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# Vertical Axis Wind turbines (OELP End – Term Report)

## Objective:

Our aim is to find the potential of power generation using induced air currents attained due to moving vehicles on highways. Since the movement of vehicles of different size at different speed and different frequencies will induce different air velocity magnitudes over time, relating the transient state velocity to steady state velocity using Fourier transform will help to predict the transient power production potential with varied traffic conditions. Developing the prototype of such wind machines considering the blade design, optimal space for installation, material, durability and varied environmental conditions such as temperature changes, humidity, raining etc. is an engineering challenge. Thus, the objectives of our study are:
• To study and understand various wind turbine designs used for power production using the induced air velocity by vehicles moving on highways.
• To develop a prototype of a vertical axis wind turbine and investigate its power production potential for varied wind conditions by wind tunnel testing.
• To develop a system to measure and log transient air velocity induced by the movement of vehicles on a highway.
• Developing an algorithm to predict the transient power potential of turbines by analyzing the transient velocity variations recorded over a period.

**Materials Required:**

- Orange Planetary Gear 24 V, Dc Motor PG36M555-19.2K
- Elbow joint, T joint, and straight PVC pipe (with 1-inch diameter)
- PVC pipe (6-inch and 4-inch diameter)
- ACP sheets
- Motor Coupling hub
- L clamps
- Multi-meter
- 3D Printed objects used as connectors

- 2 Pressor Sensor for ( for measuring the speed of the vehicle)
- Ultra-sensitive Pressure Sensor for logging the pressure change due to induced wind velocity.
- Data Logger
- Anemometer for measuring the wind speed
- Pneumatic tubes

**Processes Used**

- Drilling
- Cutting
- Finishing
- 3D printing
- Welding

## Methodologies Used:

**Prototype Development**

- We developed two kind of prototypes namely savonius type(3 blades) and Darrieus type (4 blades) rotor.
- For Savonius kind we used the following specifications:

| | |
|---|---|
| Height | 30 (cm) |
| Blade Diameter(160 deg arc) | 15(cm) |
| No. of Blades | 3 |
| Rotor Diameter | 21.4(cm) |
| Base Height | 50 (cm) |

- For H Darrieus Type we used the following specifications:

| | |
|---|---|
| Height | 30(cm) |
| Blade Diameter(20 deg arc) | 15(cm) |
| No. of Blades | 4 |
| Base Height | 55(cm) |
| Rotor Diameter | 21.4(cm) |

First, we tried to find the maximum torque that will be generated due to max wind speed of 24 m/s.

- <u>Procedure for selecting the appropriate motor to handle the excessive stresses</u>

We have $r = \frac{D}{2} = 10.65$ cm (Rotor Radius)

$\rho_{air} = 1.27\ kg/m^3$

Assuming $V_{max} = 24$ m/s (Wind Speed)

Power $\propto V^3$

$P_s = \rho \times A \times V^3$

$P_s = 1.27 \times 0.3 \times 0.214 \times 24^3$

$P_s = 1127.1$ W (max Power)

$V = \frac{\omega}{r}$

$\Rightarrow \omega = \frac{24}{0.1065}$ rad/s

$\Rightarrow \omega = 225.4$ rad/s

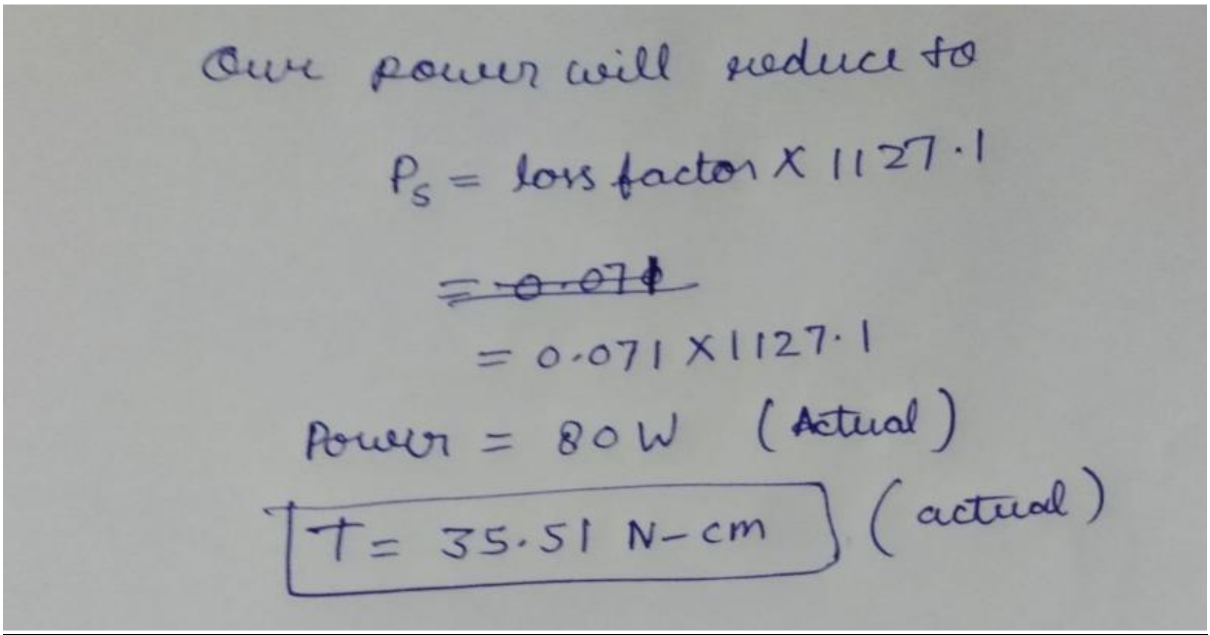
So $N = \frac{60 \times \omega}{2\pi} = 2152.411$ rpm

Torque $= (\rho \times A \times V) \times V \times r$

$= 1.27 \times 0.3 \times 0.214 \times (24)^2 \times 0.1065$

$T = 500.2$ N-cm

However due to various losses like mechanical friction, sudden impact losses and coefficient of Savonius rotor



Our power will reduce to

$$P_s = \text{loss factor} \times 1127.1$$

$$= \cancel{0.071}$$

$$= 0.071 \times 1127.1$$

$$\text{Power} = 80\,W \quad (\text{Actual})$$

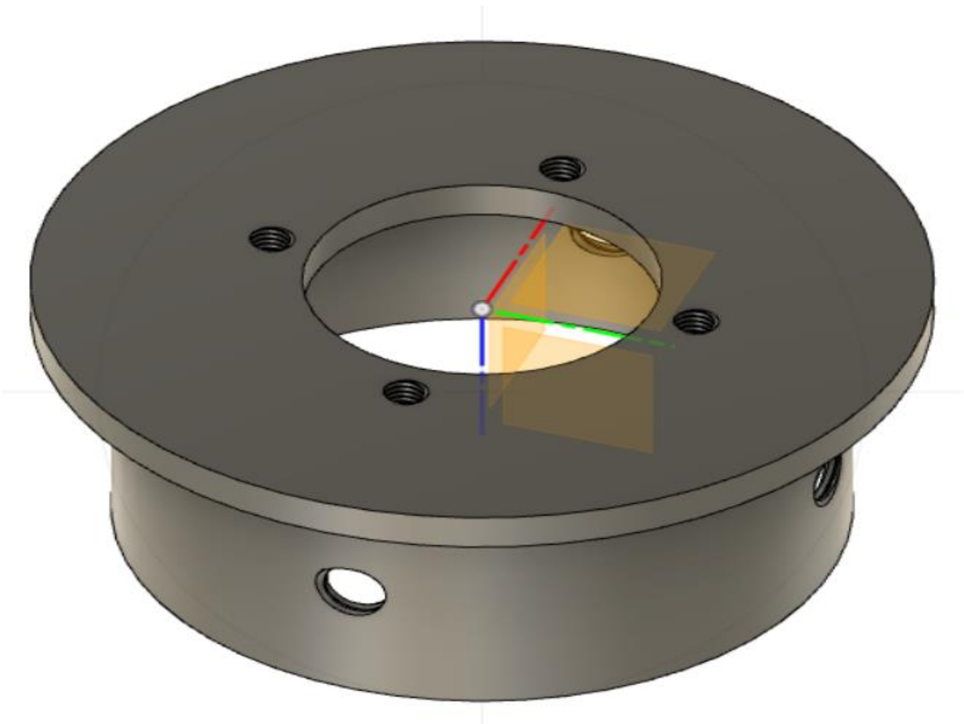
$$\boxed{T = 35.51\ N\text{-}cm} \quad (\text{actual})$$

So, we selected

Orange Planetary Gear DC Motor 24V 468 RPM 72.6 N-cm motor, for our prototype.

- **<u>Design Of the required coupling using fusion -360</u>**

In order to hold the motor near the upper end of motor we need one self-customized coupling, so we printed it using the 3D printer using the fusion -360 software. Following is the design for the coupling:



- Method for creating the creating the prototype:

1. We used PVC pipe, for making the stable base. After that for savonius rotor we three blades of 160 degree arc and darrieus rotor 4 blades with around 20 degree arc.
2. We used the L clamps, and nuts and bolts to fasten the blades and L clamps.
3. We attached the shaft coupling to the motor, then we connected it to L clamps with blades.
4. In order to hold the motor inside pipe we used the 3D printed design with M5 and M3 threads.
5. With the help of reducers and various pipe sizes we attached the motor to base.
6. Now we can test our prototype with the help of multi-meter in windy conditons. Get the voltage data, which varies with time. By this method we can find the average and maximum voltage produced during the testing.
7. First, we test our prototypes before some fan, or in quite windy conditions. After that we can take them to highways and try to do the noise reduction, vibration reduction and thus making it smoother.
8. We will show the working of prototype in our presentation.

## Analytical Models for predicting the induced wind velocity due to vehicle

We have got a method by which we can predict the induced wind speed and pressure difference, given the details of the locations of the prototype, speed and dimensions of the incoming vehicle.

**Method 1 for finding the velocity**

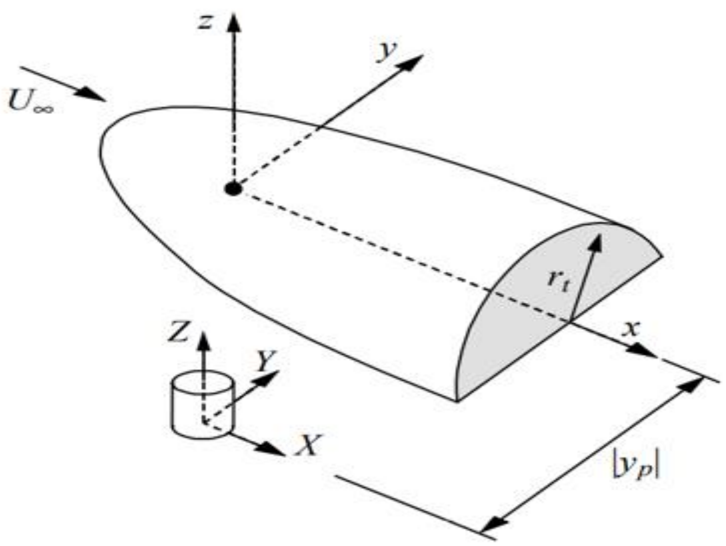


Fig 1: Model of the flow around a vehicle body moving at speed U (∞): (x; y; z) vehicle fixed reference system. (X; Y; Z) center of prototype fixed reference frame. $r_t$: radius of the vehicle cross-section. |yp|: distance of vehicle path to prototype location.

In this model we can assume, no effect of prototype on the surroundings, so velocity is axisymmetric around the x axis. Also, we assume, a velocity potential Φ, is present, from which air speed components can be derived

So, $u = \Phi_x$

$w = \Phi_r$

where u = longitudinal component of velocity

w = radial component of velocity

Also

$$r = \sqrt{(z^2 + y^2)}$$

Standard solution for the potential flow around the cylinder using Laplace equation, and appropriate boundary conditions we can get,

$$w = U_\infty * \left[\frac{{r_t}^2 * (0.25) * r}{(r^2 + x^2)^{3/2}}\right]$$

From the (X,Y,Z) coordinate system,

Using

$X = x - U_\infty t$;

$Y = y + y_p$;

$Z = z$;

We get final speed as $V_p = \sqrt{(U^2 + W^2)}$

$$V_p = \frac{U_\infty * r_t^2}{4*(r^2+(X+U_\infty t)^2)}$$

Using the Bernoulli expression and assuming that our overall prototype height is much bigger than the radius of the rotor. We get

Coefficient of pressure, as $C_p = (\frac{V_p}{U_\infty})^2 - \frac{2*\emptyset_t}{U_\infty^2}$

In order to get these values near the prototype, we put X = 0 and r = $y_p$, in overall velocity equation. $r_p$ = radius of the prototype;

$$V_p = \frac{U_\infty r_t^2}{4 * (y_p^2 + U_\infty^2 * t^2)}$$

The pressure coefficient at stagnation point then becomes,

$$C_p(P_s) = \frac{\left[ R_t^4/16 - 2 * R_p * T * R_t^2 \right]}{(1 + T^2)^2}$$

Where $T = \frac{t * U_\infty}{y_p}$, $R_p = \frac{r_p}{y_p}$ and $R_t = \frac{r_t}{y_p}$, are the dimensionless parameters in the problem.

Following is the MATLAB code for predicting the induced wind Velocity due to large, medium and small sized vehicles:

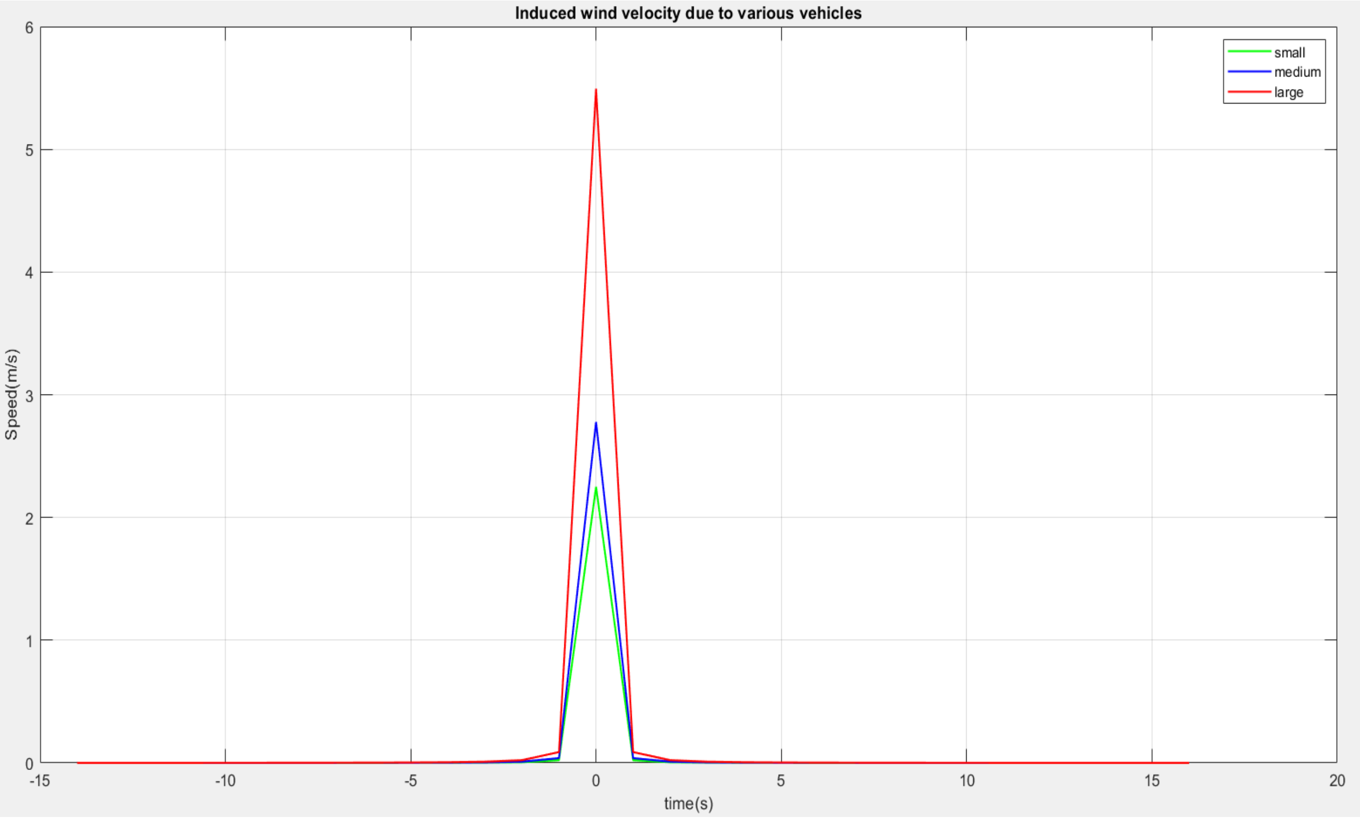
```
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXStartofCodeXXXXXXXXXXXXXXXXXXXXXX
clear all;
close all;
clc;
y_p = 1.25;
U_inf = (25);
d_t = 1.5;
d_p=0.21;
r_t = (d_t)/2;
r_p = (d_p)/2;
R_p = (r_p/y_p);
R_t = (r_t/y_p);

for i=1:31
    t(i) = i-15;
    T(i) = t(i)*U_inf/y_p;
    V_p(i) =
(U_inf*((r_t*r_t)))./(4*y_p*y_p+(U_inf*t(i)).*(U_inf*t(i)));
    C_p(i) = (((R_t^(4))/16 -
2*R_p*R_t*R_t*(T(i)))./((1+(T(i).*T(i)))*(1+(T(i).*T(i)))));
```

```
end

plot(t,V_p,'LineWidth',1.25,'color', 'g')
title('Induced wind velocity due to various vehicles')
xlabel('time(s)')
ylabel('Speed(m/s)')
hold on
% figure(2)
% plot(t,C_p,'LineWidth',2)
% title('Pressure Coefficient vs time')
% xlabel('time(s)')
% ylabel('Pressure coefficient')
% legend('coefficient')
% grid
y_p = 1.5;
d_t = 2;
d_p=0.21;
r_t = (d_t)/2;
r_p = (d_p)/2;
R_p = (r_p/y_p);
R_t = (r_t/y_p);

for i=1:31
    t(i) = i-15;
    T(i) = t(i)*U_inf/y_p;
    V_p(i) =
(U_inf*((r_t*r_t)))./(4*y_p*y_p+(U_inf*t(i)).*(U_inf*t(i)));
    C_p(i) = (((R_t^(4))/16 -
2*R_p*R_t*R_t*(T(i)))./((1+(T(i).*T(i)))*(1+(T(i).*T(i)))));
end
plot(t,V_p,'LineWidth',1.25,'color', 'b')

hold on
%%%%%%%%%%%%
y_p = 1.6;
d_t = 3;
d_p=0.21;
r_t = (d_t)/2;
r_p = (d_p)/2;
R_p = (r_p/y_p);
R_t = (r_t/y_p);

for i=1:31
    t(i) = i-15;
    T(i) = t(i)*U_inf/y_p;
    V_p(i) =
(U_inf*((r_t*r_t)))./(4*y_p*y_p+(U_inf*t(i)).*(U_inf*t(i)));
    C_p(i) = (((R_t^(4))/16 -
2*R_p*R_t*R_t*(T(i)))./((1+(T(i).*T(i)))*(1+(T(i).*T(i)))));
end
plot(t,V_p,'Linewidth',1.25,'color', 'r')
```

```
legend('small','medium','large')
grid
hold off
```

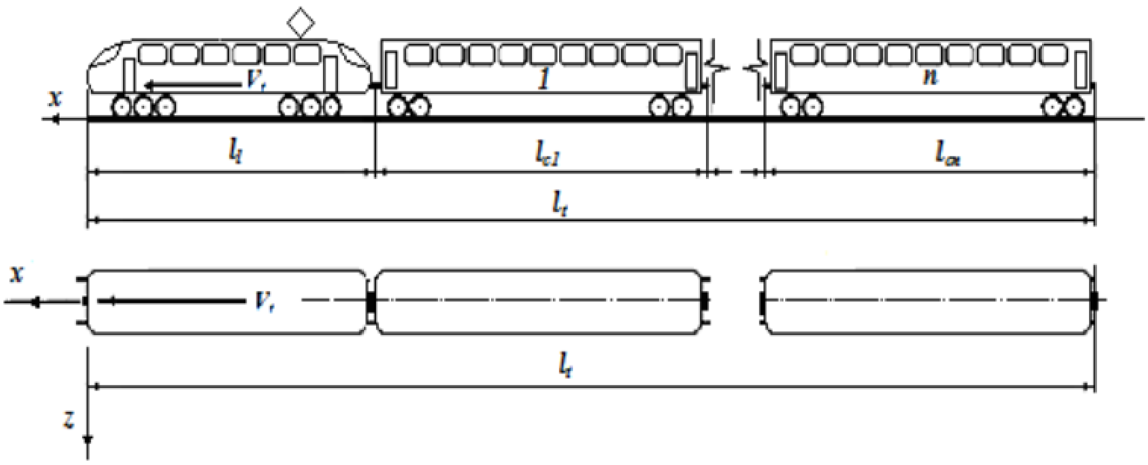
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXEndofCodeXXXXXXXXXXXXXXXXXXXXXXXX

Following is the output of the code




**Method 2(Model -2) for finding the induced velocity**

In this model instead of assuming the single vehicle on road we assumed multiple vehicles are moving at the same speed on the road, hence they can be assumed as one train which is moving at same speed. Following picture shows the description:




So, our problem is to find the swirl velocity u, due to moving train of vehicles, at a rate at some point N with the coordinates (x, y, z).
To understand the flow nature, we calculate the Reynolds number using the formulae.

$$Re = \frac{U_p L}{\nu}$$

Where $\nu$ – is air viscosity coefficient, in $m^2/s$

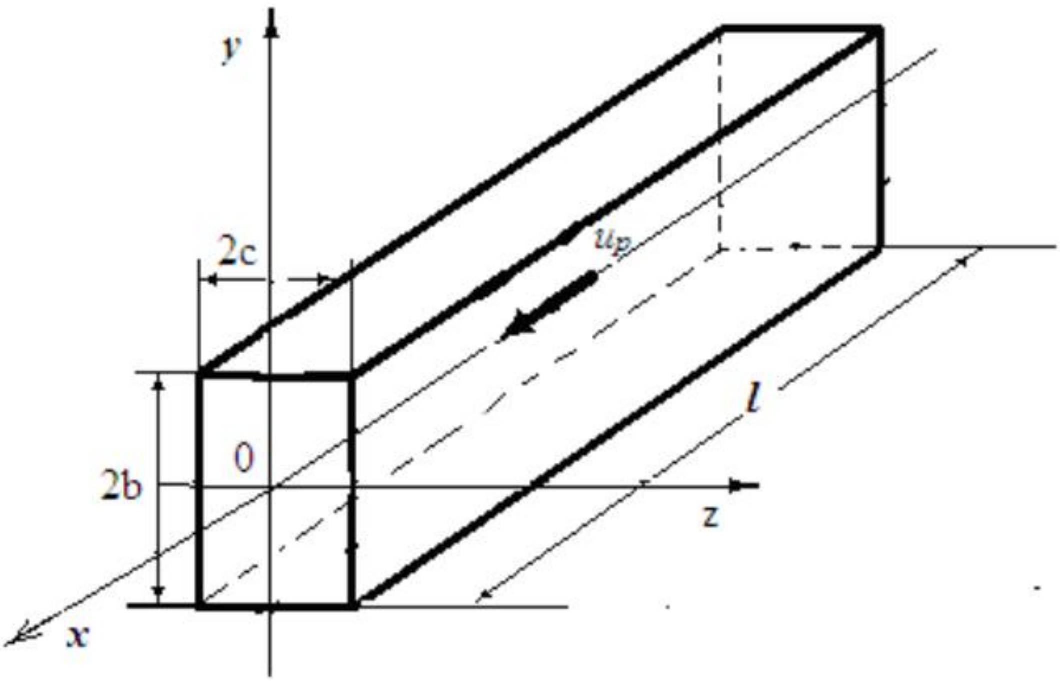



Fig: Estimated Train Scheme:

If we take

L = 25 m
$\nu$ = 1.48e(-5) $m^2/s$

$U_p$ = 25 m/s

We get Re = 4.22e+07

Which shows that it will be the turbulent flow

hence velocity component in the direction of vehicles moving must satisfy the following equations:

$$\frac{\partial V^2}{\partial \varepsilon} = \frac{\partial^2 V^2}{\partial \eta^2} + \frac{\partial^2 V^2}{\partial \zeta^2}$$

It has solution of the form

$$\frac{V^2}{{V_p}^2} = \iint_{-inf}^{+inf} f(\eta,\zeta) e^{-\frac{(y-\eta)^2+(z-\zeta)^2}{4*\zeta}}$$

Where $\quad {V_p}^2 = \rho * {u_p}^2$

And f is the function describing the distribution of the speed pressure when $\xi = 0$.

Thus, we have final solution as

$$\frac{V^2}{{V_p}^2} = \frac{1}{4} * \left[erf\left(\frac{y+b}{2*(\delta(x))}\right) - erf\left(\frac{y-b}{2*\delta(x)}\right)\right] * \left[erf\left(\frac{z+c}{2*(\delta(x))}\right) - erf\left(\frac{z-c}{2*\delta(x)}\right)\right]$$

Where $\qquad \delta(x) = 0.37 * x * \left(\frac{V_p * x}{\nu}\right)^{-\frac{1}{5}}$

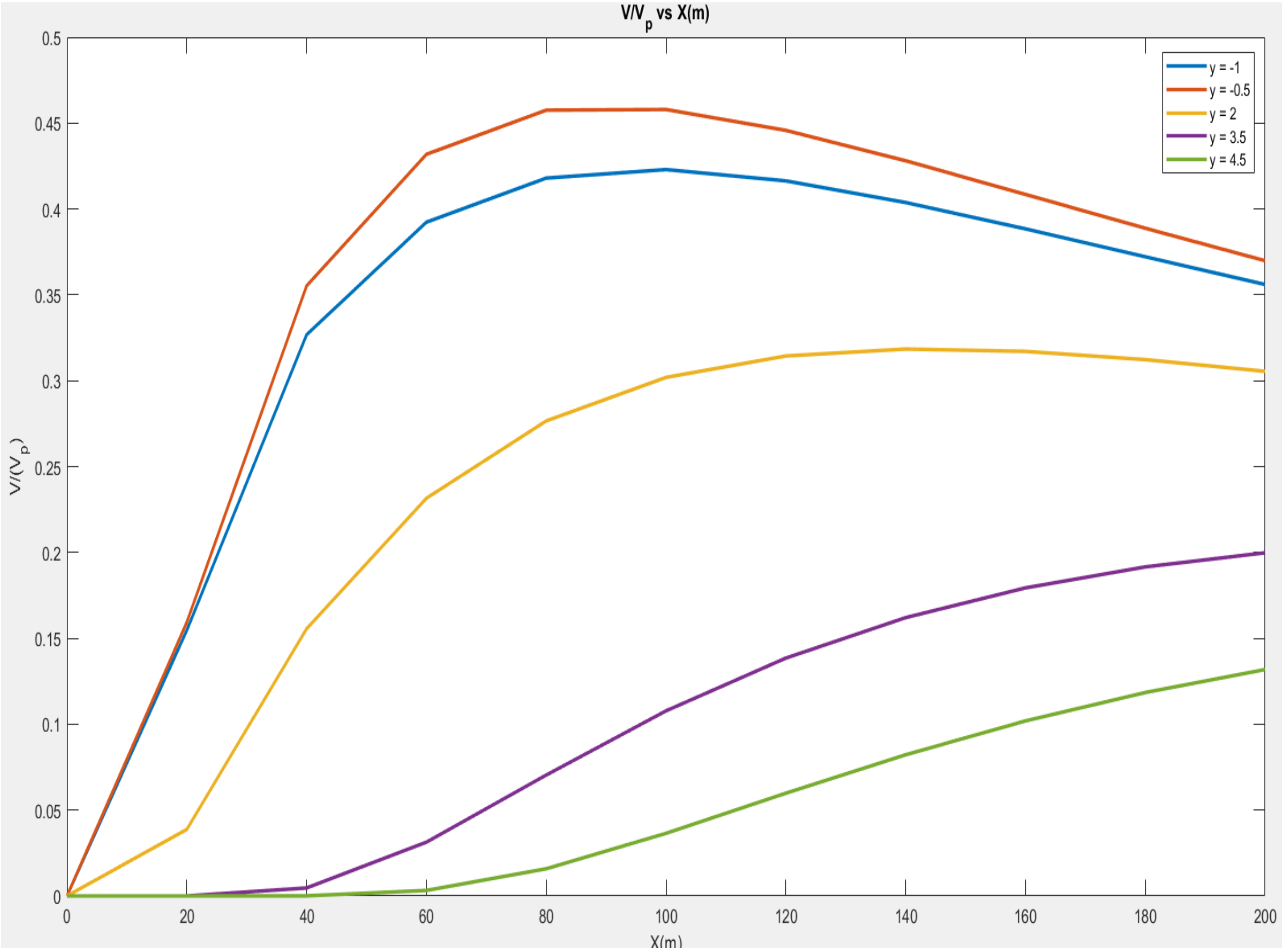
Following is the MATLAB code for predicting the induced wind Velocity due to such a train of vehicles:

```
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXStartofCodeXXXXXXXXXXXXXXXXXXXXXX


clear all
close all
clc
L = 25;
meu = 1.48*10^(-5);
```

```
u_p = (25);
b = 1.5;
c=1.75/2;
Re = (u_p*L./meu);
v_p = (1.225*(u_p*u_p)).^(0.5);
z = 1.5;
y=[-1,-0.5,2,3.5,4.5];
for i=1:11
    x(i) = 20*(i-1);
end
for j=1:5
    for i = 1:11
        delta(i) = 0.37.*x(i).*(v_p.*(x(i))./(meu)).^(-
0.2);
        vbyvp(i) = (0.25.*(erf((y(j)+b)./(2*delta(i)))-
erf((y(j)-b)./(2*delta(i)))).*(erf((z+c)./(2*delta(i)))-
erf((z-c)./(2*delta(i))))).^(0.5);
    end
    vbyvp(1)=0;
    plot(x,vbyvp,'linewidth',2);
    hold on;
end
hold off
title("V/V_p vs X(m)")
xlabel("X(m)")
ylabel("V/(V_p)")
legend('y = -1','y = -0.5','y = 2','y = 3.5','y = 4.5')
```

XXXXXXXXXXXXXXXXXXXXXXXXXXXXEndofCodeXXXXXXXXXXXXXXXXXXXXXXXX

Following is the output of the above code

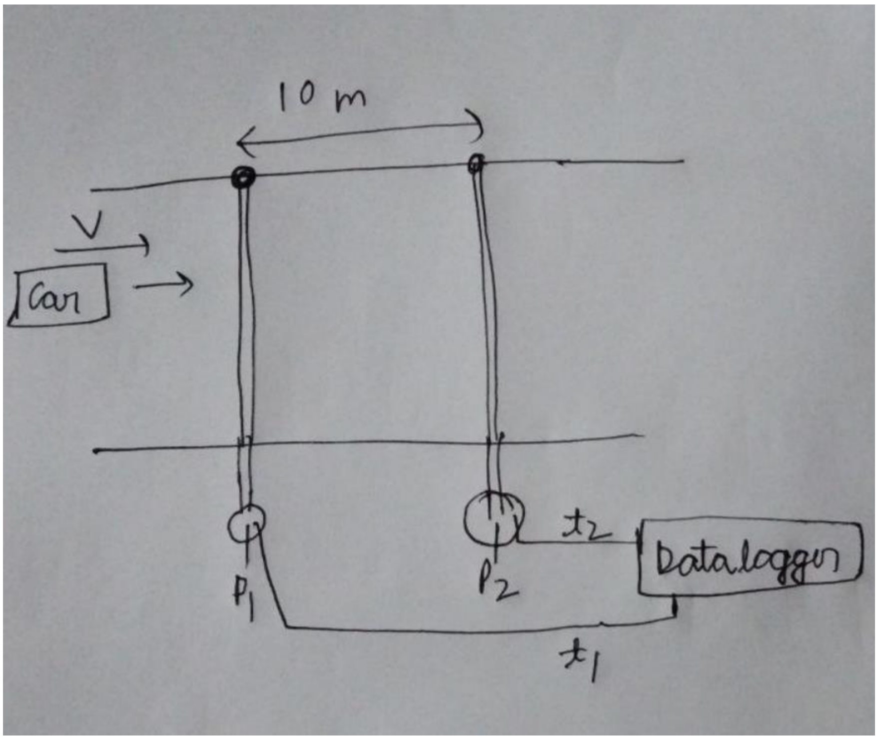



Where y represents the height from the prototype coordinate system, we are measuring the Relative wind speed induce due to the speed of train of vehicles.

## Methods for measuring the speed of the vehicle on road:

- Here we take two pressure sensors with max capacity of 5 kPa, and connect it with the help of pneumatic tubes.
- We block the pneumatic tubes with the help of china clamp, Teflon tape and mechanical stopper for tube, so that air does not leak from there.
- We give the pressure sensor a required initial voltage with the help of power source and breadboard, which in provides some output in millivolts that we can measure with help of multi-meter.
- Now if there is sudden pressure due to passing of the vehicle then there is sudden change in the voltage, the time at which pressure spike occurs can be logged via datalogger.
- Now if we place two 5- meter tubes at a distance of 10 meter on road. So, whenever a vehicle presses the tubes, we can log the respective time and get the time difference.

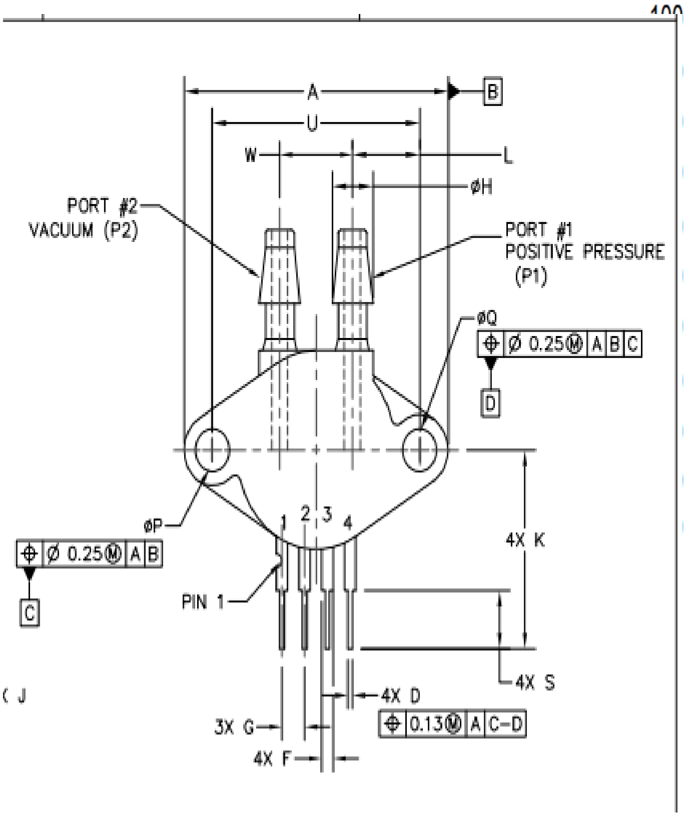
- Assuming that there is very minor acceleration of the vehicle during the 10 m distance. So, we can calculate velocity as distance/ (time difference).




Where p1 and p2 are the pressure sensors attached to one end of the tube 1 and tube 2 respectively, while the other ends are blocked. We can get the time difference as t2-t1, with the help of data logger. Then velocity = 10/(t2-t1).

**Procedure for Initial Measurements of the change in pressure via 50 kpa pressure gauge for testing and validating the equipment:**

We used Breadboard, pressure sensor, multi-meter, DC power source, pneumatic tubes of 1 m (O.D = 12, I.D =8) and 0.5 m (O.D = 5, I.D =3) for the testing purpose.
Above figures give us the brief description of the pressure sensor we are using, the first pin is ground, pin 2 is positive output voltage, pin 3 is source voltage, pin4 is for negative output voltage. From fig in the right, we can also observe that at 25-degree Celsius and 0 pressure difference we have output voltage as 20 mV



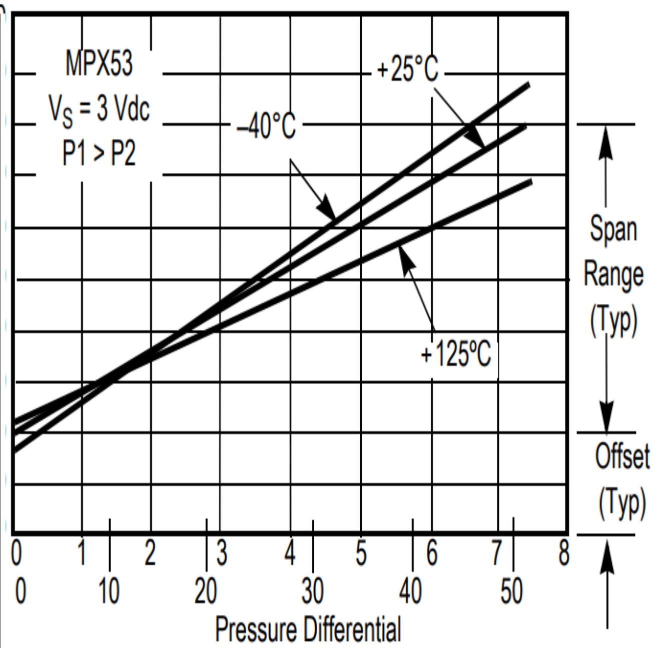




**Figure 3. Output vs. pressure differential**

. Procedure for the test is given below:

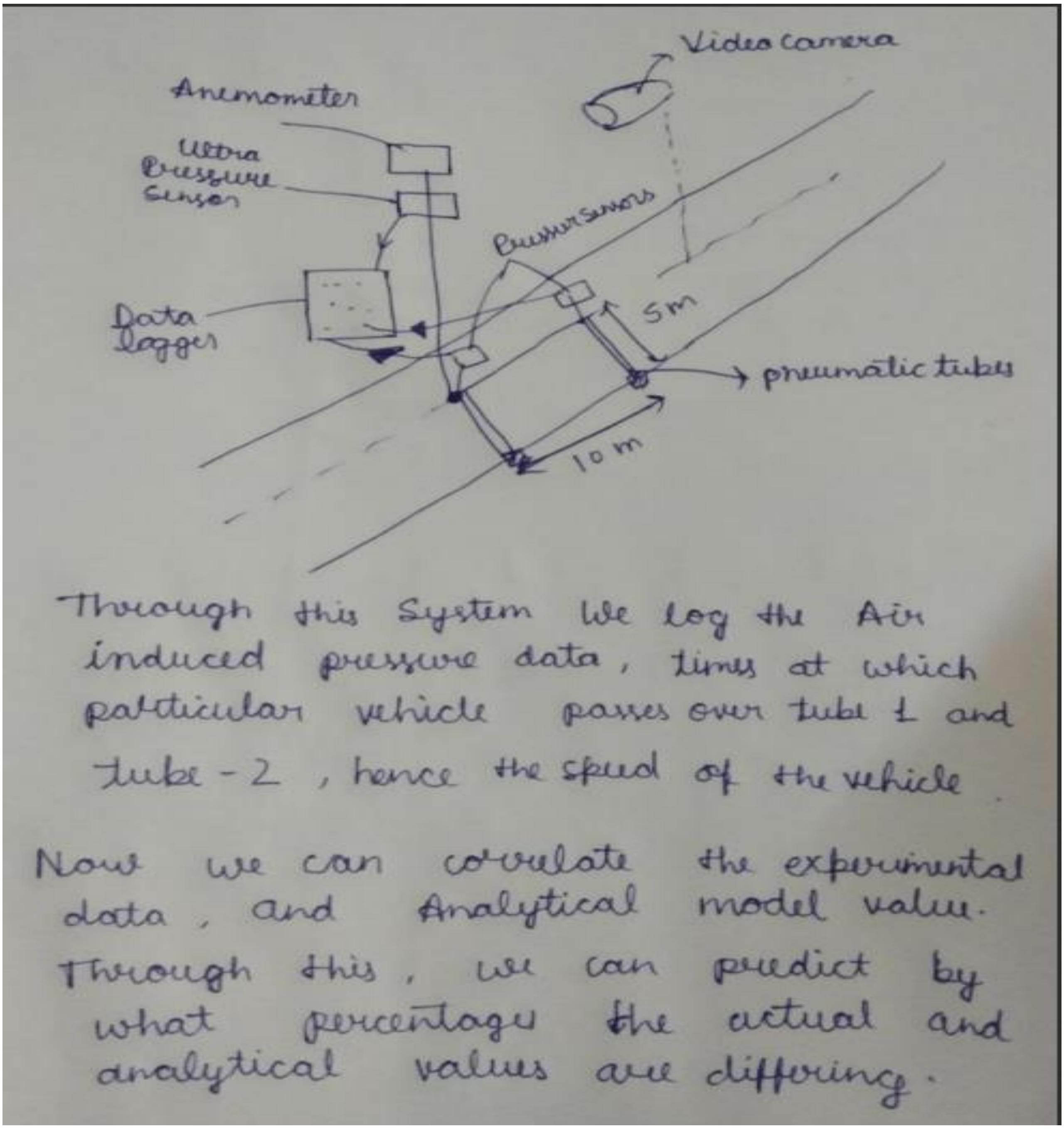
- First, we connect both the smaller and bigger diameter tube with China clamp and Teflon tape. We block the one end of the bigger tube completely.
- We connect other end of the smaller tube to the positive pressure side of the sensor.
- We connect the multi-meter, voltage source and pressure sensor with the help of the breadboard.
- We initially give 3 volt of input voltage to check that at zero pressure difference there is an output of 20 mV in the multi-meter.
- Now when we press the tube suddenly by means of some weight or some hammer, we get the 1.5 mV of voltage increase in the multi-meter.
- So, it is validated that setup is working perfectly fine.
- Also, if we increase the pressure sensitivity of the pressure sensor, we will get higher peak of the voltage instead of 1.5 mV.

## Method for measuring the air induced velocity on road due to vehicles:

- We measure the wind speed by simply putting the anemometer at various heights and then log the data with the pressure sensor.
- Anemometer has to be put on the stand where we can adjust the height of anemometer via a slider so that we can get the air induced velocity at different heights and then compare them.

- Then we need to mount the extremely sensitive pressure sensor with max limit of 500 pascal, so that we can measure the pressure change signals due to air induced velocity.

**Final Set-up for logging and measuring the transient air velocity on highways:**




- Based on the experimental and analytical modal data, we prepare the corrected version of the model.
- We feed the model to the ANSYS to generate the time varying air induced velocity.

- After that we put different designs of wind turbine in the ANSYS software to predict the power potential of various designs of blades.

## Conclusions:

- We analysed and coded the various models for predicting the induced wind speed due to moving vehicle.
- We developed the Savonius and H type Darrius wind turbines prototype. They are almost complete. We will test them and show the results and video in presentation.
- We also developed a method to measure and log the transient speed of the vehicle as well as air induced velocity.
- We can feed the data to the ANSYS software using the corrected version of the analytical model.

## THE END