ANALYZING SMA FOR SAVONIUS BLADE

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Introduction

SMA consideration :

Stress-Strain as a function of external loads and Temperature

✓ Blade design efficiency with varying wind speeds

SMA Wire Actuator :

- Improves the efficiency of active flow control; when placed on the trailing edge, the shape is dynamically altered. This reduces the drag and adjusts the airflow
- When heated by an electric current, the SMA wire contracts, causing the blade's trailing edge to deform. The deformation manipulates the airflow and controls the lift and drag forces on the blade.
- For structural control of wind turbine blades. By embedding SMA wires within the composite material of the blade, the wires can be heated to adjust the blade's stiffness and control its deflection. This mitigates the effects of wind gusts and reduces fatigue damage to the blade over time.

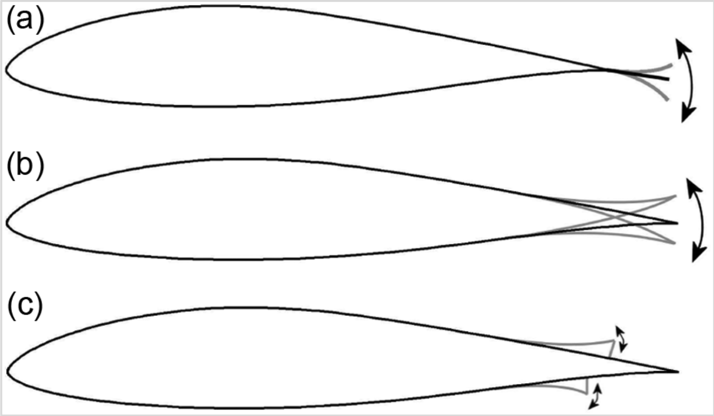


Figure 1 : *Possible implementation of a SMA actuator:*
(c) As extension to the trailing edge, (b) as trailing edge wedge
active panels [1]

Savonius Blade Designs in wind turbines

Savonius wind turbines are a type of vertical-axis wind turbine (VAWT), used for converting the force of the wind into torque on a rotating shaft. The turbine consists of a number of aerofoils.

TSR (λ)= $\dfrac{V_{rotor}}{V} = \dfrac{\omega \ x \ r}{V}$,

Vrotor = rotor tip velocity (m/s)
ω is the rotational speed (rad/s)
r is the radius of the rotor (m),
V is the wind velocity (m/s)

$$C_T = \frac{T}{T_w} = \frac{T}{0.5 x \rho x A x r x \ V\text{^}2}$$

$$C_P = \frac{P_T}{P_a} = \frac{P_T}{0.5 x \rho x A x \ V\text{^}2}$$

P_T = maximum energy output from the wind
P_a = total energy available in the wind

Maximum wind turbine power
P_T = T x ω

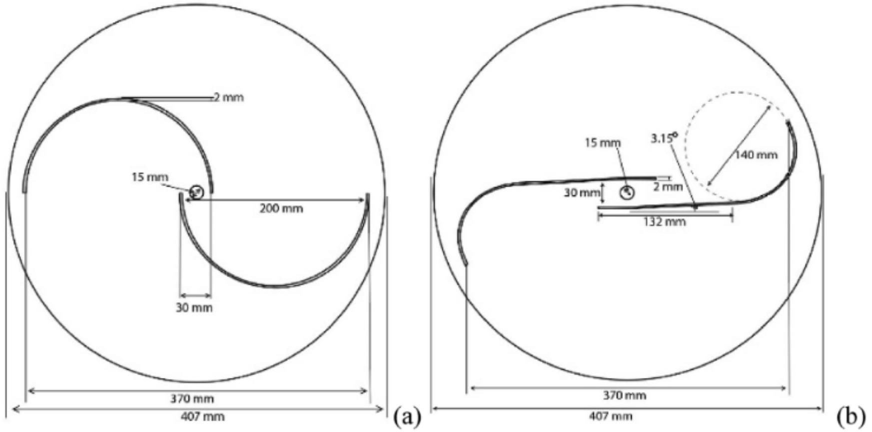


Figure 2. *Schematic 2D model of a (a) conventional semi-circular Savonius blade and a (b) modified blade model[2]*

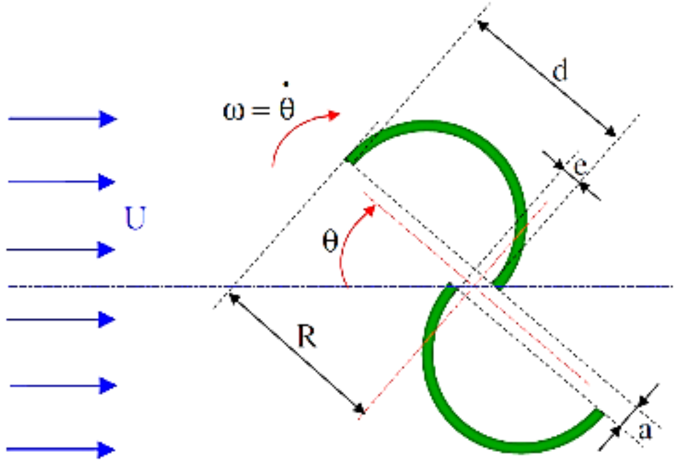


Figure 3. *Profile of Savonius[3]*

Motivation

Goal: To study the impact of SMA actuator

- Enables to withstand extreme weather conditions and stresses.
- Improves efficiency and durability.
- Enables adjustment of the pitch angle response to wind speed or direction changes
- Adjustment of pitch angle generates more power
- Controls their shape and prevents excessive bending or twisting.
- Reduced maintenance costs,
- Increase the lifespan of these renewable energy systems.

Objective

SMA embedded in the actuator of a wind turbine blade design is to creates an intelligent structure that can detect and respond to changes in wind speed, thereby enabling the turbine to operate efficiently over a broader range of wind speeds without the need for traditional actuators

- SMA embedded in the actuator here allows detecting of the deflection of blade design without actually having standard actuators
- To create blade designs and calculate the deformation with a strain of about 8
- To analyze the initial blade design and the deformed design
- To determine the pressure flow, wind speed tip ratio, dynamic pressure, and velocity contours with the CFD model

Background

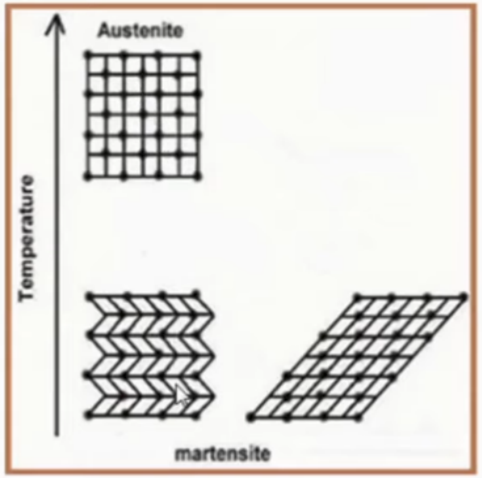
Shape Memory Alloy:

Developed in 1960

10% recoverable strain can be achieved

Recoverable under high load conditions
(High actuation densities)

Material properties:
High temperature phase = Austenite
Low temperature phase = Martensite



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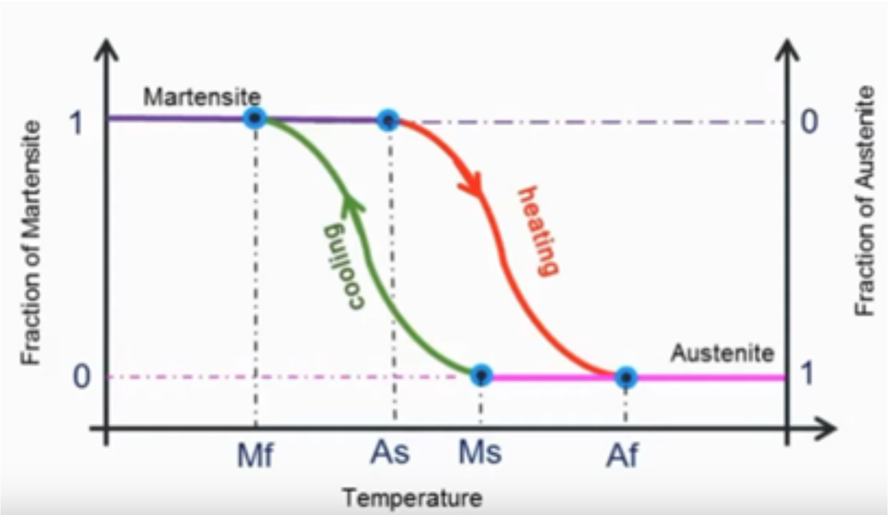

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Advantages of SMA Actuators

- Low power consumption
- Minimal space requirements
- Quiet operation
- Low cost
- Light weight
- Non-corrosive (Nickel Titanium)
- Less heat generated
- Large operating temperature

Table 1. Alloys exhibiting a shape memory effect (Shimizu and Tadaki 1987, Lexcellent 2013, Hodgsonet al 1990).

Alloy	Composition	Transformation range (°C)
Ag–Cd	44–49% Cd	−190 to −50
Au–Cd	46.5–50% Cd	30 to 100
Cu–Al–Ni	14–41.5% Al; 3–4.5% Ni	−140 to 100
Cu–Au–Zn	23–28% Au; 45–47% Zn	−190 to 40
Cu–Sn	15 at.% Sn	−120 to 30
Cu–Zn	38.5–41.5% Zn	−180 to −10
Cu–Zn–Al	3–8% Al	0 to 150
	4–6% Al; 22–28% Zn	Room temperature
In–Ti	18–23% Ti	60 to 100
Ni–Al	36–38% Al	−180 to 100
Ni–Ti	49–51% Ni	−50 to 110
Fe–Pd	30% Pd	−100
Fe–Pt	25% Pt	−130
Mn–Cu	5–35% Cu	−250 to 180
Fe–Mn–Si	32% Mn; 6% Si	−200 to 150

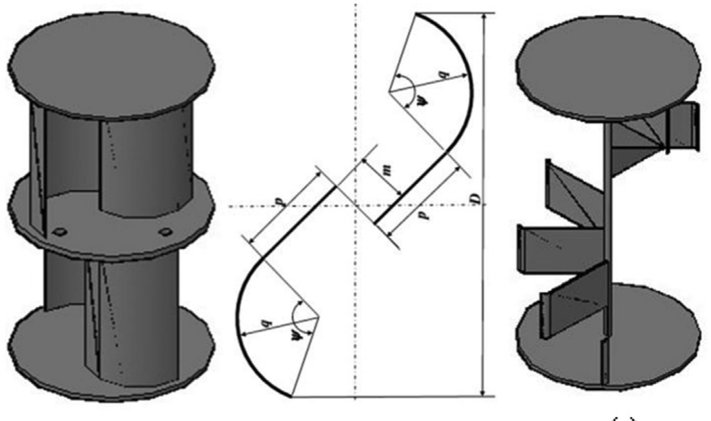
Nickel-Titanium alloys (NiTiNOL)

alloy contains 49–57% nickel,can only vary between 38% and 50% titanium by weight

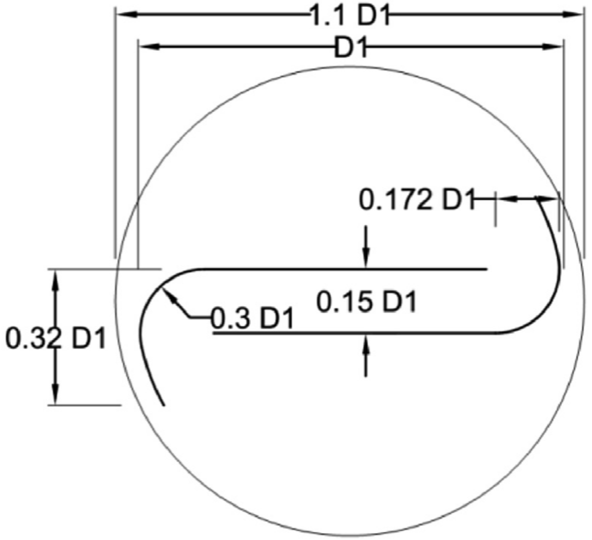
Brainstorming

- Study how SMA is embedded into Wind turbine blade designs.
- Study on actuators and their impact on SMA alloys
- Study different types of blade designs
- Analyzing which design would be the best for analyzing the impact of SMA alloys
- Choosing of Dimensions for the blade design selected (Savonius)
- 3D m of the SMA actuator in Fusion 360
- Scaling up the dimension for simulation with CFD Ansys software
- Analyzing parameters such as pressure for the blade design in Ansys

Brainstorming (Cont..)



(a) (b) (c)



Initial Proposal on the dimension

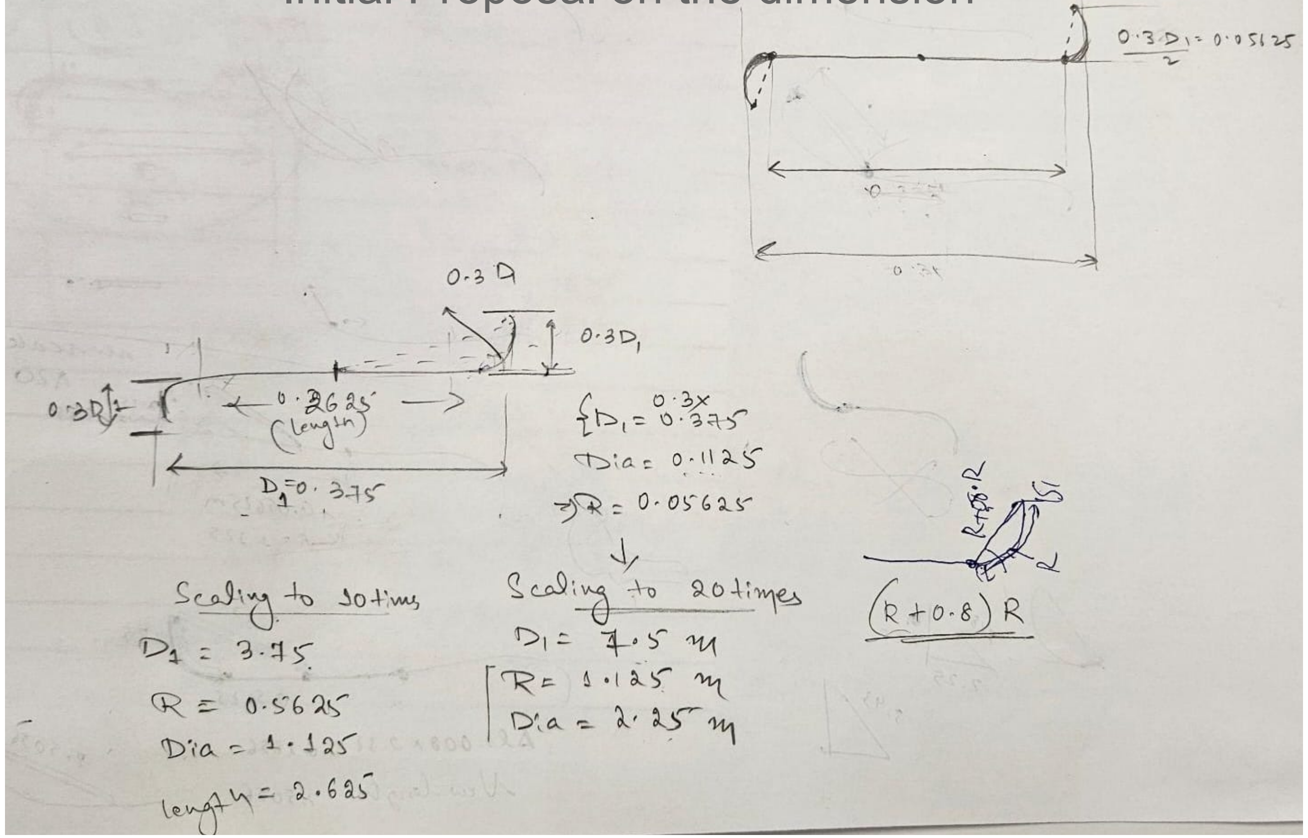


Table 1. Parameters and Values of Final Design

PARAMETERS	VALUES
Model type	Two blade conventional Savonius rotor
Height	1.25 m
Diameter	0.375 m
Area	0.456 m²
Aspect ratio	3.3
Overlap ratio	0.1
Number of stages	1
Number of Blades	2
Design of Blade	Conventional Blade

3.3 Study of the Modified Bach

The blade geometry study concerns a Modified Bach turbine as seen in figure 15. Roy and Saha showed that the Modified Bach generated the second-highest C_P for many different Reynolds numbers.[17] This blade profile also had an easily replicated geometry which is why it was chosen to be studied further. The CFD set-up established in the validation was applied when conducting the simulations on this turbine.

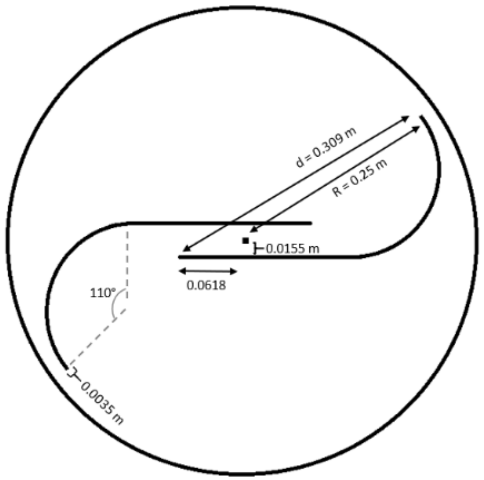


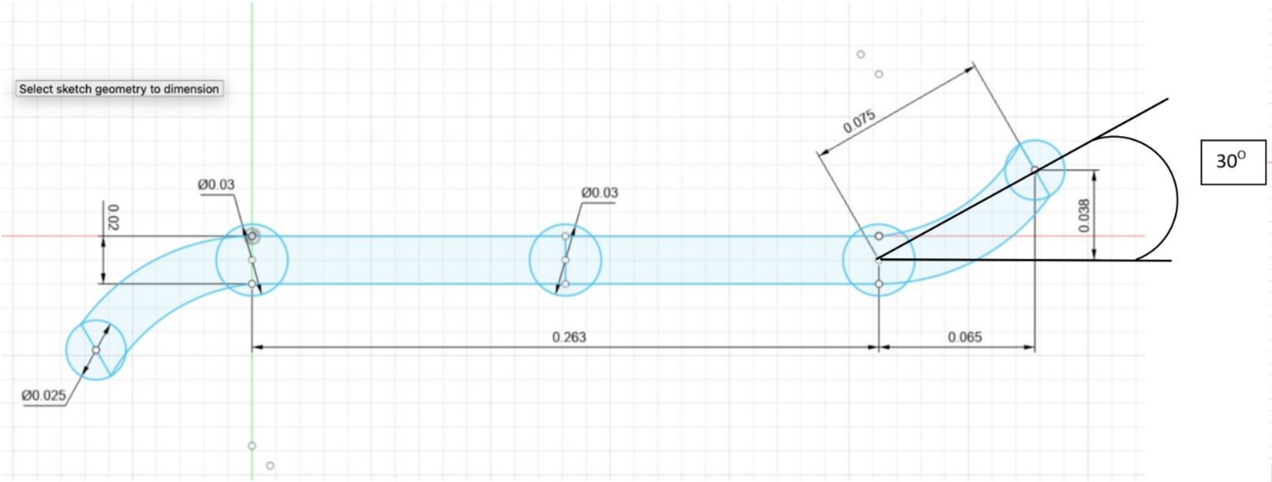
Figure 15: Modified Bach type blade.

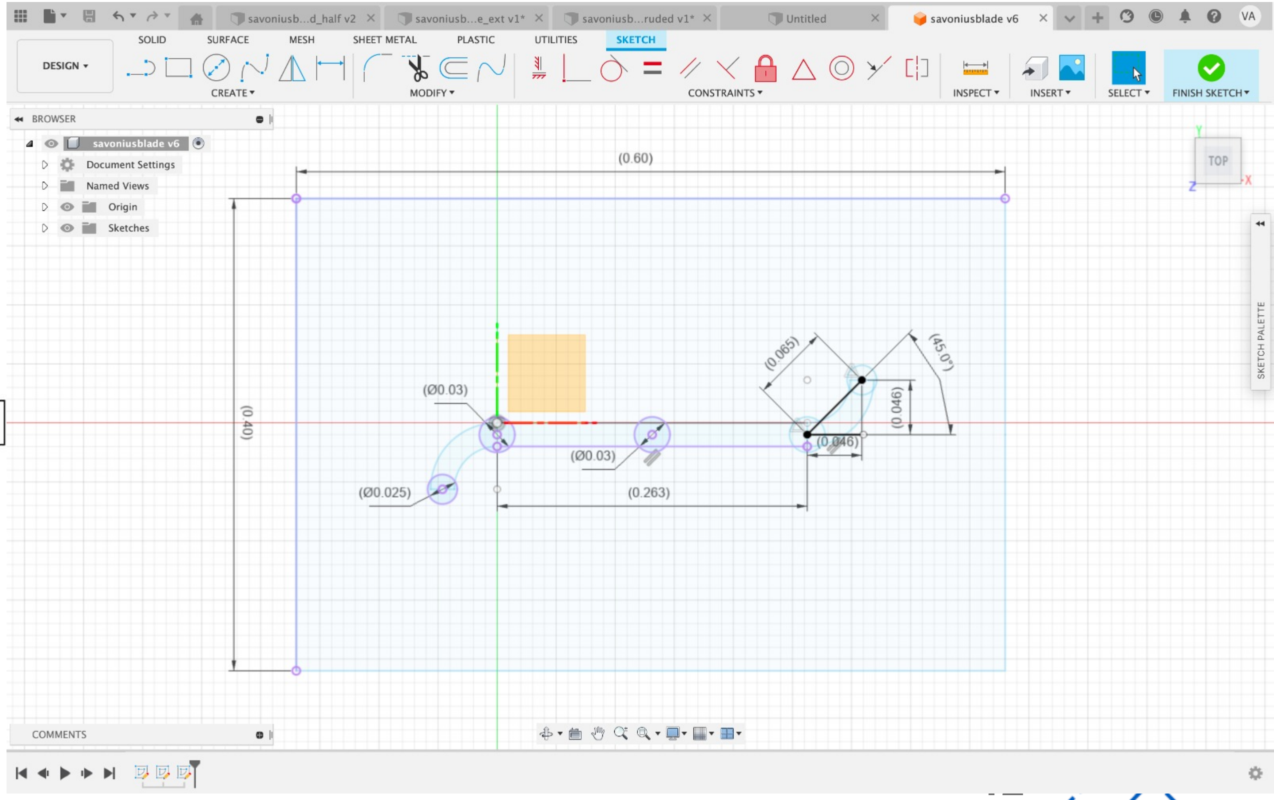
Source: Mirsad Hyder Shah and Sameer Ali Alsibiani, “DESIGN AND CONSTRUCTION OF SAVONIUS ROTOR”

Design of turbine blade

TABLE 1. Relevant dimensions for the turbine blade

Relevant dimensions	in m
L2 (Length)	0.375
Diameter	0.1125
Radius	0.0526
L1(Length)	0.2625
H (height)	0.3*Diameter





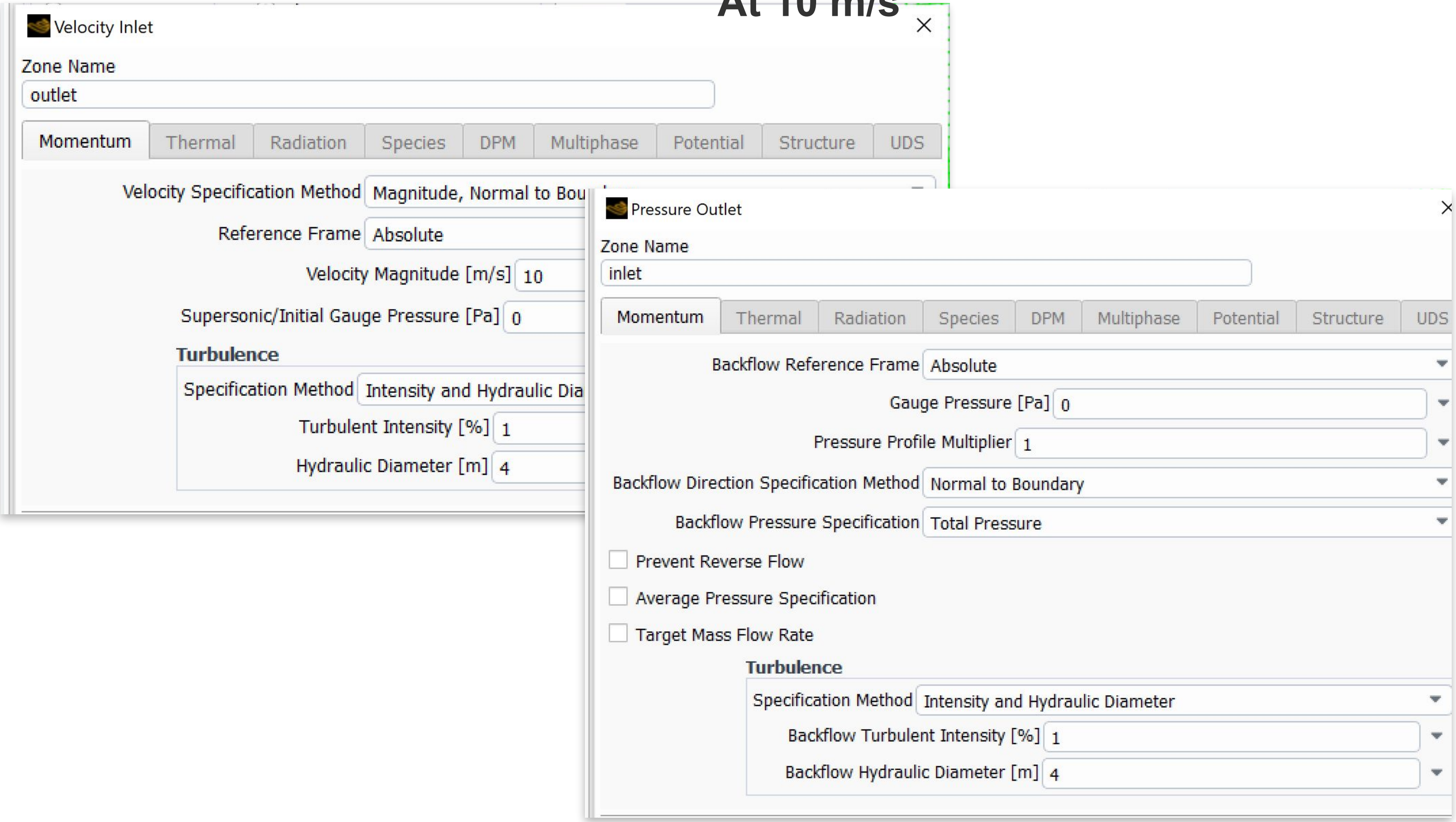
3D -Design of turbine blade

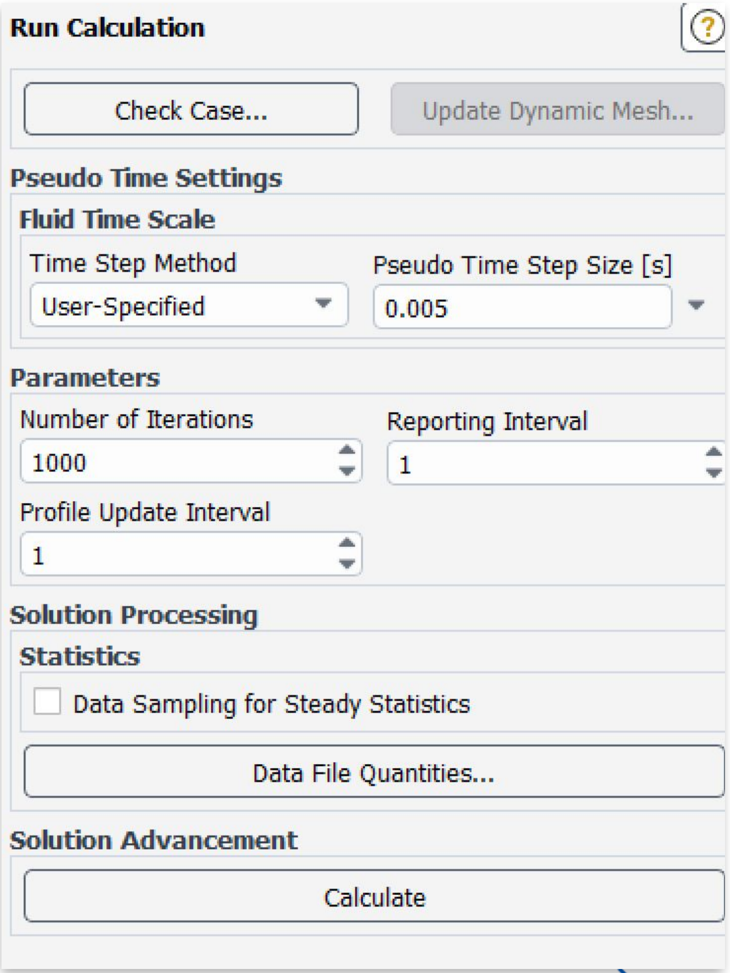
Method

- The initial design was made in solid works for the simulation of the blade design
- The actuator location was set without changing the geometry of the design
- Hinges are assumed at the start point of curvature
- The simulation was then performed in Ansys
- In the simulation, the pressure flow, wind speed tip ratio, dynamic pressure, and velocity were analyzed

Simulation Setup

At 10 m/s





Simulation

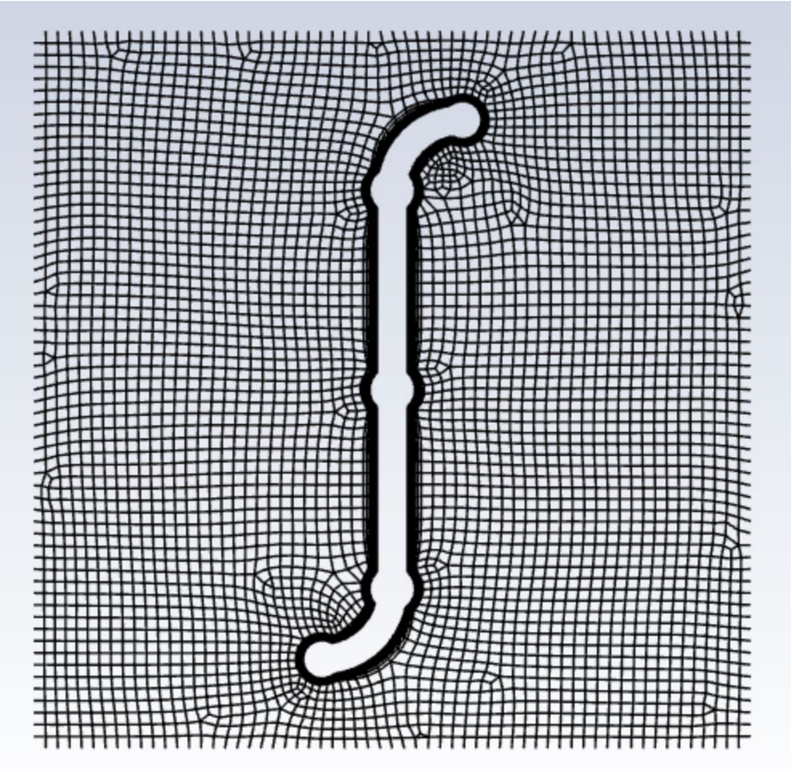


Figure x : Meshing

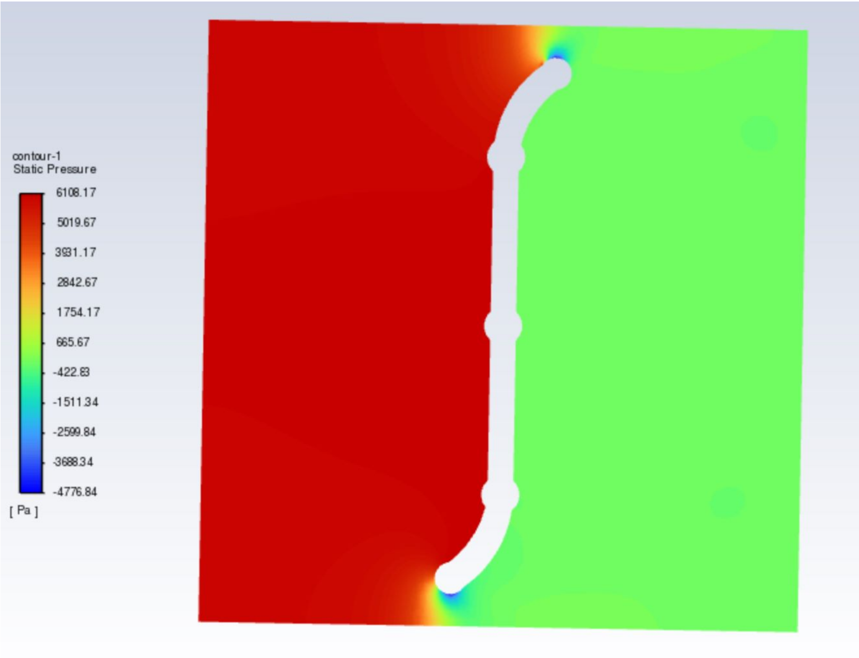


Figure x : Pressure Contours

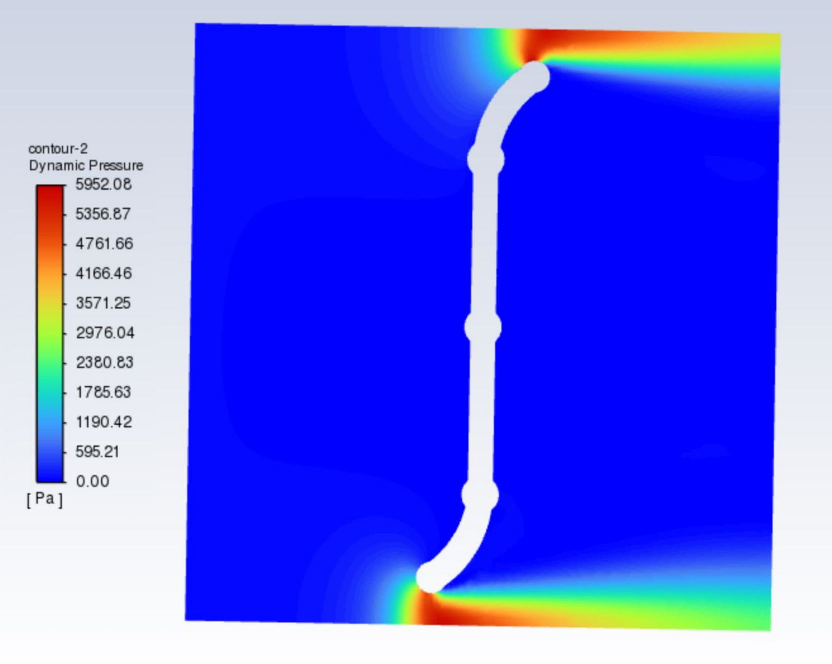
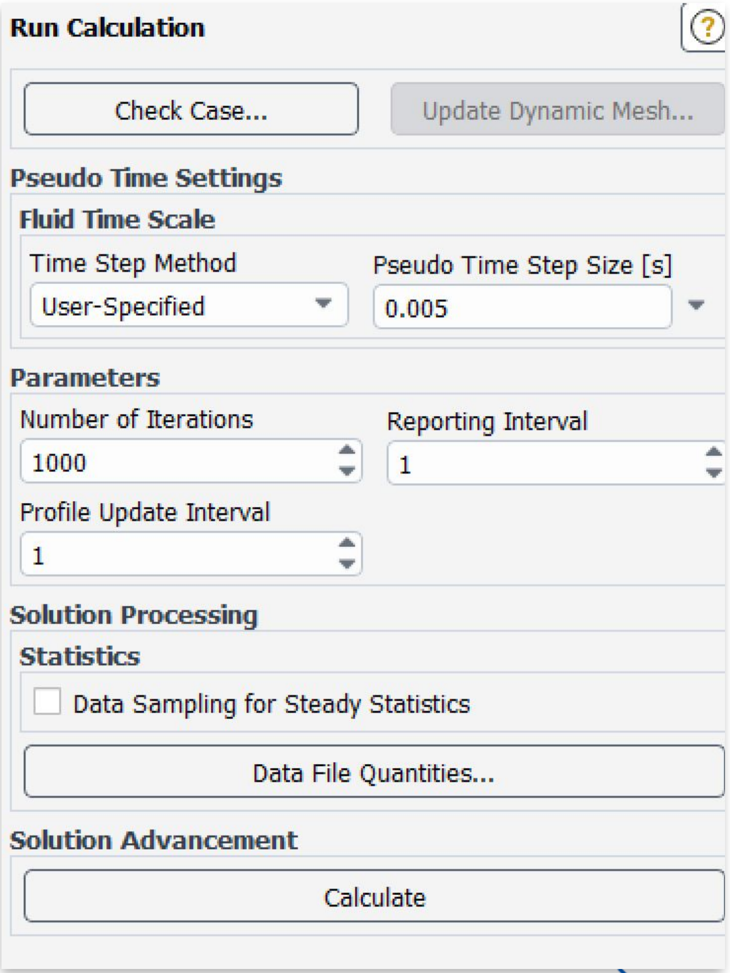


Figure x : Dynamic Pressure Contours

Simulation Setup



Simulation with 10 m/s

Results

Key Findings

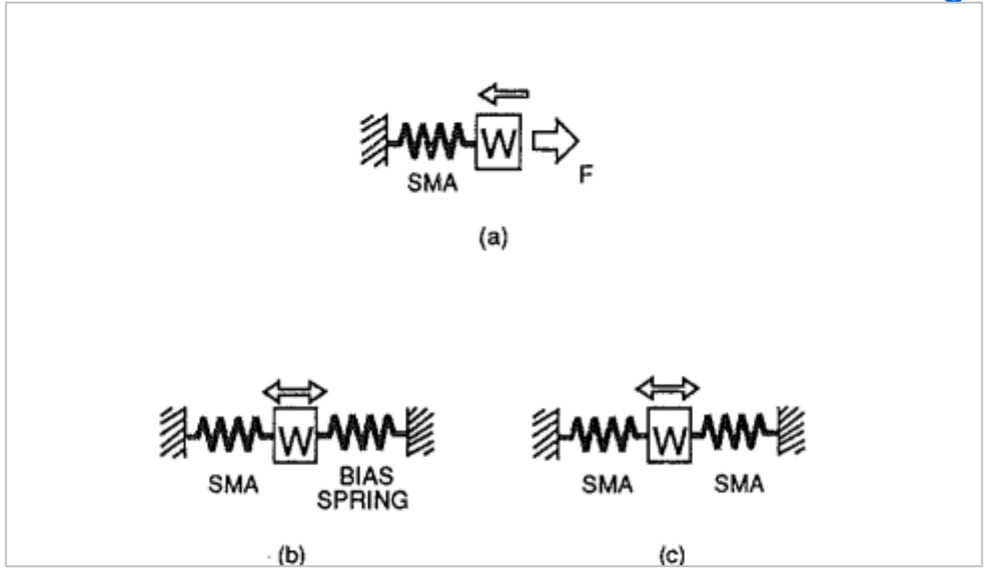
- As the flow passes through the turbine:
- The total pressure (pt)
- The temperature (Tt) decreases.
- The Dynamic pressure increases.
- The velocity increases
- The pressure drops

List all demerits

Limitations

SMA Actuators:

- ❑ The scalability of SMA actuators for large, commercial-scale turbines presents several technical challenges.
- ❑ When subjected to cyclic loading in a wind turbine blade, SMA actuators lead to fatigue failure reducing their performance and lifespan
- ❑ Exposure to moisture and temperature fluctuations can affect the performance and **reliability** of these devices over time.



a) one-directional actuator for devices
b) bias force actuator uses a spring to generate the restoring force.
c) differential SMA actuator includes an opposing SMA element used to create an active bias force and a deformation SMA element with some initially stored energy

Limitations (Cont.)

On Savonius blade design

- Implementing SMA actuators in Savonius blade designs can be complex and expensive. The actuators need to be integrated into the blade structure and connected to a control system, which can increase the overall cost and complexity of the system.
- Limited force output can limit their usefulness in applications that require high-force output, such as large-scale wind turbine designs.
- Limited stroke length limits their ability to provide the necessary movement and deformation required for optimal performance in Savonius blades.
- The harsh environmental conditions experienced by wind turbines can therefore impact the performance and reliability of SMA actuators used in Savonius blade designs.

Future Scope

Conclusion

References

1. Lara-Quintanilla, A., Hulskamp, A. W., & Bersee, H. E. (2013). A high-rate shape memory alloy actuator for aerodynamic load control on wind turbines. *Journal of Intelligent Material Systems and Structures*, *24*(15), 1834–1845. https://doi.org/10.1177/1045389x13478271

2. Pranta, M. H., Rabbi, M. S., & Roshid, M. M. (2021). A computational study on the aerodynamic performance of modified savonius wind turbine. *Results in Engineering*, *10*, 100237.

3. Marín, E. a. S., & Rodríguez, A. R. (2019). Design, assembly and experimental tests of a Savonius type wind turbine. *Scientia Et Technica*, *24*(3), 397–407. https://doi.org/10.22517/23447214.20411