Wake Features of Aerodynamic Fairings under Flow Misalignment

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Aerodynamic fairings can be used to cover bluff bodies to reduce negative aerodynamic effects. Conventional fairings tend to have thick airfoil shapes to minimize chord length with a sharp trailing edge and are designed to have low drag and wake near zero angle of attack. However, they can lose their performance benefits when the fairing loses its alignment with the flow direction, which can cause large flow separation. Herein, rounded trailing edges are used to improve the fairing robustness to angle of attack. The rounded trailing edge at high angle of attack helps to move the upper and lower separation points closer to each other, which reduces the wake effect. To understand the fluid physics of such fairings, flow visualization and particle image velocimetry were employed at different misalignment angles. At 20° angle of attack, a fairing without any trailing edge rounding was found to have the largest wake width of all geometries considered. The fairing with the largest degree of rounding was found to be the most robust yielding smaller wakes (in terms of length and width) than even the cylinder for angles of attack as large as 20°.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Re</td>
<td>Reynolds number with cylinder diameter or max fairing thickness as characteristic length</td>
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<tr>
<td>D</td>
<td>cylinder diameter</td>
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<tr>
<td>χ</td>
<td>misalignment angle</td>
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<tr>
<td>(V_{inlet})</td>
<td>free stream tunnel velocity</td>
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<tr>
<td>V</td>
<td>local velocity magnitude</td>
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<tr>
<td>(\bar{V})</td>
<td>average local velocity magnitude</td>
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<tr>
<td>(u_x)</td>
<td>local streamwise velocity component</td>
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<td>PIV</td>
<td>particle image velocimetry</td>
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<tr>
<td>(Re_{crit})</td>
<td>Reynolds number threshold leading to turbulent boundary layer separation</td>
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<tr>
<td>x</td>
<td>streamwise distance from the center of the cylinder</td>
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<tr>
<td>y</td>
<td>streamwise normal distance from the center of the cylinder</td>
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<tr>
<td>TI</td>
<td>two-dimensional turbulence intensity</td>
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I. Introduction

For mass efficiency, a cylindrical geometry is often an ideal solution for many structural designs. However, if such cylindrical structural designs are subjected to aerodynamic or hydrodynamic loads, the wake and drag effects must be considered [1]. The drag and wake associated with flow over a cylinder is a function of Reynolds number based on diameter (D) with dynamic viscosity (v) and flow speed (V)

\[
Re = \frac{VD}{v}
\]  

A Reynolds number of more than 150 is characterized by a large unsteady wake which can lead to vortex-induced vibrations that can compromise the structural integrity of a system [2]. The unsteady wake may also cause unwanted acoustic noise in certain applications, such as air flight [3]. For downwind turbines, the wake from the cylindrical tower can negatively affect the turbine rotor blades [4,5]. Flow control or fairings can be employed to minimize the unsteady aerodynamic wake behind a cylinder. Since the deficit and width of a wake is proportional to the drag an object, reducing the wake effects can be addressed by reducing the drag on the object.

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Many forms of cylinder flow control operate on the principle to delay the point of boundary layer separation as long as possible so as to reduce drag. This leads to a thinner wake, less pressure drag, and mitigating other potentially negative flow characteristics. For sub-critical Reynolds numbers, $Re<10^5$, a simple solution to reduce drag is to artificially trip the boundary layer so that it is turbulent and less prone to separation, and thus will have a lower drag. This trip can be accomplished by the use of a surface perturbation such as a spanwise wire in order to cause transition to turbulence [6].

If the boundary layer is already in the turbulent regime prior to separation, a method for delaying separation further is to add energy to the boundary layer. Passively, energy can be added into the boundary layer profile by introducing streamwise vorticity, by means of vortex generators, grooves, helical strakes, tabs, or other methods [7,8,9,10]. Active methods include, plasma actuators, synthetic jets, ion wind, and many more. The strengths and limitations of these methods have been studied in depth in the literature [11,12,13,14]. The above methods tend to reduce the drag by about 50% and reduce, but do not eliminate the large-scale wake unsteadiness.

An approach that can more dramatically reduce the drag and wake unsteadiness is to surround the structural geometry with an aerodynamic fairing. Well-designed fairings may decrease the drag of a cylinder by as much as 97.5% in aligned conditions [15]. Such fairings over cylindrical cross-sections have been used to reduce vortex induced vibrations [16,17], diminish noise from airplane’s landing gear axels [18], and lower drag and minimize the unwanted and potentially damaging wake [19].

However, one disadvantage of most aerodynamic fairings is that they are generally designed to be aligned with the flow in the streamwise direction. If the fairing becomes misaligned with the flow, it can exaggerate the problems that it was designed to mitigate [15]. Thus, for applications where flow direction is unknown, or might change more quickly than the fairing can be re-aligned, a more robust fairing is desired. A key application where such fairing could be employed is downwind wind turbines, which are recently being considered. In such turbines, the rotors downwind of the tower and therefore “see” the tower wake each time that pass downstream of the tower, i.e. when pointed downward. While this is problematic, relocating the rotor downwind of the tower leads to structural advantages. To take advantage of these benefits, it is important to minimize the effects of the wake from the cylindrical tower on the rotors [19]. A fairing could be used to substantially reduce the wake of the tower [4], however due to wind gusts in the atmospheric environment, aligning the fairing to the wind direction at all times becomes impossible. In order to improve and understand fairing performance when misaligned, this study experimentally analyzes the wakes behind three aerodynamic fairings, two with rounded trailing edges, at misalignment angles of 0°, 10° and 20°. The angles were chosen to mimic similar work done by O’Connor [15], for more conventional fairing geometries. To the author’s knowledge, this is the first study to investigate the physics and wake characteristics of rounded trailing-edge fairings in comparison to that of a cylinder which could be inscribed in such fairings.

II. Methods

An E863 profile [20], a thick, symmetric airfoil, was used as the base fairing as this is perhaps the lowest drag fairing for a given encapsulated cylinder [15]. This baseline was then circularly rounded at the trailing edge to create the E863r40 and E863r45 fairings which allowed the thickness to chord ratio to increase from 35.7% to 40% and 45% respectively, Fig. 1a. A rounded trailing edge was chosen was chosen with the objective to minimize both drag and lift at a given flow angle of attack, since both forces are structurally problematic for aerodynamic and hydrodynamic surfaces. Note that flatback airfoil have been recently proposed for wind turbine rotors as a means to reduces the chord length to improve structural efficiency. However, a flatback airfoil is intended to create lift at an angle of attack and tends to increase drag compared to a sharp trailing edge, and thus is not a practical alternative to a rounded trailing edge.
For installation in the water channel, the three fairings were manufactured using a Fortus 3D printer by Stratasys and compared to a cylinder (made of PVC). The water channel had a flow cross sectional area of 0.38m x 0.38m. The fairings and the cylinder tested all spanned the test section width with a length of 381 mm. In the context of the test section height of 381 mm, the cylinder diameter (D) was set at 67 mm in order to maximize the Reynolds number in the water tunnel while keeping within reasonable blockage constraints, less than 18%, similar in magnitude as in experiments by Dobrosel’skii [21]. In addition, a skim plate was used to help ensure a horizontal boundary condition of the water channel so that the flow was symmetric top to bottom.

For the fairings, the maximum thickness was set equal to the cylinder diameter so that ReD was preserved for all cases (where D represents the cylinder diameter or airfoil maximum thickness and used as the characteristic length, Eq.1). This yielded the following three chord lengths (in increasing order) 149 mm for the E863r45, 167mm for the E863r40 and 188mm for the E863. The cylinder and the three fairings were tested at misalignment angle, $\chi$, (defined in Fig. 1b) of 0°, 10° and 20°. At these angles the cross-section blockage was always less than 20%. As such, the fluid dynamic blockage effects on the wake region are expected to weak relative to effects associated with the faring geometry changes.

Qualitative understanding of the fluid flow physics was obtained by injecting dye into the fluid boundary layer near the leading edge of the models. For quantitative analysis the instantaneous wake velocity field was obtained using a Particle Image Velocimetry (PIV) system. The PIV system used a New Wave Yag Solo laser to illuminate the PIV window twice, separated by a delay of 1ms. A TSI Power View Plus camera was used to capture the images which would later be processed into 63x63 element vector arrays by Insight 4G. The process was repeated 500 times at a frequency of 7.25 Hz. The PIV interrogation window had dimensions of 3D x 3D (201mm x 201mm), and was taken at two locations downstream of the model in order to characterize the wake. The concatenation of both PIV windows led to an effective window of velocity data spanning from 2-8 cylinder diameters (or airfoil thicknesses) from the cylinder center (or chord of airfoil at maximum thickness), Fig. 2.

Fig. 1 Chord view schematics of fairings: a) the profiles of all four models, and b) inlet velocity and fairing misalignment angle displayed.

Fig. 2 Schematic of water channel, skim plate, and PIV setup, not to scale.
The water channel allowed a free-stream speed ($V_{\text{inlet}}$) of 1 m/s which led to a Reynolds number, $Re$, of 6.82x10^4 for all cases. This Reynolds number is less than the critical Reynolds number for cylinders, $Re_{\text{crit}} \approx 10^5$, for which the boundary layer will transition to turbulence prior to aft flow separation. Motivated by large-scale applications for which Reynolds number would be much larger than $Re_{\text{crit}}$, the boundary layers were artificially tripped to ensure a turbulent flow transition before flow separation.

It has been found by Igarashi [22] that effective tripping of the boundary layer on a cylinder to ensure a turbulent boundary layer before separation by use of a trip wire can be sensitive to both wire diameter and wire location. Based on this study, two 1.6 mm diameter wires were placed on the top and bottom surfaces of the cylinder, 50° from the leading edge. Fig. 3 illustrates flow over a cylinder with different boundary layer separation physics. Fig. 3a illustrates flow with laminar boundary layer separation (i.e. sub-critical flow), whereas Fig. 3b shows a flow with turbulent boundary layer separation (i.e. super-critical flow). The experimental boundary layer separation from the dye visualization of Fig. 3c was measured to be 114° and the boundary layer was seen to have strong unsteady perturbations prior to separation. This shows that the trip wire was successful in attaining a super-critical flow on the cylinder consistent with higher Reynolds number conditions [23].

![Diagram of boundary layer separation](Image)

**Fig 3.** Boundary layer separation at different Reynolds numbers: a) laminar boundary layer separation at $Re << 10^5$, b) turbulent boundary layer separation at $Re >> 10^5$, c) separation at $Re = 6.82 \times 10^4$ with the use of trip wires for the present study & d) trip tape located at 3% chord length from the leading edge of fairing. Approximately located at 50° based on leading edge curvature.

However, when the trip wires were placed on the fairing models using the same wire diameters and maintaining the same arc length from the leading edge, the result varied from the cylindrical case. In many cases, the trip wire caused premature boundary layer separation from the fairings. In the literature for airfoil studies [24], the boundary layer is often artificially tripped into its turbulent mode using trip tape between 2-5% the chord length from the leading edge. This is much closer to the leading edge and a much smaller dimension trip tape than used for cylinder conditions. This can be related to differences in the geometry and the flow field near the leading edge between the cylinder and the airfoil fairings. To account for this, trip wire dimensions and location for the airfoil case can be specified based on the leading edge geometry, using an effective cylinder radius based on the radius of airfoil’s leading edge curvature. In this case, the smaller trip tape at 3% of the chord length is consistent with that of a stand-alone cylinder whose radius is consistent with leading edge curvature. This is shown in Fig. 3d. Therefore, a trip tape placed at 3% the chord length for all the fairings for the detailed investigations, in order to ensure appropriate super-critical conditions, as would occur at the higher Reynolds numbers associated with most fairing applications.
III. Results

The flow experiments are qualitatively summarized with dye flow visualization in Fig. 4. The flow over a cylinder shown in Fig. 4a indicates a large recirculation region directly behind the cylinder. This can be inferred because the dye is spread evenly behind the cylinder (both top and bottom surfaces) even though the dye is injected only into the upper boundary layer. Farther downstream of the cylinder, the flow is characterized by a Kármán vortex street as is typical for cylinders at this Reynolds number [23]. Plots 4b – 4j show the flow over the fairings. At $\chi=0^\circ$, the fairings drastically reduce the thickness of the wakes compared to the wake of the cylinder. As the trailing edge rounding increases, there is a corresponding increase in the wake, but is much smaller than that of the cylinder. For $\chi=10^\circ$, all three fairings yield boundary layer separation at ~50% of the chord on the suction side. This creates a low velocity (wake) region bounded between two higher velocity regions, with two separate shear layers leading to flow oscillations similar to Kármán vortex oscillations seen in Fig. 4a. At $\chi=20^\circ$, the boundary layer separation on the faired geometries occurs further upstream at ~30% of the chord. This leads to a thicker velocity deficit region and wake eddies of a slightly larger size.

Fig 4. Dye flow visualization for Reynolds number based on cylinder diameter or fairing thickness of 6.82 x 10^4: a) the flow over a cylinder & b-j) the flow over fairings at various misalignment angles.

Since the dye visualization cannot provide quantitative information on the velocity deficit in the wake, or the rate that the wake recovers, Particle Image Velocimetry (PIV) was used to obtain velocity fields. The PIV results were examined in terms of both instantaneous and averaged data flow fields to characterize the influence of model geometry.
Figures 5-7 show the instantaneous velocity magnitude downstream of all four models. The discontinuity in the PIV vector fields at x/D=5 arises because each field of view is a combination of two instantaneous realizations measured (one upstream of x/D=5 and one downstream of x/D=5) at two different times. The instantaneous fields are placed together herein to give an indication of the size of the flow structures throughout the wake.

From Fig. 5 with χ=0°, it can be seen that the wake of the cylinder (5a) is unsteady and fully turbulent, with eddies larger than the cylinder diameter (e.g. extending as far as y/D=1 to y/D=-1). This is as expected for cylinder wakes at super-critical conditions [25] that produce strong alternating vortices associated with a Karman vortex street. In contrast, the flow behind all three fairings (5b-5d) is much more uniform and steady, as can be expected from fully- or nearly-attached flow airfoil wakes. Compared to that for a cylinder, the fairing wakes are thus drastically thinner and have significantly less variation in velocity magnitude and direction. As the trailing edge rounding becomes more extreme (the progression from E863 to E863r40 to E863r45), it can be seen that the wake grows slightly in width, and includes a weak vortex-shedding pattern, associated with the trailing-edge cylindrical shape. This is consistent with thin shear layers being created at two distinct points of flow separation on the rounded trailing edge (seen in dye flow visualization of Fig. 5f). As a result, this small portion of the flow acts qualitatively similar to that of a cylinder wake, for which the effective cylinder diameter is conservatively approximated by the vertical distance between the two separation points. This effective distance is about 40% of the chord maximum thickness (where this thickness inscribes a cylinder of diameter D).

As the misalignment angle is increased to 10° as shown in Fig. 6, the wakes behind the fairing models become much larger and more turbulent compared with those at χ = 0°. In addition, the wakes have larger velocity deficits, i.e. regions of flow where the velocity magnitude is much less than the free stream value (which is 1 m/s). In general, the wakes behind the fairing models become more similar to the wake behind the cylinder than that behind an aligned airfoil. From Figure 6e & 6f, the vertical separation height for the E863 and E863r45 airfoils have both grown to 85% of the airfoil maximum thickness. This indicates that flow misalignment causes increased trailing edge separation.
but that this airfoil ensures that this separation height is still significantly less than that which would occur for a pure cylinder.

**Fig 6. Instantaneous velocity field at fairing misalignment angle of 10°: a) cylinder, b) E863, c) E863r40 d) E863r45, and dye visualization for e) E863 & f) E863r45.**

In Fig. 7, the misalignment angle for the fairing cases is set to 20°. The velocity deficit regions (with velocity below the freestream) in the wake behind the E863 model fairing is now even larger and of greater magnitude than that behind the cylinder. This fairing has clearly entered a stall region, and this wake increase can be expected to correspond with a large drag increase. The velocity deficit wake behind the E863r45 appears to be the smallest measured from all four models, in length, width and magnitude. As can be seen from the dye images, the vertical separation height for the E863r45 airfoil (Fig. 7f) has less vertical extent than that for un-faired E863 airfoil (Fig. 7e) and is instead more similar to that of a cylinder wake (Fig 4a). One would therefore expect that the E863r45 fairing to behave qualitatively similar to the cylinder while the E863 fairing should have a more severe wake. Thus, the E863r45 maintains a moderate wake condition even at substantial flow misalignment as large as 20 degrees. Such a large angle indicates substantial misalignment robustness since this angle is consistent with stall on most airfoils.
To quantify the above effects and use such data for modeling, the PIV data was further processed. Data from the 500 frames was used to calculate the average velocity magnitude over the domain (Figures 8, 10 & 12), to calculate turbulence intensity (Figures 14-16), and for modeling purposes profiles of the streamwise component of velocity and turbulence intensity are plotted at various distances downstream of the model (Figures 9, 11 & 13).

Figures 8 and 9 show the average velocity for the flows with $\chi = 0^\circ$. The average velocity deficit for the cylinder is severe. The flow near the centerline is less than 50% of Vinlet for $x/D < 3.44$ and is less than 65% of Vinlet for $x/D < 4.05$. In comparison, Schneck & O’Brian [26] measured the wake behind a smooth cylinder had regained to ~65% Vinlet at $x/D = 4.5$, for equivalent Reynolds number. This differing result is attributed to the use of trip strips to change the mode of separation from laminar to turbulent. This would decrease the drag and lead to faster recovery of the flow to free stream velocity. Compared to that of the cylinder, the average velocity wake behind all three aligned fairings is minimal, e.g., the velocity magnitude never drops below 50% of Vinlet. The wake behind the E863r45 fairing is somewhat thicker than for the other two fairings, and has a faster flow recovery (easily seen in Fig 9) towards Vinlet, which may be due to the increased mixing cause by the flow unsteadiness (Fig. 5f).
The average velocity deficit wake behind the fairing models at $\chi_F = 10^\circ$ shown in Figs. 10 and 11 is much more significant than at $\chi = 0^\circ$, in terms of width, length and magnitude. In fact, the wake deficit from the E863 airfoil is more comparable with the wake from the cylinder. The near centerline velocity is less than 50% $V_{inlet}$ for $x/D < 3.69$ for E863 compared with $x/D < 3.44$ for the cylinder and inferred from Fig. 11 both models at the centerline have zero average streamwise velocity component at $x/D = 3$. However the wake widths (in the y direction) of all three fairings are thinner than that of the cylinder. The wake from E863 fairing (Fig. 10b & Fig. 11b) is larger by all metrics, length, width and magnitude, than the other two fairings.
Fig 10. Average velocity field at fairing misalignment angle of 10°: a) cylinder, b) E863, c) E863r40 and d) E863r45.

Fig 11. Normalized streamwise velocity component (black) & turbulence intensity (red) at fairing misalignment angle of 10°: a) cylinder, b) E863, c) E863r40 and d) E863r45.

Figures 12 and 13 show the average velocity wake at χ = 20°. The wake from the E863 model (Fig. 12b) is again the largest by all metrics, length, width, and magnitude in terms of the fairings, but now is even larger than that of the cylinder. For the E863 model, the region up to x/D = 4.5 actually yields an average flow in the negative x-direction and the mean velocity does not recover to 50% of Vinlet until x/D = 5.28. The other models, E863r40 & E863r45, have only slight average recirculation regions, and the mean velocity recovers to 50% of Vinlet at x/D of 3.87 and 3.14, respectively. The wake from the E863r45 has the smallest wake in both length and width as compared to all of the tested models, although only slightly less than the cylinder, both have near zero average streamwise velocity.
component at the centerline at x/D = 3. Since drag is proportional to wake deficit and width, this model can be expected to have the lowest drag, and the lowest mean aerodynamic or hydrodynamic load on a structure enclosed by such a fairing.

![Diagram of average velocity field at fairing misalignment angle of 20°: a) cylinder, b) E863, c) E863r40 and d) E863r45.]

**Fig 12.** Average velocity field at fairing misalignment angle of 20°: a) cylinder, b) E863, c) E863r40 and d) E863r45.

![Diagram of normalized streamwise velocity component (black) & turbulence intensity (red) at fairing misalignment angle of 20°: a) cylinder, b) E863, c) E863r40 and d) E863r45.]

**Fig 13** Normalized streamwise velocity component (black) & turbulence intensity (red) at fairing misalignment angle of 20°: a) cylinder, b) E863, c) E863r40 and d) E863r45.

Wake unsteadiness is also important for fairing performance since it is related to acoustics and dynamic loads. Wake unsteadiness can be especially important for wind turbine towers whose wake can impact downwind rotor blades. A measure of the unsteady component of the present wakes can be obtained by analyzing a two-dimensional Turbulence Intensity (TI), defined in terms of the velocity components in the x and y coordinate directions (u_x and u_y) as
\[ TI \equiv \frac{\sqrt{\frac{1}{2}(u'_{rms,x}^2 + u'_{rms,y}^2)}}{V_{inlet}} \quad (2) \]

In this expression, the prime (') indicates the instantaneous deviation from the velocity average at the location and the rms is defined as the root mean square operator.

Figures 9 and 14 shows this turbulence intensity at \( \chi = 0^\circ \). It can be seen that turbulence intensity in the cylinder wake is far more significant compared with any of the fairing models, and can be attributed to the dynamics of the Karman vortex street. While the fairing turbulence levels are small, increasing trailing edge rounding increases the width and strength of the wake TI. This is due to the shedding wake structure seen in the instantaneous representations of the data, Fig. 5f.

Fig 14 Turbulence intensity field at fairing misalignment angle of 0°: a) cylinder, b) E863, c) E863r40 and d) E863r45.

At \( \chi = 10^\circ \), Figs. 11 and 15 indicate that the turbulence intensity wakes from the faired models are significantly less than that of the cylinder, in length, width, and in magnitude. This differs from the results of average velocity at the same misalignment angle, where the mean velocity wakes were of comparable size and magnitude (and even larger for E863). This difference between the trends of velocity magnitude and turbulence intensity (Figs. 10 and 15) is best seen in Fig 11 a & b, where the magnitudes of the velocity deficit (black lines) are of similar magnitude however the E863 has a much tighter turbulence intensity profile (red lines). It may be that relatively higher turbulence intensity will increase the rate of wake recovery to free stream speeds, because of the addition of turbulent mixing of momentum.
Figures 13 and 16 show the TI-wake behind all the models at misalignment angle of 20°. Up to \(x/D=5\), the TI-wake from the E863 is in general of lower magnitude than any of the other models. This contrasts with the result of Fig. 12, where the E863 had the largest average velocity deficit wake of all the tested models. Regions of greater TI can correlate with shorter velocity deficit wakes because turbulent mixing of momentum helps entrain more high-speed surrounding flow into the wake region so as to more quickly recover this region to free stream conditions. This explains why the E863r45 has the highest measured TI as well as the shortest average velocity deficit wake. Additionally, areas with especially low average velocities (dead zones, as in Fig. 12b) lead to especially low turbulence intensities (Fig. 16b). This is because proportionally equivalent deviations from the local mean flow will lead to lower turbulence intensities for slower flow than for faster flow as they are both normalized by the free stream velocity. By \(x/D=8\), it can be seen that the width and strength of the TI is lowest for the E863r45 fairing, indicating the strong mixing combined with a low mean velocity deficit just downstream of the trailing edge contributes to faster velocity deficit recovery and faster reduction of the TI in the wake. As such, this geometry, which has the largest thickness to chord ratio of all the fairing tested can lead to significant flow unsteadiness reduction far downstream \((x/D>8)\) but can lead to increase unsteadiness in the near flow region \((x/D<5)\).
IV. Conclusions

The wakes of three aerodynamic fairings with varying degrees of trailing edge rounding were investigated and compared against an un-faired cylinder. These fairings were tested at several misalignment angles to give insight into the performance at a variety of inflow conditions, up to a maximum misalignment angle of 20°. All fairings at aligned flow decreased the wakes compared with the (un-faired) cylinder. Fairings with greater rounding at a perfectly aligned flow (0° of misalignment) had slightly wider wakes with slightly more turbulent intensity. This can be attributed to an increase in the vertical distance between the two separation points at the trailing edge, as the rounding become more pronounced. As the flow angle increased, the vertical distance between the two separation points for the fairing cases increase, which was lead to an increase in wake severity (stronger and wider mean velocity deficits). In general, the vertical distance between separation points for the E863r45 was less than the other fairings for misalignment angles greater than 10°. Additionally the E863r45 has the greatest thickness to chord ratio, which can be advantageous for certain designs where clearance or weight are concerns.

For more quantitative analysis PIV data was analyzed. The fairings lessened the velocity deficit and the turbulence intensity compared to the cylinder with zero misalignment angle. When the misalignment angle is increased there is both a larger velocity deficit and greater turbulence intensity. Fairings with greater rounding (E863r45) lose its effectiveness at minimizing velocity deficit slower as misalignment angle is increased compared to fairings with less rounding (E863). Although, fairings with greater rounding also tend to increase the turbulence intensity faster as misalignment angle is increased compared to fairings with less rounding. This relationship could be due to the additional mixing of momentum gained by slightly higher turbulence intensities, with could allow flow speeds to recover to free speed comparably faster. In summary, only the fairing with the most rounding (E863r45) was able to reduce the velocity deficit of the wake, in terms of length, width and magnitude, compared to the cylinder at misalignment angles as great as 20°.

Recommended future work includes investigating other test conditions such as higher Reynolds numbers, effects of incoming inflow turbulence, higher angles of misalignment and even further increases in trailing edge rounding (and how this may effect three-dimensional flow features). Furthermore, it would be helpful to better understand the fluid-structure interactions by measuring acoustic signals in a wind tunnel, and by measuring mean and instantaneous fluid dynamic forces on the fairing model. For the case of downwind wind turbines, force measurements could also be considered for the blades passing thorough the tower wake, with and without a tower fairing.

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References


