Ain Shams University

Faculty of Engineering

Design and Production Engineering Department

Design and Manufacturing of Inflatable Wind Turbines Blade

A Thesis Submitted in Partial Fulfillment for the Requirements of the Degree of Master of Science in Mechanical Engineering

by

Sherif Amin Mohamed Hassan Okda

Bachelor of Science in Mechanical Engineering

Design & Production Engineering

Faculty of Engineering, Ain Shams University, June 2013

Supervised by

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Statement

This thesis is submitted in partial fulfillment for the degree of Master of Science in Mechanical Engineering, to Faculty of Engineering, Ain Shams University. The author carried out the work included in this thesis at the laboratories of the Design and Production Engineering department, Faculty of Engineering, Ain Shams University. No part of this thesis has been submitted for a degree or qualification at any other university.

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Thesis Summary

The size of wind turbine blades is continuously growing in order to capture more energy from the wind. An innovative approach for the design and manufacturing large wind turbine blades is introduced. In this approach, blades are built of polymeric fabric which can be inflated to take the form of a HAWT (Horizontal Axis Wind Turbine) blade.

In order to withstand the wind loads, the blade is pressurized to increase its stiffness. Inflatable blades have the potential to overcome the drawbacks of traditional wind turbine blades. When compared to traditional blades made of fiberglass or carbon fibers, inflatable blades are lighter, less expensive, safer, easily manufacturable and transportable than traditional wind turbine blades.

This thesis starts by introducing inflatable structures, their applications and the motivation behind building an inflatable blade. Afterwards, a literature review is made to present the previous work done on inflatable structures that is related to the thesis topic. Related work includes: studying the bending behavior of inflatable beams, manufacturing of inflatable wings, and investigating different materials used in inflatable structures. An inflated wind turbine blade is then designed and tailored for Egyptian wind conditions. A NACA 0021 airfoil is selected for the inflatable blade. The wind turbine blade is designed using the Blade Element Momentum theory which helps to deduce the blade geometry and wind loads. After the design of the wind turbine, comes the phase of the inflatable blade fabrication. Beginning with choosing the inflatable fabric material, testing different fabric joining methods, then fabricating circular cross/section beams and testing their bending behavior. Afterwards, four prototypes of inflatable blade sections are manufactured and finally a full-size blade is fabricated.

In order to validate the inflatable blade concept, two inflatable blade sections are tested for geometrical accuracy. It is found that the average normalized error of the chord length and thickness are 3.37% and 1.67%, respectively. Afterwards the inflatable airfoil section is validated aerodynamically. They are tested in a wind tunnel in Chalmers university in Sweden, where the lift forces are measured using a six-component balance, while the drag forces are calculated from the wake measurements. The lift and drag coefficients are compared to those of a standard NACA 0021 airfoil. A good agreement between the inflatable and standard airfoils is observed. Moreover, the flow visualization is examined using both smoke generation and by using tufts. Measurements show that the boundary layer separation begins at an angle of attack not less than 15°, then it gradually increases to reach full stall at 25°. Moreover, the full-size blade is tested structurally by subjecting it to static bending loads representing the wind loads. Finally, the outcomes and conclusions of this study and future recommendations are presented.

Keywords: Inflatable blade - Inflatable airfoil - Inflatable structures - Wind tunnel testing

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List of Abbreviations

HAWT	Horizontal axis wind turbine: Wind turbine whose rotor axis is substantially parallel to the wind flow
UAVs	Unmanned Aerial Vehicles
FE	Finite Element
BEM	Blade element Momentum
NACA	National Advisory Committee for Aeronautics
PVC	Poly Vinyl Chloride
CFD	Computational Fluid Dynamics
3D	Three-Dimensional

List of symbols

a	Axial induction factor
a'	Angular induction factor
B	Number of blades
c	Chord length
c_l	Lift coefficient
c_d	Drag coefficient
c_p	Coefficient of performance
C_{lu}	Uncorrected lift coefficient
C_{du}	Uncorrected drag coefficient
F	Tip loss correction factor
h	Wind tunnel width
N	Number of blade elements
p	Pressure
P	Power
P_t	Total pressures inside wake
P_{t_0}	Total pressures outside wake
r	radius and radial direction
R	Blade tip radius
Re	Reynolds number
t	Airfoil thickness
V	Inlet flow velocity
U	Expected free wind velocity
U_{rel}	Relative wind velocity
α	Angle of attack
γ	Twist angle
ε_{Sb}	Solid blockage
ε_{wb}	Wake blockage
λ	Tip speed ratio
λ_2	Body shape factor
ρ	Air density
σ	Solidity factor
ϕ	Angle of relative wind
ω	Angular velocity of the air stream.
Ω	Rotational blade speed

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1- Introduction

1.1 What are inflatable structures?

Inflatable structures, also known as tensile structures, are thin walled fabric structures that rely on the pre-tension of the fabric to gain their stiffness and carry external loads. The internal pressure applies tensile forces through the whole structure, while the external lateral loads superimpose more tensile and compressive stresses to the fabric material. The structure material cannot withstand net compressive loads as they lead to local buckling (wrinkling) in the fabric which may in turn lead to the collapse of the structure. The more the inflation pressure is, the more rigid the structure becomes. However, the fabric material has a tension limit that, if exceeded, will result in a mechanical failure.

1.2 Applications of Inflatable Structures

Inflatable structures have many advantages; they are light in weight, can be easily folded thus easily transported, easily installed or assembled, fast deployed, easily manufactured, not expensive as other structures and has a reversible behavior if subjected to a failure load as it can return to its initial position after unloading.

As a result of these advantages, inflatable structures are used in many civil, space, aeronautical and military applications. In civil applications the inflatable structures are used in air supported structures [1] such as stadium roofs, temporary buildings, and inflated tents. They can be used in aircraft escape slides and ship life rafts. Due to their light weight and ease of transportation, inflatable structures find more applications in space applications. For instance, they are used in the manufacturing of space antennas and reflectors [2-3] , as shown in Fig. 1, as well as re-entry vehicles and inflatable habitats [4-6] , as shown in Fig. 2. A review of inflatable structures applications in space is introduced by H. M. Jenkins [7].

In aeronautical applications inflatable structures are used in the manufacturing of airships, aerodynamic decelerators [8-9] and inflatable wings [10].

On the other hand, the use of inflatable structures in wind energy applications is very limited. A commercial company called Altaeros [11] introduced the Buoyant Airborne Turbine, which is shown in Fig. 3 and 4. The idea of this turbine is to install conventional small turbines at high altitudes using inflatable balloons in order to benefit from the high wind speeds. Otherwise, inflatable structures have never been used in wind energy.

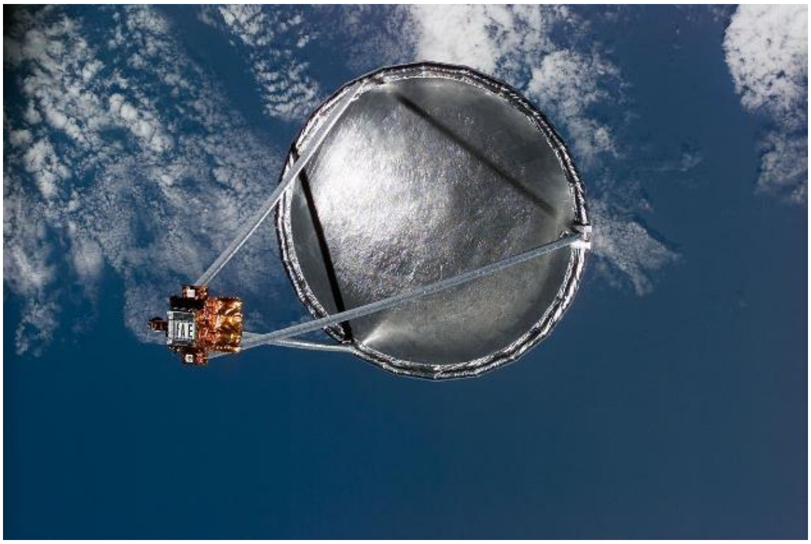

Fig. 1. Space antenna [12].

Fig. 2. Inflatable habitat [13].