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Twin Wind Tunnel tests of a very thick flatback airfoil

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1 Introduction

The need for lower Levelized Cost of Energy (LCOE) for wind energy, requires, among others, an increase in rotor diameter for modern Wind Turbines. Consequently, the need for novel solutions that can support this size increase arises. One of these solutions is the use of flatback (FB) airfoils, i.e. thick airfoil profiles with a blunt trailing edge (TE), at the root region of the Wind Turbine blade as they provide several aerodynamic, structural, and aeroelastic advantages [1]. Namely, FB airfoils can provide higher lift values due to the reduced adverse pressure gradient over the aft part of the suction side [1]. In addition, their aerodynamic performance is insensitive to surface roughness when compared to that of traditional sharp TE airfoils when certain design conditions are met [1]. Early studies performed on the $100m$ long SNL100-03 blade designed by Sandia National Laboratories, showed that, blades with FB airfoils can be up to 16% lighter than blades with traditional airfoils [2]. Additionally, due to the blunt TE and increased blade cross-sectional area, FB blades have increased flapwise stiffness.

These benefits, however, come with an increase in profile drag. Furthermore, due to their relatively high thickness, they may exhibit three-dimensional flow separation both at their pressure and suction side. The maximum lift is observed at relatively low angles of attack and for certain cases the lift curve may exhibit a minimum in between two maximums. Flow separation also leads to a bifurcating behaviour, related to three-dimensional instabilities, that can be observed in the load and pressure timeseries. This observation, in conjunction with the vortex shedding from the blunt TE, makes experimental studies of FB airfoils a troublesome endeavour. Additionally, the scarcity of relevant experimental studies [1, 3, 4, 5, 6], makes clear the need to investigate the effects of different WT facilities and operating conditions on FB airfoil performance and behaviour.

Here, we present a Twin Wind Tunnel Test for a FB airfoil at two different facilities, taking place in Spring 2025. The utter goal is to elucidate the effect of freestream turbulence intensity, Reynolds number and blockage ratio on airfoil performance, 3D flow separation and wake behaviour. The Twin Wind Tunnel Test is part of the TWEET-IE[1] project, a Horizon Europe project on wind tunnel testing for energy and the environment. Wind tunnel tests will be carried out in two of the partners of the TWEET-IE project, namely at the National Technical University of Athens (NTUA) and at Politecnico di Milano (POLIMI).

2 Twin Wind Tunnel Test outline

2.1 The airfoil model

In both facilities, the same model will be tested. Namely, the FB4286-0802 airfoil present in the SNL-03 reference wind turbine [2]. The maximum thickness of the model is 42.86% of the chord and the TE thickness is 8.02% of the chord. The chord length is $c = 0.5m$ and the model span is $1m$, leading to an aspect ratio of $AR = 2$. Different setups will be used in each facility with the same model. The airfoil model, installed at the NTUA WT is shown in Fig. 1.

[1] *http://www.tweet-ie.eu/* (accessed 31/01/2025)

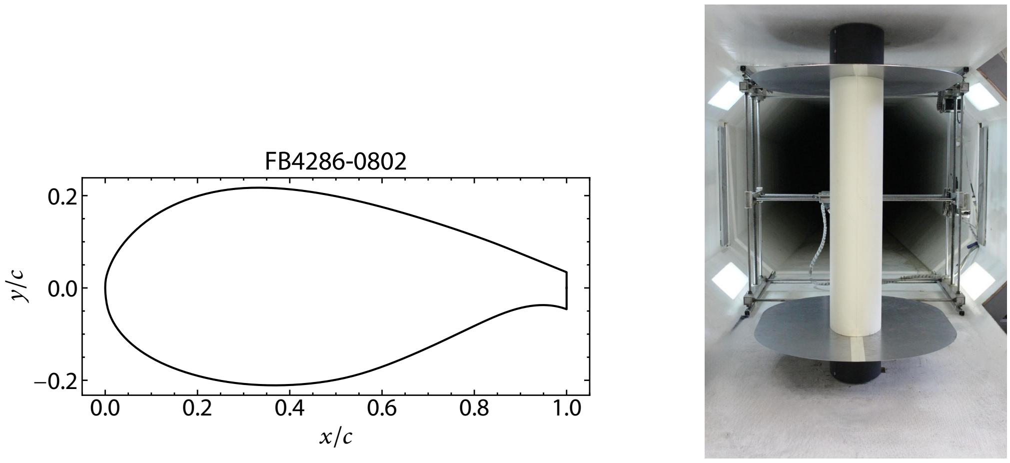

Figure 1: Left: The FB4286-0802 airfoil profile and right: the installed model at the NTUA wind tunnel, the endplates (in silver) and the profile extensions (in black) are also visible.

2.2 The participating facilities

2.2.1 NTUA

Tests are carried out at the small test section of the closed-loop Wind Tunnel of the National Technical University of Athens (NTUA)[2]. The test section is $3.75m$ long and has an octagonal cross-section of main dimensions $1.8m \times 1.4m$ (width $\times$ height). The maximum wind speed is $45m/s$, with a turbulence intensity (TI) lower than 0.2% and the blockage ratio is 11.9%. The NTUA tests will consist of surface pressure measurements, hot-wire measurements, flow visualization with tufts and Stereo Particle Image Velocimetry (SPIV) measurements. The pressure measurements will allow for determining the basic performance characteristics of the airfoil, and the hot-wire measurements will provide information about the primal shedding frequency. Additionally, the tufts coupled with image processing will help to explain the three-dimensional effects due to flow separation and the SPIV measurements will provide a basic understanding of the wake structures. Both fixed and free transition cases will be tested at a single Reynolds number of $Re = 1.3 \times 10^6$.

2.2.2 POLIMI

The tests for POLIMI will be conducted in the Low Turbulence Test Section of the Galleria del Vento del Politecnico di Milano (GVPM)[3]. The facility is a closed-loop wind tunnel and the utilized test section measures $4.0m$ in length with a cross-section of $4m \times 3.84m$. The maximum wind velocity is $55m/s$, with a free-stream TI level below 0.1%, while the blockage, with this model, is about 1.88%. The POLIMI tests will consist of surface pressure measurements, force balance and hot-wire measurements. The pressure measurements will allow for determining the basic performance characteristics of the airfoil as well as comparing facilities. Next, the force balance measurements will provide insights on the effect of the 3D separation to the airfoil loads and the hot-wire measurements will allow for determining the spanwise wake correlations. Both fixed and free transition cases will be tested at two Reynolds numbers of $Re \approx 1.3 \times 10^6$ and 1.8×10^6. A summary of the Twin Test is shown in Table 1.

Table 1: Summary of the Twin Test.

Facility	Surface Pressure	Hot-wire	Balance	Tufts	SPIV	Reynolds number	Transition
NTUA	✔	✔	✖	✔	✔	1.3×10^6	Both
POLIMI	✔	✔	✔	✖	✖	$(1.3, 1.8) \times 10^6$	Both

[2] *http://wt.fluid.mech.ntua.gr/* (accessed 31/01/2025)
[3] *https://www.windtunnel.polimi.it/* (accessed 31/01/2025)

3 Preliminary results

The uncorrected force coefficients of the FB4286-0802 airfoil at $Re = 1.3 \times 10^6$ as tested at NTUA can be seen in the left and middle panels of Fig. 2. Additionally, in the right panel of Fig 2, the unsteady lift coefficient C_l timeseries is shown for a single angle of attack for the fixed transition case. The timeseries demonstrate bifurcating behaviour that is correlated to three-dimensional flow separation. Additionally, the airfoil exhibits stall at a low angle of attack (5°) for the free transition case, while the lift at the fixed transition cases indicates that the flow separates both from the suction and pressure sides. All the aforementioned observations further highlight the need of the Twin Test.

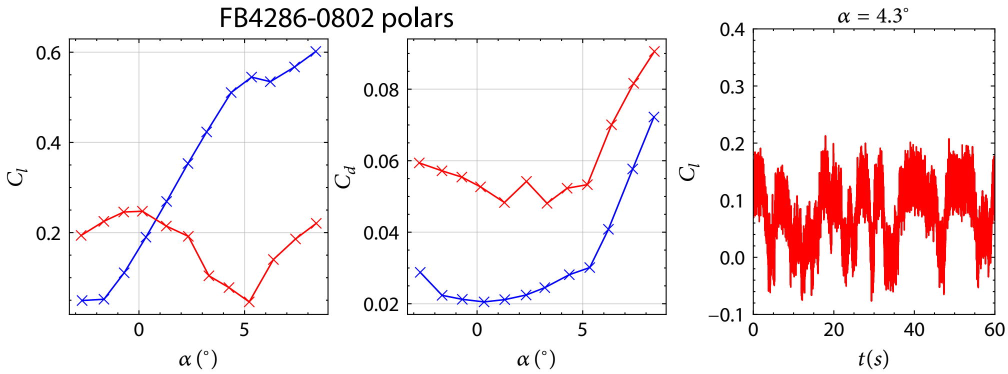

Figure 2: Uncorrected FB426-0802 force coefficients for the free (in blue) and fixed (in red) transition cases. Left: C_l, middle: C_d. Right: the C_l timeseries for fixed transition at 4.3°.

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