The PHY 357: Intermediate Physics Lab final projects presentation

First experiments from the SUNY Cortland wind tunnel

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Emily DeClerck

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Zachary Fernandez

Cody Johnson

Victoria Kilfeather

Avery Tompkins

Cody Wagner

Demani Williams

and Dr. Eric Edlund

Assistant Professor, Physics

May 7, 2021

Outline of the presentation

- History of the wind tunnel
- Brief overview of fluid dynamics theory
- Project 1: characterization of the wind tunnel
- Project 2: drag forces on sports balls
- Project 3: drag forces on vehicles
- Project 4: lift forces on wings
- Conclusions and outlook

Wind tunnels in many sizes, shapes, and speeds

Large & full-scale wind tunnels

NFAC (US Air Force)

16S (US Air Force)

Medium-scale wind tunnels (usually recirculating)

Textron Aviation

Ferrari

Small-scale wind tunnels (usually open)

Tec Equipment, Inc.

Original Wright brothers wind tunnel

History of the SUNY Cortland wind tunnel

January: construction begins

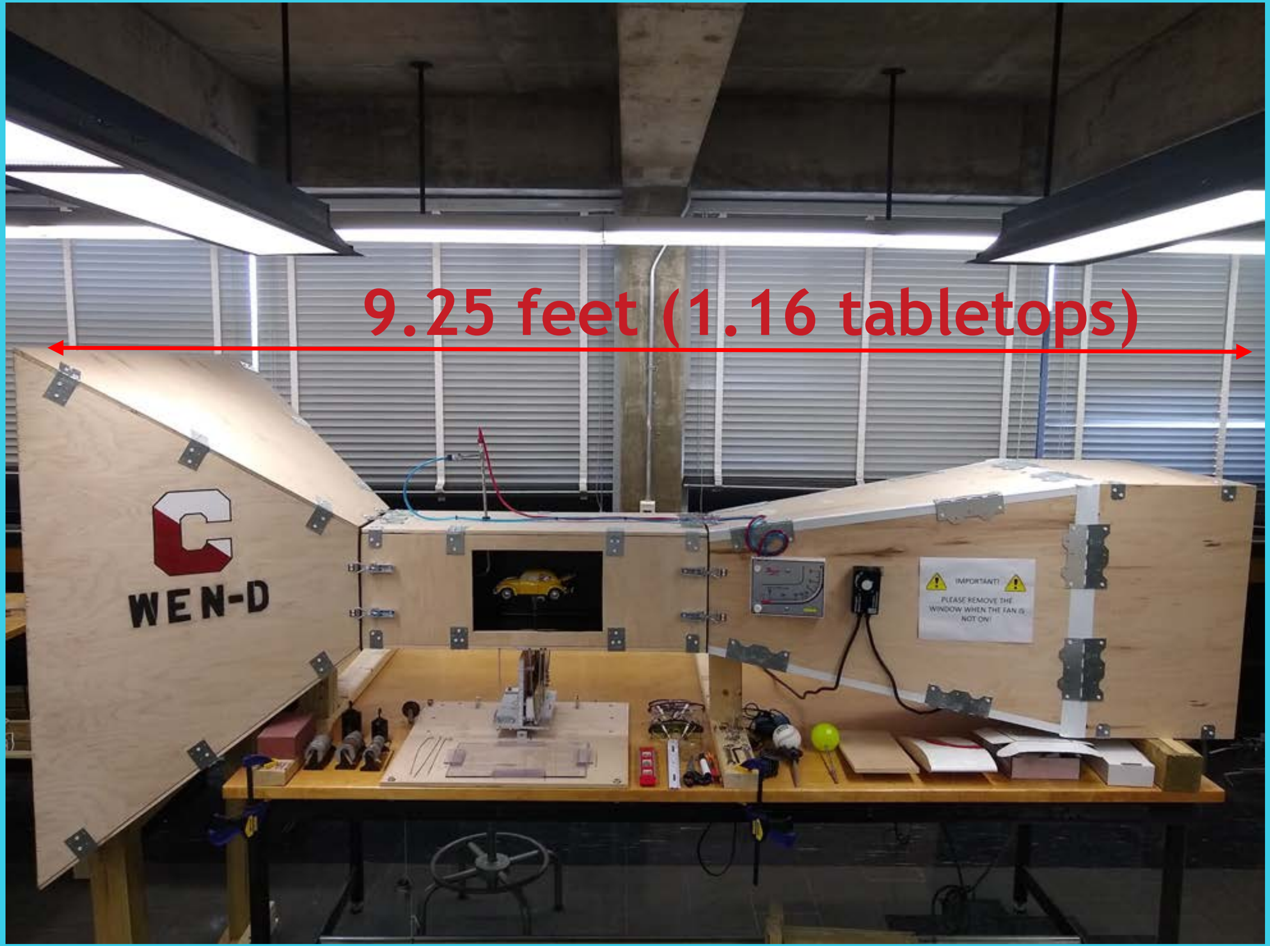
February: construction complete

March: faculty development grant to purchase measurement equipment

April: first measurements

May 7: first presentation of experiments

Windy ENvironment Developer (WEN-D)



Velocity measurements: Pitot tube

Lift and drag measurements: 2-axis force balance

Theory part 1: the force law

Navier-Stokes equation:

$$\rho \frac{d}{dt}\vec{v} = -\vec{\nabla}p + \mu\nabla^2\vec{v} + \sum\vec{F}_{ext}$$

response internal forces external forces

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response internal forces external forces

A special case of Newton's 2nd law:

$$m\frac{d}{dt}\vec{v} = \sum\vec{F}$$

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response internal forces external forces

A special case of Newton's 2nd law:

$$m\frac{d}{dt}\vec{v} = \sum\vec{F}$$

In dimensionless form:

$$\frac{d}{dt}\vec{v} = -\frac{1}{\mathrm{M}^2}\vec{\nabla}p + \frac{1}{\mathrm{Re}}\nabla^2\vec{v} + \ldots$$

Mach number: $\mathrm{M} = \frac{v}{v_{th}} \sim \frac{\text{inertial motion}}{\text{thermal moton}}$

Reynolds number: $\mathrm{Re} = \frac{\rho v L}{\mu} \sim \frac{\text{inertial force}}{\text{viscous force}}$

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(experiment < 0.05)
(can treat air as uniform)

Reynolds number: $\mathrm{Re} = \frac{\rho v L}{\mu} \sim \frac{\text{inertial force}}{\text{viscous force}}$

(experiment: 10^4 - 10^5)
(car @ 60 mph ~ 3 x 10^6)

Theory part 2: conservation laws

The Bernoulli equation:

(conservation of energy)

$$p + \frac{1}{2}\rho v^2 = p_0$$

background pressure
(where v = 0)

pressure

density
of air

flow velocity

Theory part 2: conservation laws

The Bernoulli equation:

(conservation of energy)

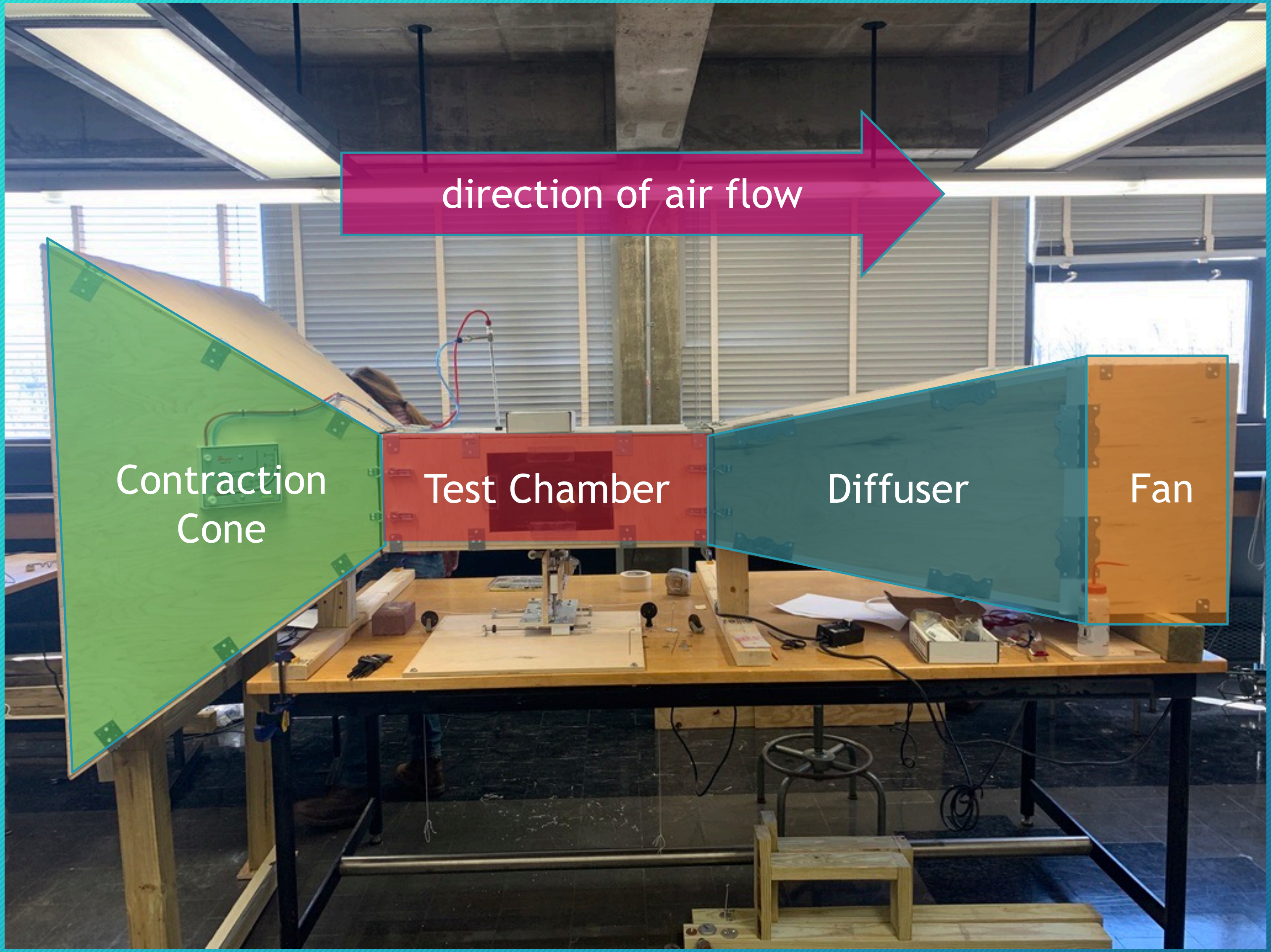
$$p + \frac{1}{2}\rho v^2 = p_0$$

- pressure
- density of air
- flow velocity
- background pressure (where v = 0)

Conservation of mass for **systems with 1D motion:**

$$Av = \Gamma$$

- cross-sectional area
- flow velocity
- mass flux rate (a constant)



<u>Contraction Cone</u>

High Pressure

Low Velocity

<u>Test Chamber</u>

High Velocity

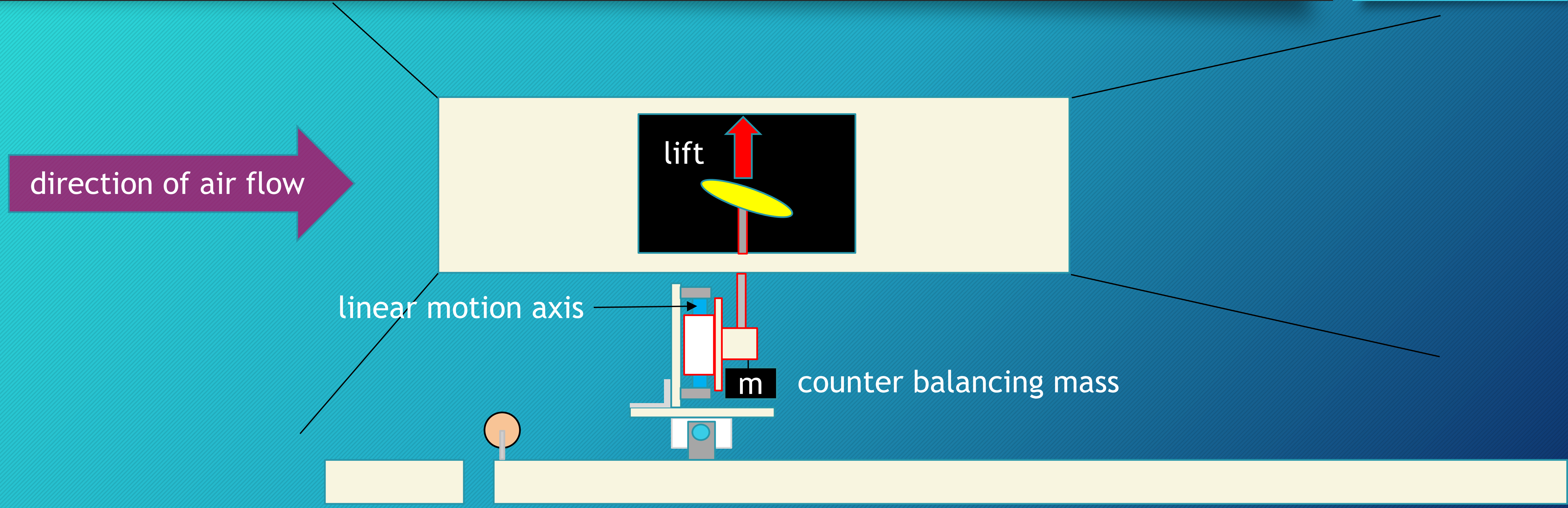
Low Pressure

<u>Diffuser</u>

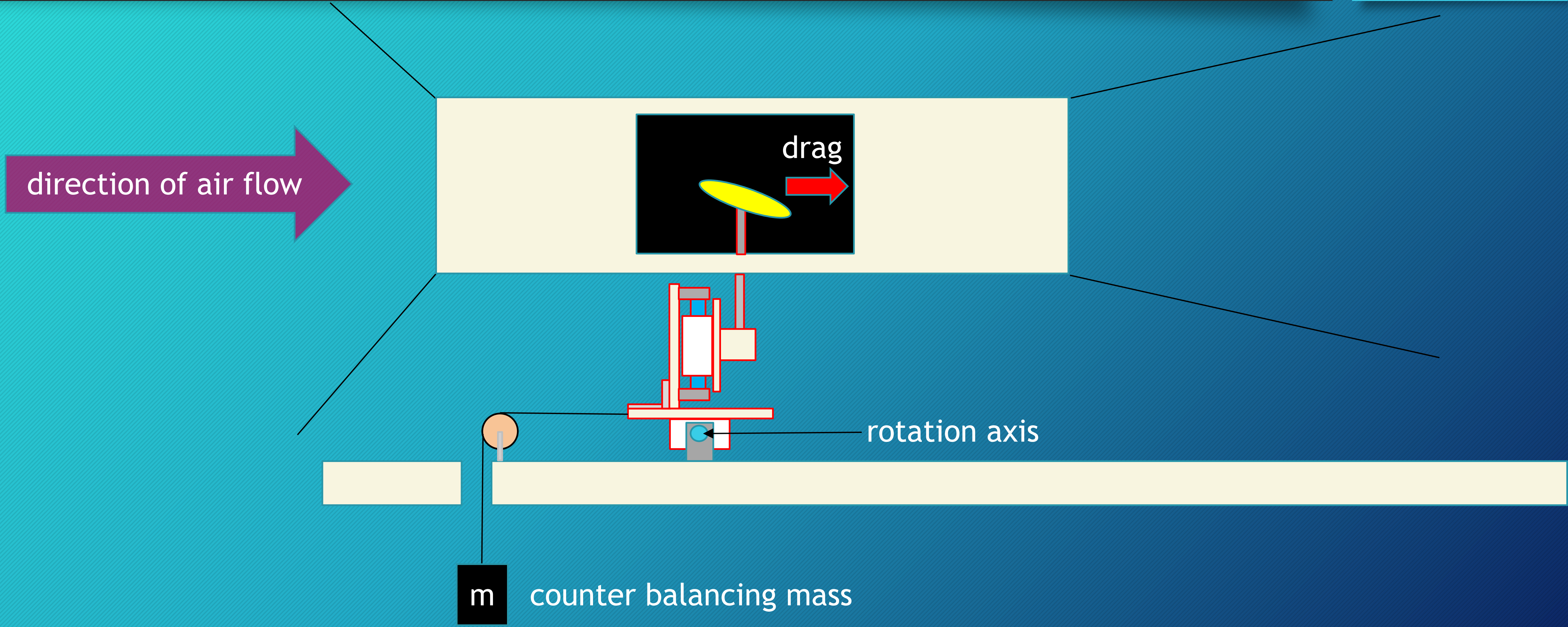
High Pressure

Low Velocity

The force balance: measuring LIFT forces



The force balance: measuring DRAG forces



Project 1: Wind tunnel characterization

Chelsea Allain, Greg Cassiano, Victoria Kilfeather

- How can a Pitot tube be used to calculate for velocity in a wind tunnel?
- What are the differences in velocity throughout the wind tunnel?

Two methods for measuring wind speed

Method 1: the anemometer

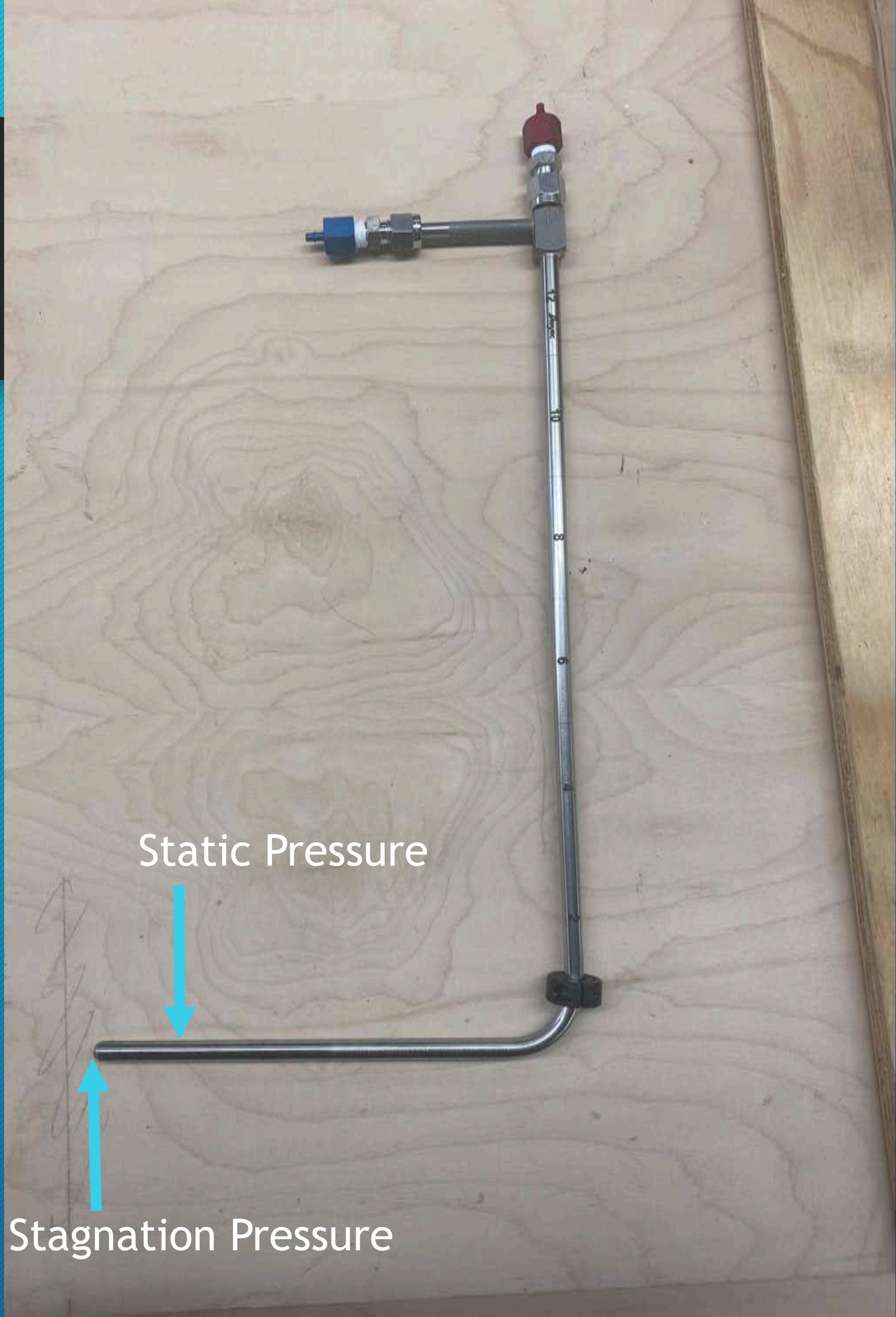
Method 2: the Pitot tube

Measure pressure at two locations

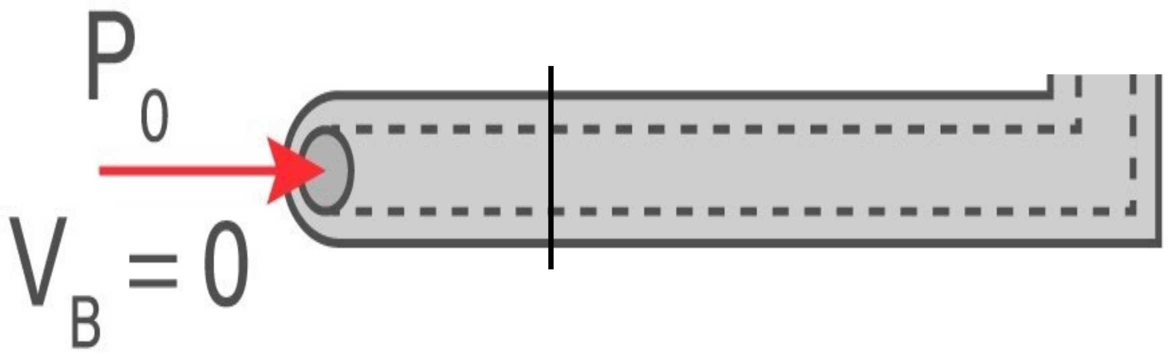
Rearrange the Bernoulli equation to solve for velocity:

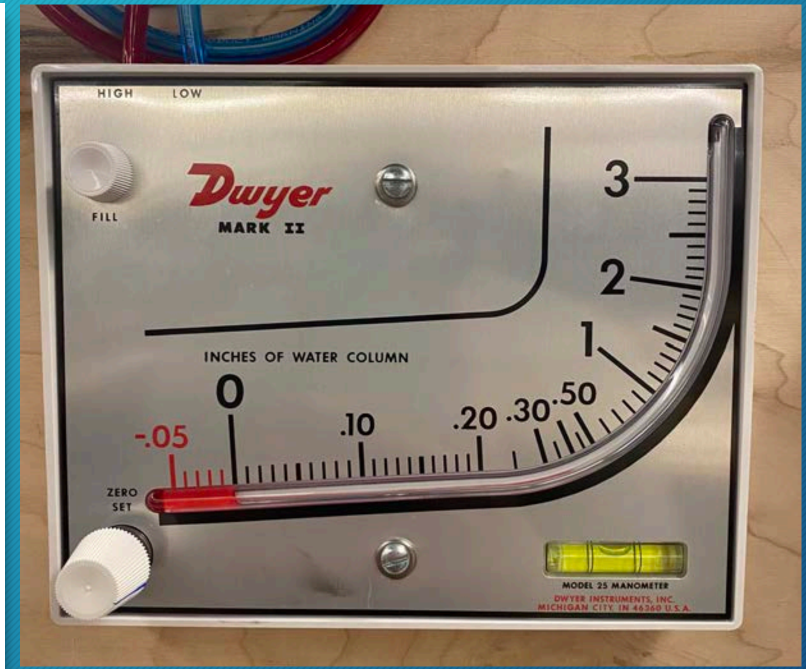
$$v = \sqrt{\frac{2\,\Delta p}{\rho}}$$

Δp = Stagnation Pressure – Static Pressure



PITOT TUBE EXPERIMENT





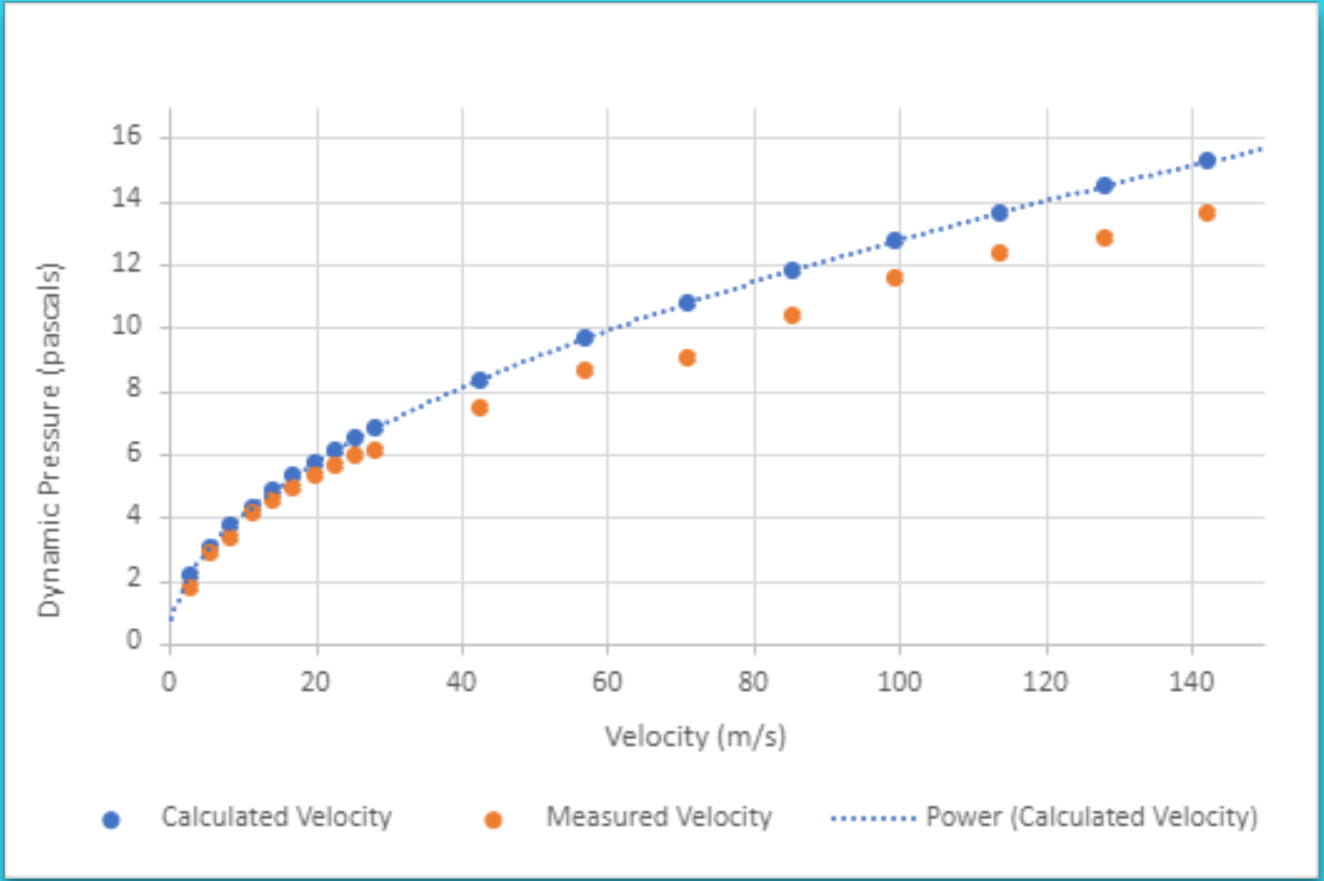
Pressure gauge uses units of inches of water

Conversion equation is $V\ {}^{m}/_{s} = \sqrt{\frac{2(\Delta P * 284.84)}{1.225\ {}^{kg}/_{m^3}}}$ or $V\ {}^{m}/_{s} = 21.56\sqrt{\Delta P}$.

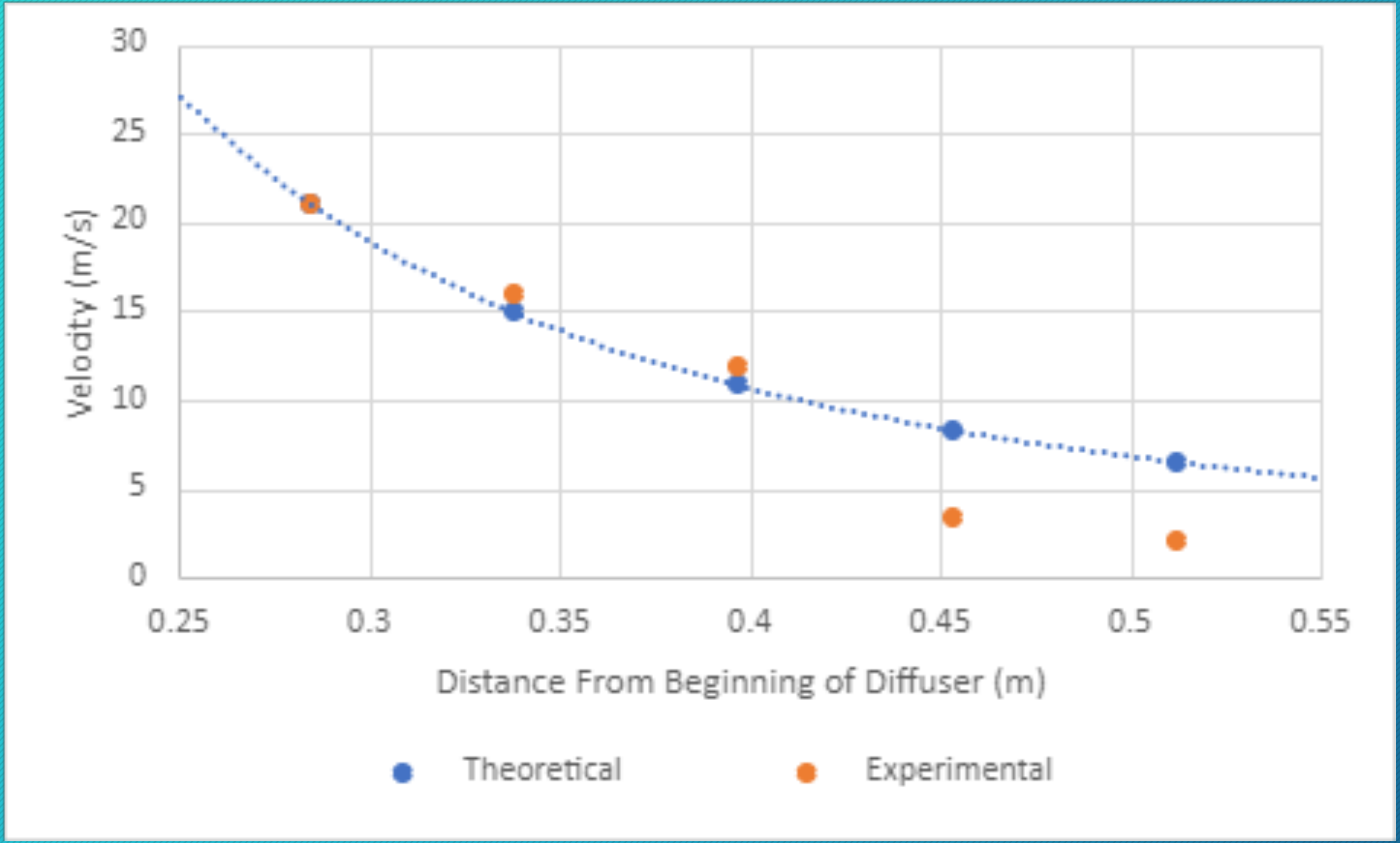
Pitot Tube

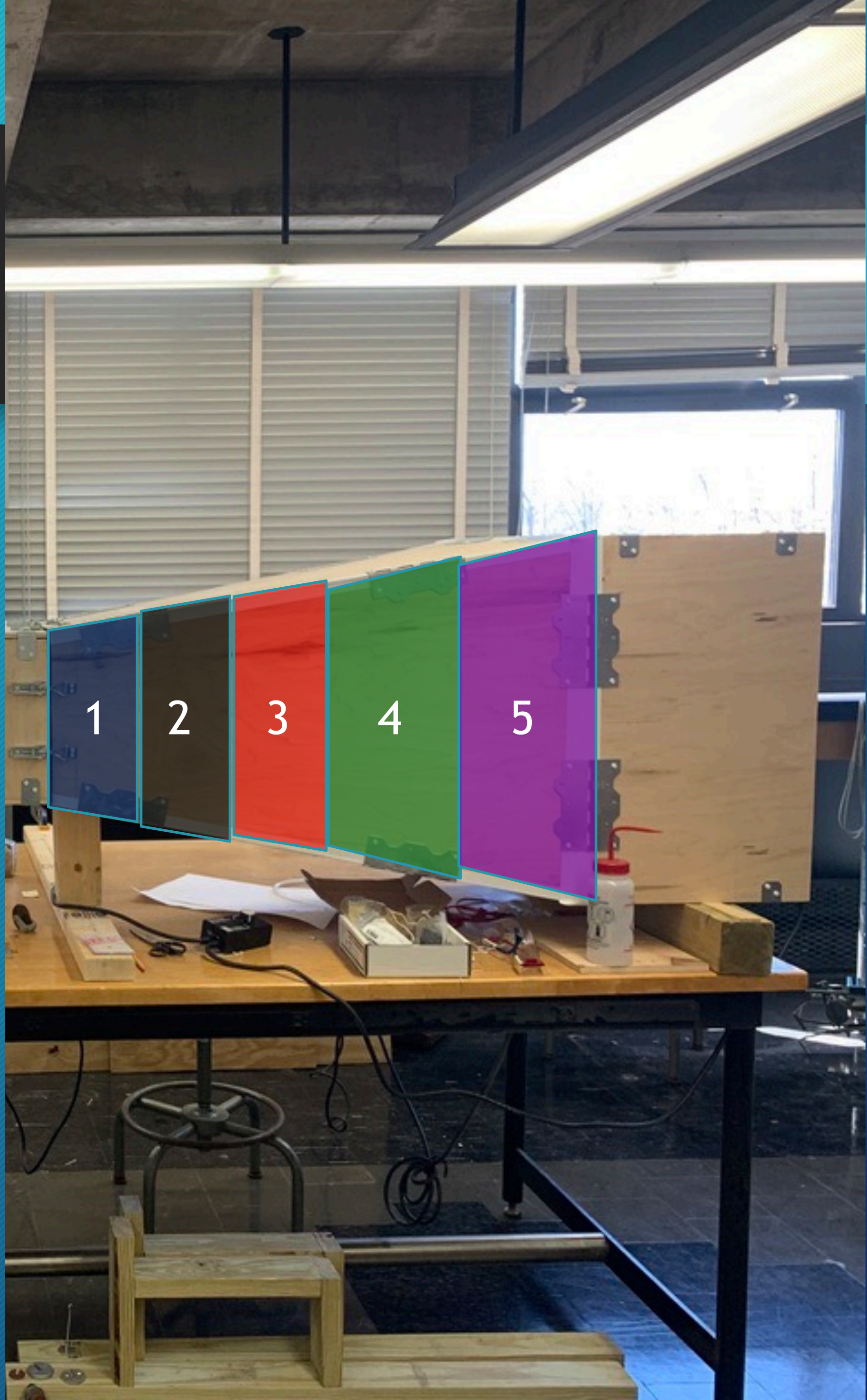
Comparing Pitot tube and anemometer data

- All measurements shown on this graph were taken in the testing chamber
- The pitot tube and the anemometer were in the middle of the testing chamber.



Velocity variation in the diffuser





Project 2: Measuring drag coefficients of sports balls

Jose Diaz Duran, Avery Tompkins, Dakota (Cody) Wagner

- How much does the surface texture of a sphere impact the force of drag?
- Using the wind tunnel, we measured the drag of spheres of different surface texture
- Measured the drag forces on a lacrosse, tennis, blitz, and baseball
- Balanced at zero wind speed, then increased the speed to measure the force of drag on each sphere

Theoretical model of turbulent drag

Drag force: $F_{drag} = \frac{1}{2}\rho v^2 C_d A$

Solving for the drag coefficient:

$$C_d = \frac{2\,F_{drag}}{\rho_{air} v^2 A}$$

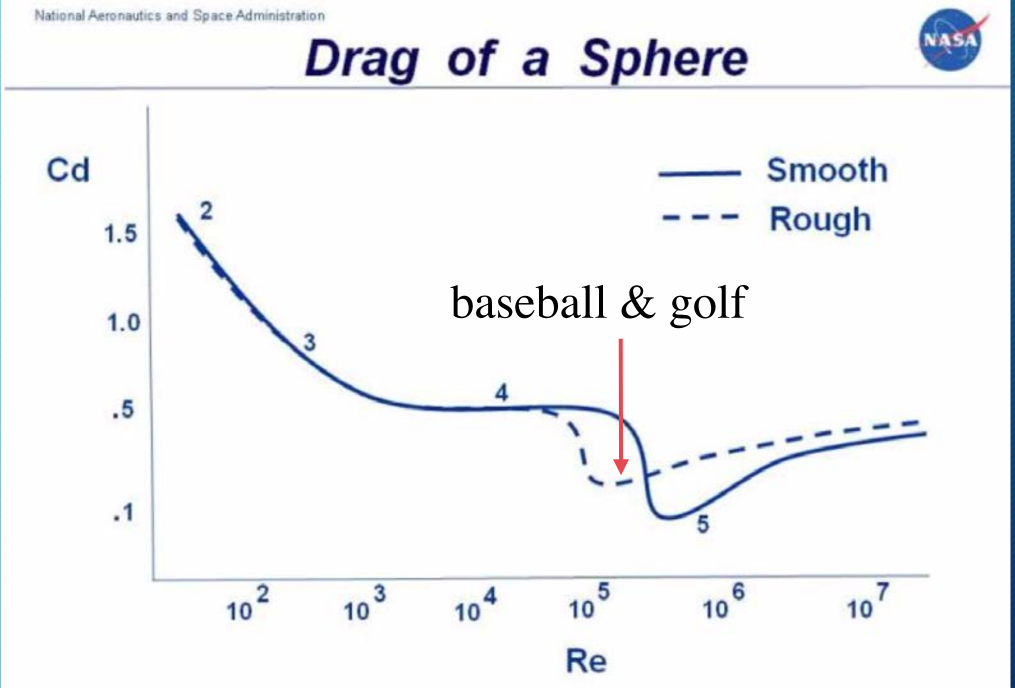
Where:

ρ = density of air

v = wind speed

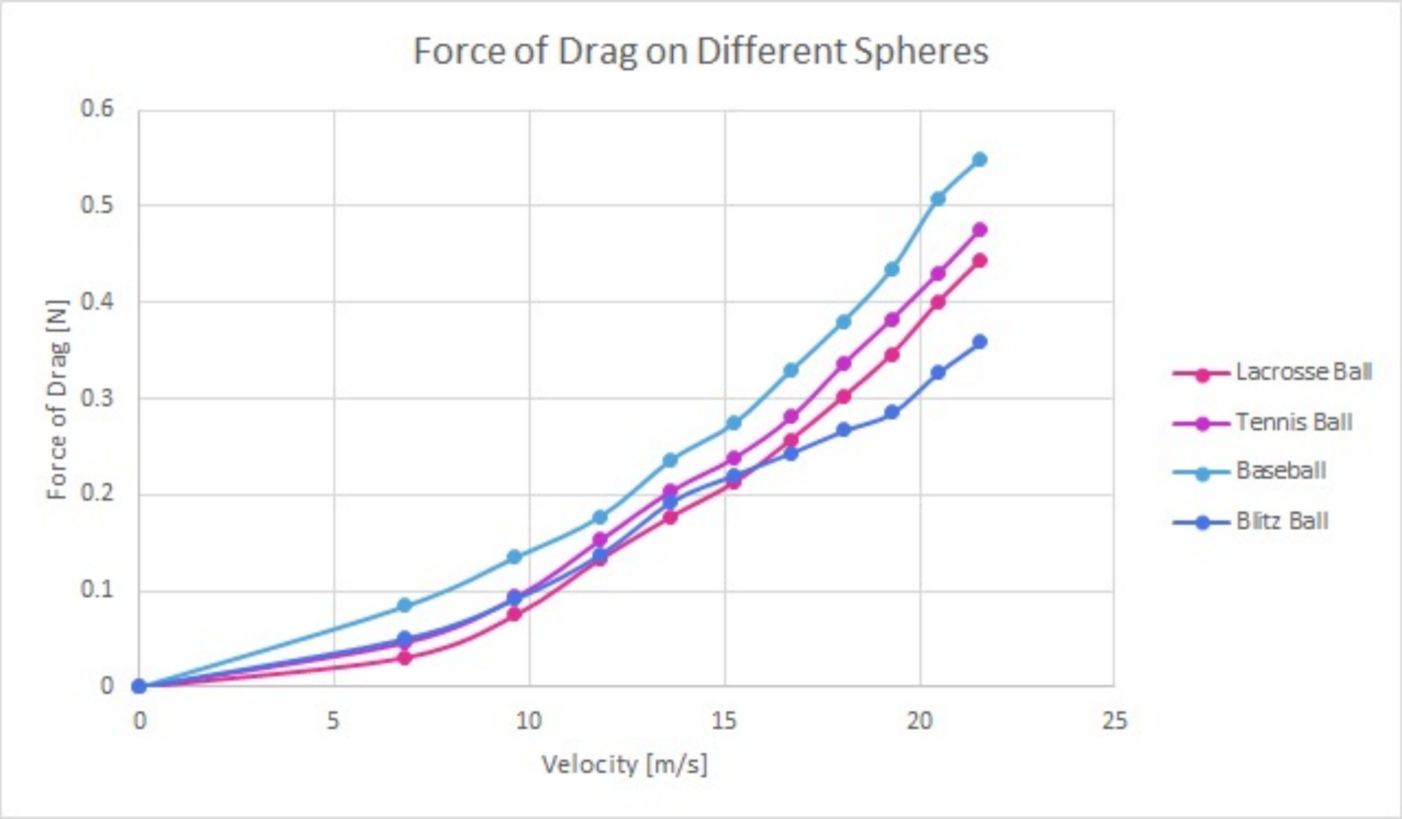
C_d = drag coefficient

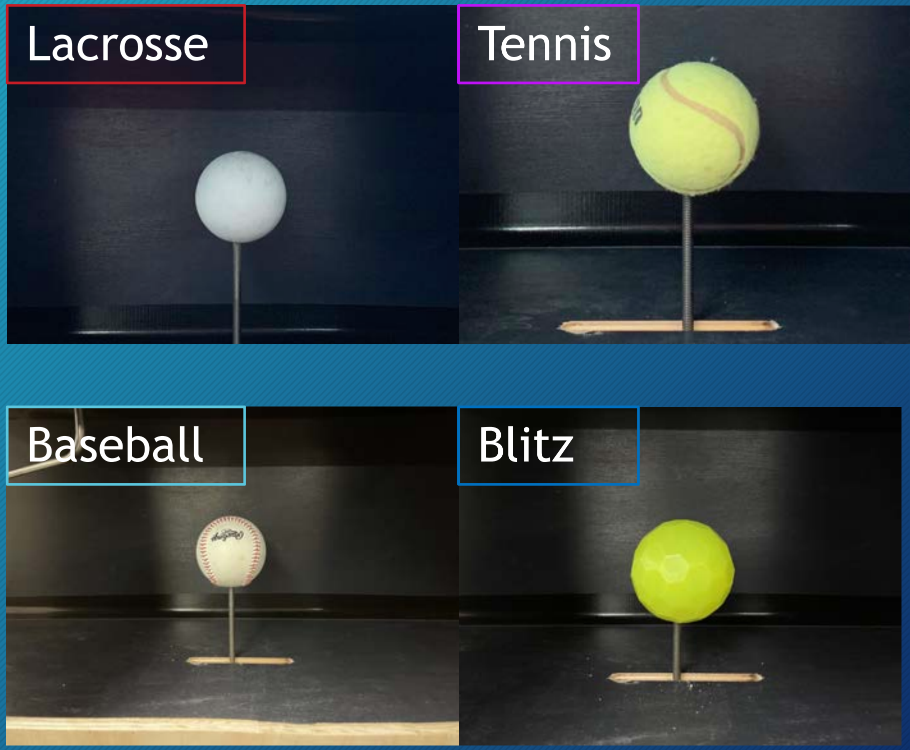
A = cross-sectional area



From: www.grc.nasa.gov/www/k-12/airplane/dragsphere.html

Drag forces measured at different speeds

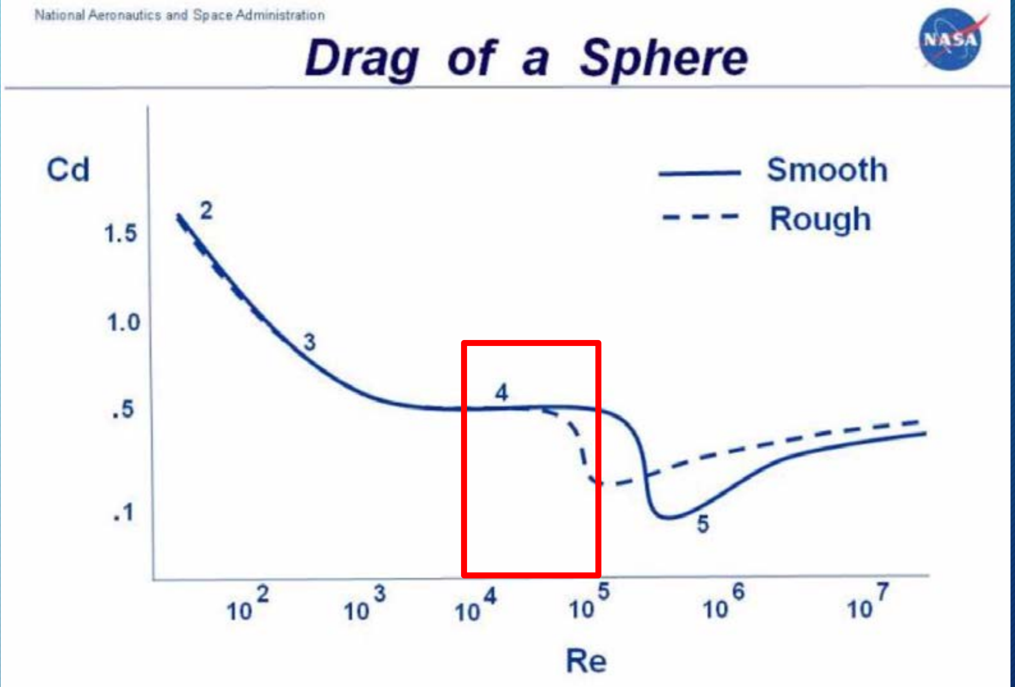




Analysis

Spherical Object	Coefficient of Drag
Blitz ball	0.45 ± 0.06
lacrosse ball	0.49 ± 0.05
tennis ball	0.51 ± 0.02
baseball	0.64 ± 0.10

- These measurements support the idea that the shape/surface features affect the aerodynamics.
- All 4 balls behaved as expected with the coefficient of drag equal to 0.5 (within error bars).



Project 3: Drag forces on cars

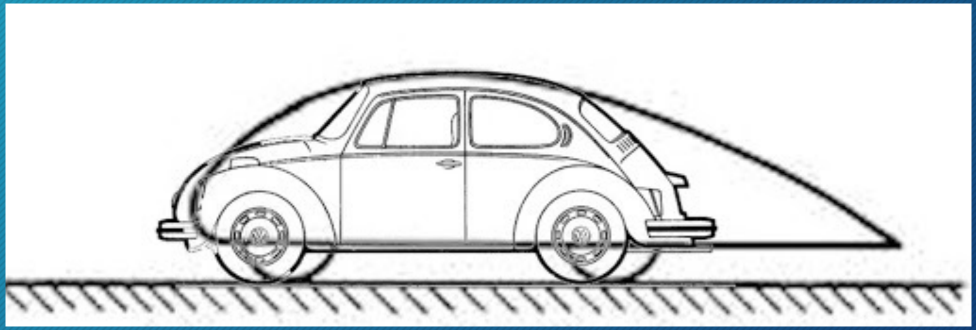
Joseph (Joey) Cirillo, Cody Johnson, Demani Williams

Drag can be a good thing or a bad thing, depending on the application.

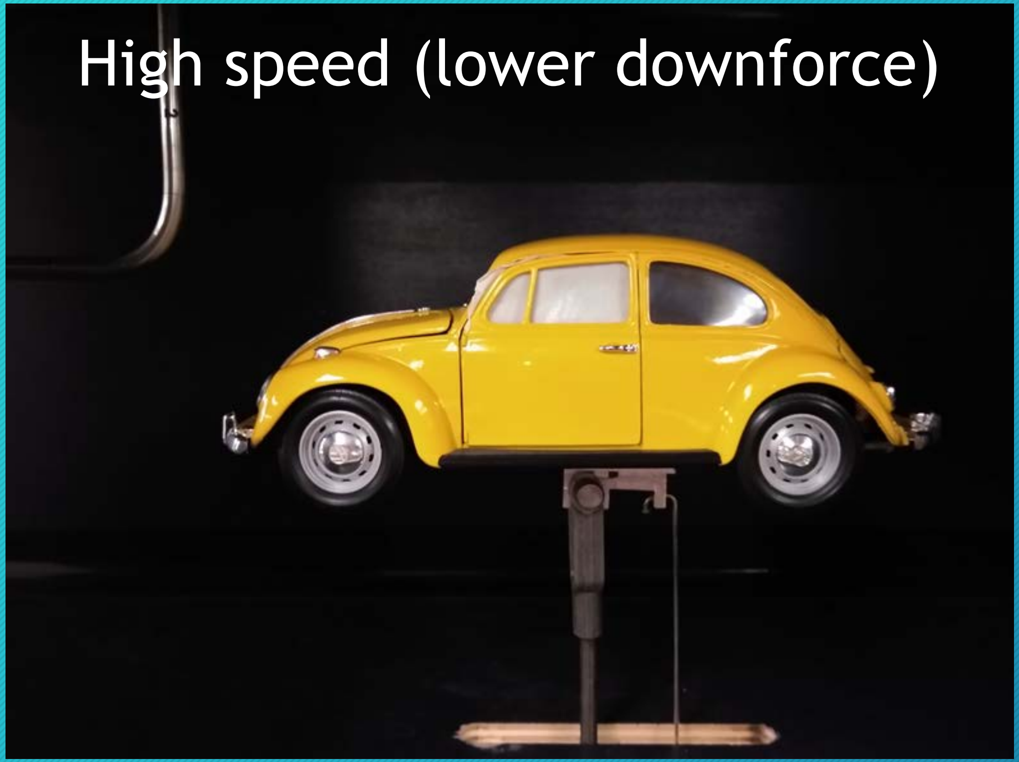
- Modern efficiency vehicles: C_d ~ 0.2
- Volkswagen Beetle: C_d ~ 0.5
- Formula 1 racecar: C_d ~ 0.7 - 1.1

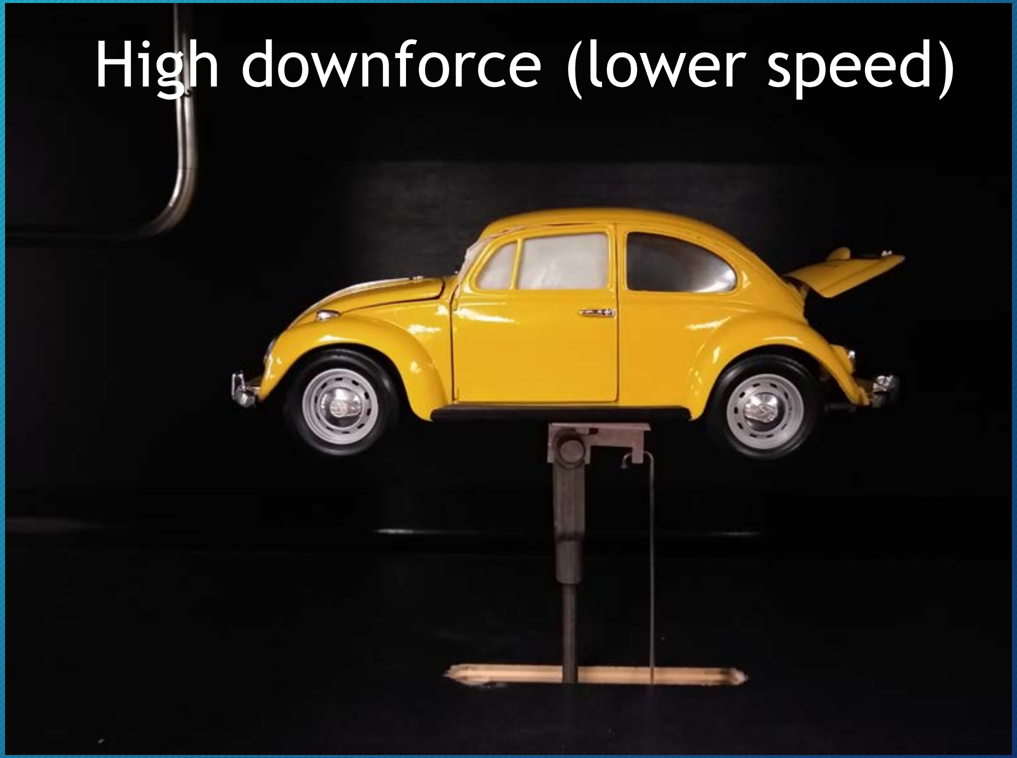
Background Information

- Most vehicles are designed to be as aerodynamic as possible
  - Lower Coefficient of Drag (Cd) requires less energy to travel through air
- Vehicles require downforce to create the appropriate normal force
  - Increase in normal force causes increased friction between tires & surface
  - Example: Formula 1, NASCAR, Sports Cars, etc... (Cd> 0.5)

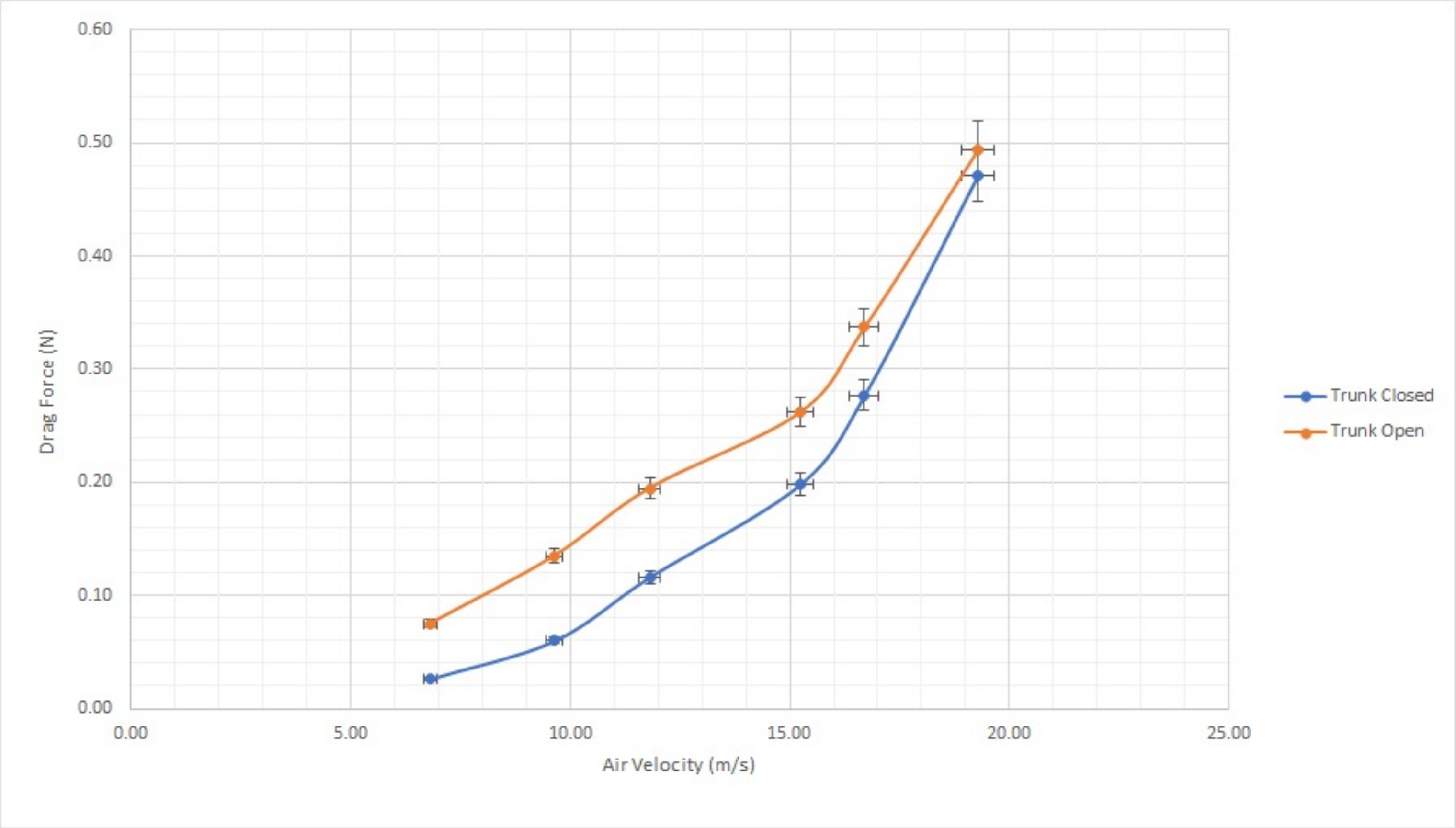


Modeling the F1 rear wing





Drag Force vs. Air velocity of Scale VW Beetle



- Results do not exhibit a simple v^2 relationship

Drag Coefficients (Cd):

- Trunk closed = 0.26
- Trunk open = 0.40

- The trunk open C_d is larger, in agreement with expectations.

Using the measured C_d to calculate max speed

- Characteristics of a 1967 VW Beetle
  - Stock engine: 53 HP (@ 85% efficiency = 34 kW)
  - Actual size is 20x larger than scale model
  - C_d (trunk closed) = 0.26
  - C_d (trunk open) = 0.40

- $P_{max} = (F_{drag})(v_{max})$
  - Solving for v_{max} →

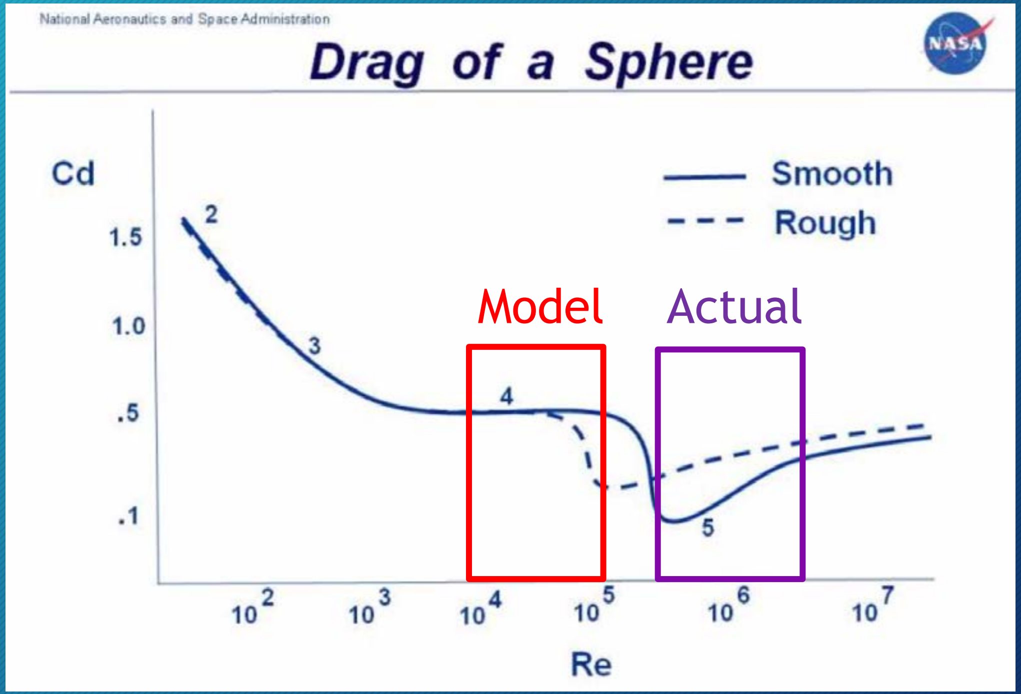
$$v_{max} = \sqrt[3]{\frac{Power}{\frac{1}{2}\rho_{air} C_d A}}$$

- Trunk Closed: v_{max} = 103 mph
- Trunk Open: v_{max} = 89 mph

Actual 67' Beetle Top Speed: 70 mph

Summary

- Calculated v_{max} is higher than actual v_{max}
- It is possible that the turbulent drag forces in the wind tunnel are not the same as full-scale flows.
  - Re_{model} ~ 100,000
  - Re_{actual} ~ 2,000,000

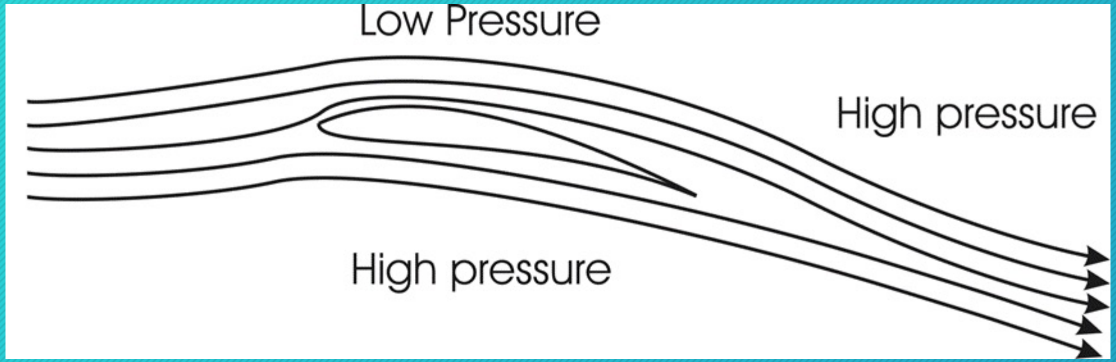


Project 4: The influence of wing shape on lift

Emily DeClerck, Zachary Fernandez

- How does wing shape affect lift?
- How does the angle of the wing affect lift?

Introduction of Wings



- Two main effects create lift in wings:
  - Lower pressure above the wing (shaping)
  - Redirection of the air flow (angle of wing)

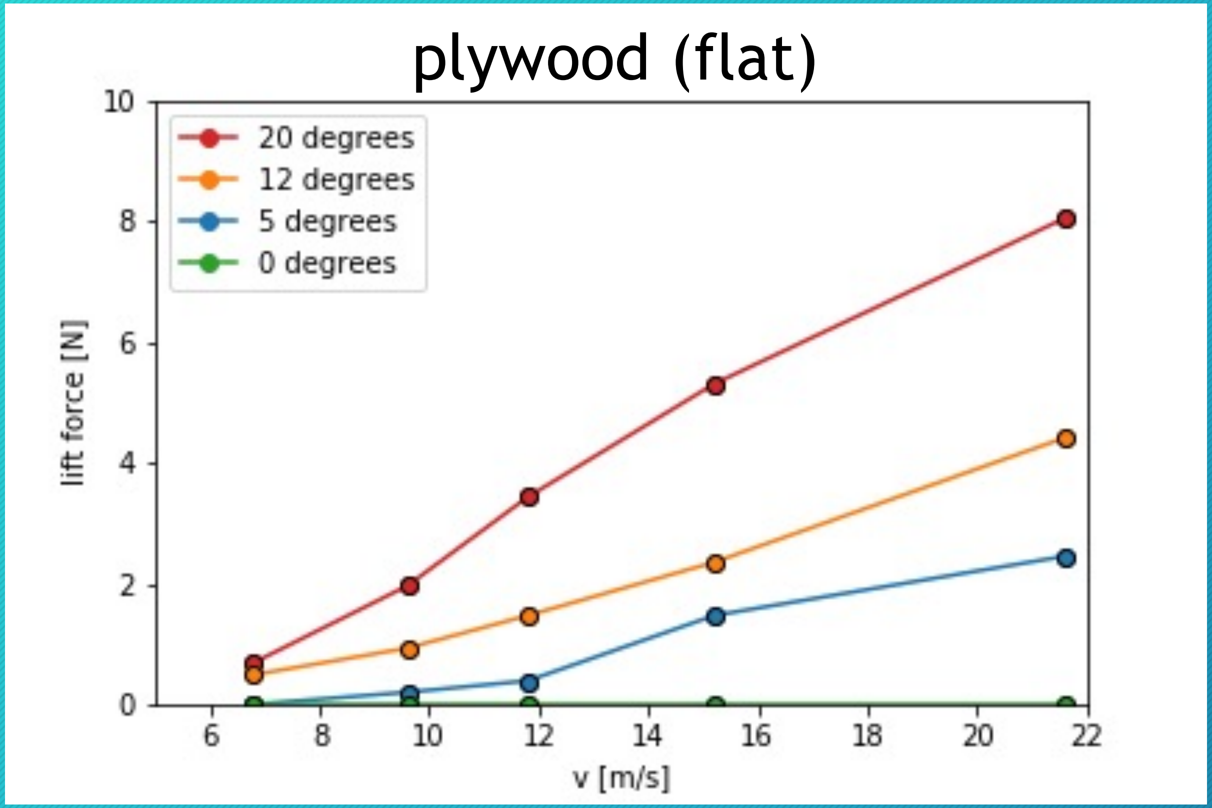
Types of Wings

- Wing #1: flat plywood
- Wing #2: a shaped wing from a model airplane

Types of Wings

- The wings have the same base area and mounting locations.

Lift increases with pitch angle (stall point not observed)



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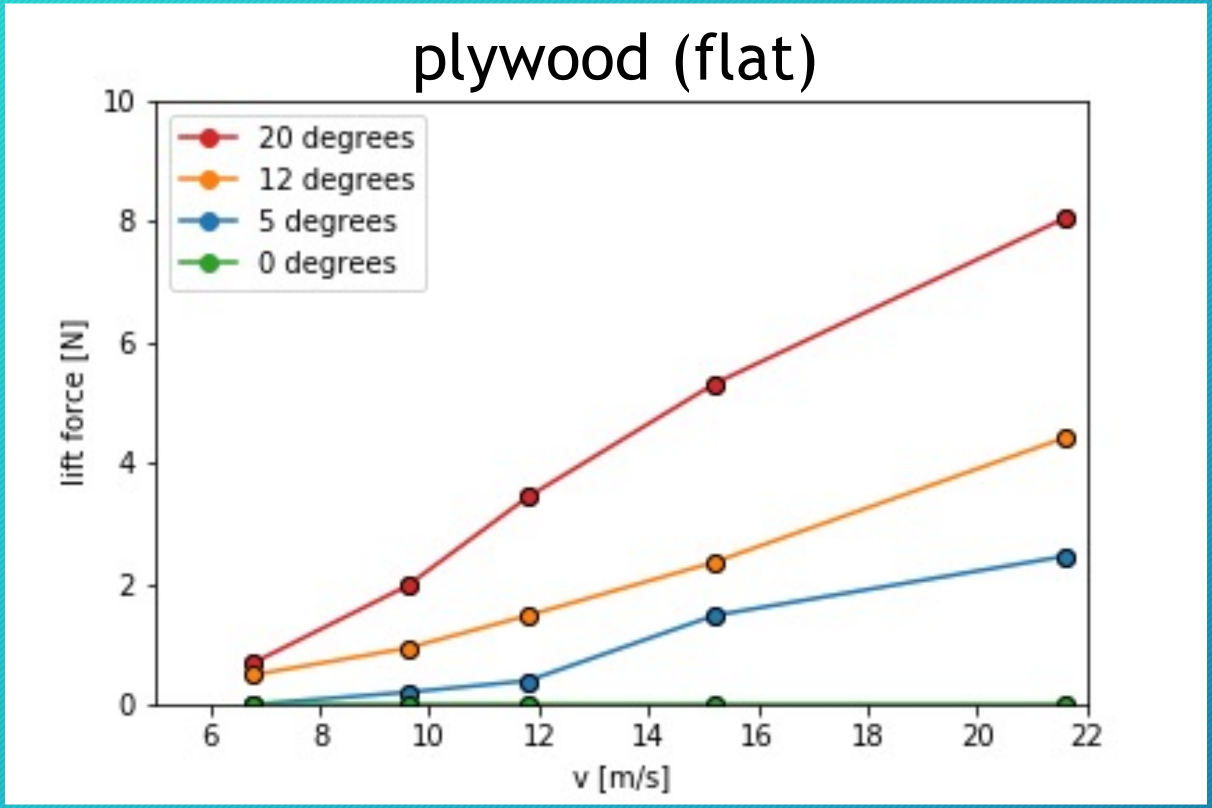
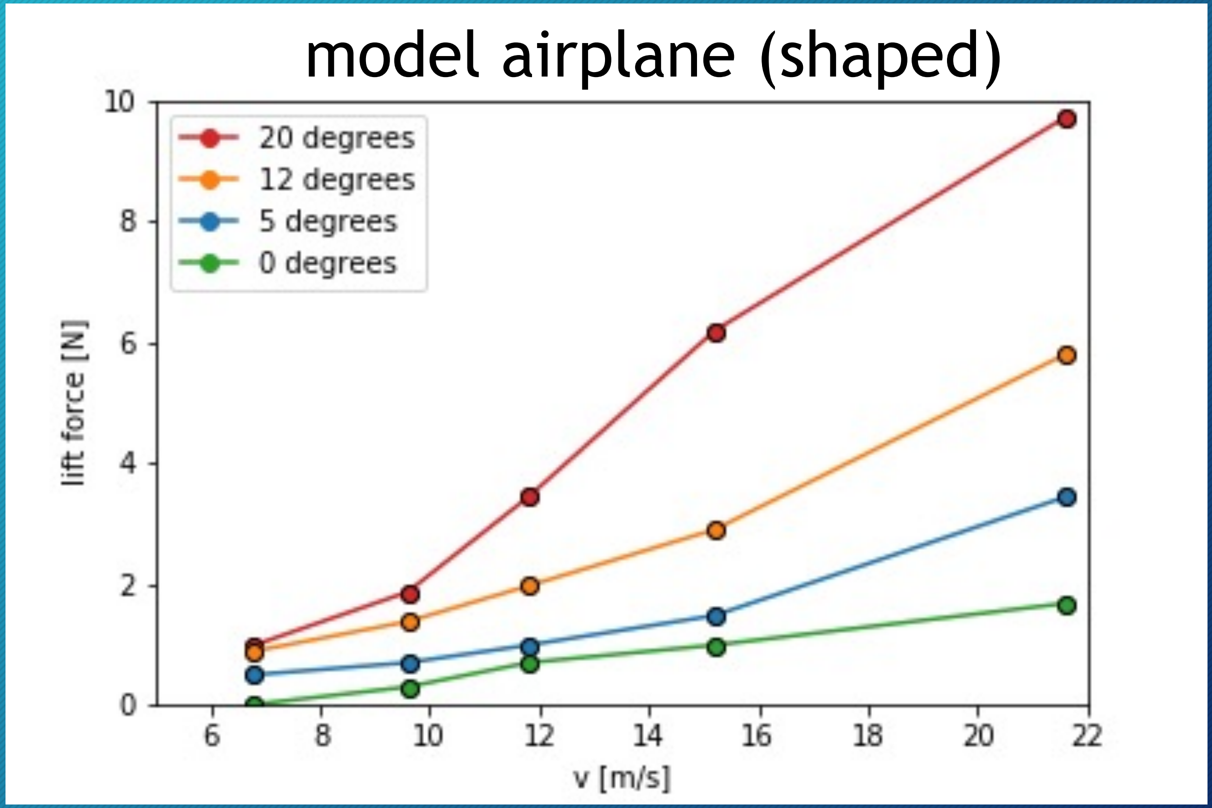
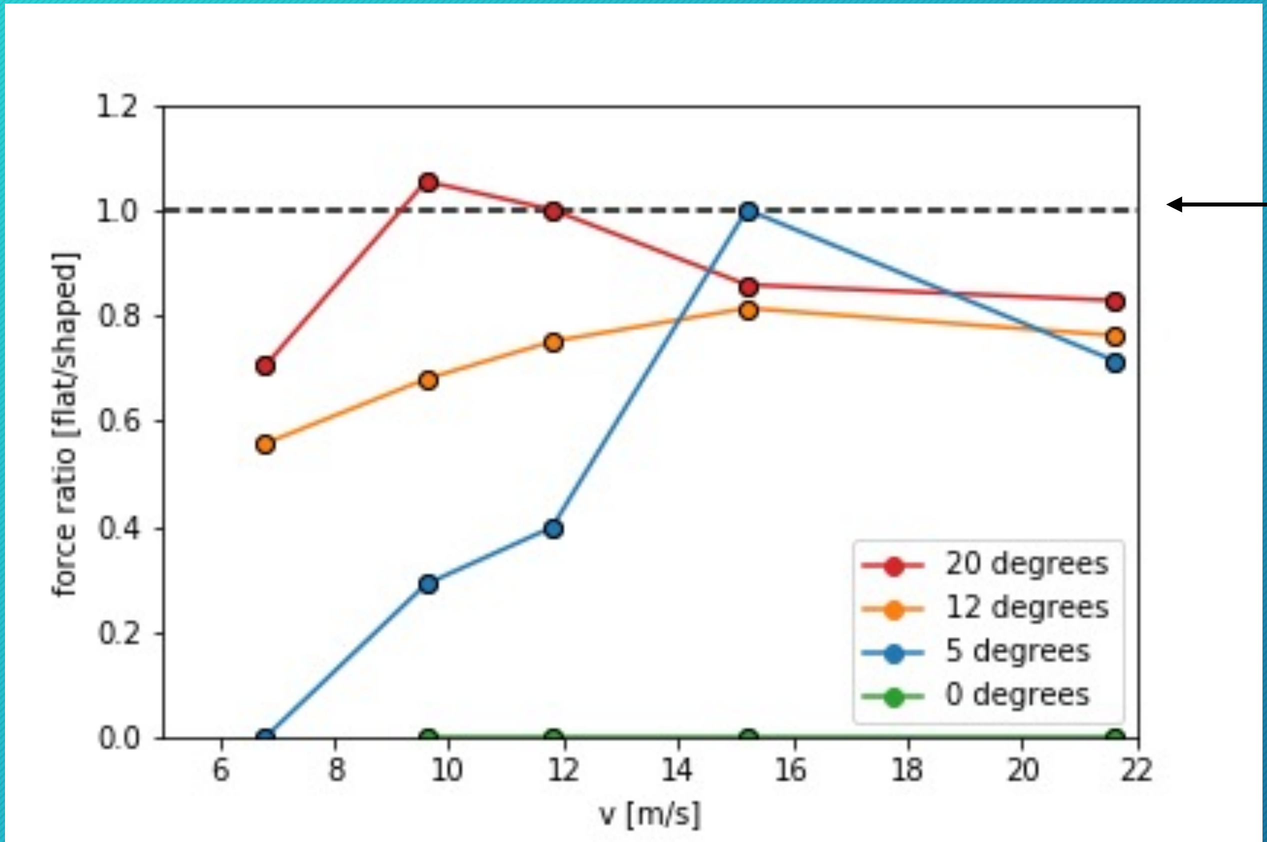




Pitch angle is more important than shaping at pitch angles above ~10 degrees



At a ratio of 1 the two wings behave the same

Conclusions and outlook

- Project 1: wind tunnel characterization
  - Pitot tube seems reliable, but further work needed to refine accuracy

•Project 2: drag forces on sports balls

  - Measurements strikingly close to the expected value of 0.5
  - Some tantalizing results about a ball with an unusual ball (the Baseball)

•Project 3: drag forces on vehicles

•Seem to be measuring drag coefficients considerably lower than expected

•This may be due to problems with extrapolation to higher Re

- Project 4: lift forces on wings

•Lift force from shaping (pressure effect) is measurable

•For non-zero angles of inclincation the dominant effect rapidly becomes the pitch angle