D1.3

Comparison of computational work against the experiments

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1.0 Executive Summary

This report (Deliverable 1.3) summarizes our efforts to validate the experimental work of SSPA against our computations. These tasks are identified in the Grant Agreement as Tasks 1.1, 1.2, and 1.3. This work package uses a widely used open-source tool Qblade/Xfoil.

As been documented in the previous report (Deliverable 1.2), our full-scale single turbine simulations matched well with the BEM simulations of the Magallanes. But very high mismatch in the coefficient of power and coefficient of thrust was noticed while a comparison against the experiments of SSPA was made. So, in addition to comparing the turbine results we also started comparing the results (coefficient of lift and coefficient of drag) of the 2D slices of the SSPA against the Qblade/Xfoil simulations. These performance parameters (coefficient of lift and coefficient of drag) are vital inputs for the full-scale 3D turbine simulations model (called as ALM method).

We performed Qblade simulations at the radial distance of 5 m and 8 m from the turbines' hub center at different Reynolds numbers. These simulations are performed to obtain the performance coefficients of the hydrofoil (coefficient of lift and coefficient of drag) for the angle of attack ranging from -180^{o} to $+180^{o}$. In the Qblade simulations, -10^{o} to 20^{o} Xfoil simulations are done, while for the remaining range Montgomerie and/or Viterna interpolation scheme is used. We found that for the same Reynolds number, there is a good match between the SSPA experiments and the Qblade/Xfoil simulations corresponding to that particular 2D slice/station of the blades. URANS simulations are also performed for varying inlet turbulence conditions and for different Reynolds numbers. The URANS simulations confirm the effect of Reynolds number on the C_L and C_D values. Now, since the experiments (turbine) of SSPA are scaled down in the range of 1:38; thus, the corresponding Reynolds number will also correspondingly 38 times lower than the full-scale blade computations. Thus, using the present report, we can conclude that the disparity in the results of turbine simulations (full scale) and SSPA experiments (1:38 model) could be attributed to the difference in the Reynolds number.

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2.0 A note on SSPA experiments

The experiments of SSPA were conducted on the scaled-down model (1:7) of Magallanes blade at the radial distance of 0.5R and 0.8R from the center of the turbine's hub, where R is the radius of the turbine (R=9.5 m). Corresponding to the slice location, chord length and different inlet velocities, the Reynolds numbers are defined as:

At radial distance of 0.5R

For chord length of 0.25 m, kinematic viscosity of water (ν) at 18ºC is 1.0533×10^{-6} m^2/s, the Reynolds number (Re_c) for different inlet velocities are given as:

- velocity=5 m/s, Re_c =1190476.19 = 1.190476×10^6
- velocity=7 m/s, Re_c =1666666.67 = 1.666666×10^6

At radial distance of 0.8R

For chord length of 0.129 m, kinematic viscosity of water (ν) at 18º C is 1.0533×10^{-6} m^2/s, the Reynolds number (Re_c) for different inlet velocities are given as:

- velocity=5 m/s, Re_c = 619047.6 = 6.19047×10^5
- velocity=7 m/s, Re_c = 866666.7 = 8.666667×10^5
- velocity=9 m/s, Re_c = 1114285.7 = 1.1142857×10^6

2.1 Effect of Reynolds number and external pressure

In sections 2.1.1 and 2.1.2, the performance characteristics (coefficient of lift and drag) of hydrofoil at a radial distance of 0.5R and 0.8R are described. It is evident that the Reynolds number, in the range in which the experiments were conducted, has no effect on the C_L and C_D values; however, there is a substantial effect of the external pressure on the C_L and C_D curves.

2.1.1 At radial distance of 0.5R

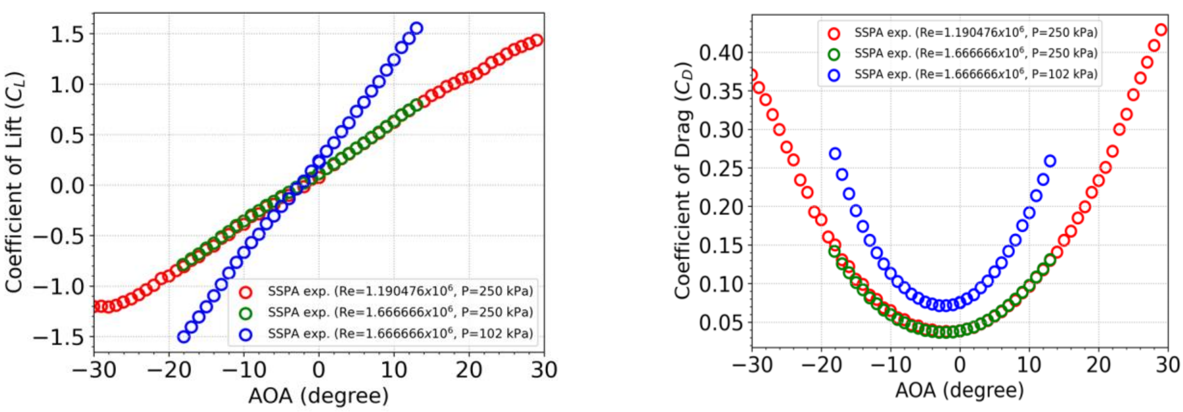


Figure 1:Effect of Reynolds number and external pressure at radial distance of 0.5R on coefficient of (left) lift C_L and (right) drag C_D

2.1.2 At radial distance of 0.8R

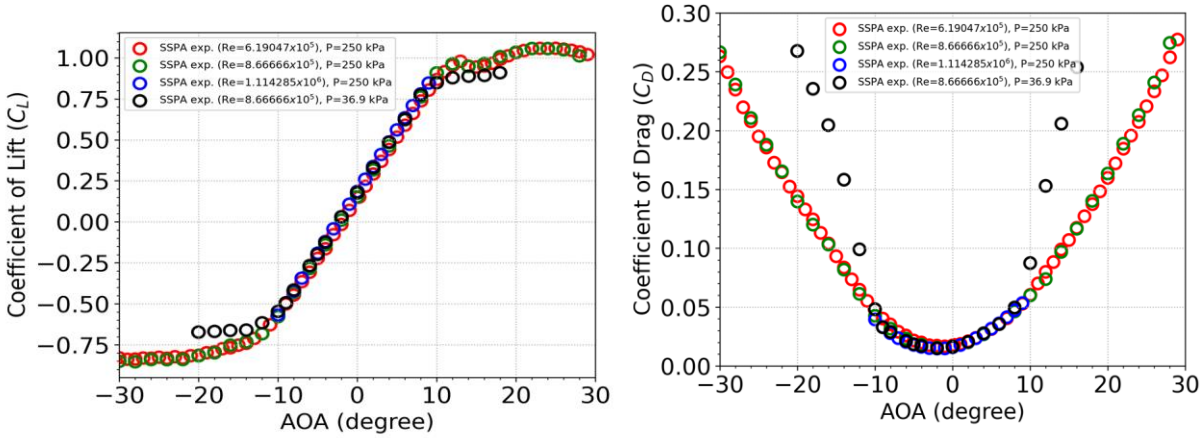


Figure 2:Effect of Reynolds number and external pressure at radial distance of 0.8 R on coefficient of (left) lift C_L and (right) drag C_D

2.2 Effect of slice location on the C_L and C_D curves

Figure 3 shows that with the change of slice location, i.e., from a radial distance of 0.5R to 0.8R, there is a significant shift in the coefficient of drag (C_D) as compared to the coefficient of lift (C_L).

So, conclusions from this section are:

• At a particular slice/station location, there is no effect of Reynolds number (in the range of experiments were conducted) on the C_L and C_D values, but there is an appreciable effect of changing the external pressure on these curves.

• Comparing the C_L and C_D curves of the different slices/stations, we found that the C_D curves have a significant effect as compared to the C_L curves.

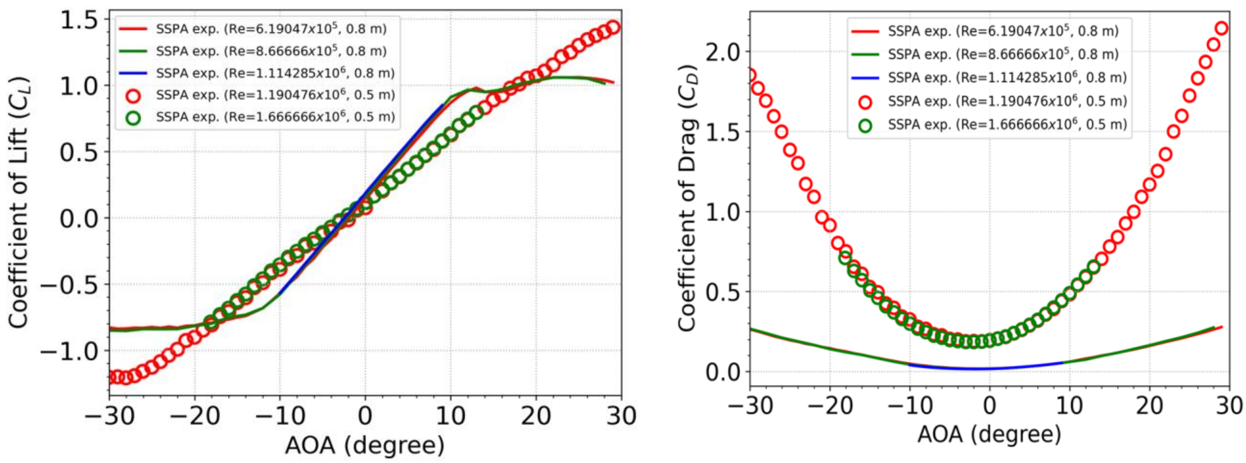


Figure 3:Effect of slice location on coefficient of (left) lift C_L and (right) drag C_D

3.0 Comparison of Qblade simulations with the SSPA experiments

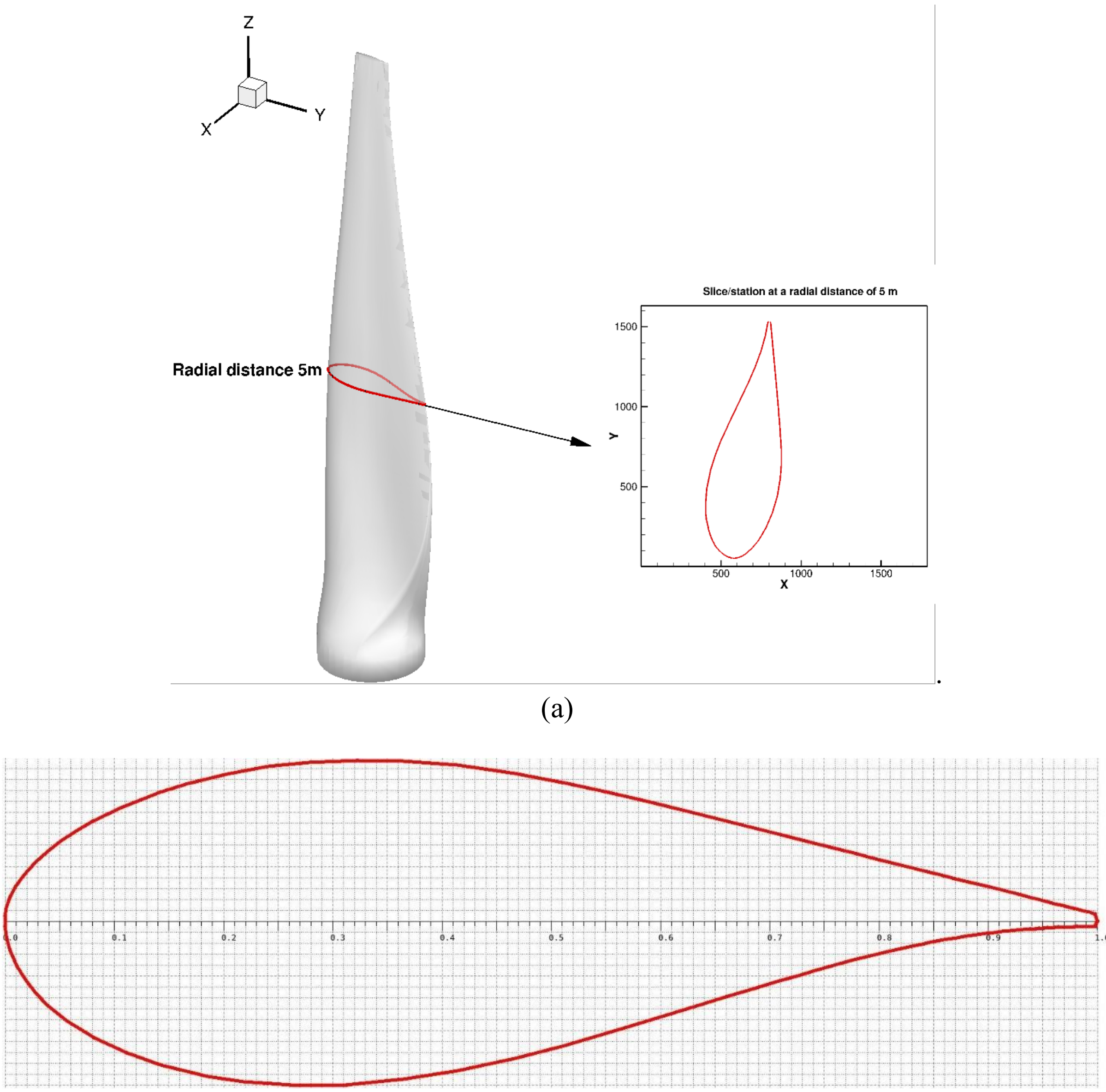
Table 1 shows the slice/station details of the Magallanes blade. To compare the experimental work of SSPA at the slice location of 0.5R and 0.8R we are assuming the slice/station S6 and S9 of the full -scale Magallanes blade (table 1).

Slice/station name	Reynolds number	Radial distance (m)	Relative maximum speed (m/s)	Speed angle	Chord (m)
S2	3.67×10^6	1.02	3.3	40.2	1.3
S3	5.22×10^6	2.0	4.3	54.6	1.4
S4	8.08×10^6	3.0	5.9	64.7	1.6
S5	1.03×10^7	4.0	7.5	70.4	1.6
S6	1.19×10^7	5.0	9.2	74.2	1.5
S7	1.14×10^7	6.0	10.9	76.7	1.22
S8	1.03×10^7	7.0	12.6	78.5	0.95
S9	8.90×10^6	8.0	14.3	79.9	0.72
S10	7.82×10^6	8.75	15.6	80.8	0.58
S11	7.16×10^6	9.5	16.9	81.5	0.49

Table 1:Definition of slice/station of the Magallanes blade

3.1 Slice S6 (at radial distance of 5 m)

Figure 4shows the cross-section of the Magallanes blade at the radial distance of 5 m from the turbines' hub center (corresponding to the slice S6 in the table 1).



(a)

(b)

Figure 4:Cross section of Magallanes blade at radial distance of 5 m (a) slice/station from Magallanes blade (b) scaled section in the range of 0 to 1

Figure 5 shows the comparison of the Qblade simulations against the SSPA experiments. The data corresponding to the SSPA experiments at the location of 0.5R is considered. The interpolation method Viterna is used. In the work of (Guo Qiang, 2015) Montgomerie method was used for the interpolation while we found that the Viterna interpolation scheme better suits our case (will be explained in the next section). In the range of negative angle of attack, the Qblade simulations accurately predict the drag coefficient, while for the positive range of angle of attack, it underpredicts the experimental value. The prediction of the coefficient of lift by the Qblade simulations shows that it overpredicts for the negative angle of attack and underpredicts for the positive angle of attack.

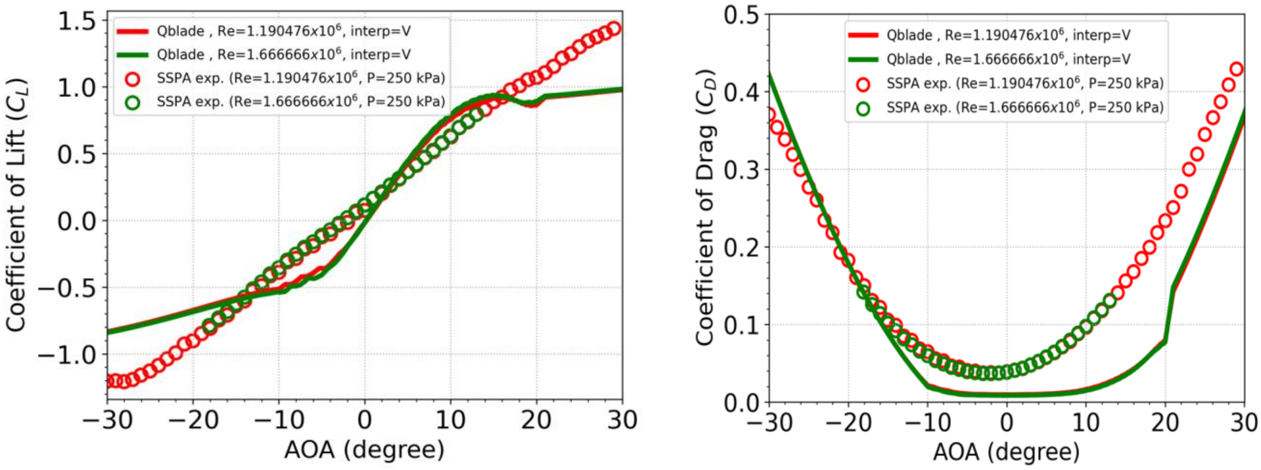
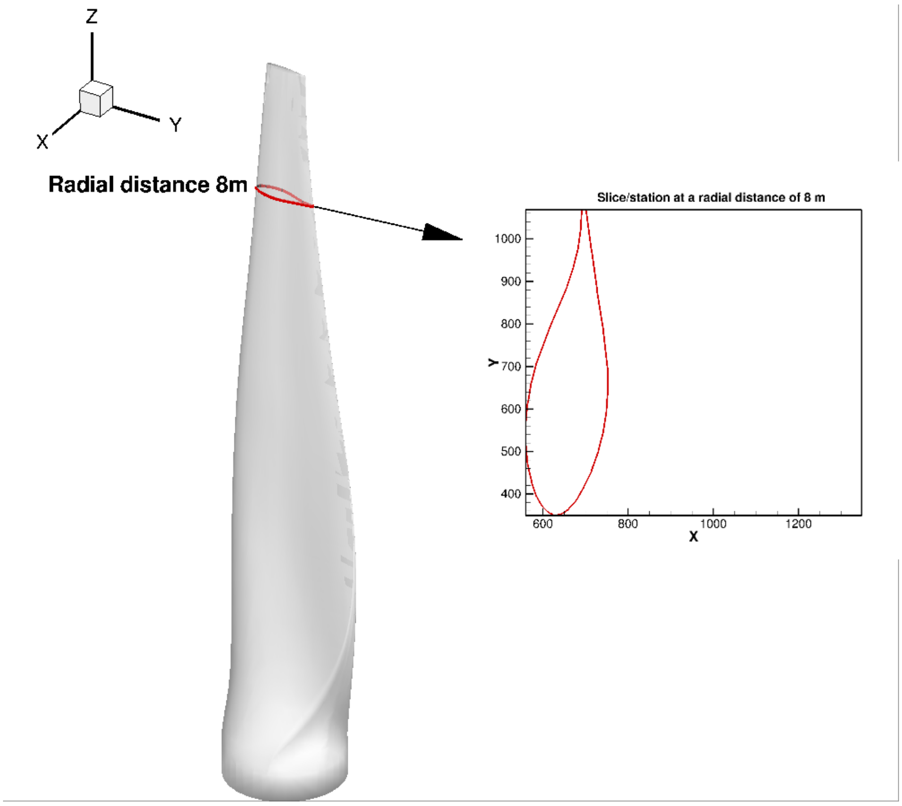


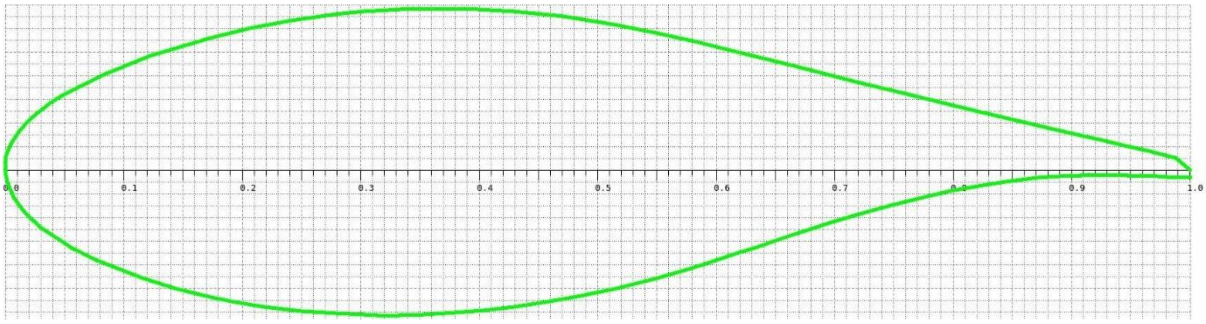
Figure 5:Comparison of Q blade simulation with SSPA experiments at location 5 m (left) coefficient of lift C_L (right) coefficient of drag C_D

3.2 Slice S9 (at radial distance of 8 m)

Figure 6 shows the cross-section of the Magallanes blade at the radial distance of 8 m from the turbines' hub center (corresponding to the slice S9 in table 1). Figure 7 shows the comparison of the cross-section (in the scale of 0-1) of the slices at the location of 5 m and 8 m from the turbine hub. In sections 3.2.1 and 3.2.2, the comparison of the Qblade simulations against the SSPA experiments is plotted. From these sections, it could be concluded that for the negative angle of attack, the Viterna interpolation method accurately captures the variation of lift coefficient for the given Reynolds number. While for the positive angle of attack, the Qblade simulations overpredict the lift coefficients.



(a)



(b)

Figure 6: Cross section of Magallanes blade at radial distance of 8 m (a) slice/station from Magallanes blade (b) scaled section in the range of 0 to 1

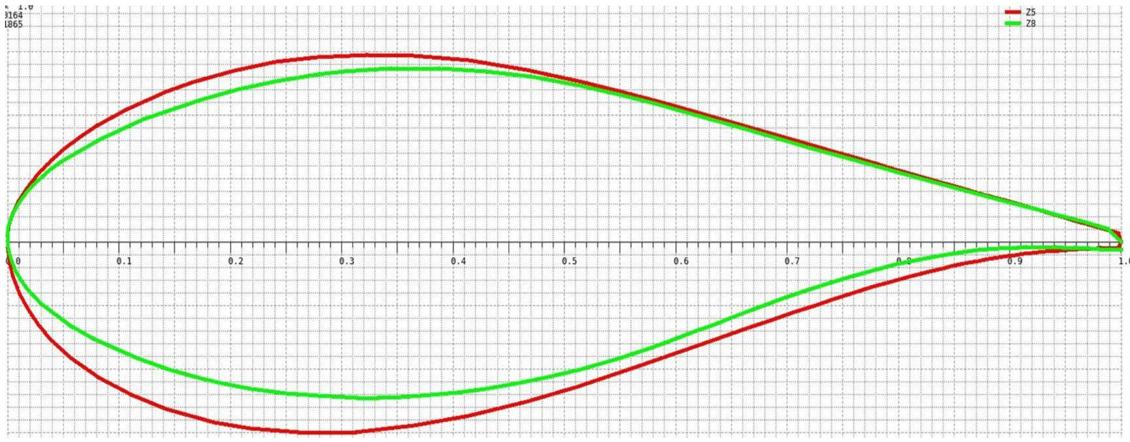


Figure 7:Comparison of cross section of Magallanes blade at radial distance of 5 m and 8 m, red color shows at a radial distance of 5 m and green color shows radial distance of 8 m (in the range of 0 to 1)

3.2.1 At Reynolds no Re_c=619047.6

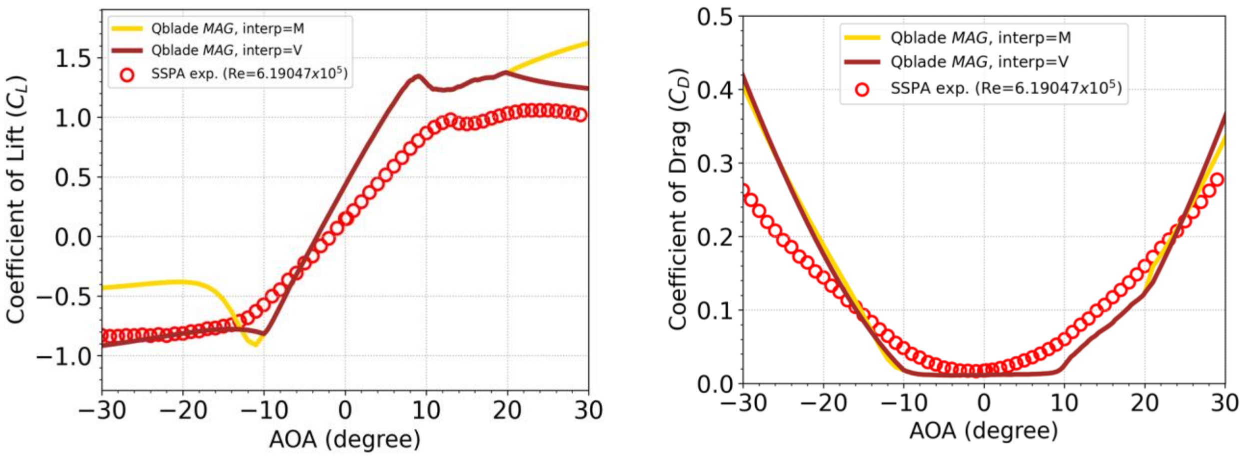
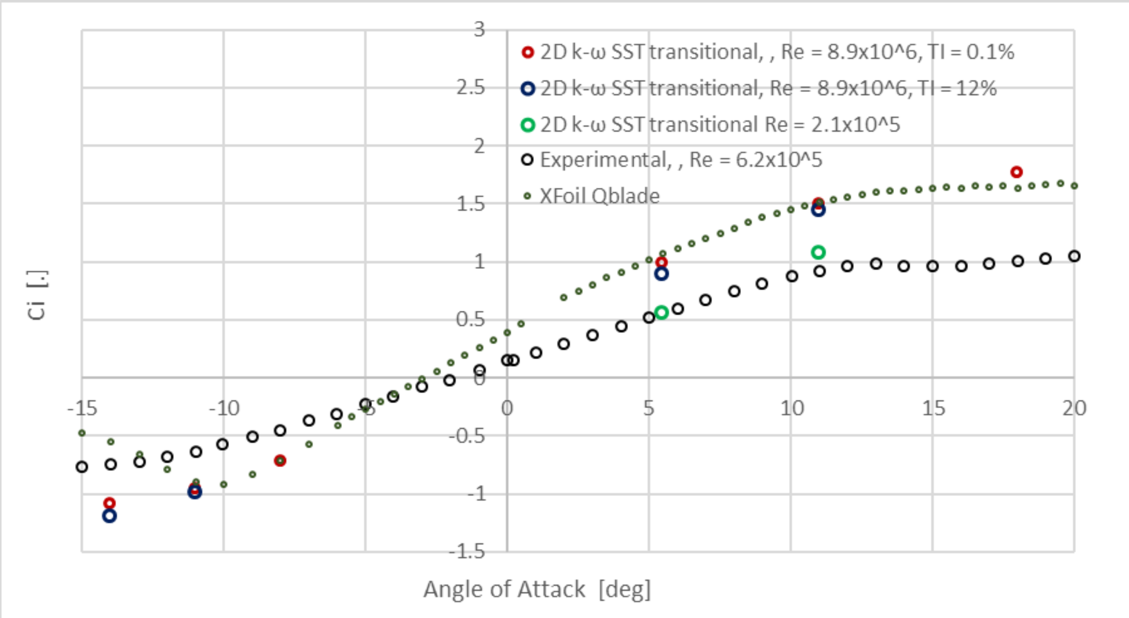
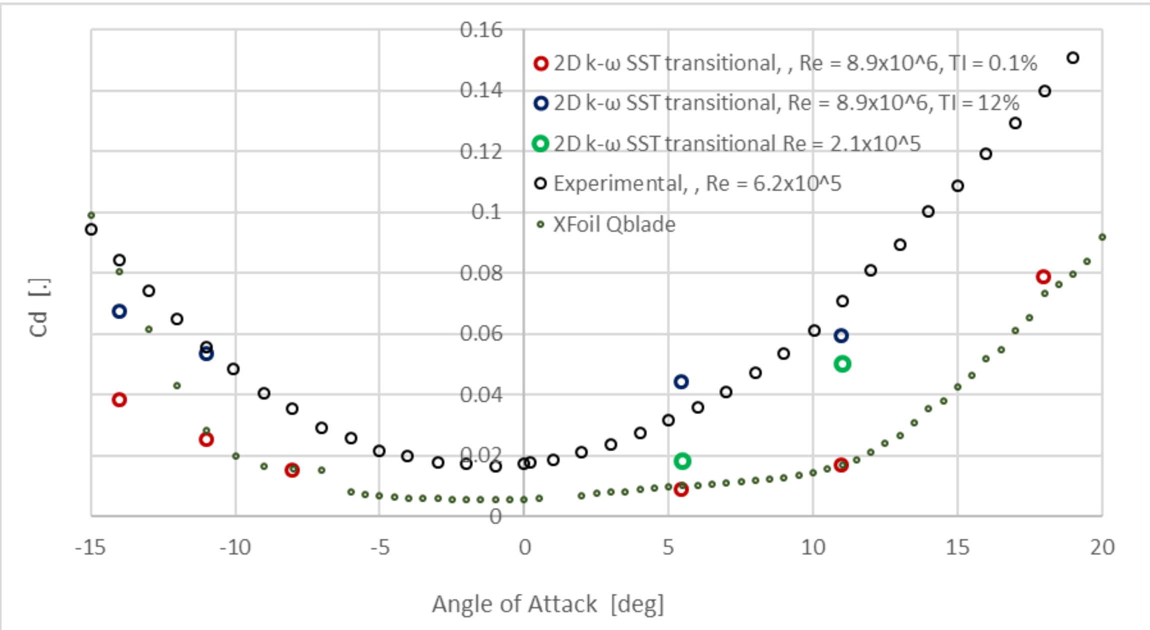


Figure 8:Comparison of Q blade simulation with SSPA experiments at Reynolds no Re_c=619047.6 (left) coefficient of lift C_L (right) coefficient of drag C_D

The QBlade – Xfoil and experimental results were further compared to lift and drag coefficients obtained from wall resolved and transitional turbulent flow simulations. The effect of the flow Reynolds number and inlet turbulence was investigated in an attempt to explain the discrepancy with experimental results. A substantial drop in lift was observed when the Reynolds number was drop below $Re = 5 \times 10^6$ that is close to the conditions of the experiments. The turbulent simulations were found to be in very close agreement with the experirmental results in this case. It was also found that the XFoil (QBlade) predictions failed to capture this effect leading to the significant differenc in slope shown in Figure 8. The close agreement between QBlade and wall resolved simulation was confirmed in particular at low inlet turbulence conditions, suggesting that the Xfoil method is a suitable method to provide the hydrodynamic performance curve required for the ALM-LES solver.



(a)



(b)

Figure 9 Predictions of time averaged coefficient of lift (a) and drag (b) for the turbine hydrofoil at 8m radial position.

3.2.2 At Reynolds no Re_c=866666.7

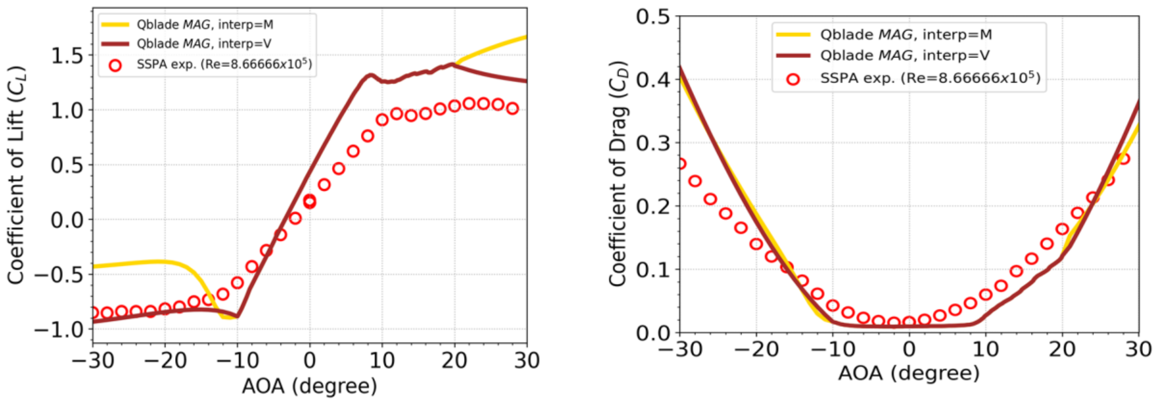


Figure 10:Comparison of Q blade simulation with SSPA experiments at Reynolds no Re_c=866666.7 (left) coefficient of lift C_L (right) coefficient of drag C_D

4.0 Closure

The present work focused on the comparison of the Qblade simulations against the SSPA experiments of the 2D slices of the Magallanes blade. We found that for some range of angle of attack, the Qblade predicts the performance coefficients (C_L and C_D) accurately, while for a certain degree of angle of attack, it either under or over predicts the experimental values.

In deliverable D1.2, we found a mismatch between the power coefficient and thrust coefficient between the full-scale turbine simulations and scale down model SSPA experiments. Since the SSPA experiments were performed at the scaled-down model of the turbines (1:38) and correspondingly, the Reynolds number of the model SSPA experiments and the actual turbine also vary in the scale of 1:38. So we investigated the effect of Reynolds number on the performance coefficient of the blade slice (at a radial distance of 8 m). Figure 11 shows the effect of the Reynolds number on the coefficient of lift and drag. It is clearly evident that with the increase in the Reynolds number, the lift coefficient also increases. In addition to that URANS simulations were performed for varying inlet turbulence conditions and for different Reynolds numbers. The URANS simulations confirm the effect of Reynolds number on the C_L and C_D values. Thus, the difference in the coefficient of power and thrust between the SSPA model experiments and the full-scale turbine simulation could be attributed to the difference in the Reynolds number.

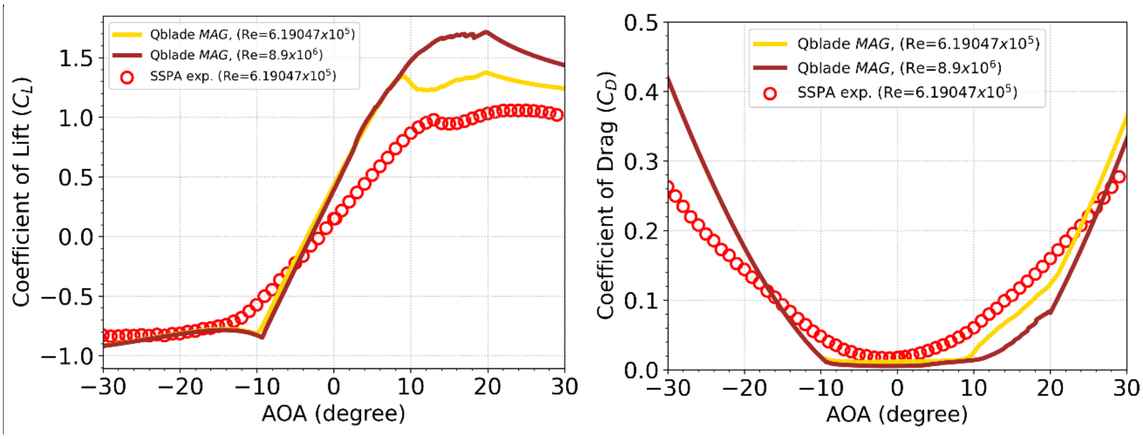


Figure 11:Effect of Reynolds number on the performance coefficients at the slice/station of 8 m.

5.0 References

1. Guo Qiang, L. Z. (2015). Comparison of BEM-CFD and full rotor geometry simulations for the performance and flow field of a marine current turbine. *Renewable Energy*, 640-648.