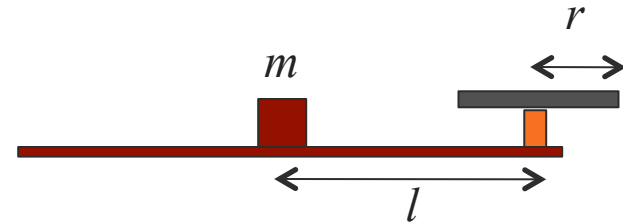# Goals

- Basic mechanics

- Control

- Design considerations

- Agility

- Component selection

- **Effects of size**

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# Agility with Scaling

- **mass, inertia**

$$m \sim l^3, \ I \sim l^5$$

since $r \sim l$

- **thrust**

$$F \sim \pi r^2 \times (\omega r)^2 \qquad \boxed{F \sim l^2 v^2}$$

*rotor angular speed*

$$a \sim \frac{F}{m} \sim l^3$$

- **moment**

$$M \sim Fl \qquad \boxed{M \sim l^3 v^2}$$

$$\alpha \sim \frac{M}{I} \sim l^5$$

**maximum accelerations**

$$a \sim \frac{v^2}{l}$$

$$\alpha \sim \frac{v^2}{l^2}$$

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# Agility with Scaling

- **mass, inertia**

$$m \sim l^3, \; I \sim l^5$$

since $r \sim l$

- **thrust**

$$F \sim r^2 v^2$$

*blade tip speed*

$$\boxed{F \sim l^2 v^2}$$

$$a \sim \frac{F}{m} \; \sim l^3$$

- **moment**

$$M \sim Fl$$

$$\boxed{M \sim l^3 v^2}$$

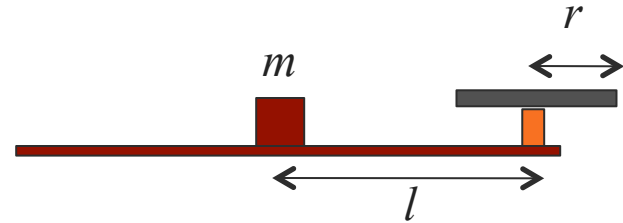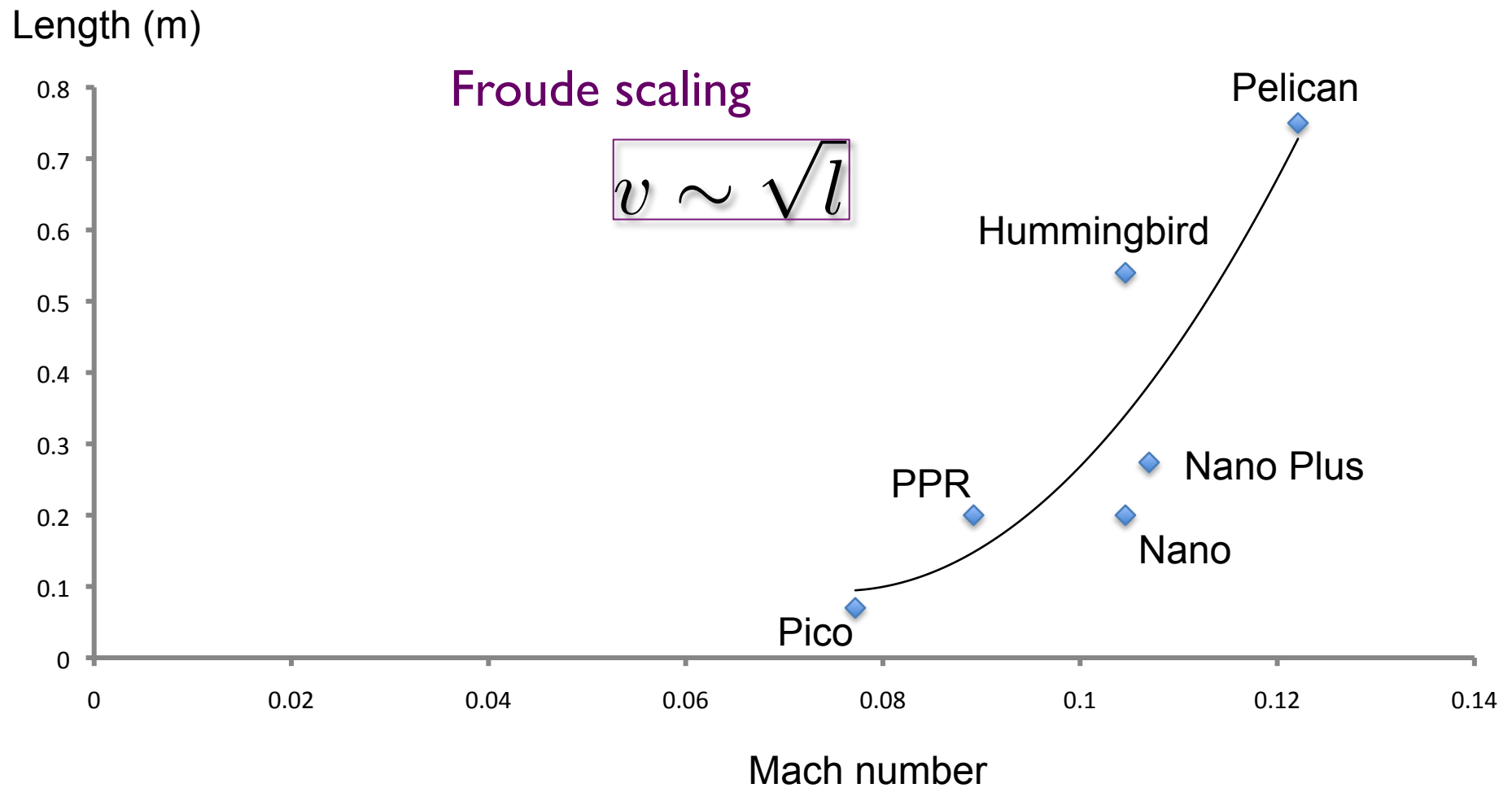$$\alpha \sim \frac{M}{I} \sim l^5$$

### maximum accelerations

$$a \sim \frac{v^2}{l}$$
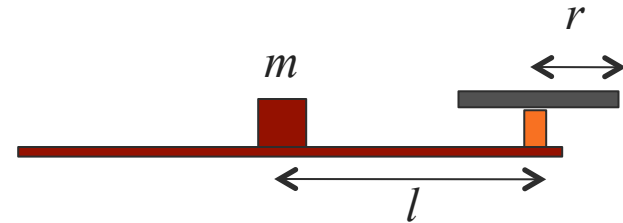
$$\alpha \sim \frac{v^2}{l^2}$$

# Scaling Experiments



**Length (m)** (y-axis)

Froude scaling

$$v \sim \sqrt{l}$$

Data points: Pelican, Hummingbird, Nano Plus, PPR, Nano, Pico

**Mach number** (x-axis)

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# Agility with Scaling



- Froude scaling

$$v \sim \sqrt{l}$$

$$F \sim l^3$$

$$\boxed{a \sim 1, \ \alpha \sim \frac{1}{l}}$$

- Mach scaling

$$v \sim 1$$

$$F \sim l^2$$

$$\boxed{a \sim \frac{1}{l}, \ \alpha \sim \frac{1}{l^2}}$$

*The maximum angular acceleration tends to be higher from smaller vehicles*