Flying High ! Drag force on the string

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In this poster, a simple model is used to mimic a slender object dragged in the fluid. The experiment is conducted with different variables such as velocities and lengths to know the steady-state of the string propelled by two motors. We can obtain the tension distribution of the string by investigating the wave created by a perturbation to the string.

EXPERIMENTAL SETUP
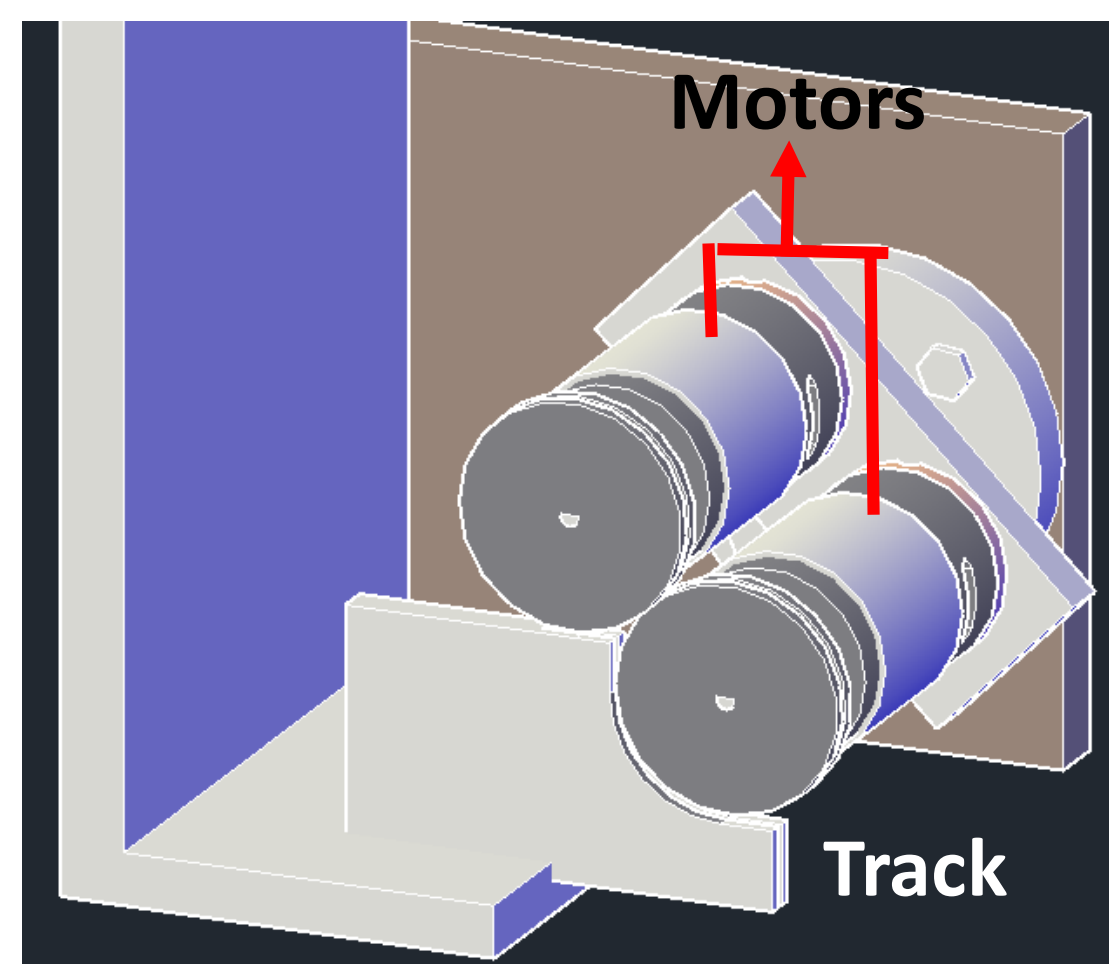
Using two motors to drive the wheels and let the wheels to propel the string. The track is made to constrain the string, making it more stable.
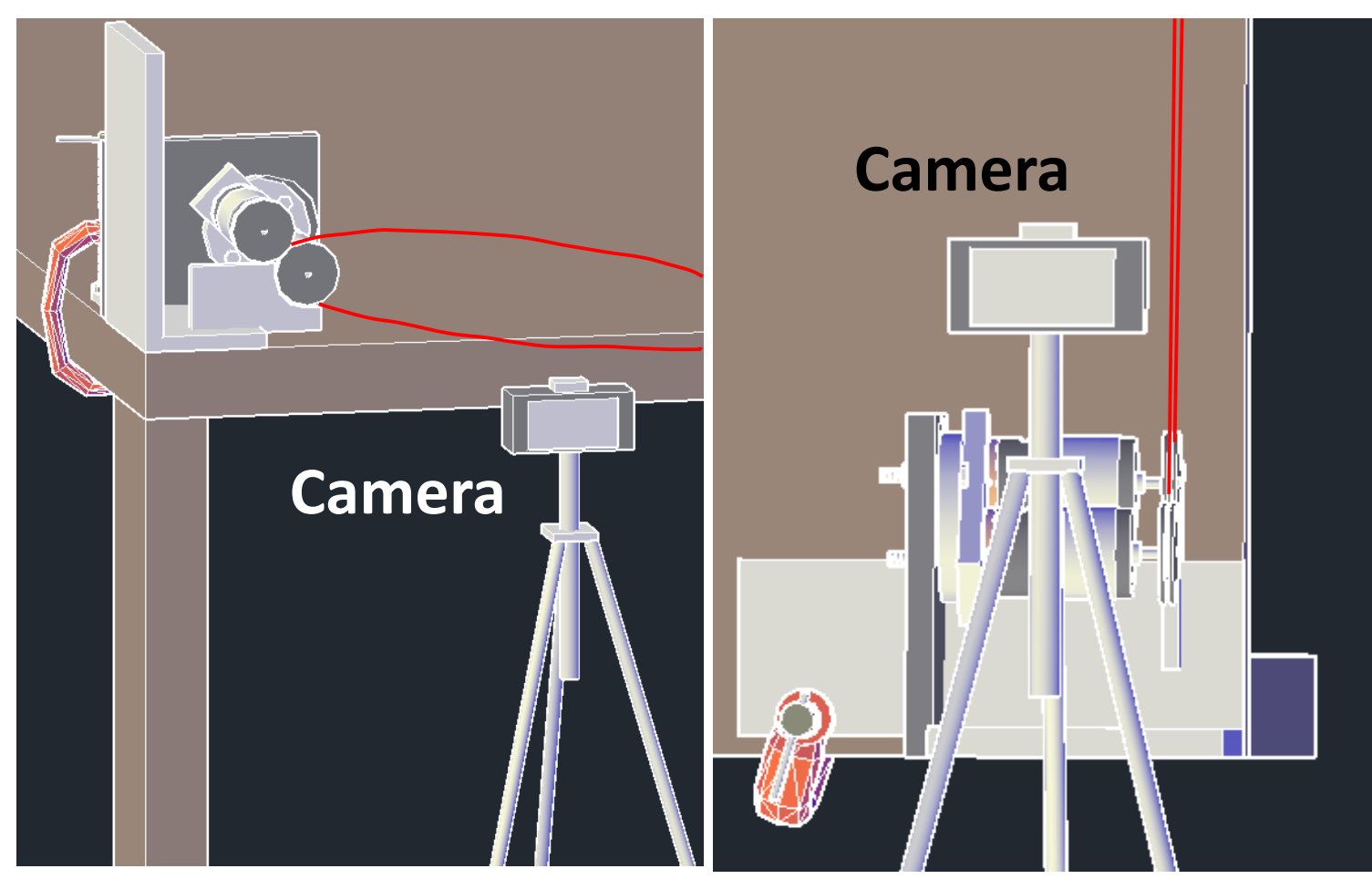
*The camera is used to take the video for further imaging analysis.*

THEORY

A typical arrangement of our experiment is shown in the figure below.

In steady-state, there is no acceleration and only two external forces :

(i) Weight of string per unit length λg

(ii) Air drag per unit length $f_d = \frac{1}{2}\rho\pi C_d R v^2$

(ρ = air density, R = radius of string, C_d = drag coefficient)

Then introducing the tension, the equation of motion read [1-3]:
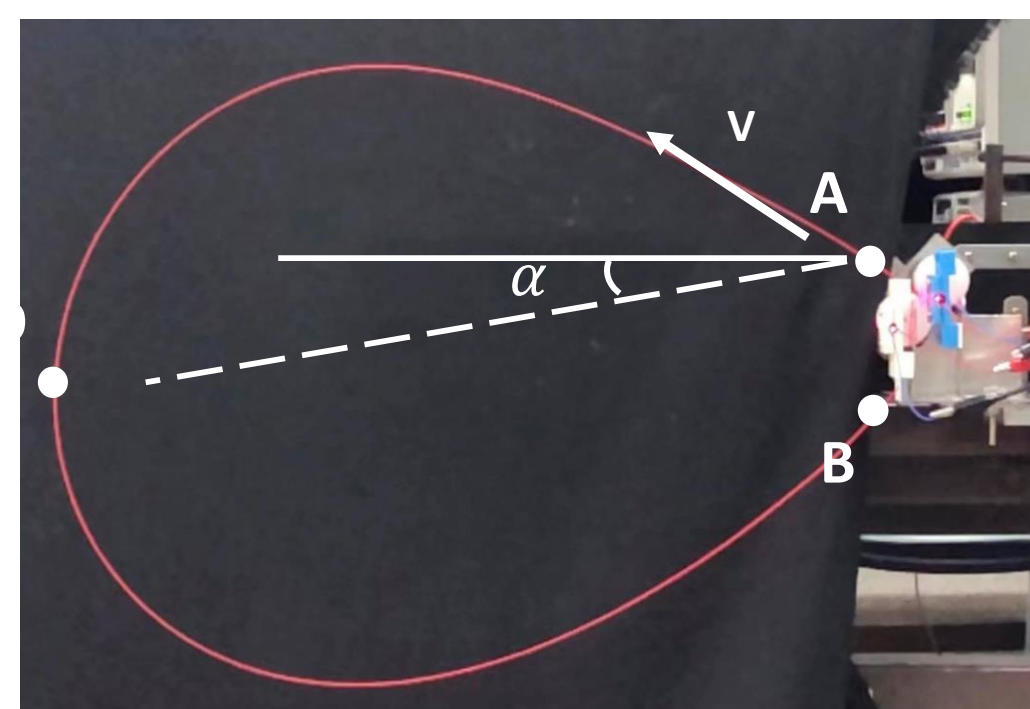
A closed string with length L and density λ propelled by motors.

$$d(T cos\alpha) = -\lambda v^2 sin\alpha d\alpha + f_d cos\alpha ds \quad (horizontal)$$
$$d(T sin\alpha) - \lambda g ds = \lambda v^2 cos\alpha d\alpha + f_d sin\alpha ds \quad (vertical)$$
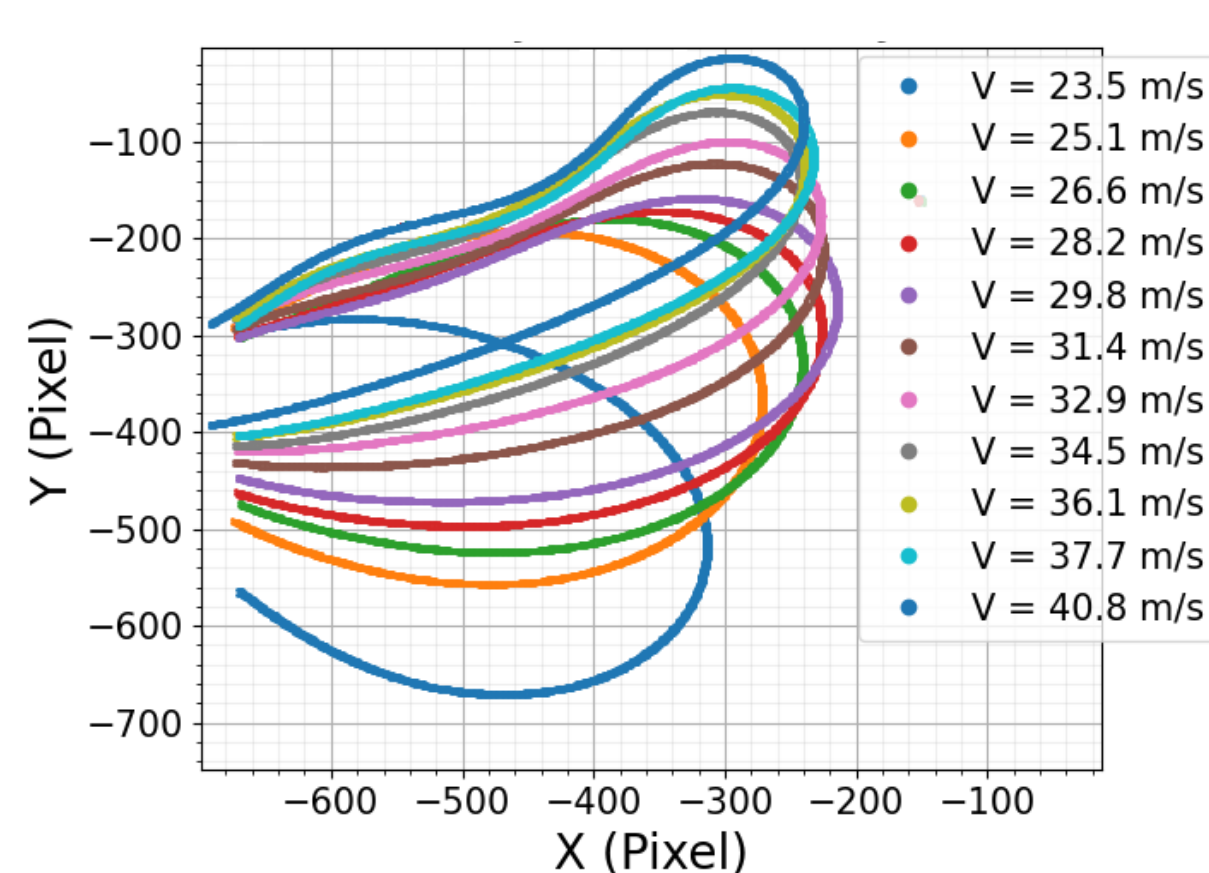
Then replace the tension(T) and curvilinear coordinate(s) with the effective dimensionless tension ($\tilde{T} = \frac{T_{eff}}{T_k} = \frac{T-\lambda v^2}{\lambda v^2}$) and the dimensionless curvilinear coordinate($\tilde{s} = \frac{s}{L}$), we obtain:

$$d(\tilde{T}cos\alpha)/d\tilde{s} = D cos\alpha$$
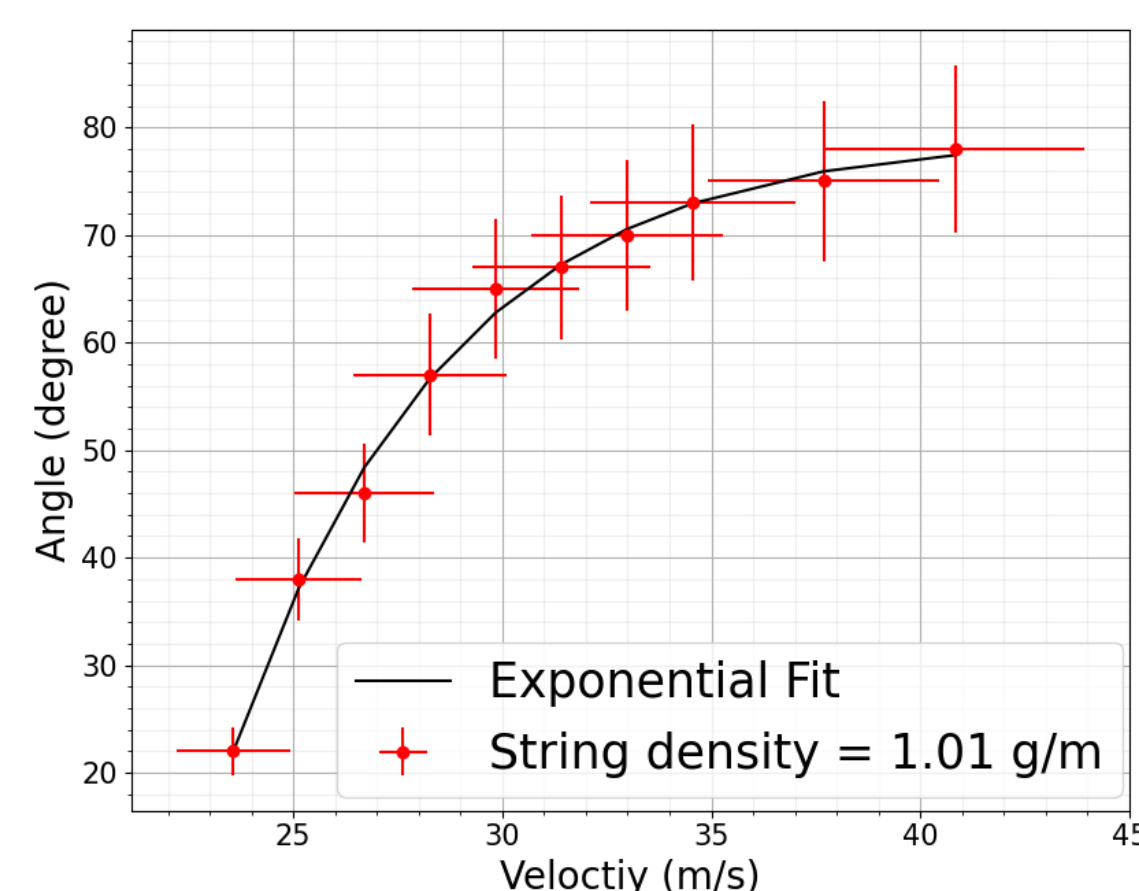$$d(\tilde{T}sin\alpha)/d\tilde{s} = W + D sin\alpha$$

We can know which force dominates from the ratio of dimensionless **weight $W = gl/v^2$** and **drag $D = f_d l/(\lambda v^2)$**.
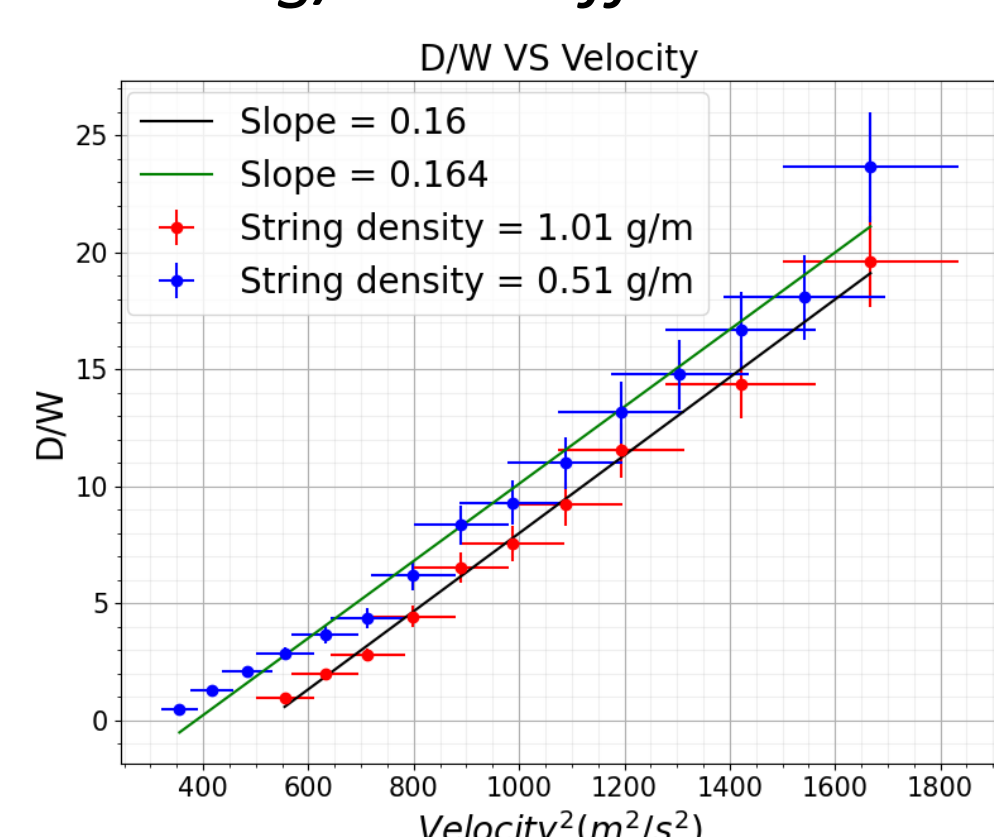
RESULTS

Angle vs. Different velocity

The shape of the string with density 1.01 g/m in different velocities.
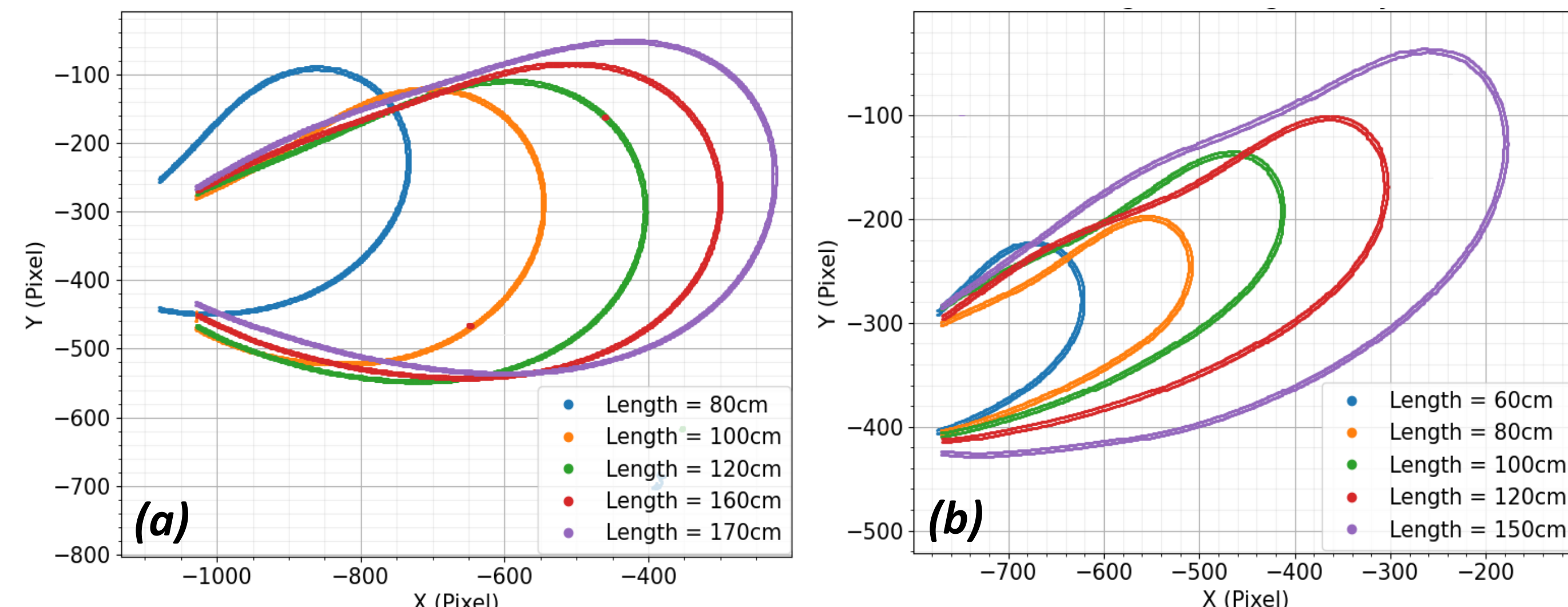
The variation of the angle when velocity changing.

D/W as a function of v^2. The data is fit by a linear function.

The angle(α) will rise exponentially when the speed increases and $\frac{D}{W}$ linearly depends on v^2. The fit slope gives C_d directly:
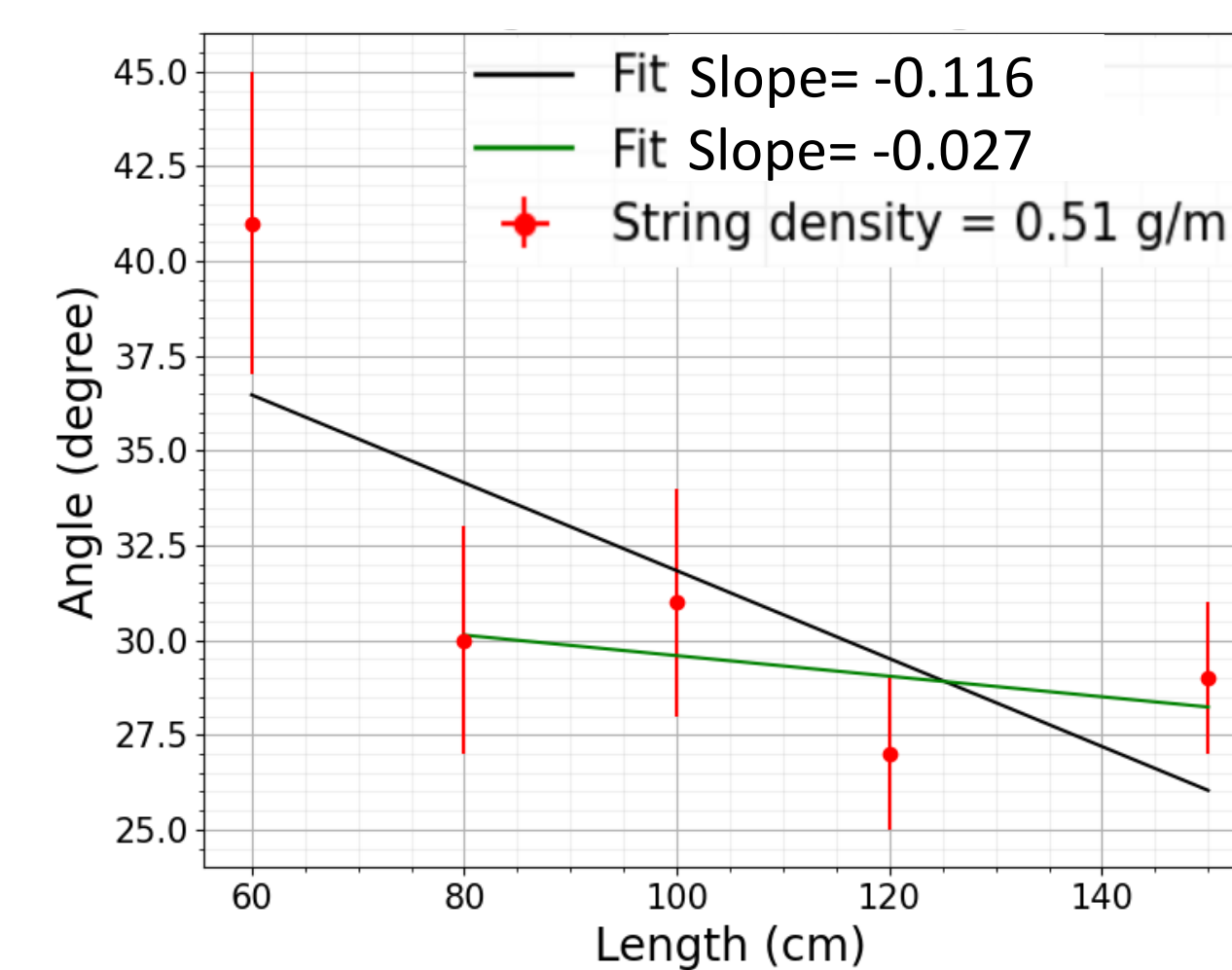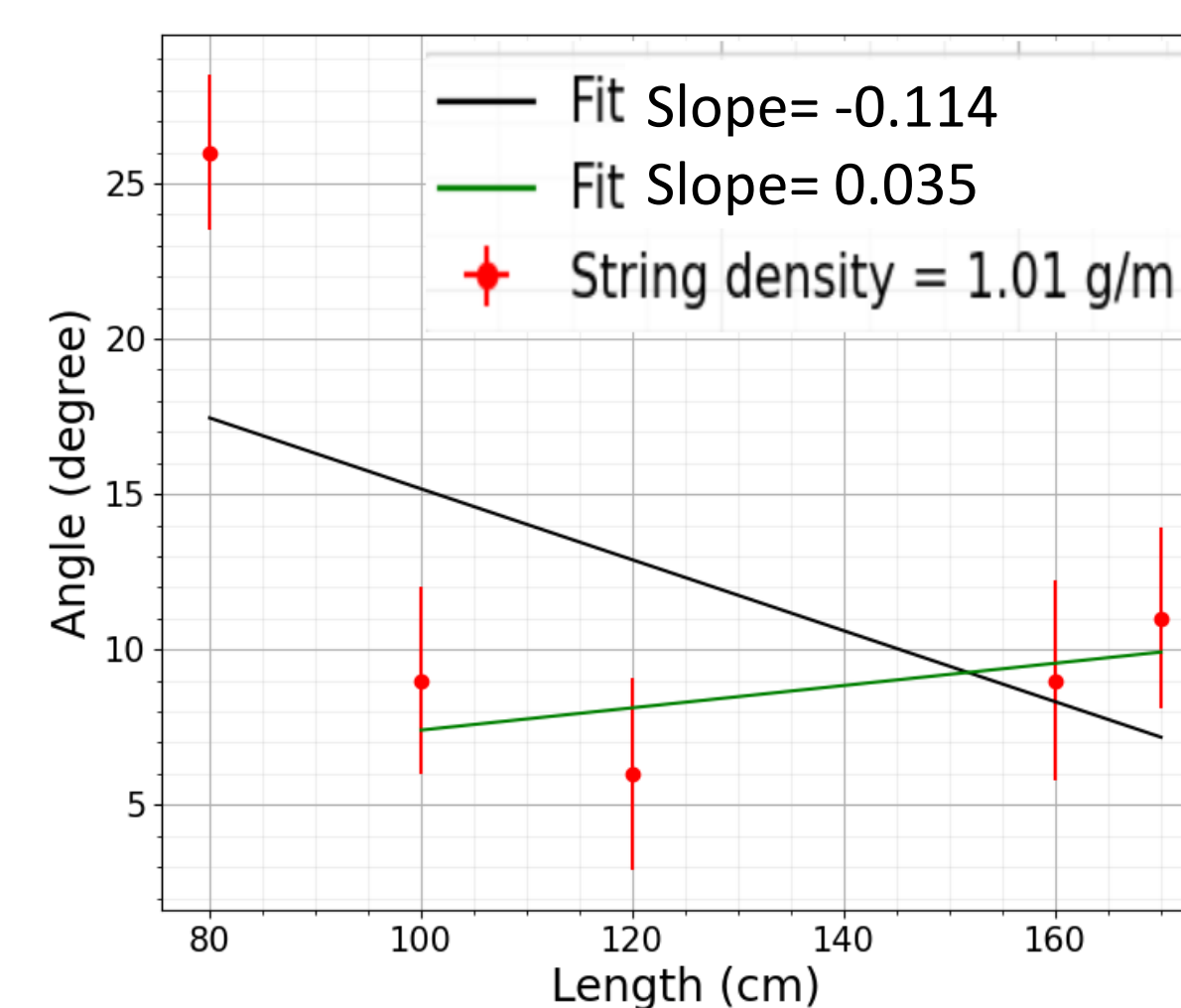
String	λ (g/m)	C_d
Heavy	**1.01**	**0.072**
Light	**0.51**	**0.050**

The smaller λ of the string , the smaller air resistance

Angle vs. Different length of string

At the same velocity $v = 28\ m/s$, the shape of (a) heavy string ($\lambda = 1.01 g/m$) (b) light string ($\lambda = 0.51 g/m$) in different lengths.

Values of angle(α) for the best analytical fit to experimental profiles as a function of L.

Same D/W string should give the same angle, while the shortest string does not obey the theory. By excluding the shortest string, we can observe the angle is independent to the length

Perturbation & Tension distribution
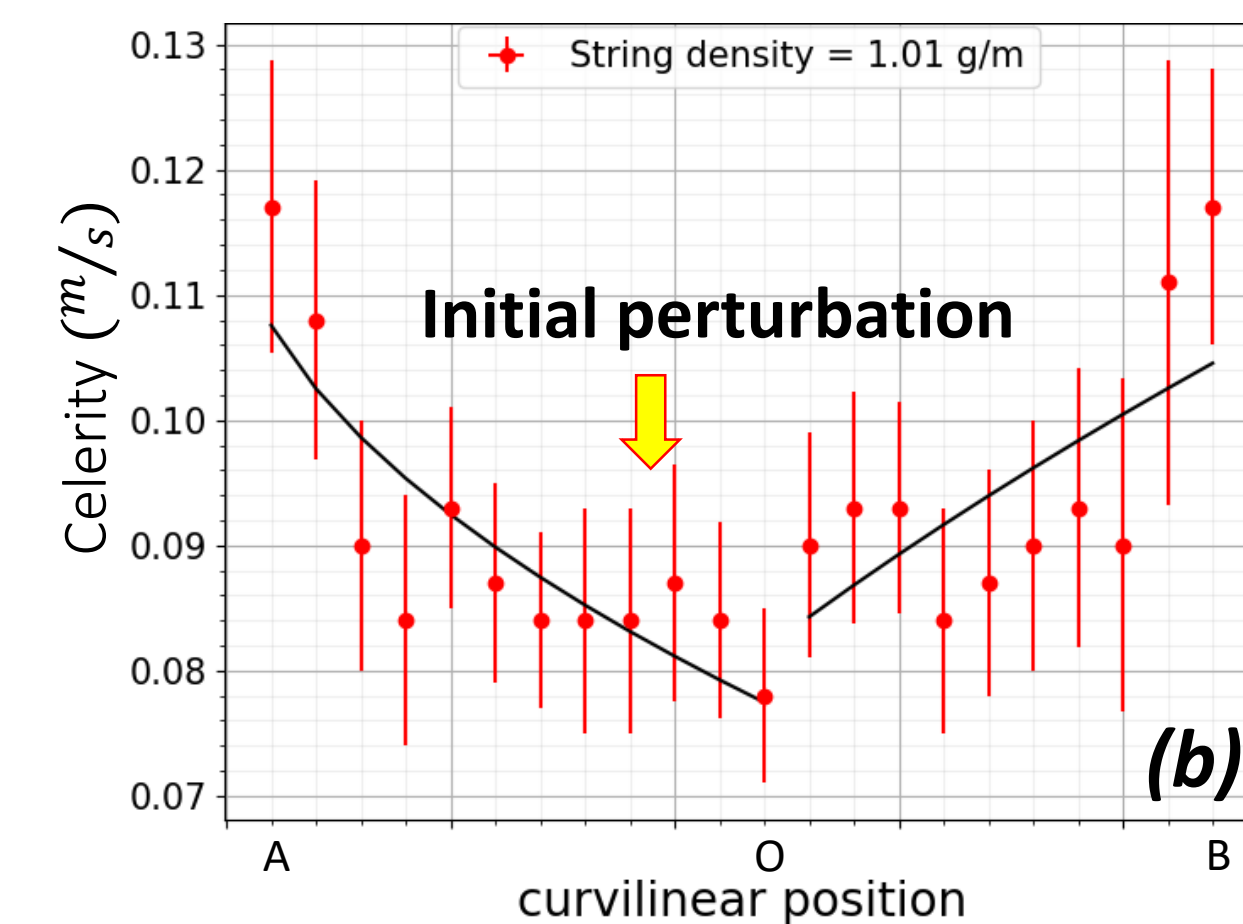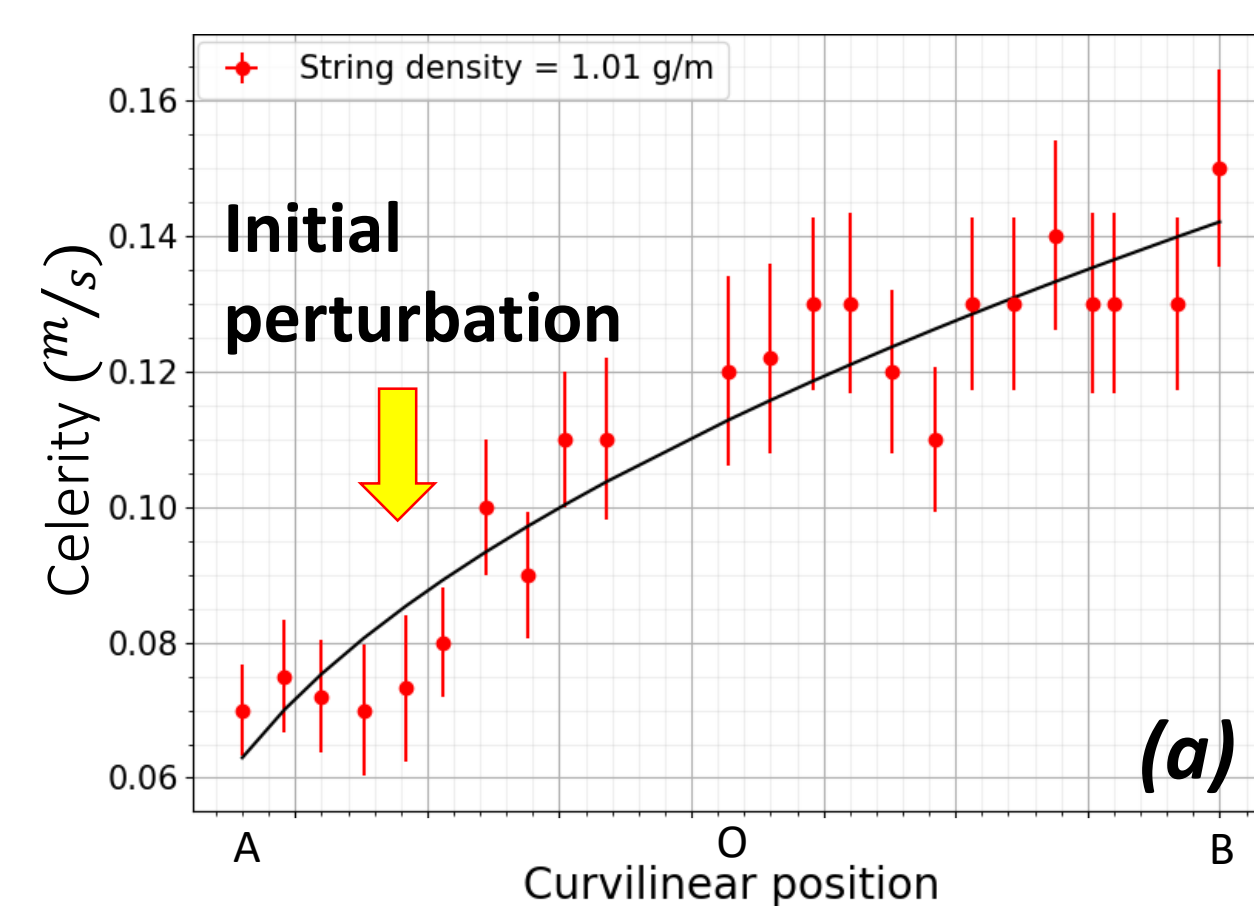
Celerity of the perturbation waves in (a) the drag-dominated regime (D/W ≫ 1) and (b) the weight-dominated regime (D/W ≪ 1).

We create a wave by perturbating the string and analyze it. Then we can get the tension distribution of the string from the relationship between the celerity and the tension($\sqrt{T}$).

CONCLUSION

- D/W is proportional to v^2.
- When the speed of the string increases, the angle increases as well.
- If the length of string is too short, the theory will not hold because D/W is same with the longer string.
- We can obtain the tension distribution by measuring the celerity.

REFERENCES

[1] Nicolas Taberlet, Jérémy Ferrand, and Nicolas Plihon, Phys. Rev. Lett. 123, 144501 (2019)

[2] A. Dowling, J. Fluid Mech. 187, 507 (1988).

[3] A. Dowling, J. Fluid Mech. 187, 533 (1988).