Evaluation of a Wind Energy Harvesting Concept for Plug In Hybrid and Electric Vehicles

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Friday, August 28, 2015
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Acknowledgements

Prof. Kaan Inal
Christopher Kohar

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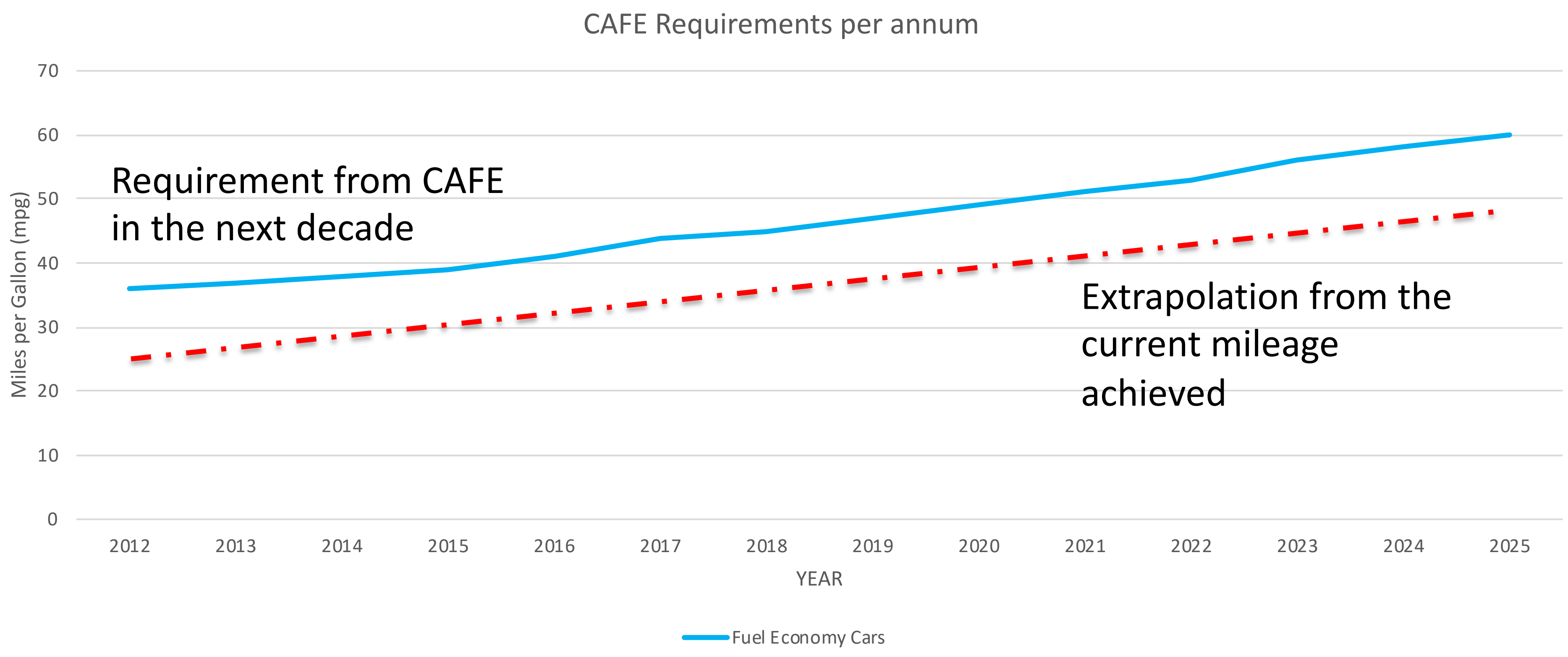
Introduction



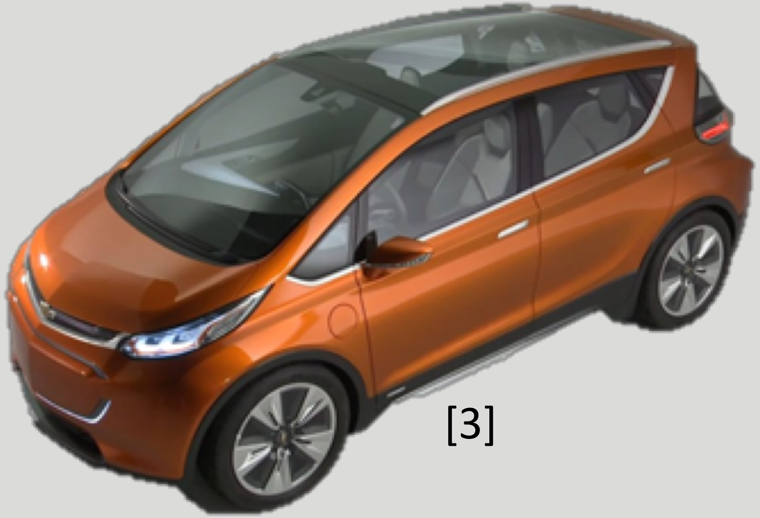
Comparing Extrapolation of the current achieved mileage, to the estimated mileage proposed by CAFE

How Car Manufacturers Control Fuel Economy

- Aerodynamics
- Weight reduction
  - » Same performance and safety for less weight
- Managing their respective powertrain system
  - » Monitoring energy consumed/generated
  - » Looking for alternative systems

GM's Alternative Powertrain Vehicles

[3]



[3]

Chevrolet Volt (2010) and Bolt (Concept shown in 2015 North American International Auto Show)

The Problem!


[3]


- Plug-in Hybrid Vehicles (PHEV); Hybrid Vehicles (HV); Electrical Vehicles (EV)
  - » Run out of electrical energy in short ranges →PHEV (30-80 km); EV (max ~300 km)
  - » Higher charging times
- **PHEV, HV, and EV cars need to have better driving ranges**

Goal Statement

- **New mechanical and/or electrical framework needed to improve the driving range for PHEV, HV, and EV cars**
  - » System needs to be self generating (Incorporate sustainable energy)
  - » Charge battery modules when vehicle in motion and/or stationary

Constraints

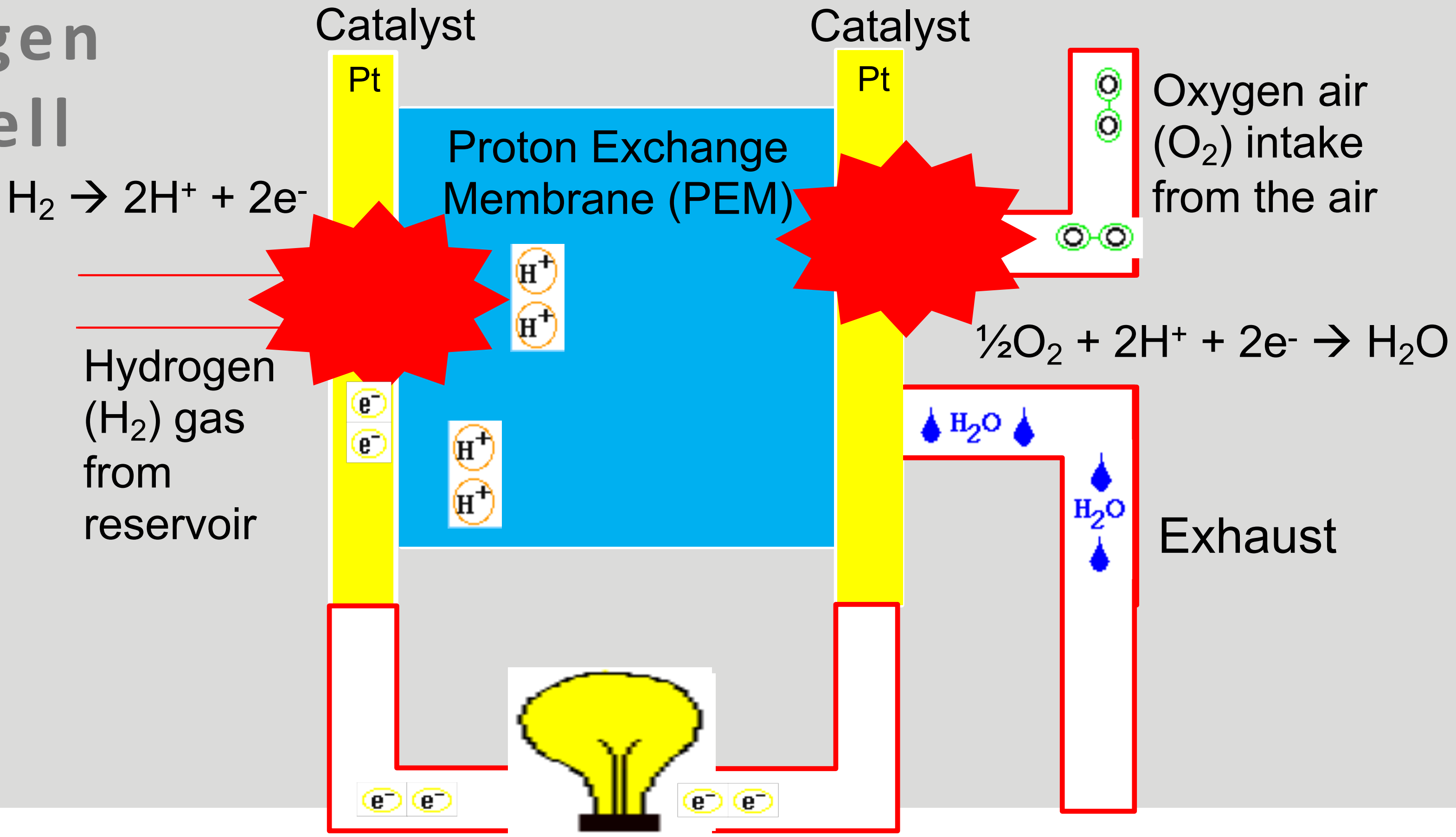
- Fit within the space limitation of the car
  - Any brand or model
- Generate enough energy and power to charge the battery
- Use sustainable energy source
- Work when automobile is stationary and/or moving

Criteria

1. Safety
   a. Risk to the passengers and operators of vehicle
2. Performance
   a. How much energy can we extract?
   b. How much weight will it add?
3. Cost
   a. Manufacturing complexity
   b. Maintenance and warranty
4. Knowledge
   a. How well understood is the performance of the system
   b. What tools do we need to develop to make system feasible

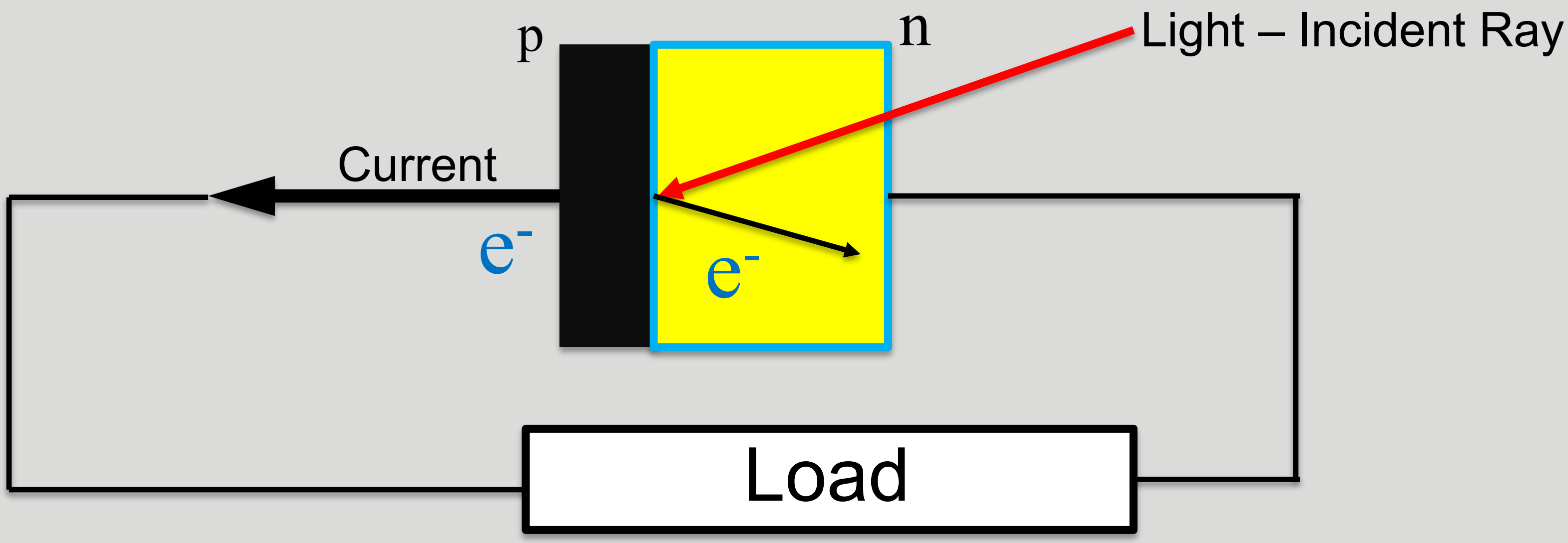
Possible Extraction Methods to Harvest Electrical Energy

Hydrogen Fuel Cell

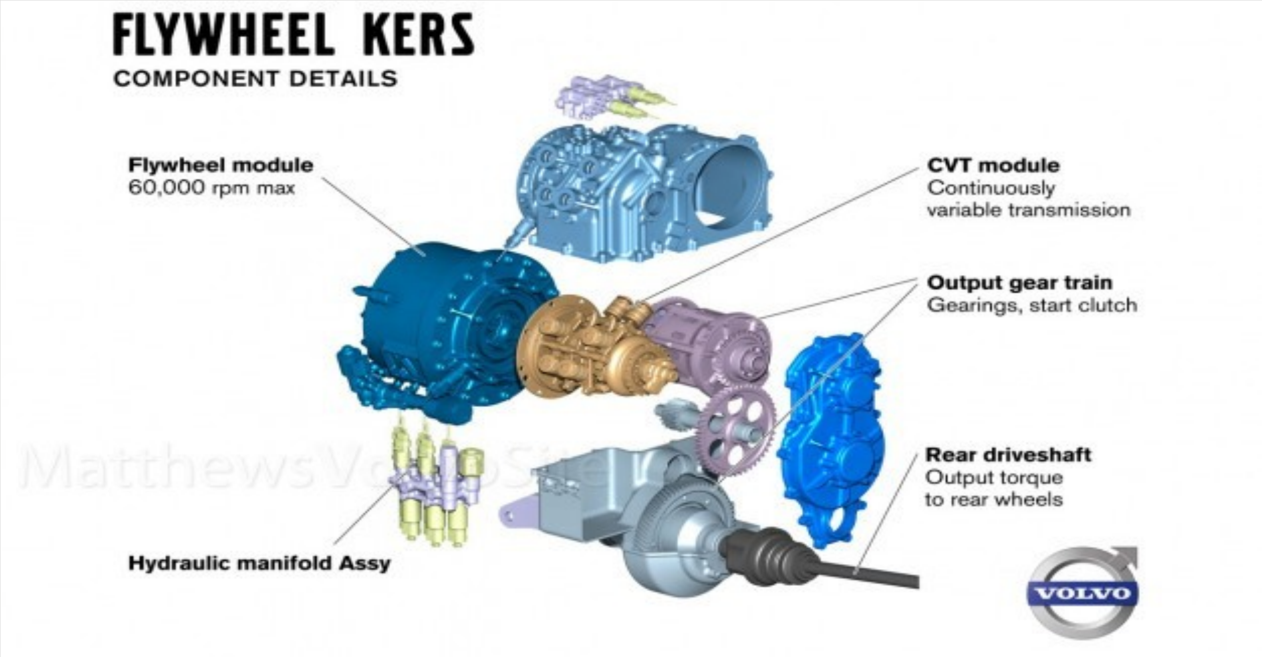


Solar "voltaic" Cells (SVC)

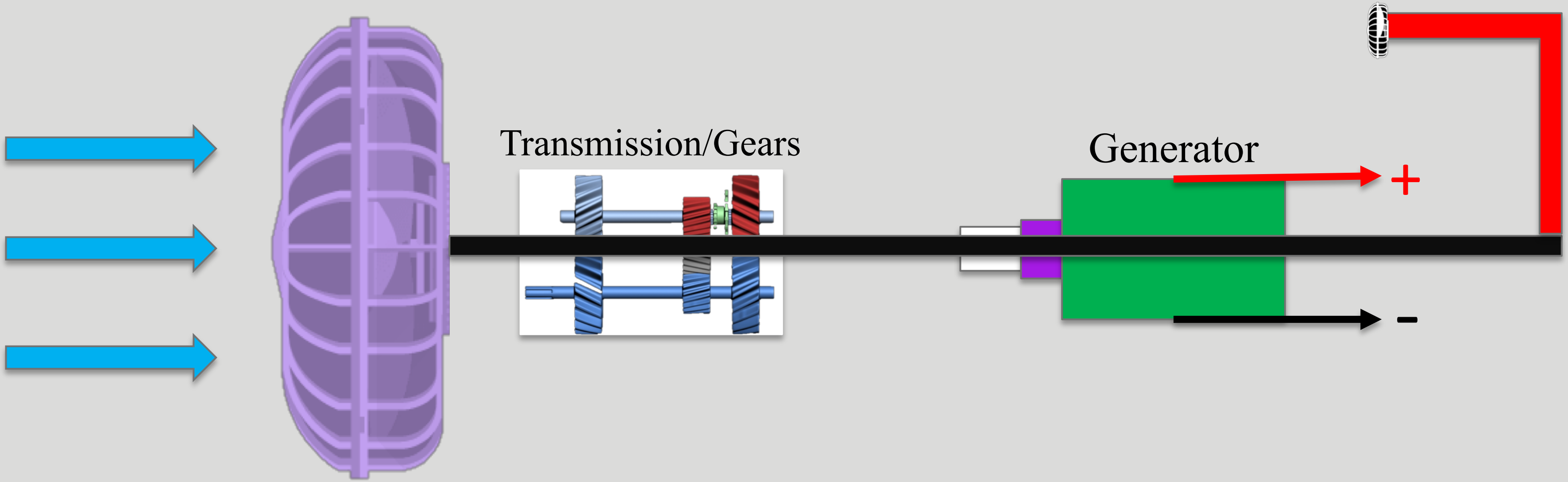
- Photoelectric Effect → light energy into electrical energy



KERS


FLYWHEEL KERS
COMPONENT DETAILS
Flywheel module
60,000 rpm max
CVT module
Continuously
variable transmission
Output gear train
Gearings, start clutch
Rear driveshaft
Output torque
to rear wheels
Hydraulic manifold Assy
VOLVO

Wind Energy



- Wind (kinetic) energy is converted to electrical energy

Solutions: →			Hydrogen Fuel Cells		Solar "Voltaic" Cells		KERS		**Wind**	
Criteria ↓	Weight	Weight (%)	#	%	#	%	#	%	**#**	**%**
Safety	10	34%	5	17%	10	34%	8	28%	**10**	**34%**
Performance	8	28%	6.5	22%	4	14%	7	24%	**6.5**	**22%**
Cost	5	17%	2.5	9%	3	10%	4	14%	**5**	**17%**
Knowledge Behind the Concept	6	21%	3	10%	4.5	16%	6	21%	**6**	**21%**
Total: →	29	100%	17	59%	21.5	74%	25	86%	**27.5**	**95%**

1 -> Lowest Concern 10 -> Highest Concern

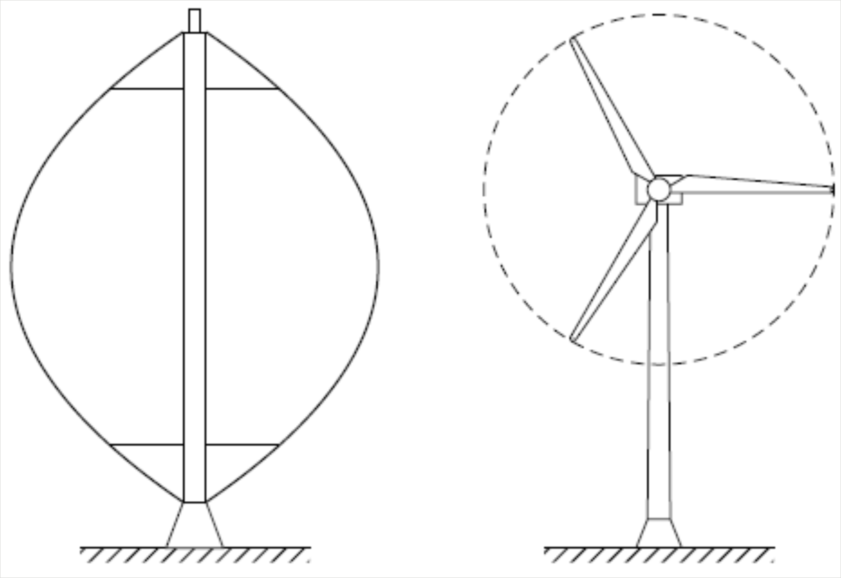
All four designs evaluated based on the criteria given above

Feasibility Study

- Current power and efficiency of current PHEV, HV, and EV
  - Chevrolet Volt: 111kW (149 bhp) @ 80 km range
  - Battery Size: 17.1 kWh
- Establish our goal for range improvement
  - + 30% range = 104km range → + 4.032 kWh of Energy Harvesting
  - + 50% range = 120km range → + 7.182 kWh of Energy Harvesting
- Determine energy harvesting capability
  - What is the maximum energy we can theoretically extract
- Determine energy harvesting efficiency
  - Mechanical losses (friction, weight increase)
  - Thermodynamic losses (entropy)
  - Aerodynamic losses (increase in drag)
- **After all of this, determine if we can ACTUALLY meet our goal of improved range**

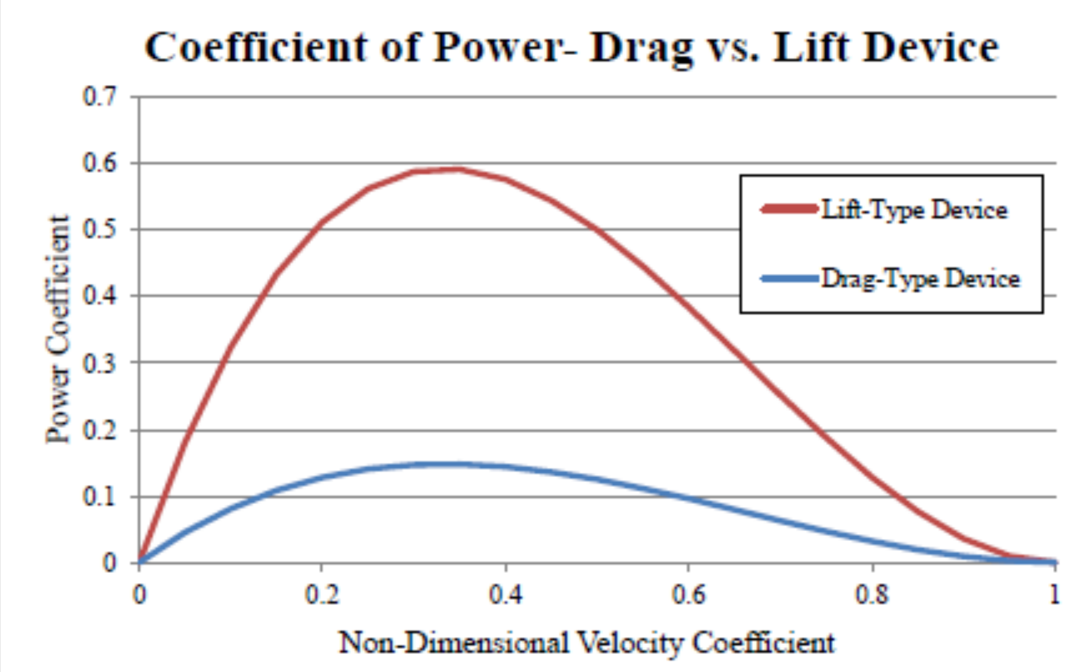
Literature Review

Vertical vs Horizontal Axis Wind Turbine

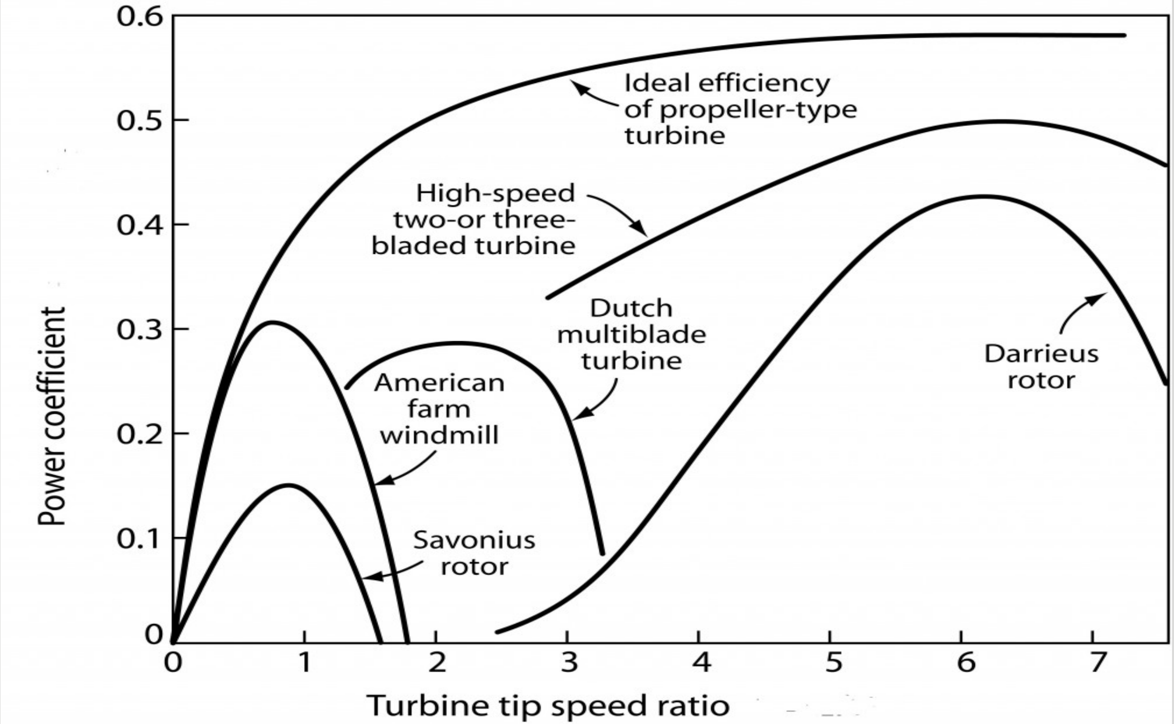


VAWT HAWT

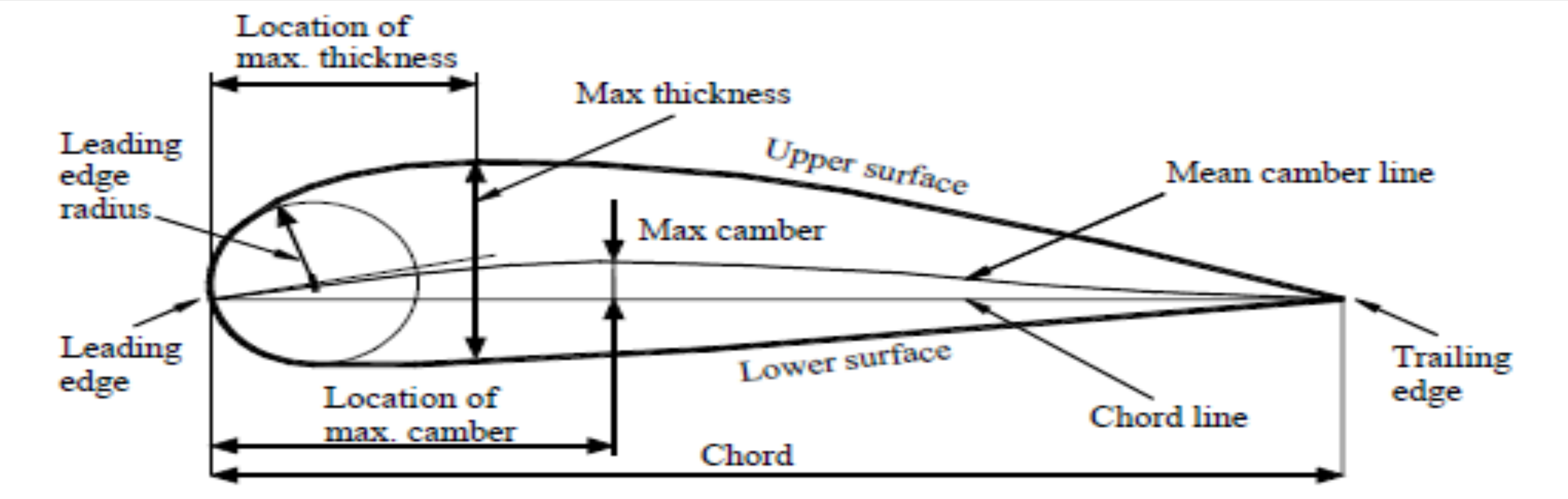
Lift vs Drag Driven turbine



Efficiency of Different Type of Turbines

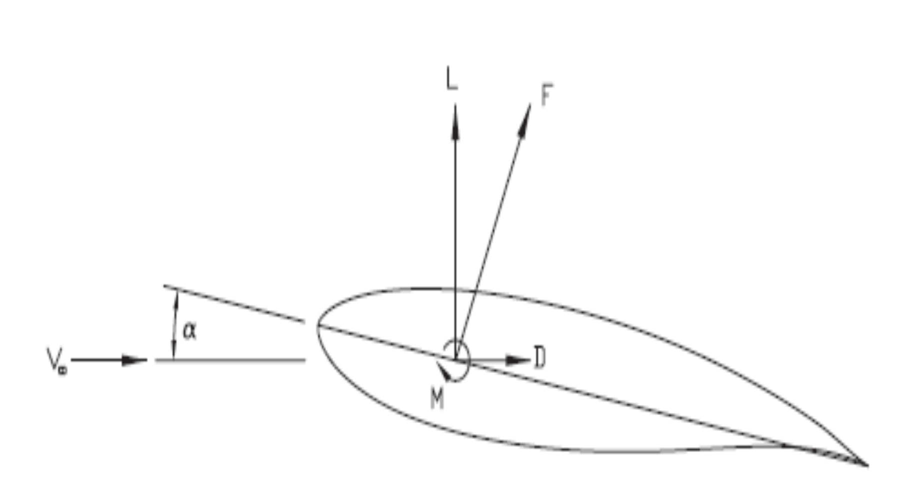


General Theory & Key Concepts



2D – Airfoil Diagram

General Theory & Key Concept



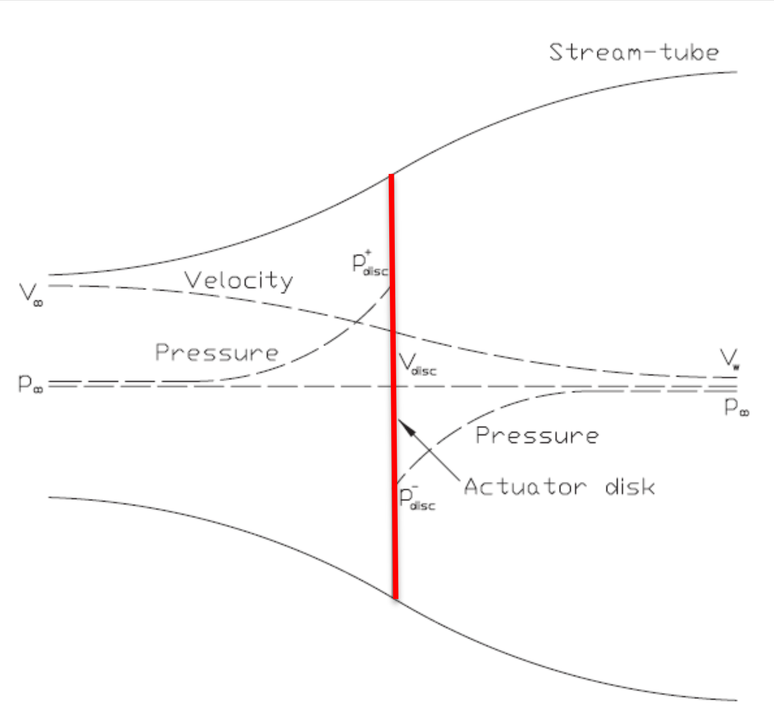
2D – Airfoil FBD, in an ideal situation with now skin drag

$$L(Lift) = \frac{1}{2} * C_l * \rho * V_\infty^2 * c$$

$$D(Drag) = \frac{1}{2} * C_d * \rho * V_\infty^2 * c$$

$$F = L * \sin(\propto) - D * \cos(\propto)$$

General Theory & Key Concepts



$$V_{disc} = V_\infty(1-a), a \text{ is axial induction}$$

$$P = 2\rho A_d V_\infty^3 a(1-a)^2,\ A_d = \pi R^2$$

$$C_p = \frac{P}{\frac{1}{2}\rho A_d V_\infty^3}$$

$$C_T = 4a(1-a)$$

$$\frac{d}{dr}C_p = 8(1-a)a'\lambda^2\left(\frac{r}{R}\right)^3 \qquad \lambda = \frac{\Omega R}{V_\infty}$$

General Theory & Key Concepts

- Airfoil used
  - » NREL and NACA are most common airfoil used to design the wind turbine

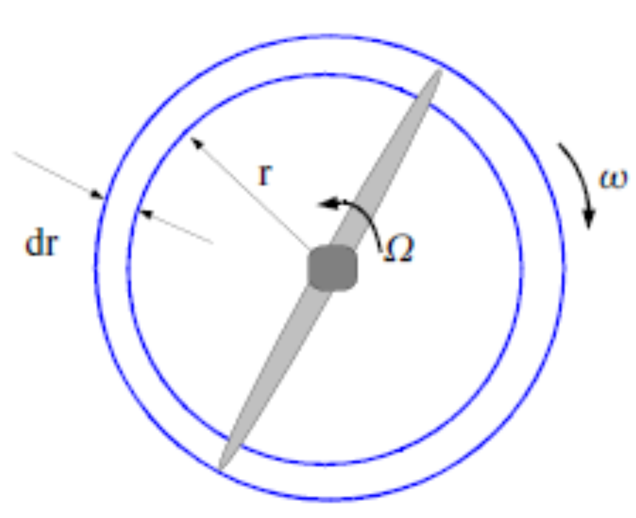
Blade Element Momentum (BEM) Theory Assumptions

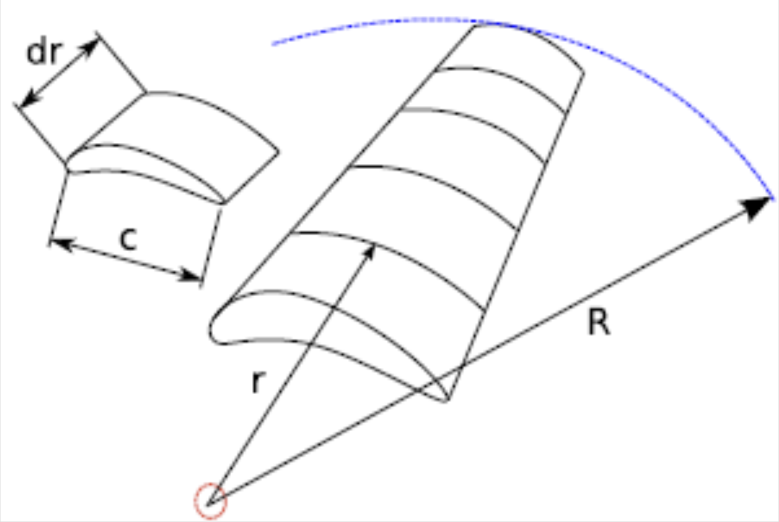
- Momentum Theory
  - » Blades operate without frictional drag
  - » A slipstream that is well defined separates the flow passing through the rotor disc from outside disc
  - » The static pressure in and out of the slipstream far ahead of and behind the rotor are equal to the undisturbed free-stream static pressure ($p1 = p3$)
  - » Thrust loading is uniform over the rotor disc
  - » No rotation is imparted to the flow by the disc
  - » Based on state flow

BEM Theory Assumptions

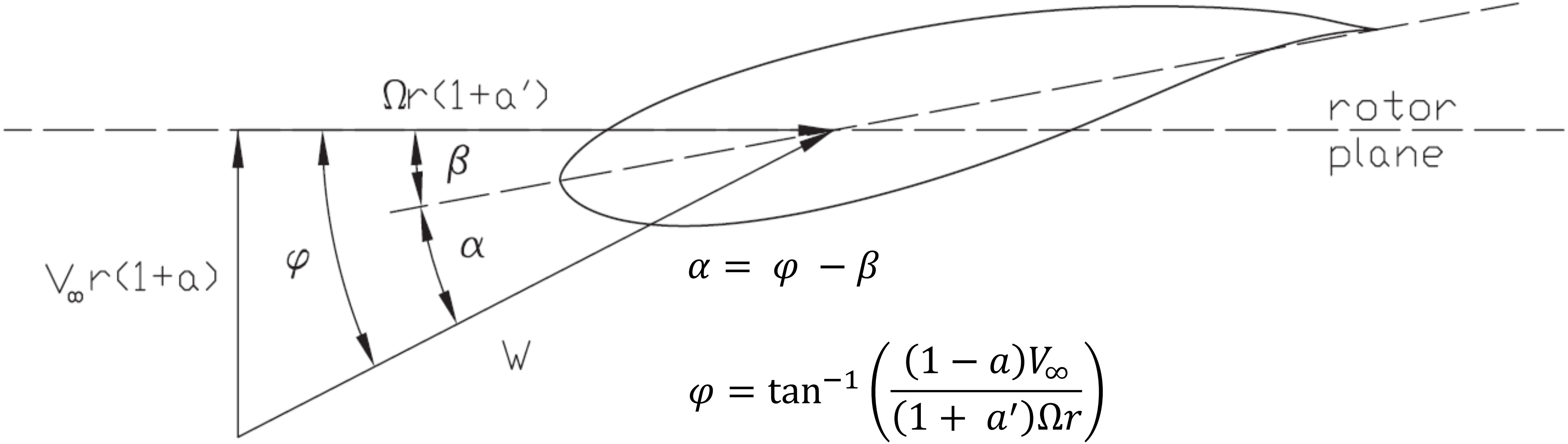
- Blade Element
  - There is no interference between successive blade elements along the blade
  - Forces acting on the blade element are solely due to the lift and drag characteristics of the sectional profile of a blade element

BEM Theory





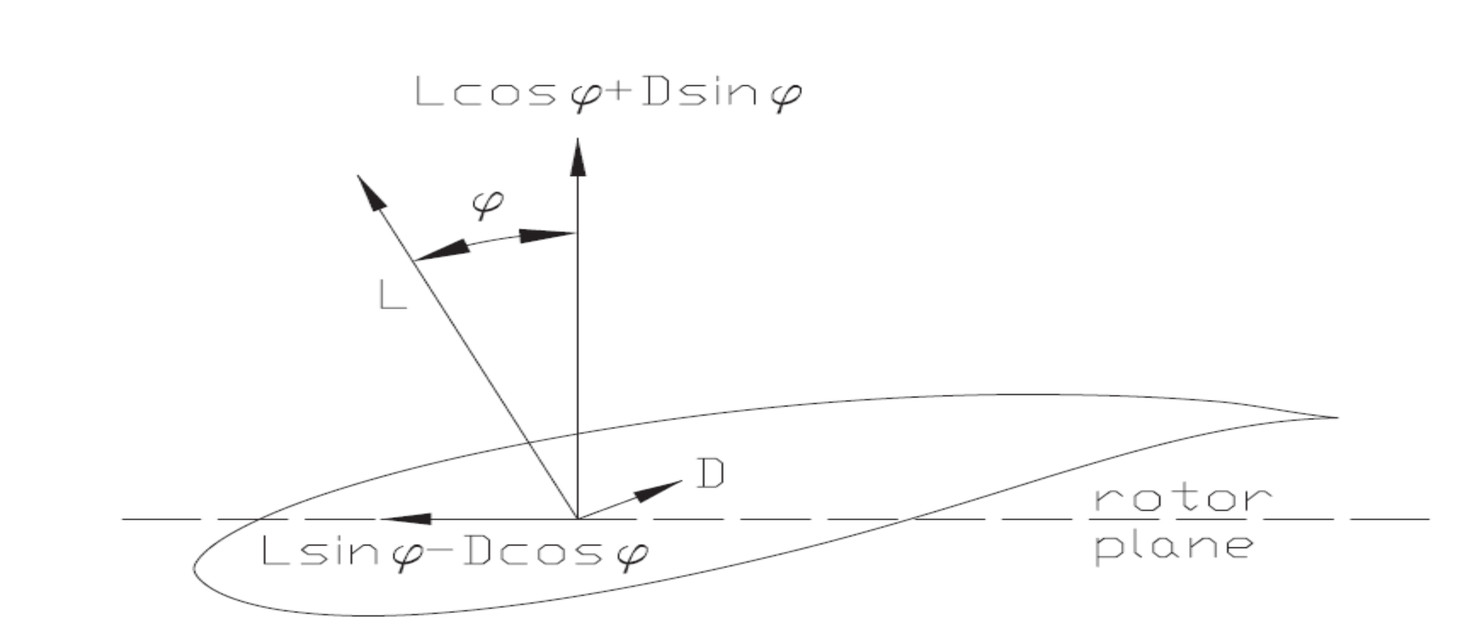
BEM – 2D Element



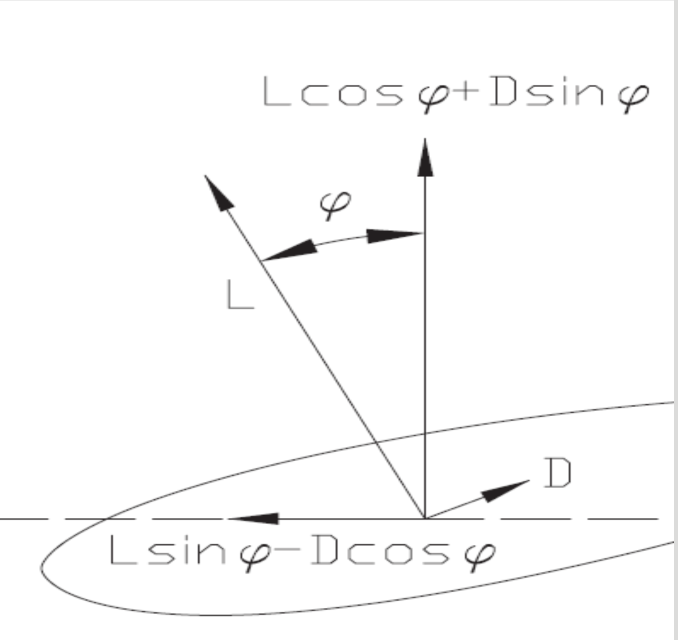
$$\alpha = \varphi - \beta$$

$$\varphi = \tan^{-1}\left(\frac{(1-a)V_\infty}{(1+ a')\Omega r}\right)$$

BEM – 2D Element



BEM – 2D Forces



$$dA = CdR$$

$$C_l = \frac{Lift}{\frac{1}{2}\rho V_\infty^2 dA}$$

$$C_D = \frac{Drag}{\frac{1}{2}\rho V_\infty^2 dA}$$

$$dL = \frac{1}{2} C_L \rho W^2 dA$$

$$dD = \frac{1}{2} C_D \rho W^2 dA$$

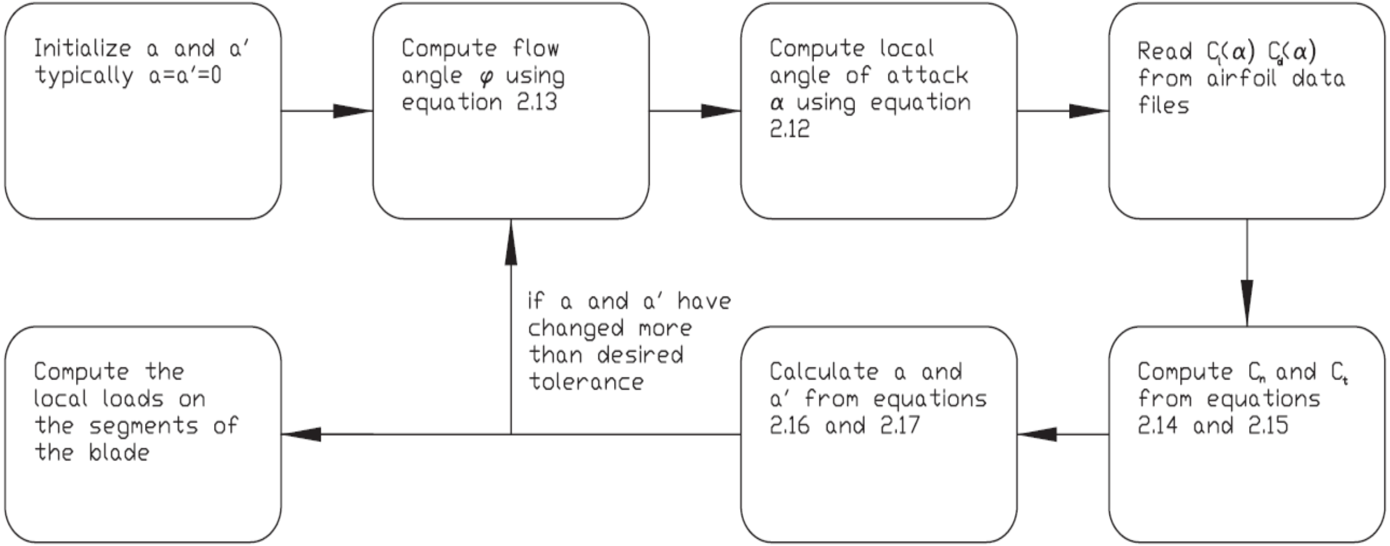
$$dF_T = dLsin(\varphi) - dDcos(\varphi)$$

$$dF_N = dLcos(\varphi) - dDsin(\varphi)$$

$$dT = rdF_t$$

$$dP = \frac{\lambda_T V_\infty}{R_T} dT$$

BEM a & a’ Iteration



$$a = \frac{1}{\frac{4sin^2\varphi}{\sigma C_n} + 1}$$

$$a' = \frac{1}{\frac{4sin\varphi cos\varphi}{\sigma C_t} - 1}$$

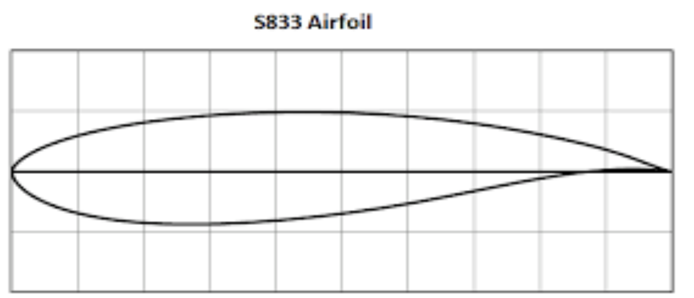
$$\sigma(r) = \frac{c(r)N}{2\pi r},$$

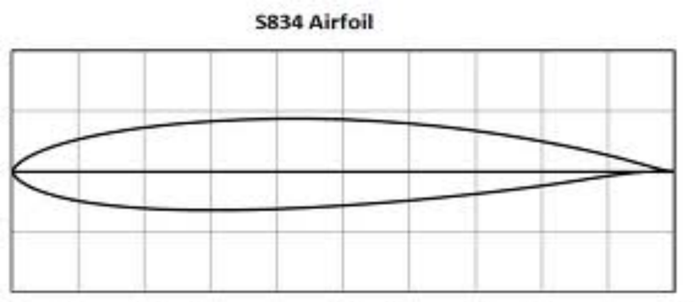
Computational Fluid Dynamics (CFD) - ANSYS

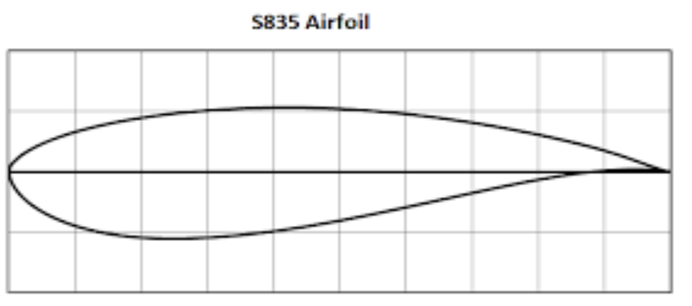
Gertz Experimental Model

- Airfoil Used: N83X series
- Number of Blades: 3
- Designed Tip Speed Ratio (TSR): 5.4
- Rotational Speed: 200 rpm
- Radius: 1.65 m
- Temperature: 300 K

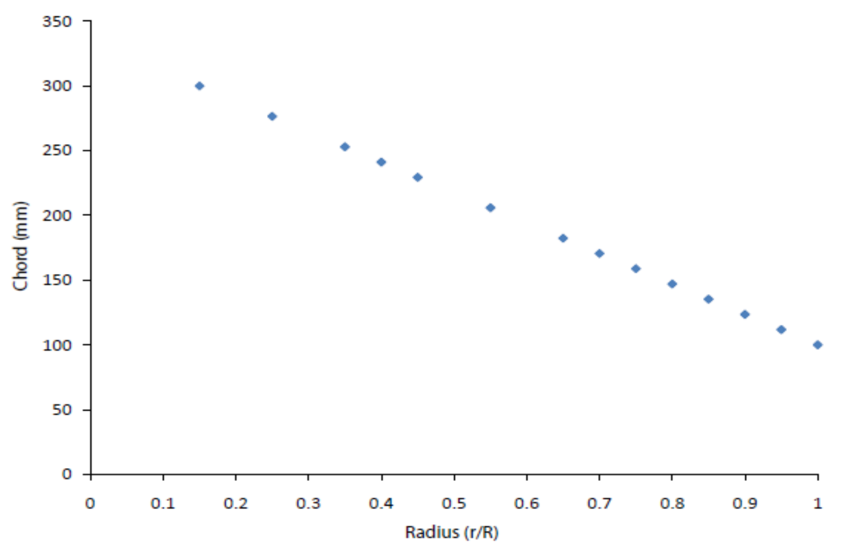
NREL S83X series

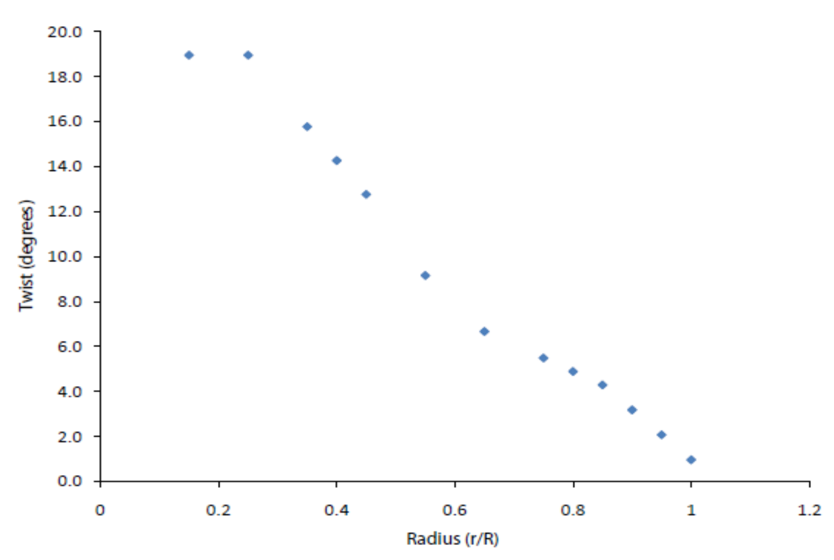






Gertz Experimental Model





Gertz chord and pitch varying throughout the blade length

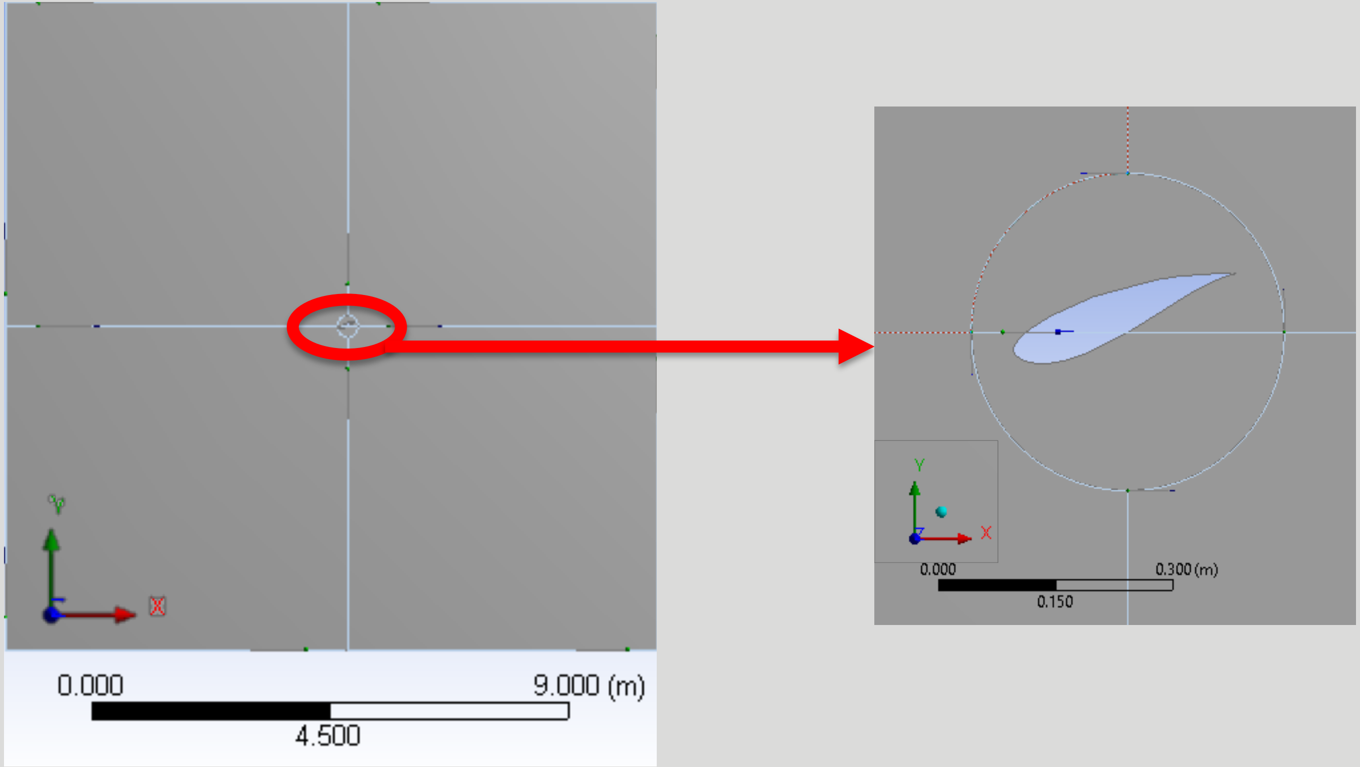
CFD Fluent Theory Model Assumption

1. Fluid is Newtonian
2. There is only one phase present
3. The problem domain throughout the analysis does not change
4. The user has to define 2 set of parameter on what type of fluid flow
   1. Fluid flow is assumed turbulent
   2. The fluid is assumed incompressible

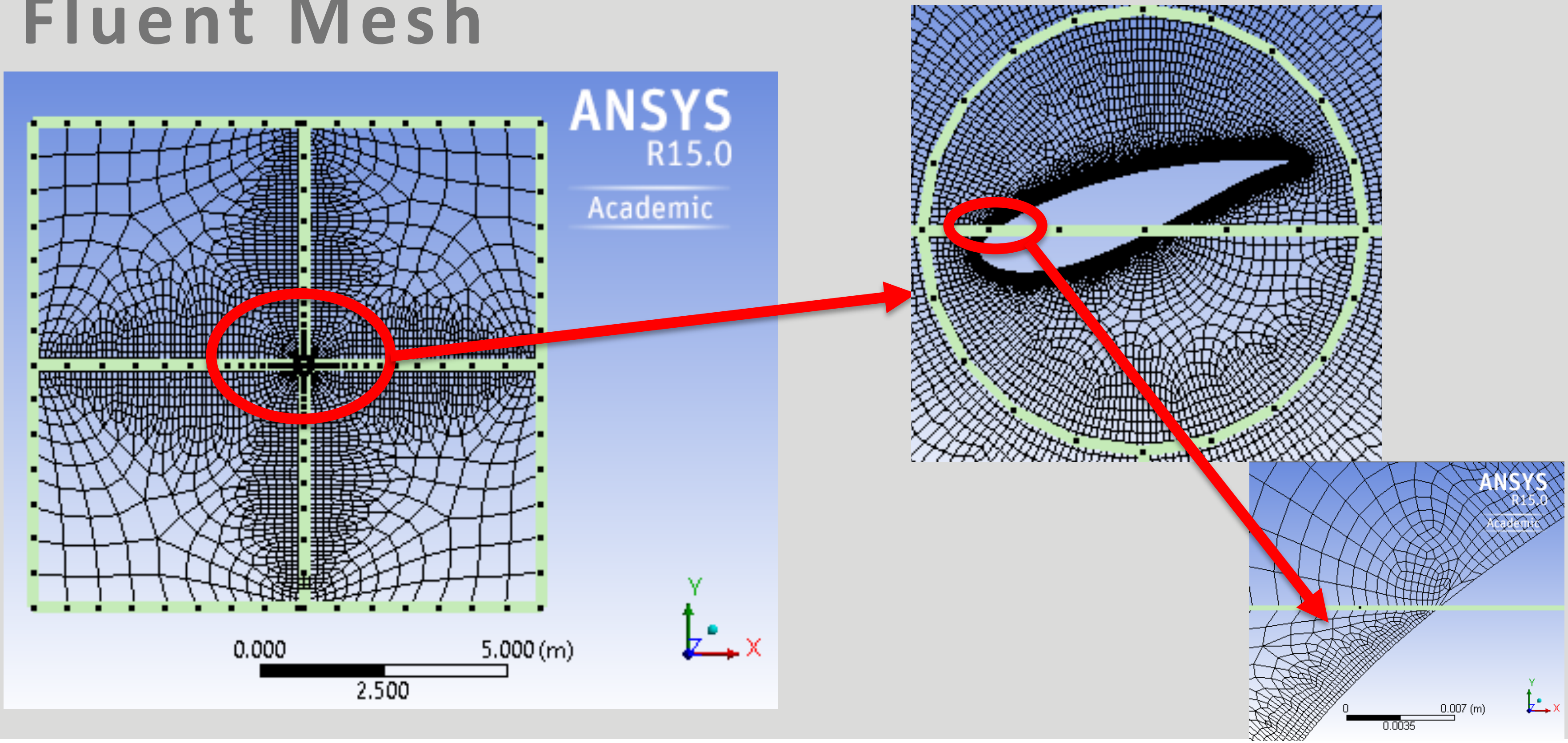
CFD Fluent Theory Model Generation

- Reynolds (Ensemble) Average
- Filtered Navier-Stokes Equation
- Hybrid RANS-LES Formulation
- Bossinesq Approach vs Reynolds Stress Transport Models

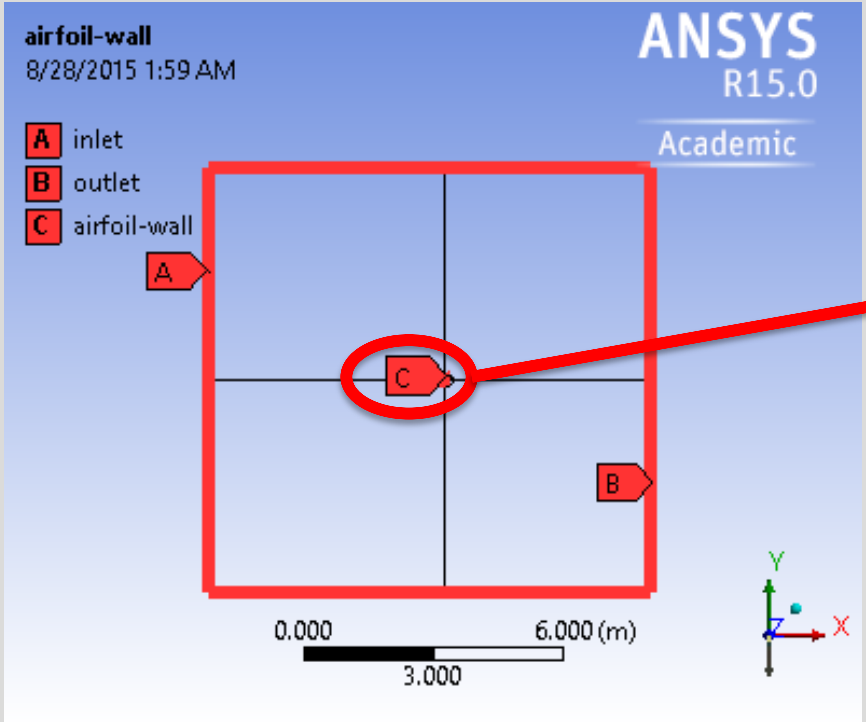
Fluent Geometry

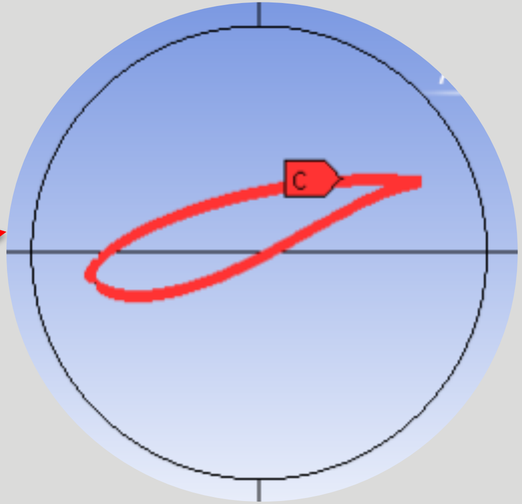


Fluent Mesh

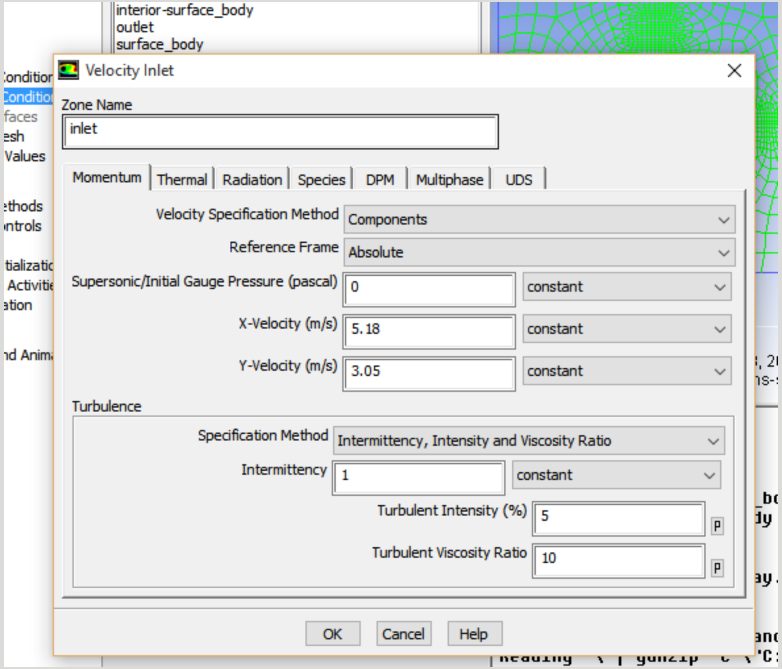

ANSYS
R15.0
Academic
0.000
5.000 (m)
2.500
Y
X
ANSYS
R15.0
Academic
0
0.007 (m)
0.0035
Y
X

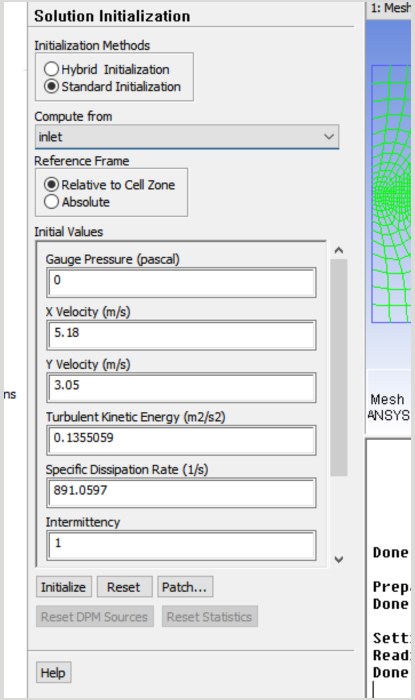
Boundary condition





Boundary Condition

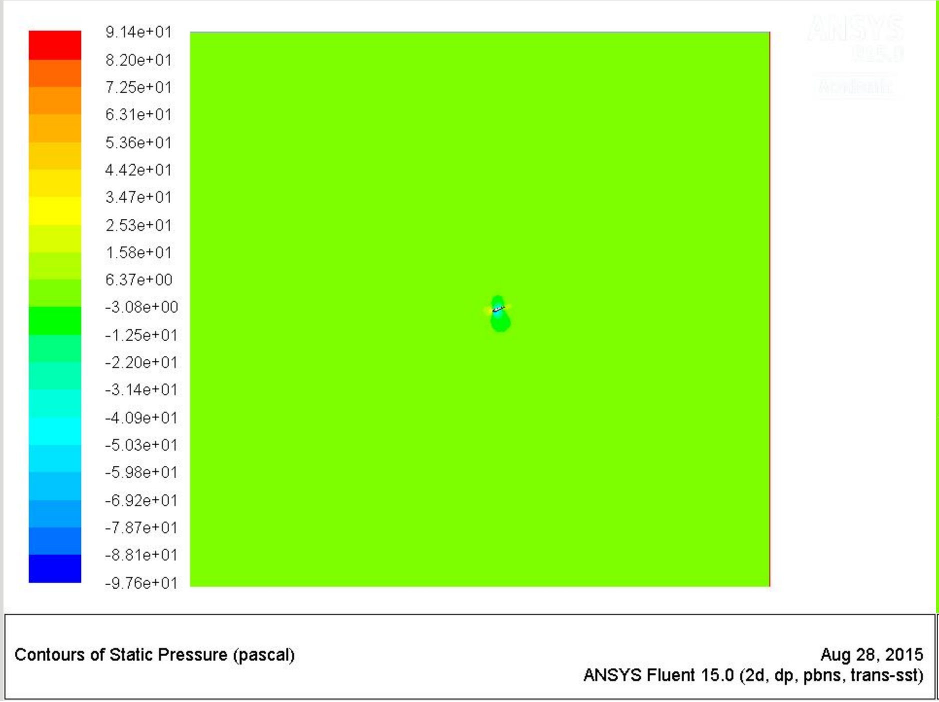


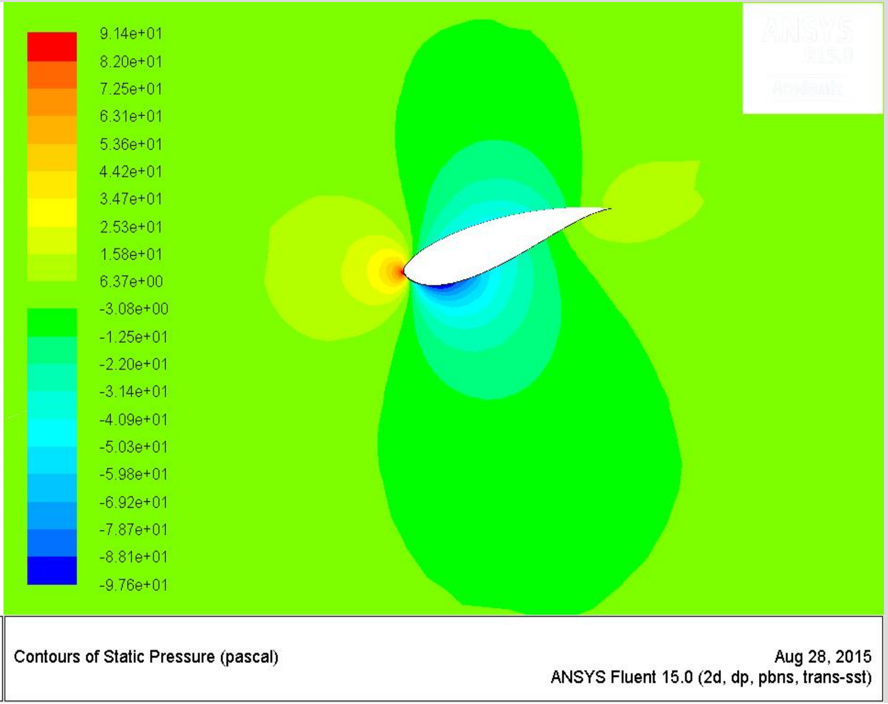


Turbulence Model

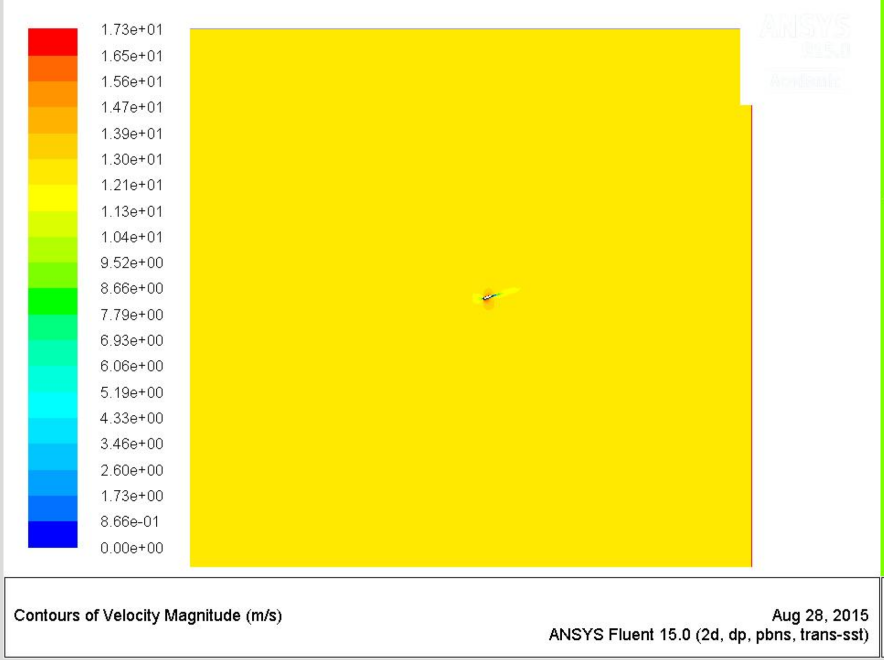
- Transitional SST
  - » Specially created to monitor airfoil flow
  - » An upgrade version of k-w SST (k-omega Shear Stress Transport) models with additional 2 transport equations
    - k-w SST model is more accurate and reliable for a wider class of flows
      - Adverse pressure gradient flows
      - Airfoils
      - Transonic shock waves

Solution


9.14e+01
8.20e+01
7.25e+01
6.31e+01
5.36e+01
4.42e+01
3.47e+01
2.53e+01
1.58e+01
6.37e+00
-3.08e+00
-1.25e+01
-2.20e+01
-3.14e+01
-4.09e+01
-5.03e+01
-5.98e+01
-6.92e+01
-7.87e+01
-8.81e+01
-9.76e+01
Contours of Static Pressure (pascal)
Aug 28, 2015
ANSYS Fluent 15.0 (2d, dp, pbns, trans-sst)


9.14e+01
8.20e+01
7.25e+01
6.31e+01
5.36e+01
4.42e+01
3.47e+01
2.53e+01
1.58e+01
6.37e+00
-3.08e+00
-1.25e+01
-2.20e+01
-3.14e+01
-4.09e+01
-5.03e+01
-5.98e+01
-6.92e+01
-7.87e+01
-8.81e+01
-9.76e+01
Contours of Static Pressure (pascal)
Aug 28, 2015
ANSYS Fluent 15.0 (2d, dp, pbns, trans-sst)

Solution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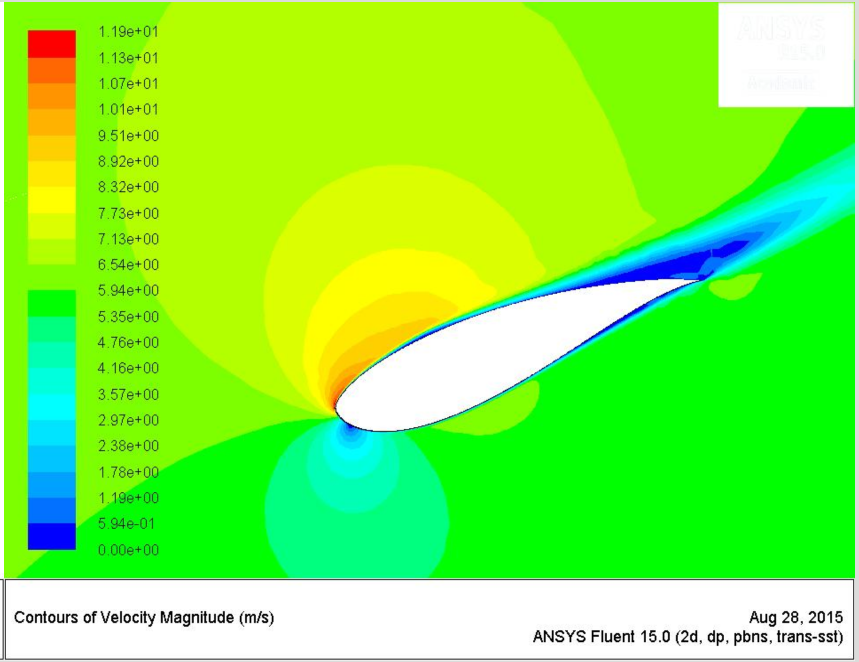
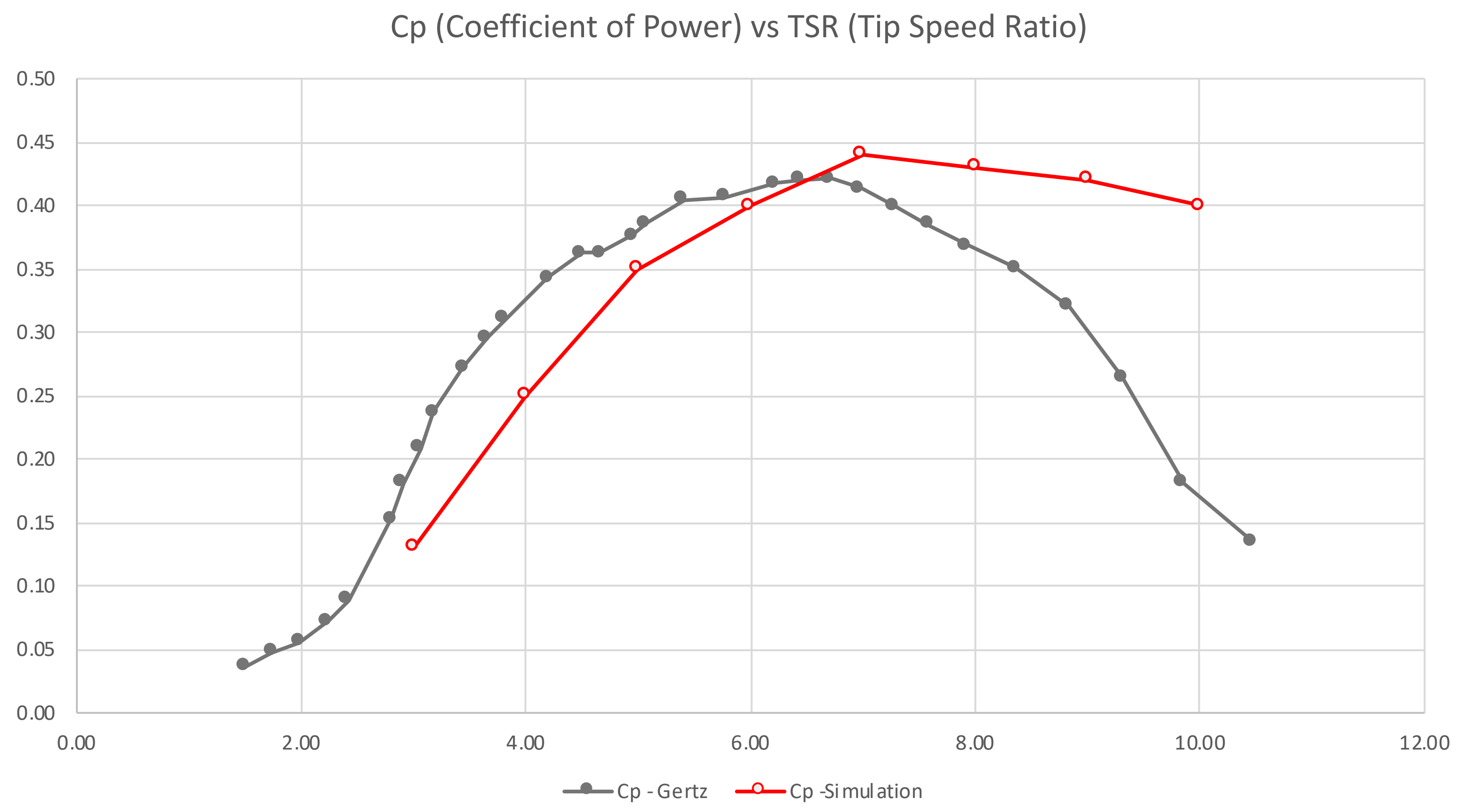
1.65e+01
1.56e+01
1.47e+01
1.39e+01
1.30e+01
1.21e+01
1.13e+01
1.04e+01
9.52e+00
8.66e+00
7.79e+00
6.93e+00
6.06e+00
5.19e+00
4.33e+00
3.46e+00
2.60e+00
1.73e+00
8.66e-01
0.00e+00
Contours of Velocity Magnitude (m/s)
Aug 28, 2015
ANSYS Fluent 15.0 (2d, dp, pbns, trans-sst)


1.19e+01
1.13e+01
1.07e+01
1.01e+01
9.51e+00
8.92e+00
8.32e+00
7.73e+00
7.13e+00
6.54e+00
5.94e+00
5.35e+00
4.76e+00
4.16e+00
3.57e+00
2.97e+00
2.38e+00
1.78e+00
1.19e+00
5.94e-01
0.00e+00
Contours of Velocity Magnitude (m/s)
Aug 28, 2015
ANSYS Fluent 15.0 (2d, dp, pbns, trans-sst)



Cp (Coefficient of Power) vs TSR (Tip Speed Ratio)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
Cp - Gertz
Cp -Simulation

Conclusion

Conclusion

- The model has less percentage error for TSR 5-8 when compared to Gertz's Model
  - » Cp of 0.42 is achievable on this airfoil
- To get better results
  - » Better and more structured mesh is needed
  - » More stricter convergence method is needed

Future Plans

Future Plans

- Adapt this model for the turbine that is going to be used in the car
- Check if the size is feasible
- Conduct Lap time simulation to see if the energy is generated

Questions?

References

- Hydrogen Fuel Cells – PEM

» [1] S. G. Chalk and J. F. Miller, “Key challenges and recent progress in batteries, fuel cells, and hydrogen storage for clean energy systems,” *J. Power Sources*, vol. 159, no. 1 SPEC. ISS., pp. 73–80, 2006.

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Visual Aids

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[2] Motertrend, “2013-tesla-model-s-front-1.” 2014.

[3] Electrovelocity, “2011-chevy-volt-front.” 2010.

[4] Newcars, “2012-Nissan-LEAF-Coupe-Hatchback-SV-4dr-Hatchback-Photo-9.” .

Thank You!

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