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SAND2008-1781
Unlimited Release
Printed March 2008

Trailing Edge Modifications for Flatback Airfoils

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Prepared by
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Trailing Edge Modifications for Flatback Airfoils

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Sandia Contract No. 15890

Abstract

The adoption of blunt trailing edge airfoils (also called flatback airfoils) for the inboard region of large wind turbine blades has been proposed. Blunt trailing edge airfoils would not only provide a number of structural benefits, such as increased structural volume and ease of fabrication and handling, but they have also been found to improve the lift characteristics of thick airfoils. Therefore, the incorporation of blunt trailing edge airfoils would allow blade designers to more freely address the structural demands without having to sacrifice aerodynamic performance. These airfoils do have the disadvantage of generating high levels of drag as a result of the low-pressure steady or periodic flow in the near-wake of the blunt trailing edge. Although for rotors, the drag penalty appears secondary to the lift enhancement produced by the blunt trailing edge, high drag levels are of concern in terms of the negative effect on the torque and power generated by the rotor. Hence, devices are sought that mitigate the drag of these airfoils. This report summarizes the literature on bluff body vortex shedding and bluff body drag reduction devices and proposes four devices for further study in the wind tunnel.

Acknowledgements

This project was supported by TPI Composites of Warren, Rhode Island under Contract 15890 – Revision 4 with Sandia National Laboratories. The primary members of the TPI team were Derek Berry (Principal Investigator) and Steve Nolet of TPI, Kevin Jackson of Dynamic Design, Michael Zuteck of MDZ Consulting and C.P. (Case) van Dam and his students (Daniel Kahn for this particular effort) at the University of California at Davis. The members of the Sandia team were Tom Ashwill, Dale Berg (Technical Manager), Daniel Laird, Mark Rumsey, Herbert Sutherland, Paul Veers and Jose Zayas.

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Introduction

In the past, many investigations have been conducted on blunt trailing edge airfoils with some of the earliest work by Hoerner [1,2] indicating that the maximum lift-to-drag ratio of thick airfoils could be increased by incorporating a blunt trailing edge, and suggesting application in the blade root region of rotors such as propellers. Most of these studies simply truncated the trailing edge to achieve the required blunt trailing edge shape. However, the change in camber created by the truncation may cause a loss in lift. Instead, the shape of these blunt airfoils seem to be optimal when the trailing edge is thickened as demonstrated by Standish & van Dam [3] and illustrated in Figure. 1. This results in a reduced adverse pressure gradient on the suction side thereby creating more lift and mitigating flow separation due to premature boundary-layer transition. Unfortunately, this trailing-edge shape also creates a steady or periodic low-pressure flow in the near-wake of the airfoil that gives rise to a drag penalty and this explains why blunt trailing edges have been largely avoided in the design of subsonic airfoils [4].

Solutions to minimize the base drag penalty have been investigated for many years and include trailing-edge splitter plates, trailing-edge serrations, base cavities, and trailing-edge fairings or wedges. The literature on these trailing-edge modifications was studied and the main findings are presented in the following section.

Review of Base Drag Reduction Devices

One of the earliest studies on the mitigation of base drag of blunt trailing edge airfoils was conducted by Nash et al [5]. The focus of their study was the low-pressure vortical zone that forms behind the blunt trailing edge. Modification of this wake region leading to an increase in pressure and, hence, a reduction in base drag, is the reason for the splitter plate, wedge, cavity, and other methods of reducing base drag. A blunt trailing edge airfoil is observed to be the most effective with a square trailing edge versus one that is rounded, as seen in Figure. 2. This is the case because the rounded trailing edge corners cause the flow to follow the curvature of the base thereby accelerating more than if the flow separates at the sharp corners of the square trailing edge. This flow acceleration causes significantly lower pressures behind the airfoil and is the cause of a larger drag penalty. Also, the rounded trailing edge leads to unsteadiness in the flow separation point and, subsequently, larger variations in the airfoil force. Hence, for airfoils with a significant trailing edge thickness (> 4% of chord), sharp corners at the trailing edge are preferred.

One solution to the problem of reducing the effect of the bluff body vortices coming off a square trailing edge is to insert a cavity, as seen in Figure. 3. A cavity that has a chord-wise depth of half to one base height tends to be optimal. When the cavity is introduced to the trailing edge, the base pressure increases significantly from that of the untreated blunt trailing edge airfoil, resulting in base drag reductions of up to 30%. Nash et al [5] theorize that the cavity is used to generate a re-circulating vortex that creates a base pressure rise with the solid cavity boundaries assisting in trapping and stabilizing the vortex. However, recent work by Molezzi & Dutton [6] indicates that the main effect of the base cavity is the downstream displacement of the low-pressure vortical flow development away from the airfoil base.

Nash [7] continued his studies on base drag mitigation with a focus on ventilated base cavities to further reduce base drag. Two types of ventilation devices were tested: a slotted base cavity (Figure. 3) and a perforated-walled cavity (Figure. 4). Results show that the base pressure was nominally the same for both, but the slotted cavity reduced drag significantly more than the perforated cavity. Factors pertaining to the perforated ventilated cavity do not depend on the size of the holes, hole density or cavity thickness but instead the total open area of the holes. On the other hand, the slotted-walled cavity had more factors to consider. A cavity with a solid boundary on the forward 15 – 20% and slots from there to the trailing edge increases pressure just as well and even more than a splitter plate. Based on his own experiments and work by others, Nash [7] observes that the basic (solid wall) cavity leads to reductions in base drag of 21 – 32% and the slotted cavity in reductions of 52 – 60%.

Tanner [8] also focused on improving base drag reduction methods; specifically, serrated (or broken) trailing edges, splitter plates and splitter wedges. A splitter plate reduces base drag by causing the vortex street to be displaced further from the base of the airfoil, therefore causing less drag on the airfoil itself. The seemingly optimized 'short' splitter plate is one that has length that of the height of the base, is relatively thick, and has a sharp trailing edge. An improvement on this idea is a wedge attached to the base of the airfoil. The optimal size for this wedge has a base that is flush with the trailing edge and has length four times that of the height of the blunt base. When a splitter plate was added, it reduced base drag by ~24% of the baseline blunt trailing-edge airfoil while the wedge reduced base drag by ~55% of the baseline airfoil. A few trailing edge configurations are depicted in Figure. 6.

Tanner [8] notes that the effectiveness of a serrated or broken trailing edge depends on the parameters shown in Figure. 7. The optimal design is characterized by the following:

$$\frac{a}{h} = 1.9$$

$$\gamma = 33.42^\circ$$

$$\frac{b_1}{h} = 5$$

$$\frac{b_1}{b_2} = 1$$

where h is the thickness of the trailing edge. The effectiveness of a ventilated cavity was not studied here, but other researchers have found them to be less effective than a broken trailing edge. At low subsonic Mach numbers, a wedge is the most effective means of base drag reduction.

Gai & Sharma [9] examined various serrations of the base of a blunt trailing edge airfoil including rectangular (or slotted), M-shaped and sawtooth shaped configurations. These discontinuous trailing edge configurations inhibit the periodic vortex shedding that creates a drop in the base pressures and increases the base drag penalty. The pressure distribution of a slotted serration versus an M-shaped serration can be seen in Figure. 8. The M-shaped configuration resulted in a recovery of 51% in the mean base pressure. The sawtooth formation is achieved using a V-shape with angles of 120° and 60°. The 120° configuration achieved a mean base pressure coefficient of –0.48 and reduced the base drag by ~22% when compared to the baseline blunt trialing edge airfoil while the 60° configuration achieved a much higher mean base pressure coefficient of –0.33 as seen in Figure. 9**.**

Rodriguez [10] conducted detailed flow measurements of the vortical system that originates at the blunt trailing edge. From the point of view of drag reduction, he observes that an M-shaped serrated trailing edge (Figure. 7) is optimal with the following dimensions:

$$b_1 = b_2 = 3.66h$$

$$\gamma = 40^\circ$$

A reduction in airfoil drag of 46% was measured for this trailing edge shape.

Discussion

Blunt trailing edge airfoils are of interest in the engineering of large wind turbine blades because they allow for a strong structure with a high aerodynamic lift to structural weight ratio. However, these airfoils also have a high drag because of the low pressures in the wake acting on the blunt trailing edge. The goal of the present research effort is to find the most effective way of reducing the base drag while retaining the favorable characteristics of the airfoil that make it of interest for application in the inboard region of large wind turbine blades. .

Most studies discuss the use of <u>a splitter plate</u> to increase the base pressure and, hence, to reduce the base drag. This is the simplest method and it has been utilized and researched more than any other base drag mitigation device. The nominally optimum dimension is one that has a length the same as the height of the trailing edge. This simply causes the once large vortex system behind the airfoil to be split into two smaller ones. With the two smaller vortices directly behind the base, the rest of the flow over the airfoil forms into the shape of a sharp trailing edge, therefore causing an increase of base pressure without loss of lift. Although simple, it does not quite generate the amount of base drag reduction that can be achieved with other, more complex devices.

Another idea proposed by Tanner [8] was one where a splitter wedge is placed at the end of the airfoil. This causes the flow to follow a streamline very similar to that of a sharp trailing edge airfoil. Although, this method tends to defeat the purpose of a blunt trailing edge by sharpening it, it does provide the type of airfoil closure that it often favored by aerodynamicists. As such it provides a useful baseline.

Trailing edge serrations seem to be quite effective in the reduction of base drag. The sawtooth and M-shaped trailing edges are both effective in that they break up the vortical system emanating from the blunt trailing edge, causing smaller, staggered vortices and therefore a higher overall base pressure. The M-shaped serration is more effective than the sawtooth because it allows the vortices to form in a pattern that causes a smaller vortex street. However, the depth of the serration is quite a bit larger than that of a sawtooth configuration or even that of a cavity. Since the optimum length ratio $\frac{a}{h}$ (see Figure 7) is 1.9, it requires a significant modification to the baseline airfoil.

Finally, base cavities are considered and their effect on the vortices caused by the separation of the flow by the sharp corners of the blunt trailing edge. When the flow separates and a large vortex is formed behind the bare airfoil, a cavity can capture that flow and stabilize it, therefore allowing a less turbulent flow to form, creating more base pressure. Nash [5] explains this phenomenon incorrectly, as later research shows [6]. But even with the most optimal depth equaling half the height of the trailing edge, this still does not reduce the drag to even the amount a splitter plate does. A few authors provide information that shows how the introduction of a ventilation system on the walls of the cavity (typically upper and lower) can help reduce the overall base drag. The idea of a ventilated cavity using slots versus holes is more beneficial because the holes simply allow air through the cavity, but are not as effective in breaking up the vortex system. The design of the slots as Nash [7] described appear to be most beneficial. A theory that could also prove to be useful is to combine the concepts of an M-shaped serrated trailing edge with a slotted ventilated cavity. Figure 8 shows that if the upstream cutouts of the slots were in the M-shape versus a square, the overall drag could be reduced even more.

Based on the above findings, we propose to test and compare the effects of the following trailing edge configurations on the lift and drag of a blunt trailing edge airfoil:

1. splitter plate
2. trailing edge wedge
3. ventilated cavity
4. M-shaped serrations

The literature on these trailing-edge modifications shows that substantially decreases in the base drag can be achieved with these devices and the proposed wind tunnel test will allow us to evaluate their effect on the aerodynamic performance characteristics of the type of blunt trailing edge airfoils considered for the inboard regions of large wind turbine blades.

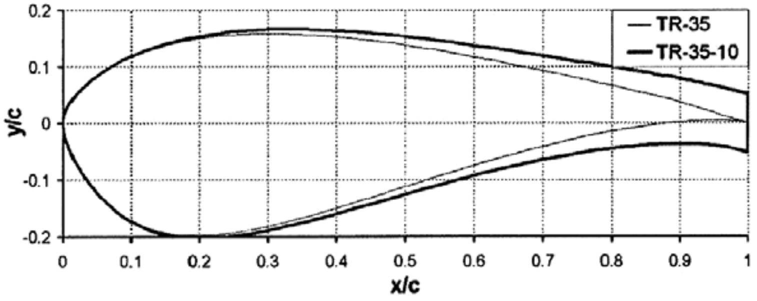

Figure 1 TR-35 sharp trailing edge airfoil compared to TR-35-10 thickened trailing edge airfoil. (Source: Standish and van Dam [3])

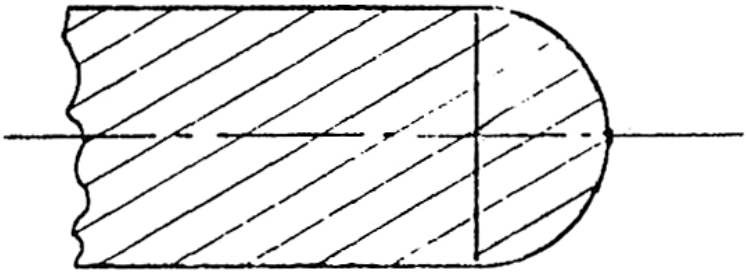

Figure 2 Rounded trailing edge (Source: Nash et al [5])

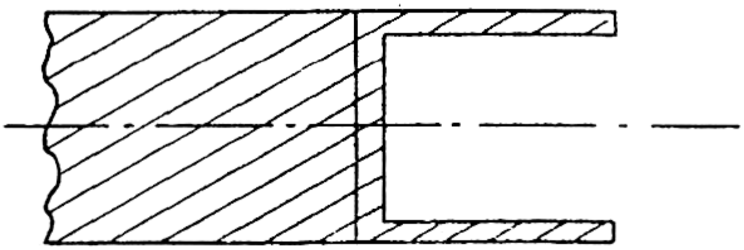

Figure 3 Base cavity (Source: Nash et al [5])

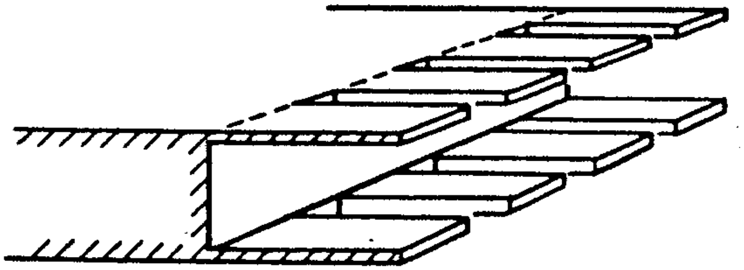

Figure 4 A slotted cavity (Source: Nash [7])

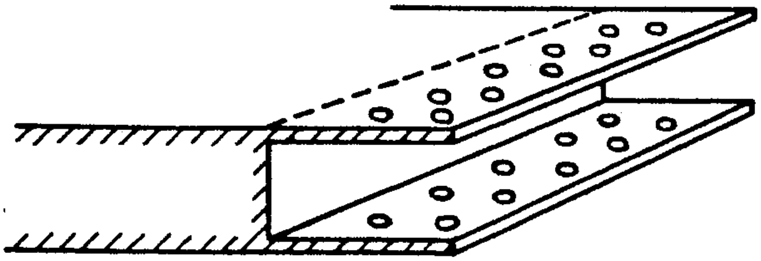

Figure 5 A perforated cavity (Source: Nash [7])

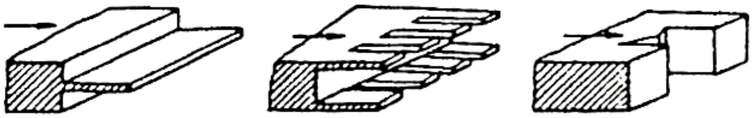

Figure 6 Base drag reduction techniques (from left): splitter plate, ventilated cavity, serrated trailing edge (Source: Tanner [8])

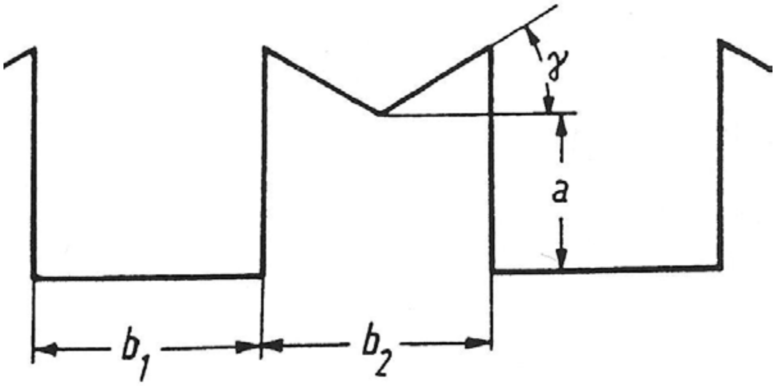

Figure 7 Dimensions of an M-shaped serrated trailing edge (Source: Tanner [8])

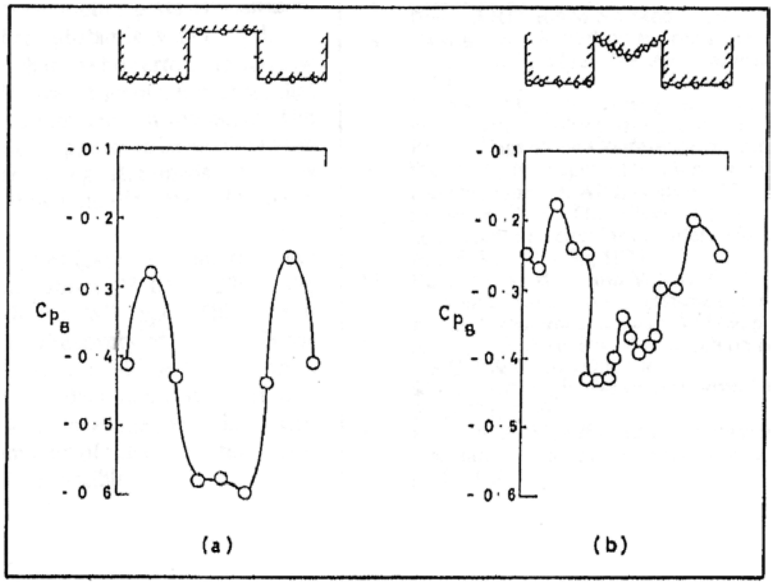

Figure 8 Base pressure of a slotted and an M-shaped serrated trailing edge (Source: Gai and Sharma [9])

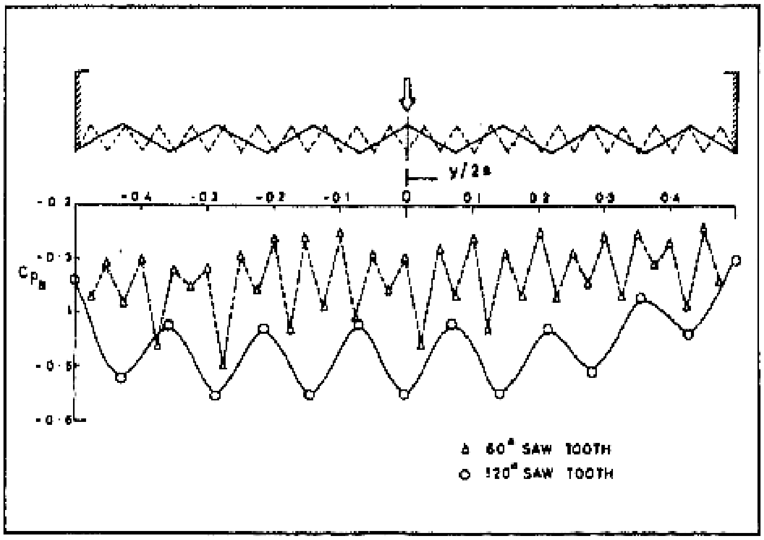

Figure 9 Base pressure of a 60˚ and 120˚ sawtooth serrated trailing edge (Source: Gai and Sharma [9])

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