*$
  - **The pressure jump is in the opposite direction, compared with the propeller case**



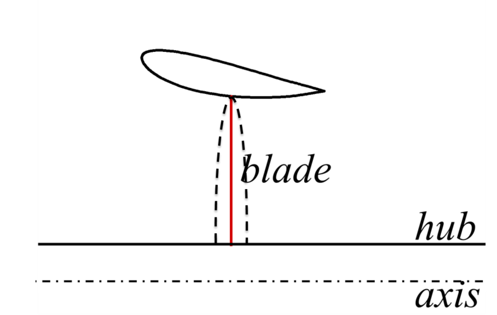
Propeller_case1

Without duct.
LLOPT



Propeller_case2

Duct is considered as image model (blade inside cylindrical tunnel).
LLOPT

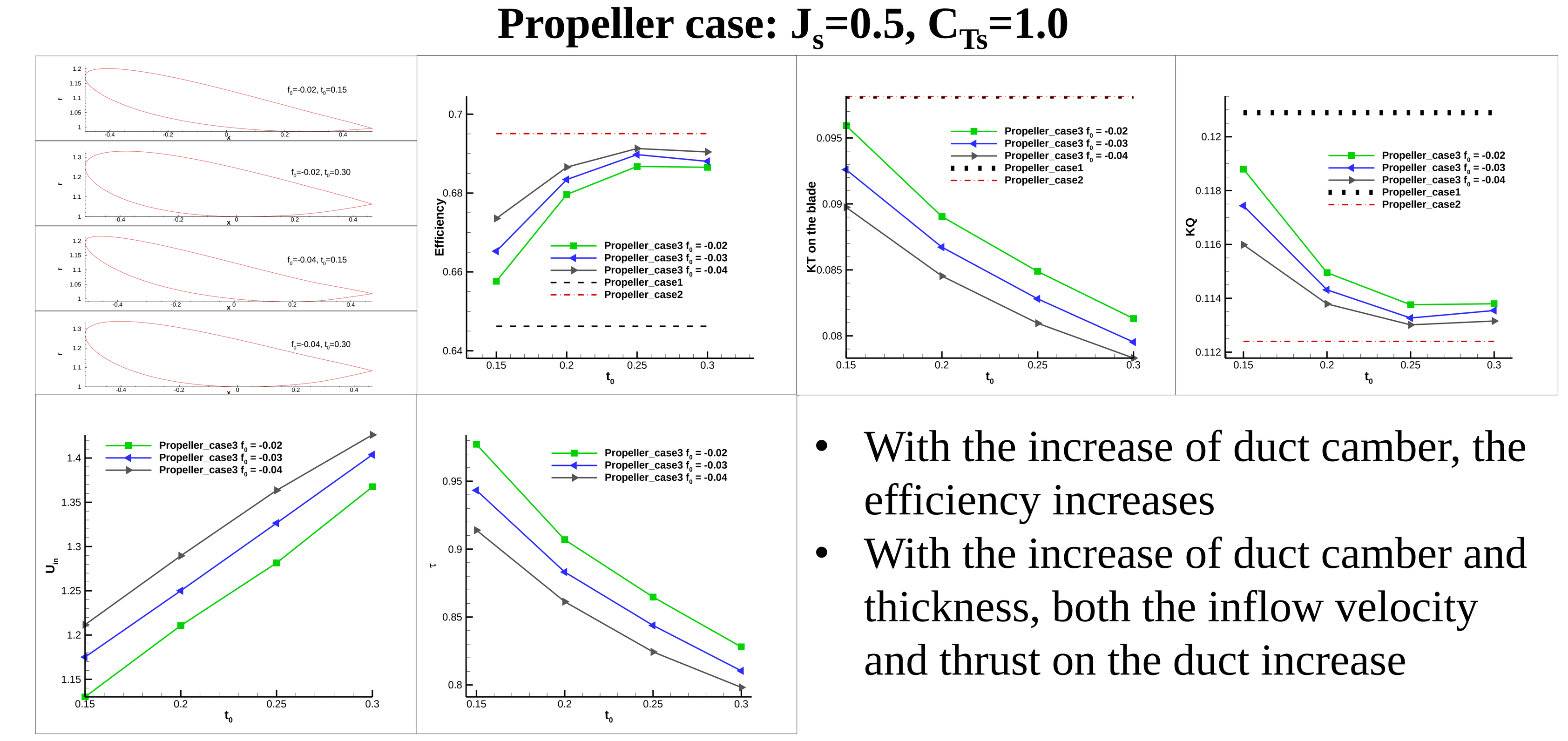


Propeller_case3

Real duct geometry is considered.
LLOPT2NS

Results

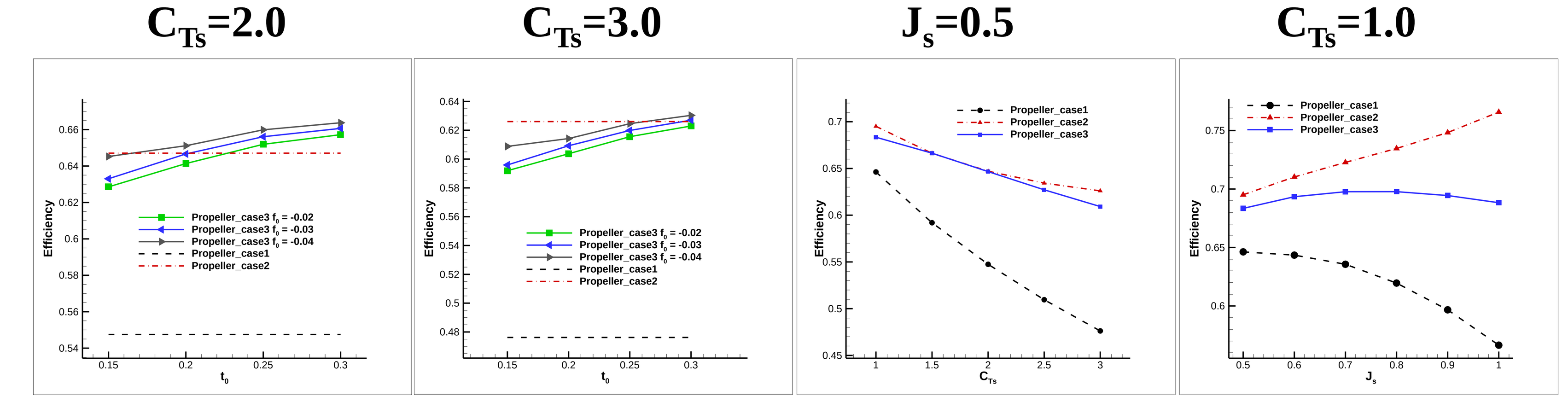
Propeller case: J_s=0.5, C_{Ts}=1.0



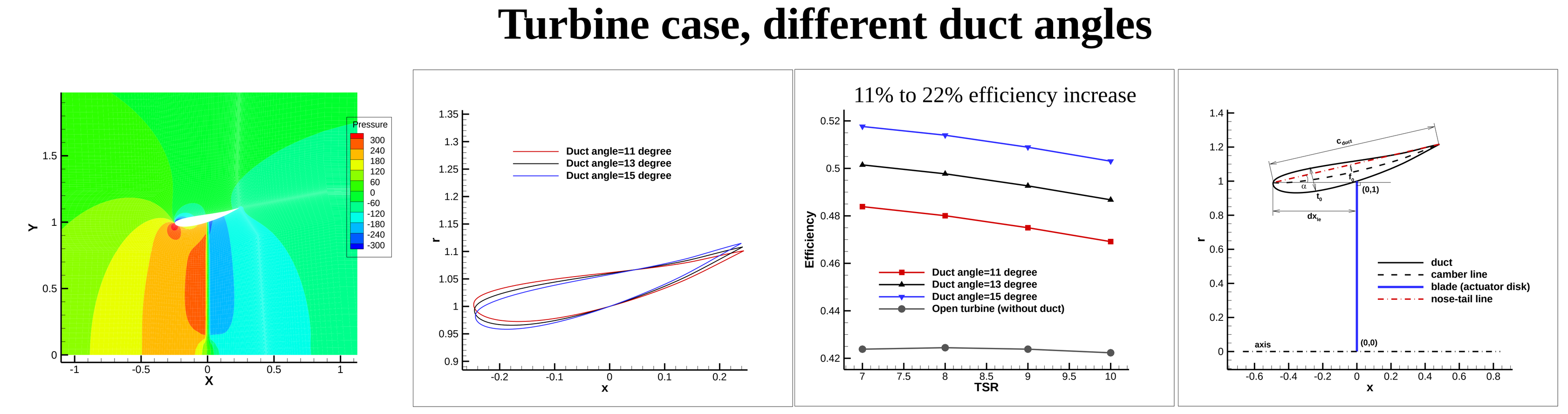
- With the increase of duct camber, the efficiency increases
- With the increase of duct camber and thickness, both the inflow velocity and thrust on the duct increase

Propeller case: J_s=0.5 C_{Ts}=2.0 C_{Ts}=3.0

Propeller case, fixed duct geometry J_s=0.5 C_{Ts}=1.0



Turbine case, different duct angles



Conclusions

- **A RANS/lifting line model interaction method is proposed for the design of ducted propellers and tidal turbines.**
- **The NACA a=0.8 camber and NACA 00 thickness are used.**
- **For the propeller case, the influence of camber and thickness is studied; for the turbine case, the influence of duct angle is studied.**
- **It is shown that the duct geometry has influence on the inflow velocity and KT on the blade for ducted propellers and turbines, which can not be taken into account in the image model. Proper designed duct can increase the efficiency significantly.**
- **This method is proved to be reliable and efficient in designing ducted propellers and tidal turbines.**