THE DYNAMICS OF A FAN-DAMPENED ROWING MACHINE

Biomedical System Dynamics

MCG 3305[A]

Project Outline

Group

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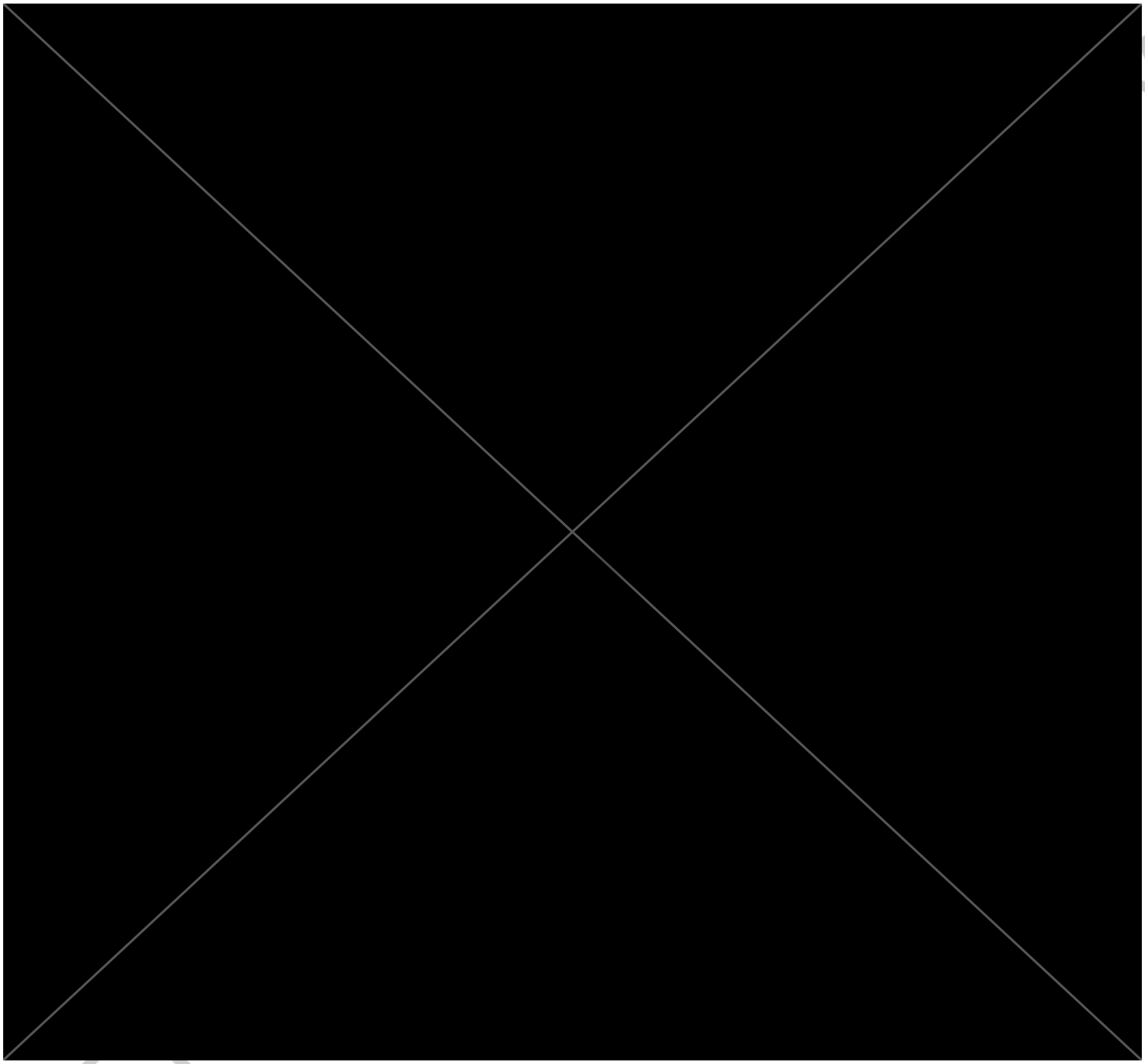
3 System of Interest



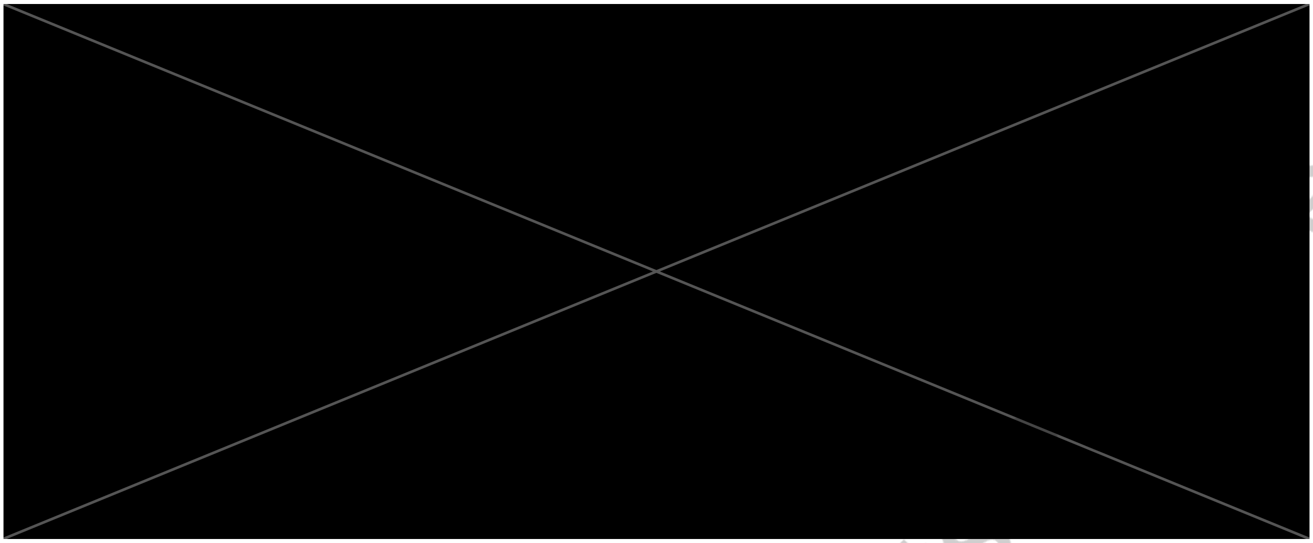


Figure 1 Air Rowing Machine Labelled Top View [2]

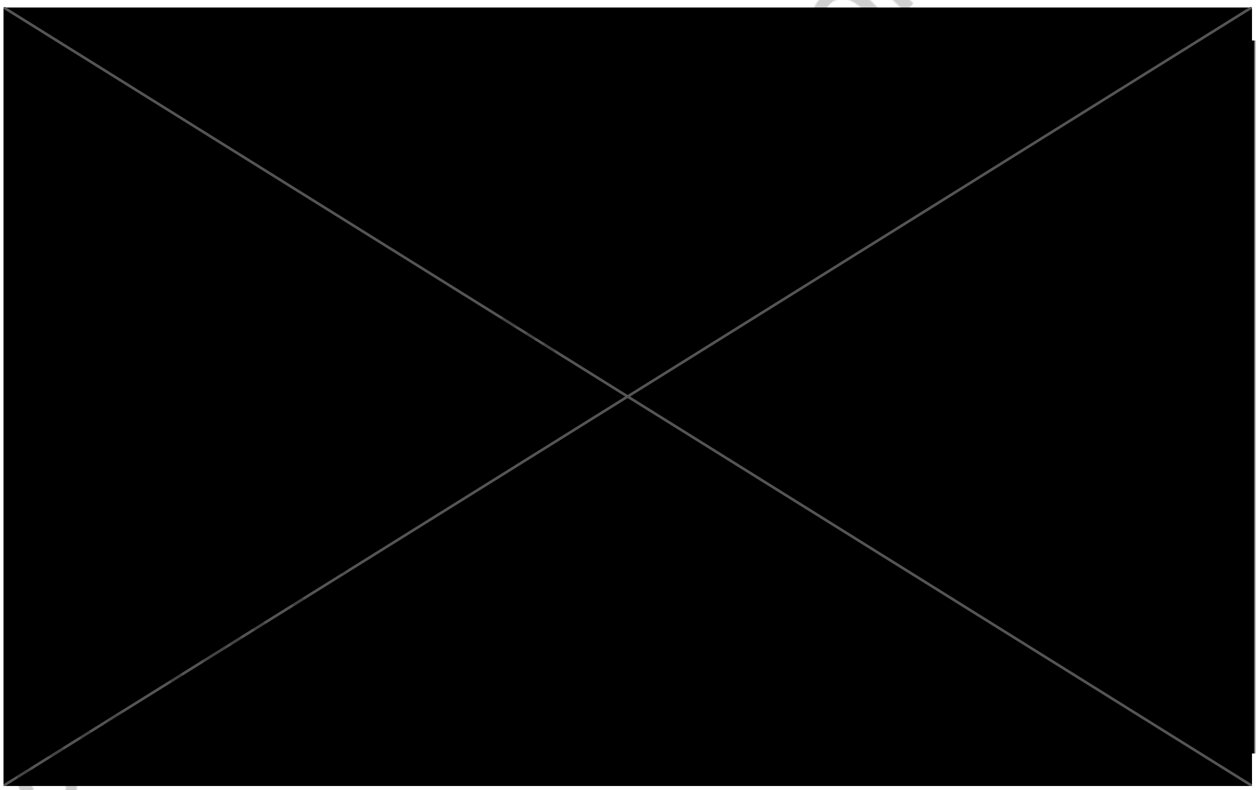


Figure 2 Housing with Sliding Door with Direction of Airflow [2]

4 Model Proposal

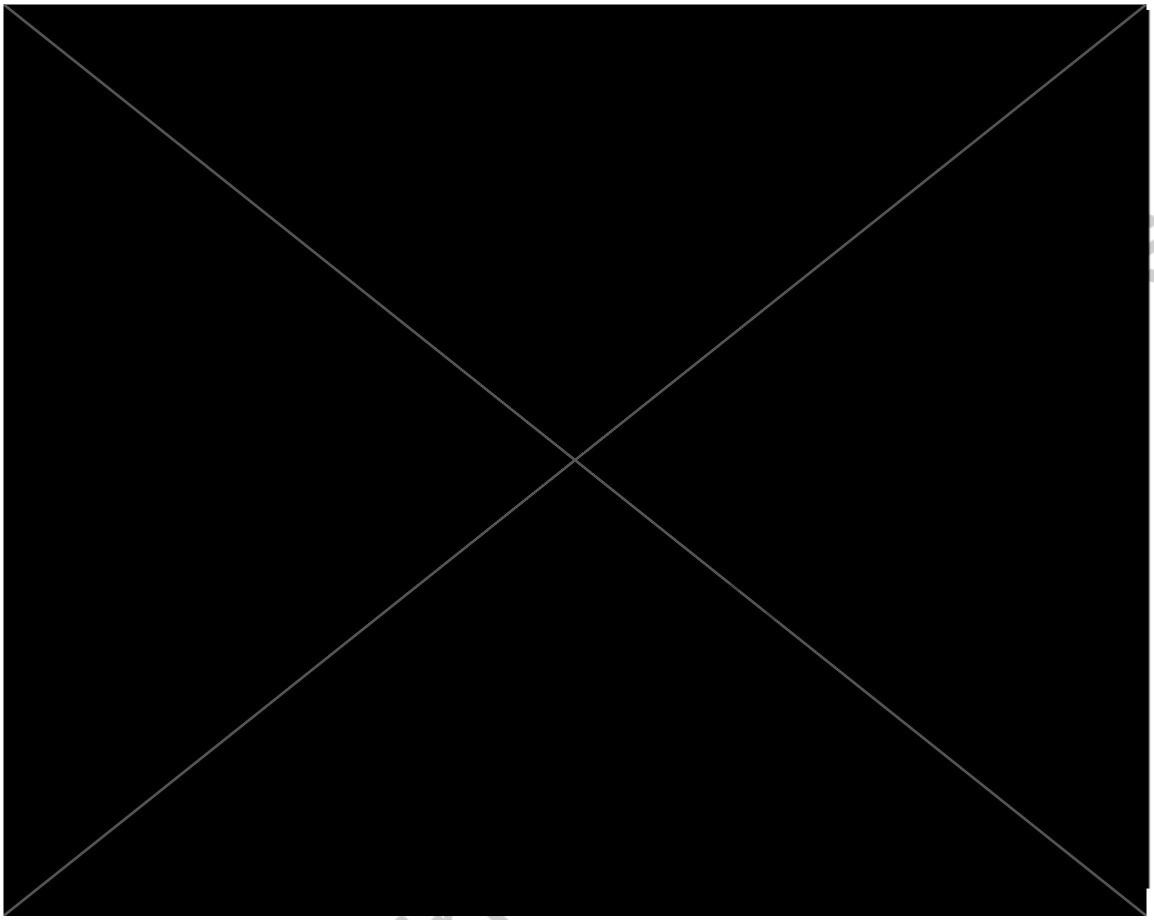
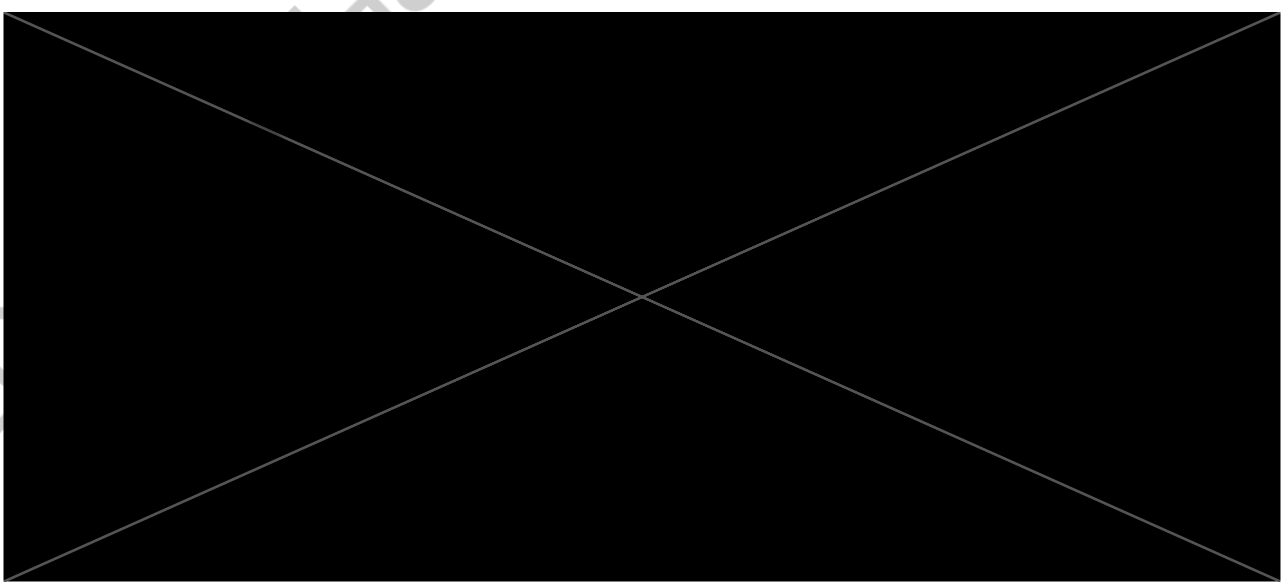
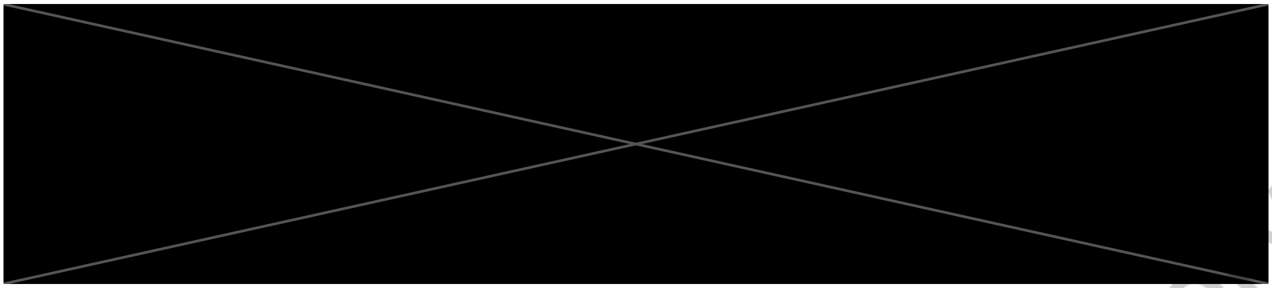


Figure 3 Model Diagram of the Rowing Machine





5 Component to be Tested

The drag damper in the rowing machine is the component of interest, and it will be modelled in two ways: with a quadratic model (air drag) and with a linearized model (viscous damping). The parameter to be found in the quadratic model and the linearized model will be a drag coefficient (k_d) and the viscous damping coefficient (D), respectively.

Drag can be simply modelled with the following equation [3]:

$$F_d = \frac{\rho C_d A}{2} v^2 = \alpha\, v^2$$

Equation 1

We apply this to the rotational domain:

$$T_d = k_d \omega^2$$

Equation 2

The constitutive equation, Equation 2, will be the basis for the equations that follow.

5.1 Equations

5.1.1 Quadratic Model (Air Drag)

In this section, k_d, the drag coefficient in $N\cdot m\cdot s^2\cdot rad^{-2}$, will be determined.

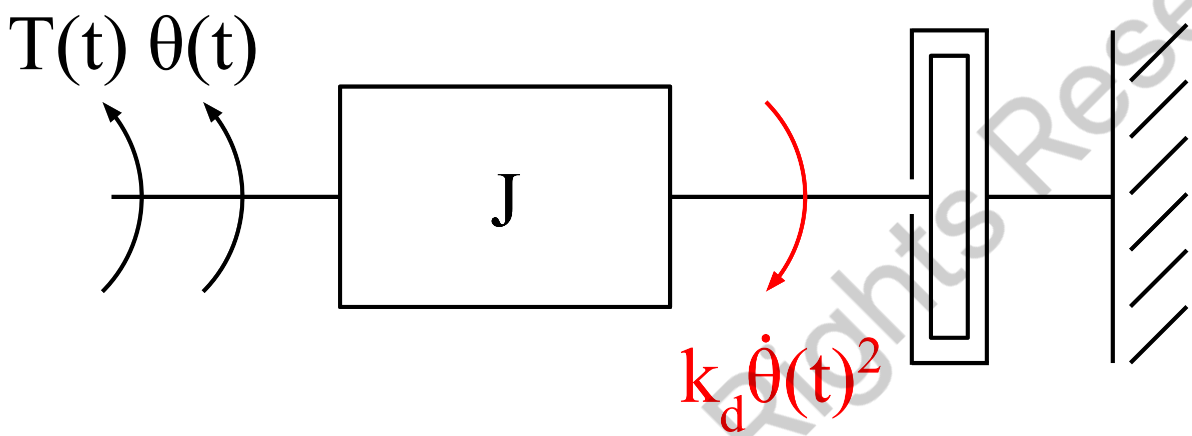


Figure 4 Fan Damper Modelled as an Air Drag Damper

First, write the topological equation for Figure 1

$$J\ddot{\theta}(t) = T(t) - k_d\left(\dot{\theta}(t)\right)^2$$

The coast down will be observed in the experiment, so let T(t) = 0

$$J\ddot{\theta}(t) = -k_d\left(\dot{\theta}(t)\right)^2$$

Solve the separable DE for ω(t)

$$\frac{d\omega}{dt} = \frac{-k_d}{J}\omega^2$$

$$\omega^{-2}d\omega = \frac{-k_d}{J}dt$$

$$\frac{1}{\omega_0} - \frac{1}{\omega(t)} = \frac{-k_d}{J}t$$

$$\frac{1}{\omega(t)} = \frac{1}{\omega_0} + \frac{k_d}{J}t$$

Equation 3

$$\omega(t) = \frac{1}{\frac{1}{\omega_0} + \frac{k_d}{J} t}$$

Equation 4

Rearrange to isolate k_d

$$k_d = \frac{J\left(\frac{1}{\omega(t)} - \frac{1}{\omega_0}\right)}{t}$$

Equation 5

5.1.2 Linearized Model (Viscous Damper)

In this section, Equation 2 will be linearized, and D_{eff}, the effective viscous damping coefficient in $N \cdot m \cdot s \cdot rad^{-1}$, will be determined.

Starting with Equation 2:
$T_d = k_d \omega^2$

The top half of speeds are more interesting, so the origin of the model will be:
$\left(0.75\omega_{initial}, T_d(0.75\omega_{initial})\right)$
Where $\omega_{initial}$ is the velocity that is being coasted down from.

Take the slope at the origin.
$$\left.\frac{dT(\omega)}{d\omega}\right|_{\omega = 0.75\omega_{initial}} = 2k_d(0.75)\omega_{initial} = 1.5k_d\omega_{initial}$$

The following is the constitutive equation near the origin:
$\delta T_d = (1.5k_d\omega_{initial})\delta\omega$

Define the effective viscous damping coefficient as:
$D_{eff} = 1.5k_d\omega_{initial}$

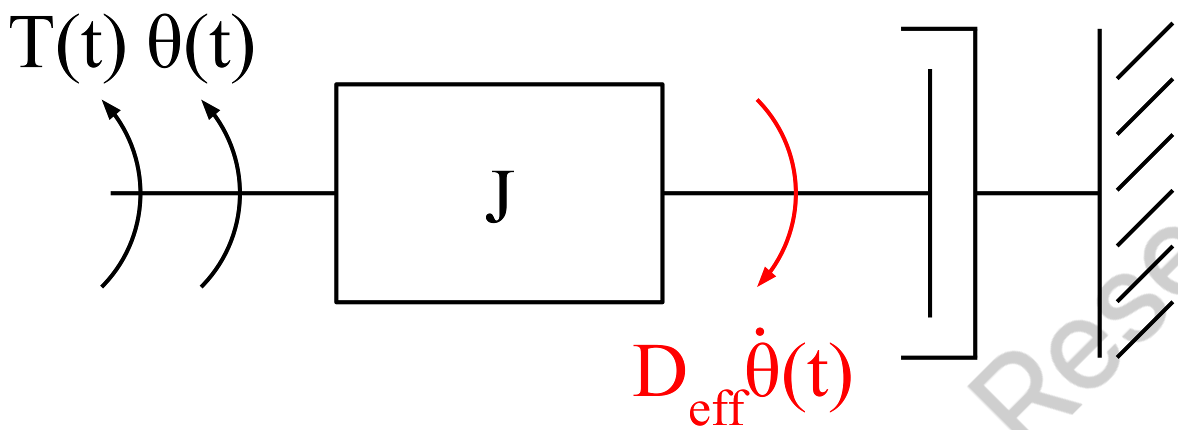


Figure 5 Fan Damper Modelled as a Viscous Damper

Write the topological equation for Figure 2:

$J\ddot{\theta}(t) = T(t) - D_{eff}\dot{\theta}(t)$

The coast down will be observed in the experiment, so let T(t) = 0

$J\ddot{\theta}(t) = -D_{eff}\dot{\theta}(t)$

Solve the DE in Laplace:

$Js^2\theta(s) - J\omega_0 = -D_{eff}s\theta(s)$

$\theta(s)(Js^2 + D_{eff}s) = J\omega_0$

$\theta(s) = \dfrac{J\omega_0}{Js^2 + D_{eff}s}$

$\omega(s) = \dfrac{\omega_0}{s + \frac{D_{eff}}{J}}$

$$\omega(t) = \omega_0 e^{-\frac{D_{eff}t}{J}}$$

Equation 6

$$ln(\omega(t)) = ln(\omega_0) - t\left(\frac{D_{eff}}{J}\right)$$

Equation 7

$$D_{eff} = \frac{-J}{t}\ln\left(\frac{\omega(t)}{\omega_0}\right)$$

Equation 8

5.2 Experiment Plan

5.2.1 Materials

Table 1 Preliminary Bill of Materials for the Experiment

Item	Description	Acquisition Method	#	Cost ($)
Fan/Blower	The drag component of the damper	SW and 3D print with PLA	1	0
Fan Enclosure	An enclosure that traps air, supports the fan, supports the damping door, and supports the tachometer.	SW and 3D print with PLA	1	0
Flywheel	The major inertial component of the system that will support a magnet on its radius for the hall effect sensor	SW and 3D print with PLA	1	0
Fan Shaft	The shaft that supports and rotates with the fan.	SW and 3D print with PLA	1	0
Damping Door	The door that will restrict air leaving the damper.	SW and 3D print with PLA	1	0
Deep Groove Ball Bearing	The components that interface with the fan enclosure and the fan shaft, allowing the shaft to spin freely with minimal resistance.	Purchase from Amazon	2	~3
A3144 Hall Effect Sensor	A hall effect sensor that can interface with an Arduino. Will be used to find the shaft speed over time.	Purchase from Amazon	1	~10 (10pcs)
Neodymium Magnet	A small strong magnet that will trigger the hall effect sensor.	Purchase from Amazon	1	~12 (60pcs)
Arduino UNO	Used to receive data from the hall effect sensor.	Already owned	1	0
Crank/Drill/Ripcord	Used to spin up the fan.	TBD	1	TBD
Computer	Used to receive data from the Arduino.	Already owned.	1	0
			Tax	3.25
			Total	28.25

5.2.2 Procedure

1. Using the materials in Table 1 and the system schematic in Figure 3, construct a drag damper and setup the hall effect sensor so that it records ω(t).
2. Set the damping door to the appropriate position for the given trial.
3. Using a ripcord on the fan shaft, spin up the system.
4. Find the desired parameters and record in Table 2.
    a. For the drag coefficient, k_d, find the slope of 1/ω(t) and multiply by it by J (Equation 3).
    b. For the effective viscous damping coefficient, D_{eff}, find the slope of ln(ω(t)) near the origin of the linearized model and multiply it by -J (Equation 7).
5. Repeat for different damping configurations.

Table 2 Experimental Parameter Results vs Damper Door Setting

Damping Door Setting (% area obstruction)	k_d ($N \cdot m \cdot s^2 \cdot rad^{-2}$)	D_{eff} ($N \cdot m \cdot s \cdot rad^{-1}$)
0		
25		
50		
75		
100		

6 References

[1] “Concept2 RowERG.” Accessed: Oct. 30, 2025. [Online]. Available: https://cms.concept2.com/sites/default/files/2024-06/RowErg_Specs.pdf

[2] “RowERG Product Manual.” Accessed: Oct. 30, 2025. [Online]. Available: https://cms.concept2.com/sites/default/files/2024-11/RowErg_Manual_1024.pdf

[3] “How to calculate aerodynamic drag force – x-engineer.org.” Accessed: Oct. 30, 2025. [Online]. Available: https://x-engineer.org/aerodynamic-drag/