What we (and our students) can learn from radio-controlled flight?

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WHERE DISCOVERIES BEGIN

Interdisciplinary Science and Engineering Partnership and Division of Materials Research

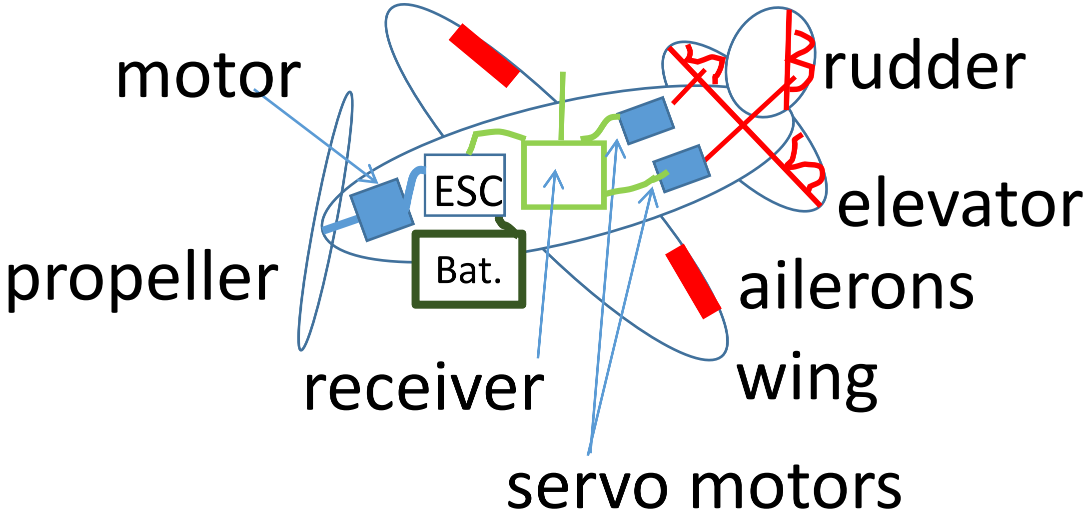
Flight

Forces, work, power, electric motors, energy storage…

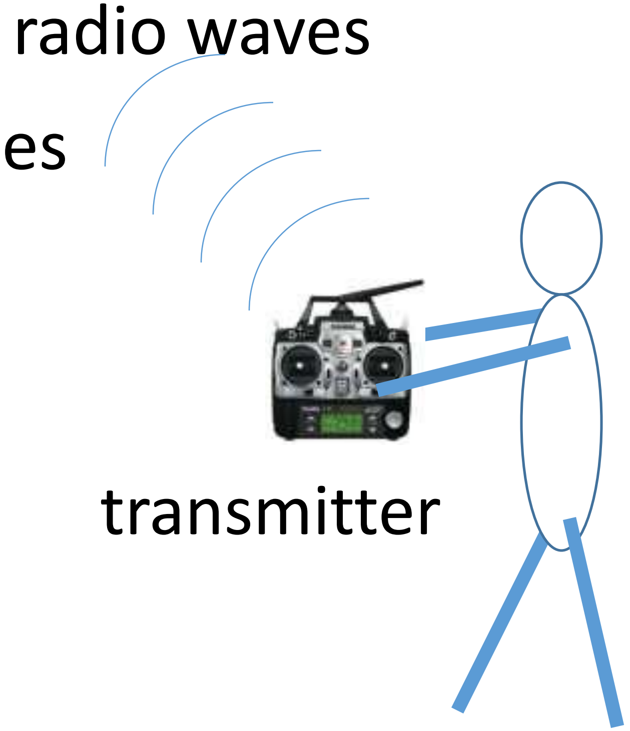
radio-controlled

Radio waves, polarization, signal, AM/FM, digital…

What is a radio controlled (RC) airplane?

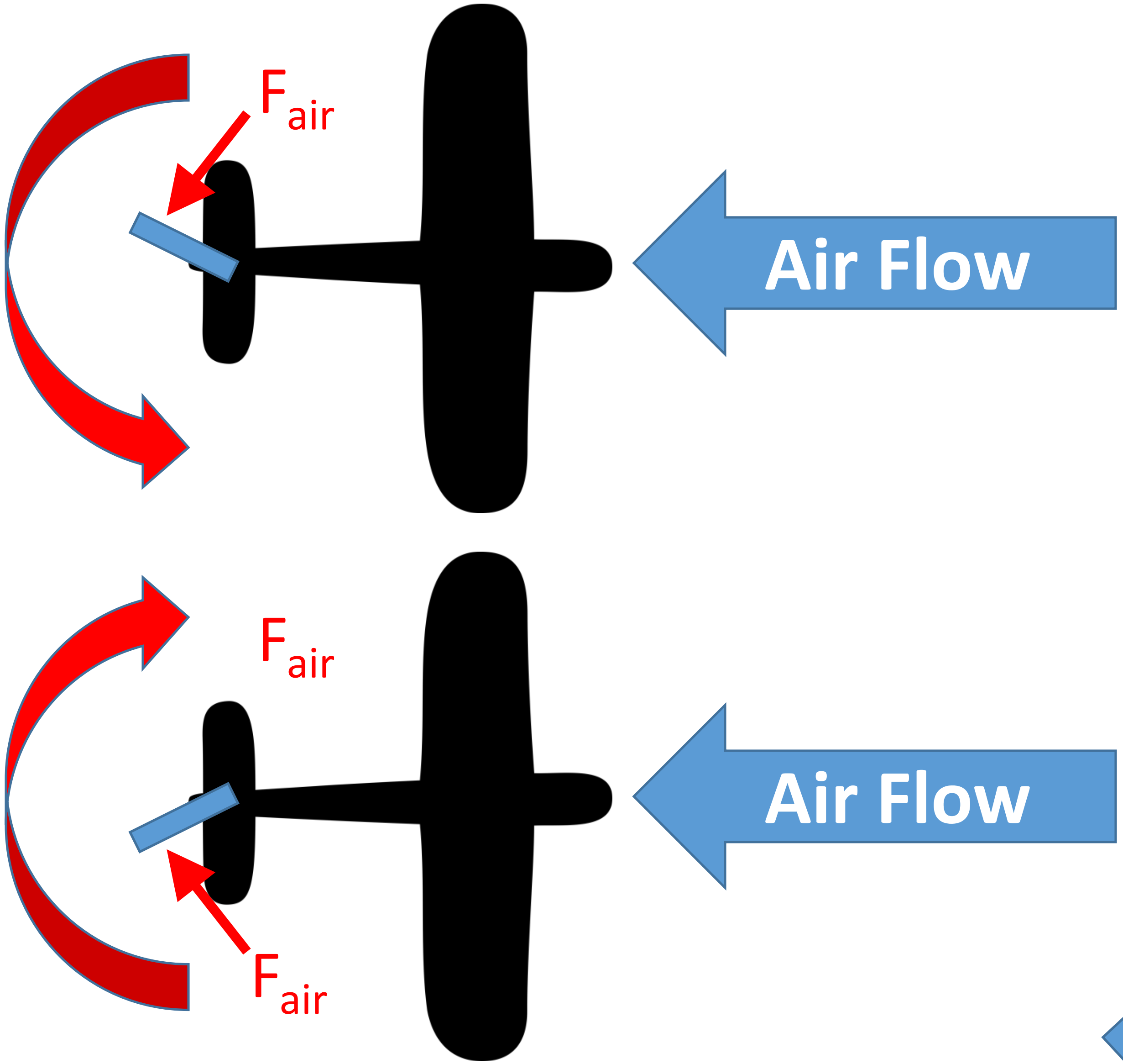


How does a plane gain altitude?

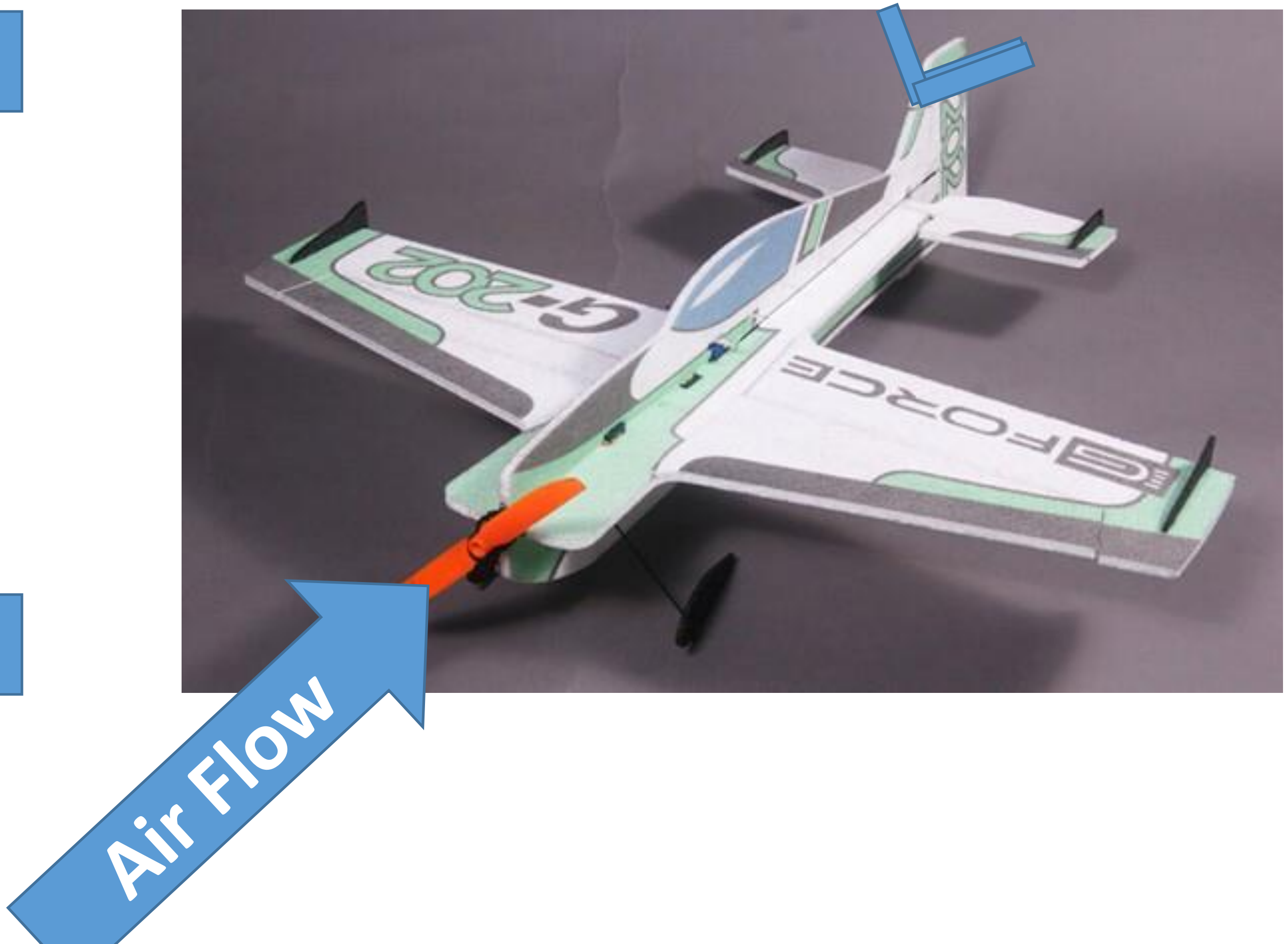


Demo 1: Using a radio to move control surfaces

How control surfaces work



Demo 2: Using rudder on model airplane



Types of RC planes:

Gas powered

Hobby
1m wingspan
1 kg (2 lbs)

Hobby, Jet turbine, 340 mph!

Military
15 m wingspan
500 kg (1100 lbs)

1900 mile flight across the Atlantic Ocean! 11 lb model took 38 hours to cross.

Commercial/law enforcement (aerial photography, surveillance, crop/drought monitoring,…)

Types of RC planes:

Electric powered

Hobby
1m wingspan
2.6 g (a raisin
has a mass of
~1g!)

Hobby
Electric ducted fan
0.5 kg and up

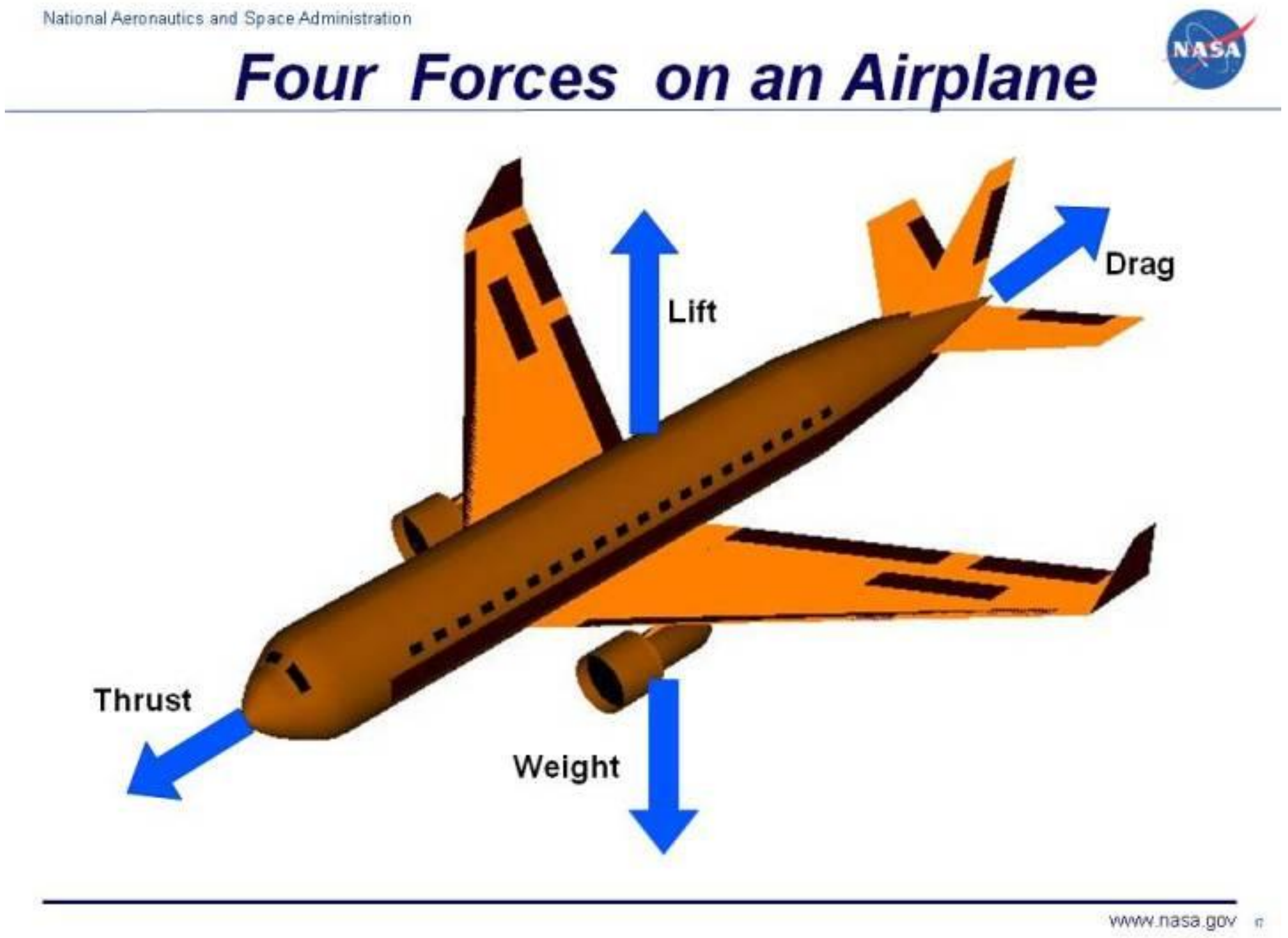
Hobby
Propeller driven
0.5 kg and up

Military
1 m wingspan
2 kg (4 lbs)

400 mph
glider
without a
motor!

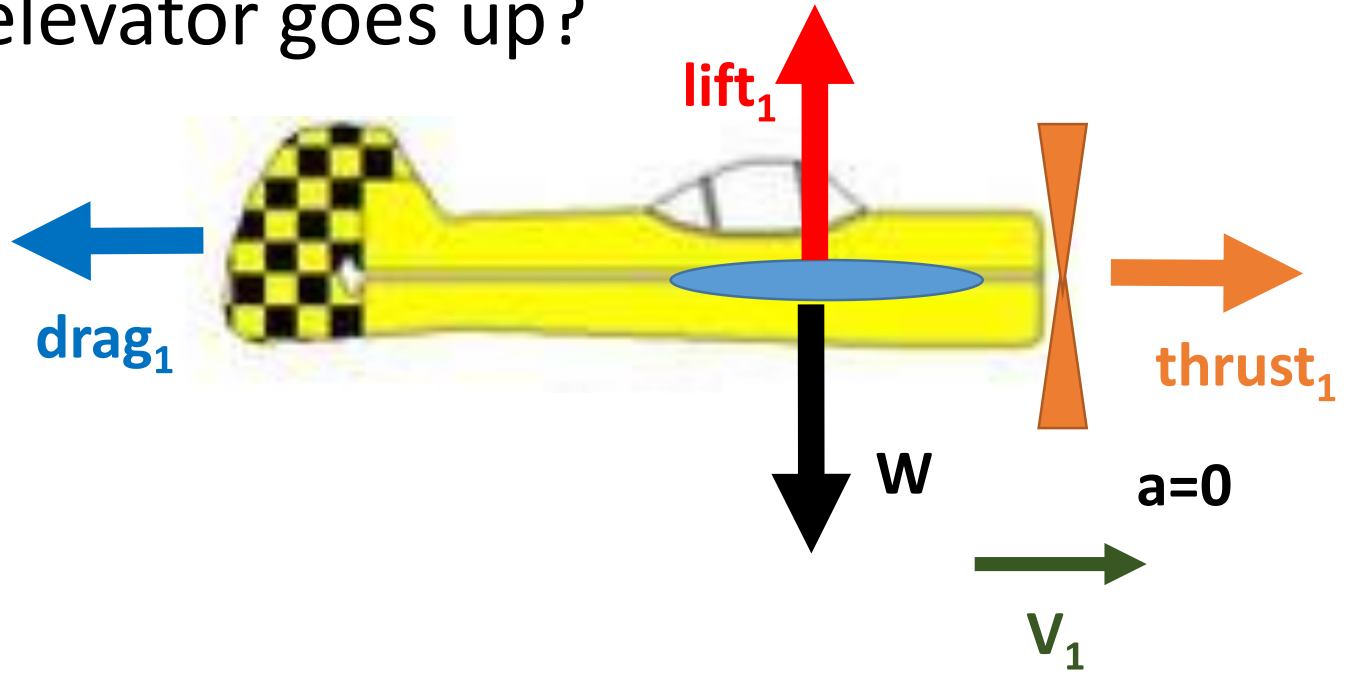
Commercial/law enforcement (aerial photography, surveillance, crop/drought monitoring,…)

How does a plane fly? Forces on a plane?



Increasing throttle?

Demo 3: Vapor flight at constant velocity
What happens if throttle increases? If elevator goes up?



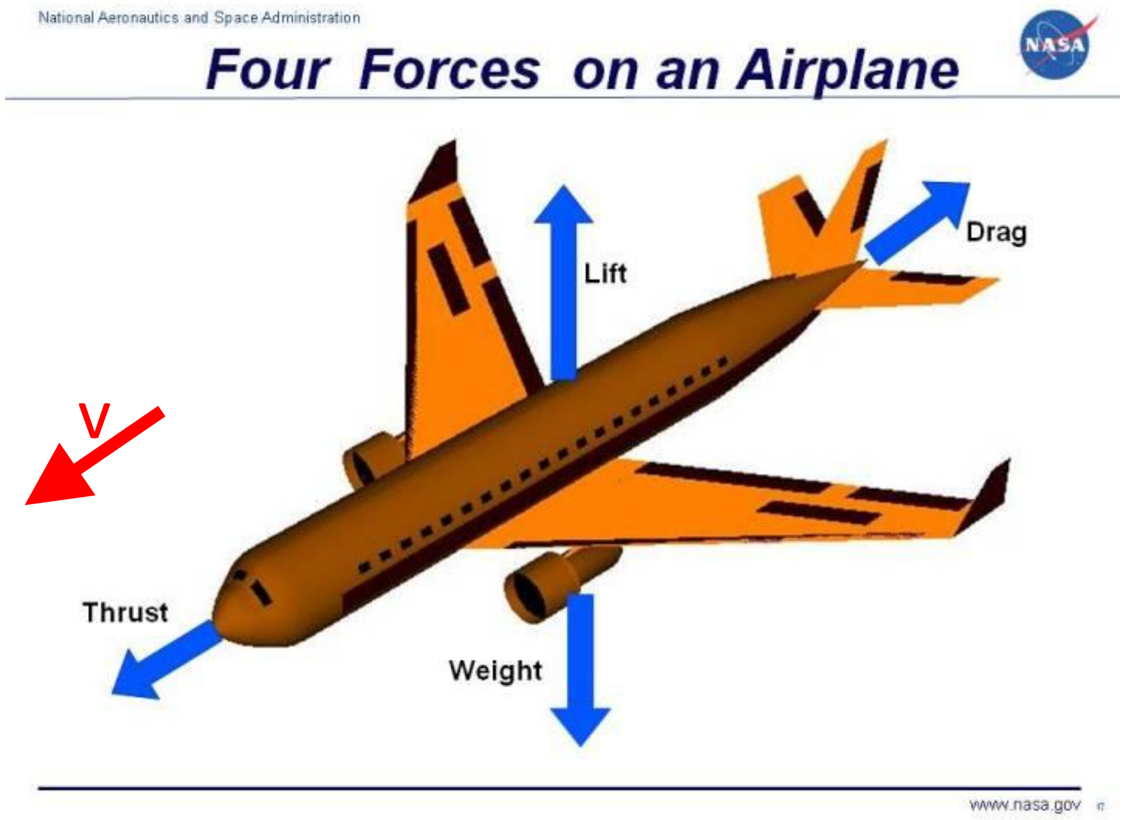
What's another example of drag increasing as speed increases until drag matches the accelerating force (canceling it) and speed becomes constant?

What are FORCE, WORK, and POWER

Force (F) causes an object to accelerate

Work (W) is energy expended by a force to move an object a certain distance
W = F d

Power (P) is the RATE at which energy is expended by a force to move an object
P = W/T= (F d)/T= F (d/T)= F V

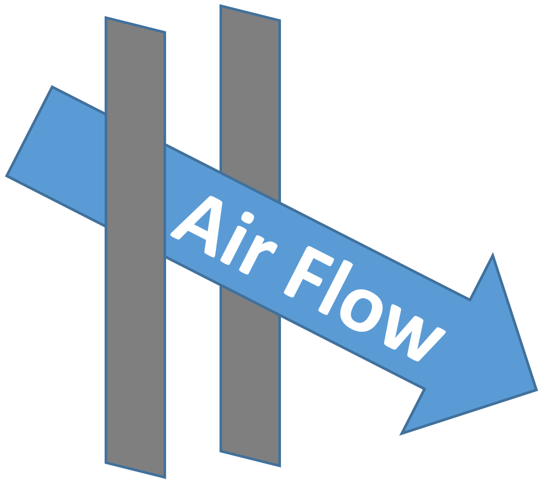


What is the power that a motor must supply to keep the airplane flying a constant speed? Assume V is large enough so the Lift cancels Weight.

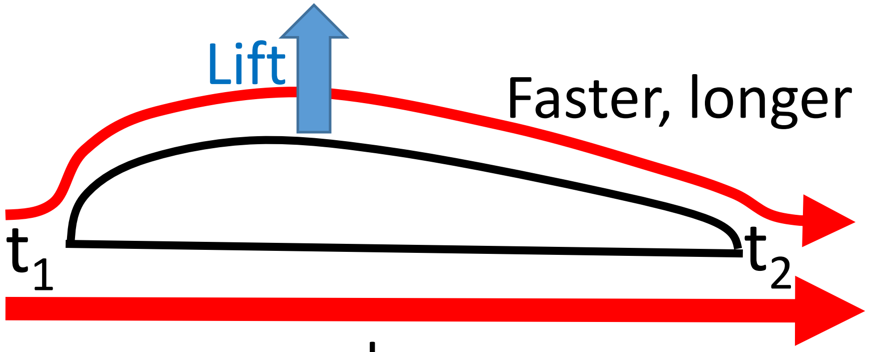
Where does lift come from?

Demo 4: inverted flight, other modes (KE, hover)?

Demo 5: Bernoulli effect using two strips of paper



Traditional explanation:

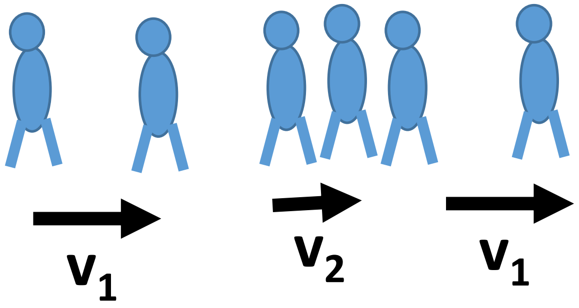


Faster, longer distance travelled in ~~same~~ time

Meet back up at trailing edge

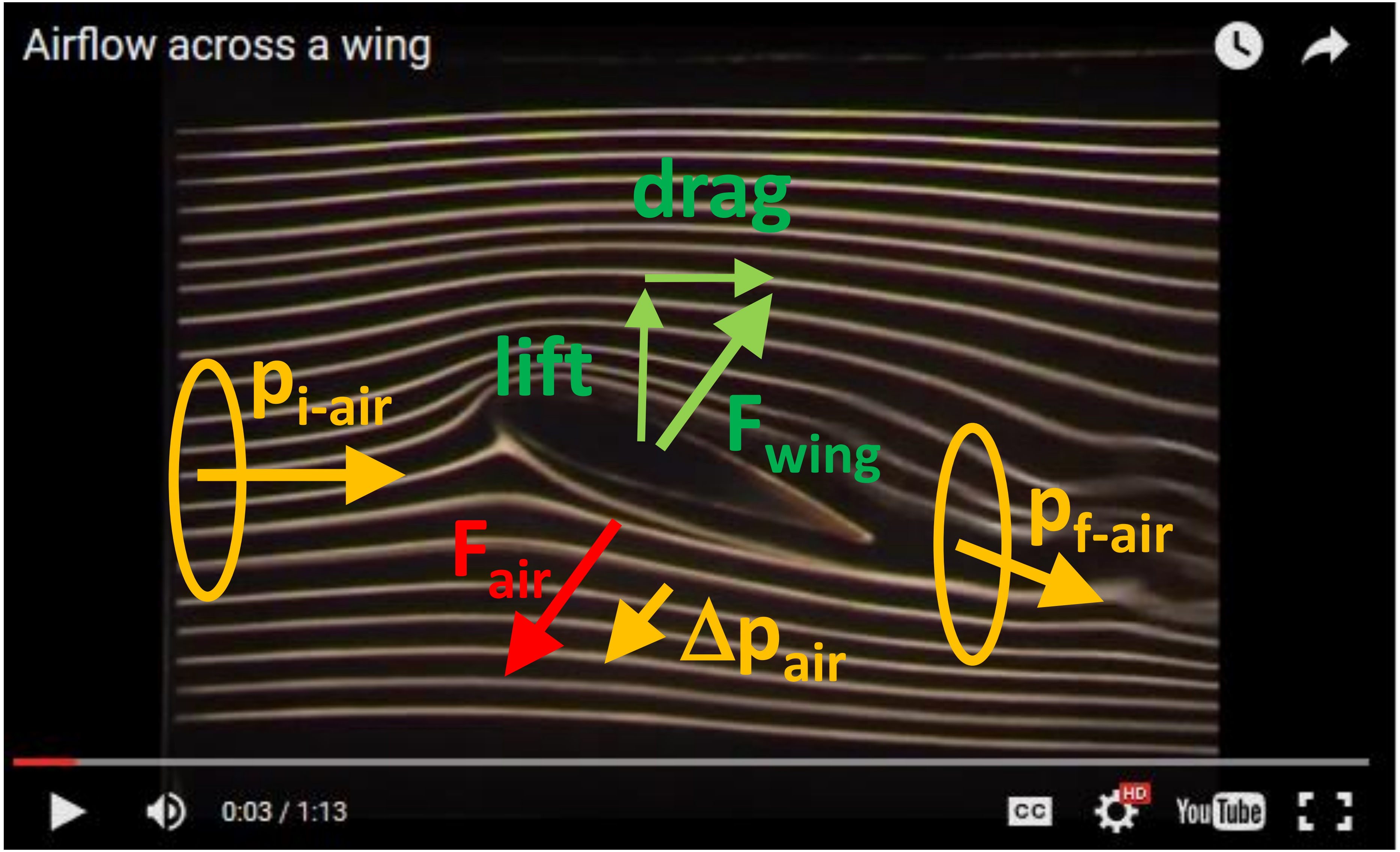
slower

Demo 6: Bernoulli effect with human train



http://www.cam.ac.uk/research/news/how-wings-really-work

Wing deflects the airstream→lift



$$\vec{F} = \frac{\Delta \vec{p}}{\Delta t}$$

$$\vec{F}_{AB} = -\vec{F}_{BA}$$

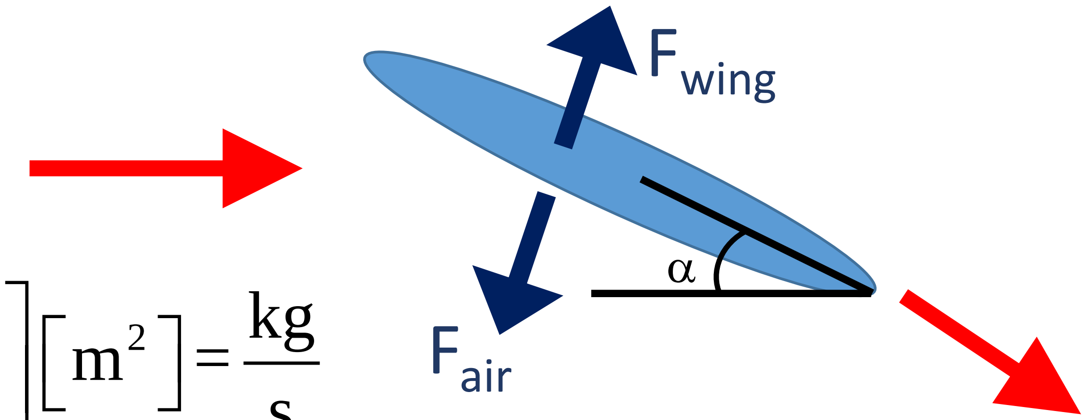
Audience Participation Question:
What physical parameters are involved in lift?
Hint: there are four

Speed V, air density ρ, wing area S, angle of attack α

What good and bad things happen as angle of attack α increases?

$$\frac{\Delta M}{\Delta t} = \rho V S$$

$$\text{units: } \left[\frac{\text{kg}}{\text{m}^3}\right]\left[\frac{\text{m}}{\text{s}}\right]\left[\text{m}^2\right] = \frac{\text{kg}}{\text{s}}$$



More lift (up to a point), more drag, airflow disturbed →stall and control surfaces don't work→Colgan Flight 3407 2/12/09

$$F = \frac{\Delta p}{\Delta t} = \left(\frac{\Delta M}{\Delta t}\right)(\alpha V) = \alpha \rho V^2 S$$

$$\text{units: } \left[\frac{\text{kg}}{\text{m}^3}\right]\left[\frac{\text{m}}{\text{s}}\right]^2\left[\text{m}^2\right] = \frac{\text{kg m}}{\text{s}^2} = \text{N} = \text{Force}$$

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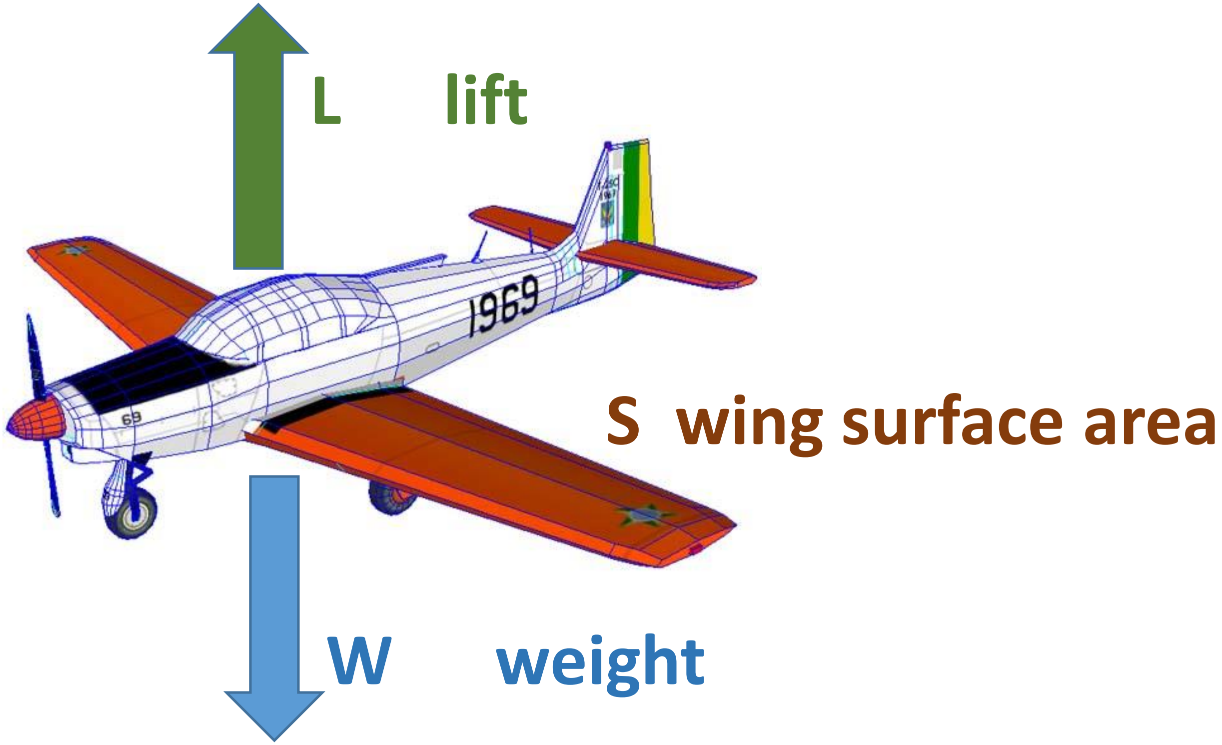
Do larger planes fly faster?

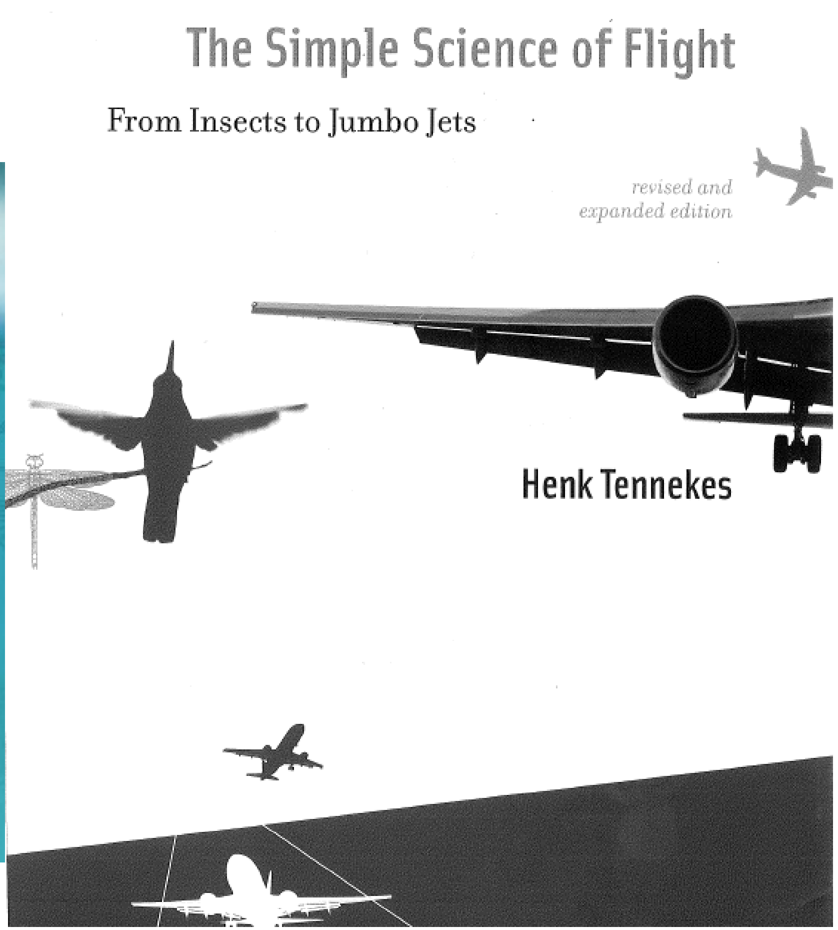
Wing loading
W/S



How does wing area and plane weight scale with size?

Aviation educational resources

www.acsupplyco.com



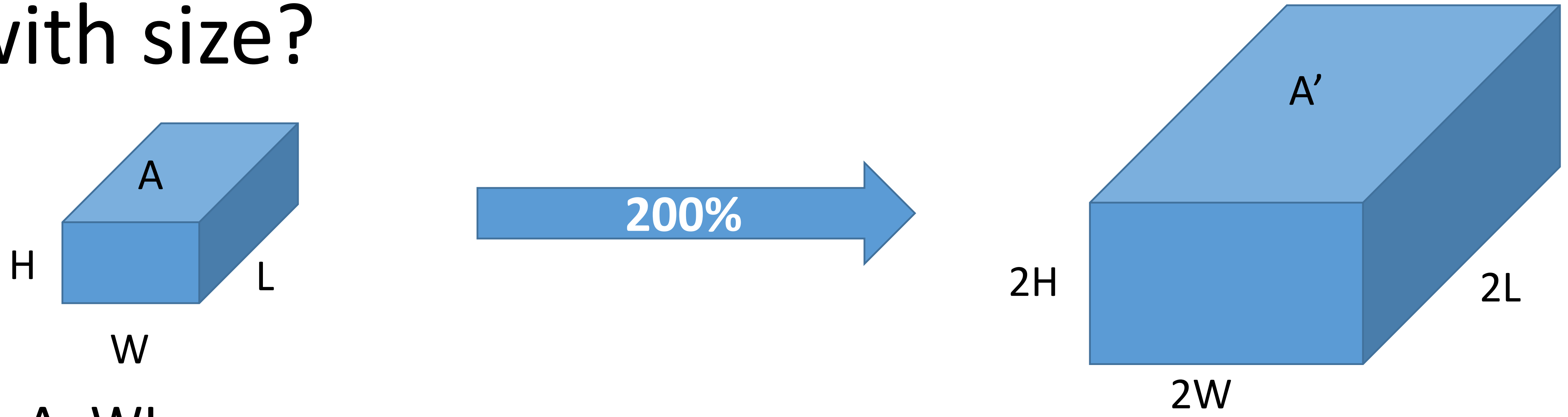
Education
- Youth Newsletter
- Education Committee
- Partners
- Contact Education

AeroLab

jcerne@buffalo.edu

for waves and polarization claw.physics.buffalo.edu

How does wing area and plane weight scale with size?



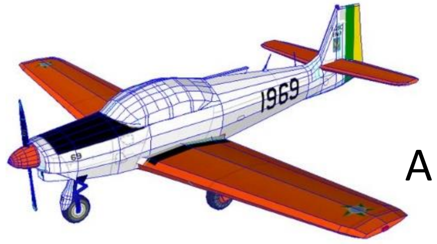
$A=WL$
$M=\rho WLH$

$A'=(2W)(2L)=4WL=4A$
$Mass=\rho(2W)(2L)(2H)=8WLH=8M$

Assuming a constant density, if all dimensions scaled up by a factor G, then $A=G^2A_0$ and $M'=G^3M_0$

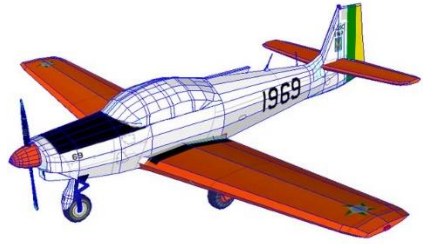
M_0  A_0

$$\frac{W}{S} \propto \frac{M}{A} = \frac{G^3 M_0}{G^2 A_0} = G\frac{M_0}{A_0} \propto G$$

M  A

How does wing area and plane weight scale with size?

$$\frac{W}{S} \propto G$$



$$W \propto \text{Volume} \propto G^3 \rightarrow W^{\frac{1}{3}} \propto G$$

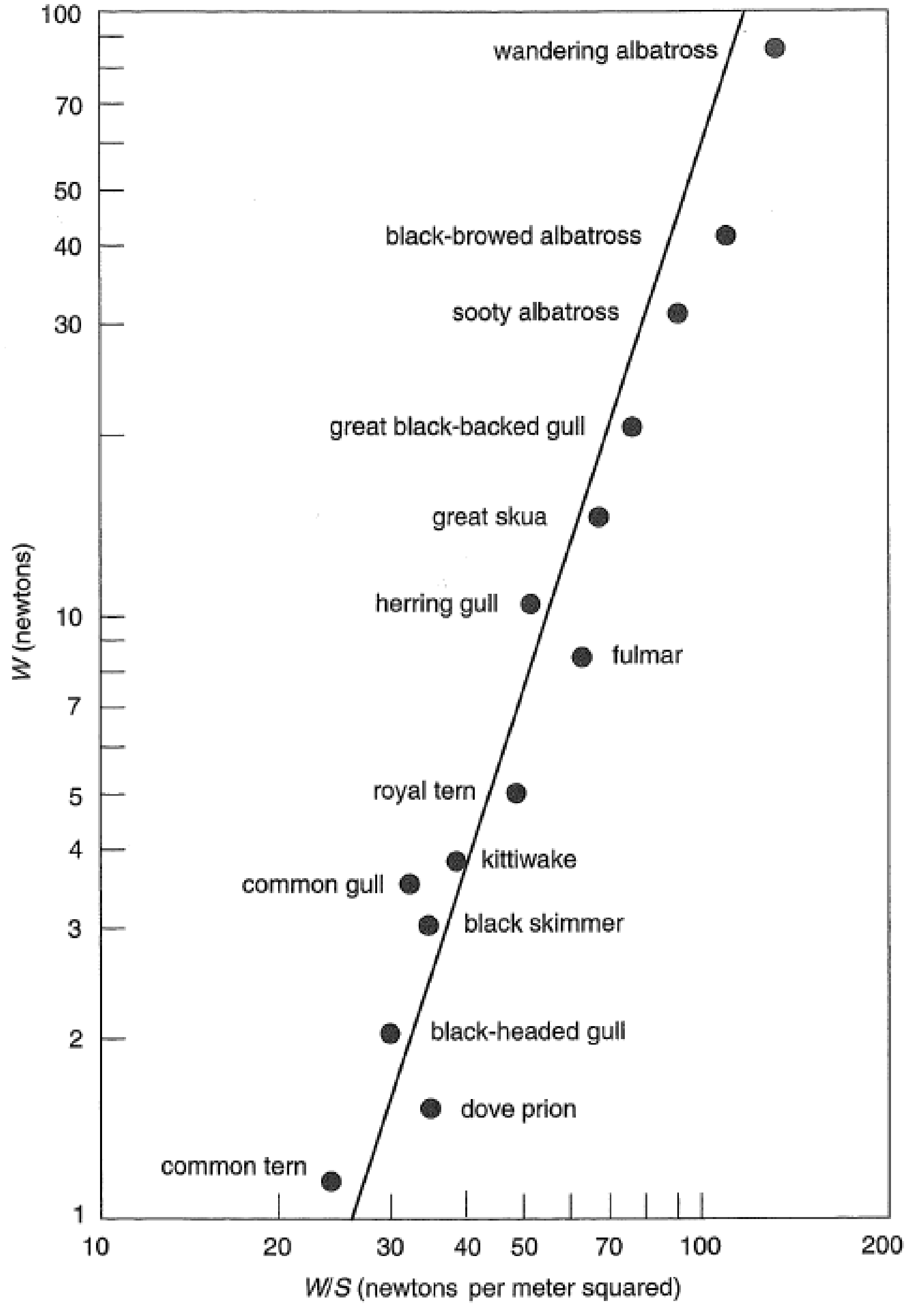
$$\frac{W}{S} \propto G \propto W^{\frac{1}{3}}$$

Relationship between W and W/S

$$\frac{W}{S} \propto W^{\frac{1}{3}}$$

$$\rightarrow W \propto \left(\frac{W}{S}\right)^3$$

The Simple Science of Flight, From Insects to Jumbo Jets, H. Tennekes-



Relationship between W and V

$$\text{Lift} \propto F = \alpha\rho V^2 S$$

$$\text{Lift} = W \propto F = \alpha\rho V^2 S$$

$$W = 0.3V^2 S \rightarrow \frac{W}{S} = 0.3V^2$$

$$\frac{W}{S} \propto G \propto W^{\frac{1}{3}} \text{ (from previous slide)}$$

$$\rightarrow \frac{W}{S} = 0.3V^2 \propto W^{\frac{1}{3}}$$

$$\rightarrow W \propto \boxed{V^6}$$

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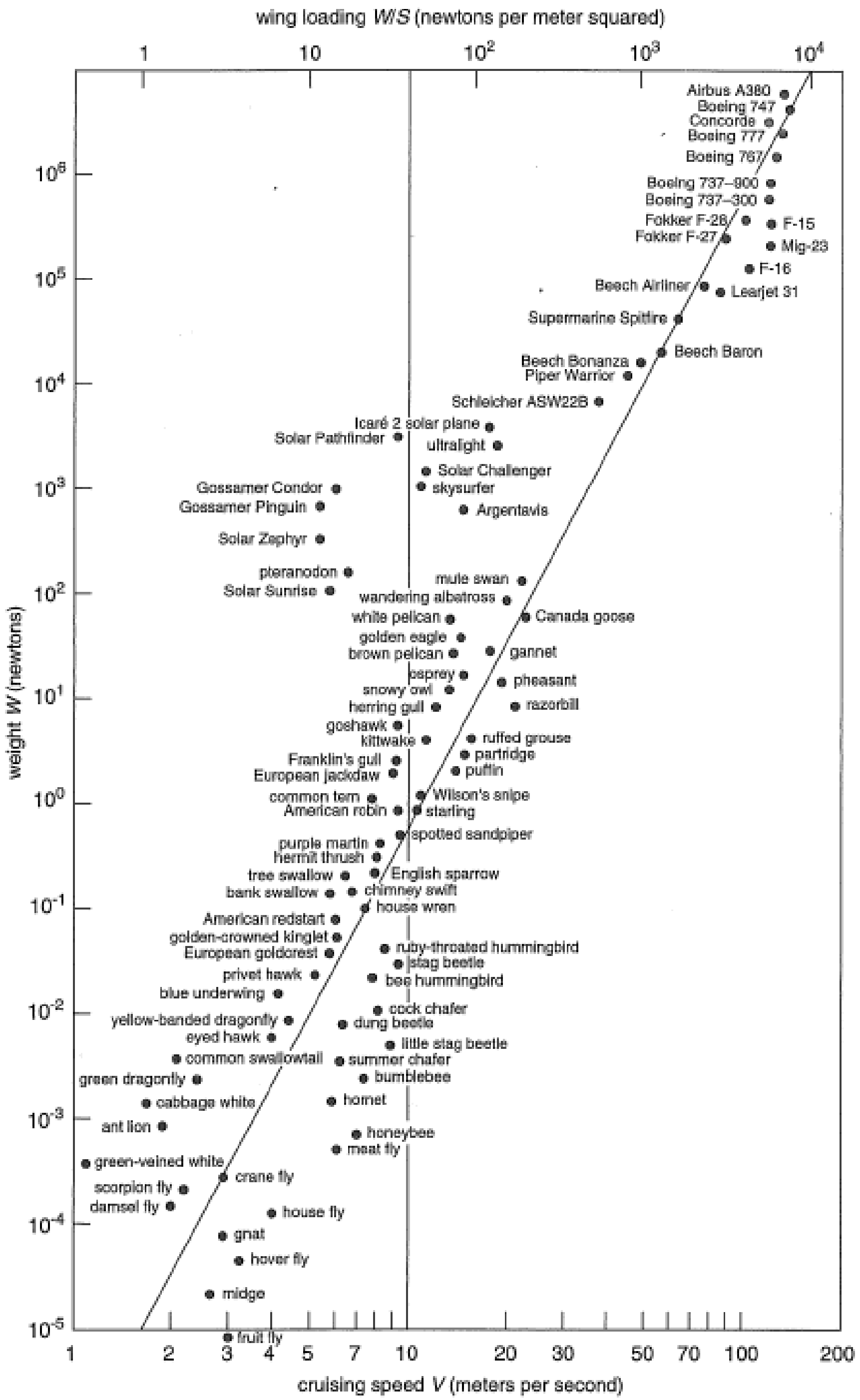
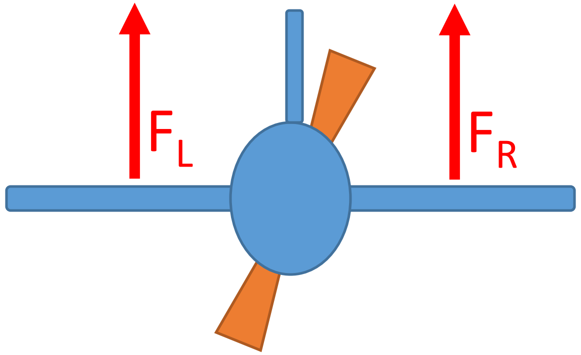
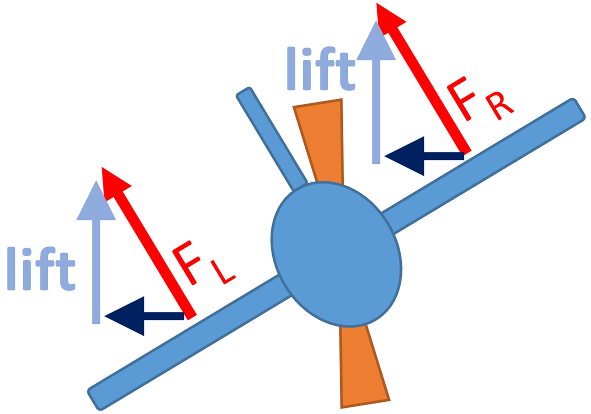


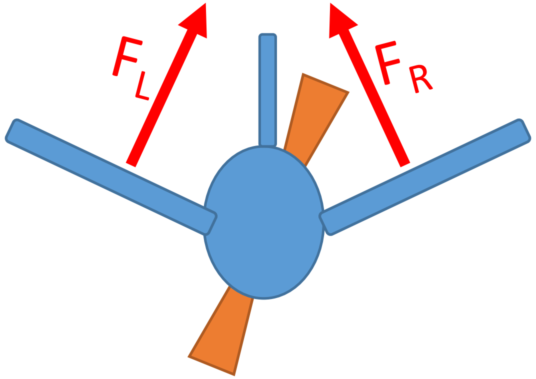
Inherent Airframe Stability: Roll stability

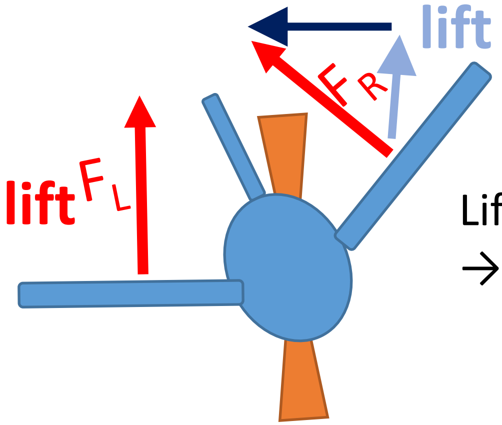




Less lift and net force to left
→ no tendency to roll back

Dihedral wing

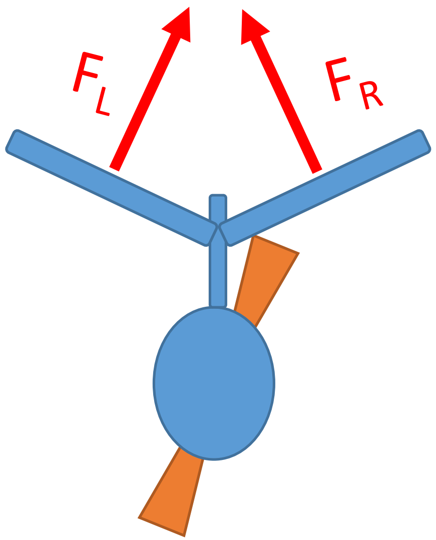


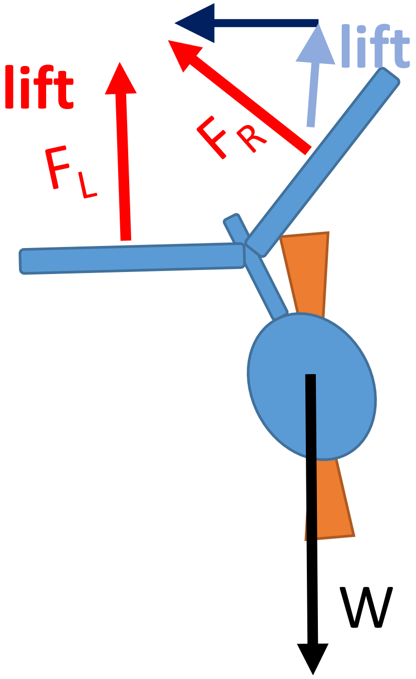


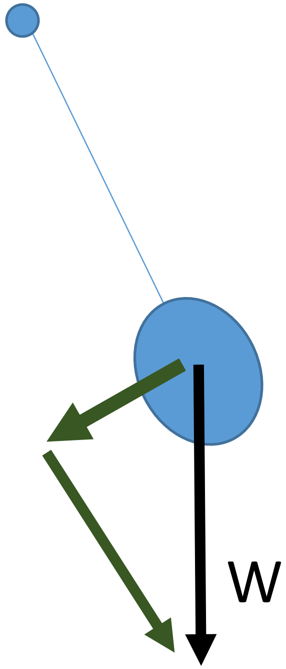
Lift on right wing less than on left wing
→ plane will roll back to level

Inherent Airframe Stability: more roll stability

Dihedral high wing

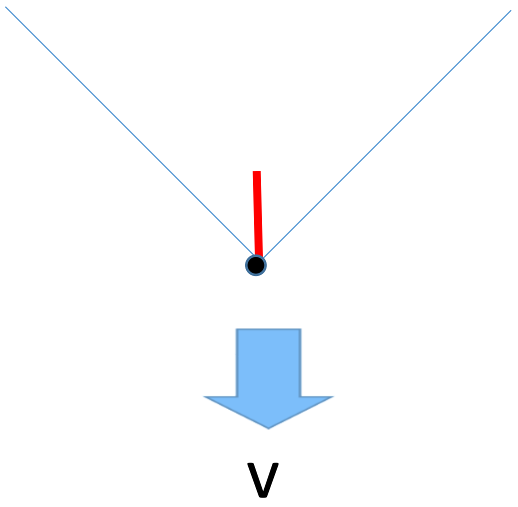


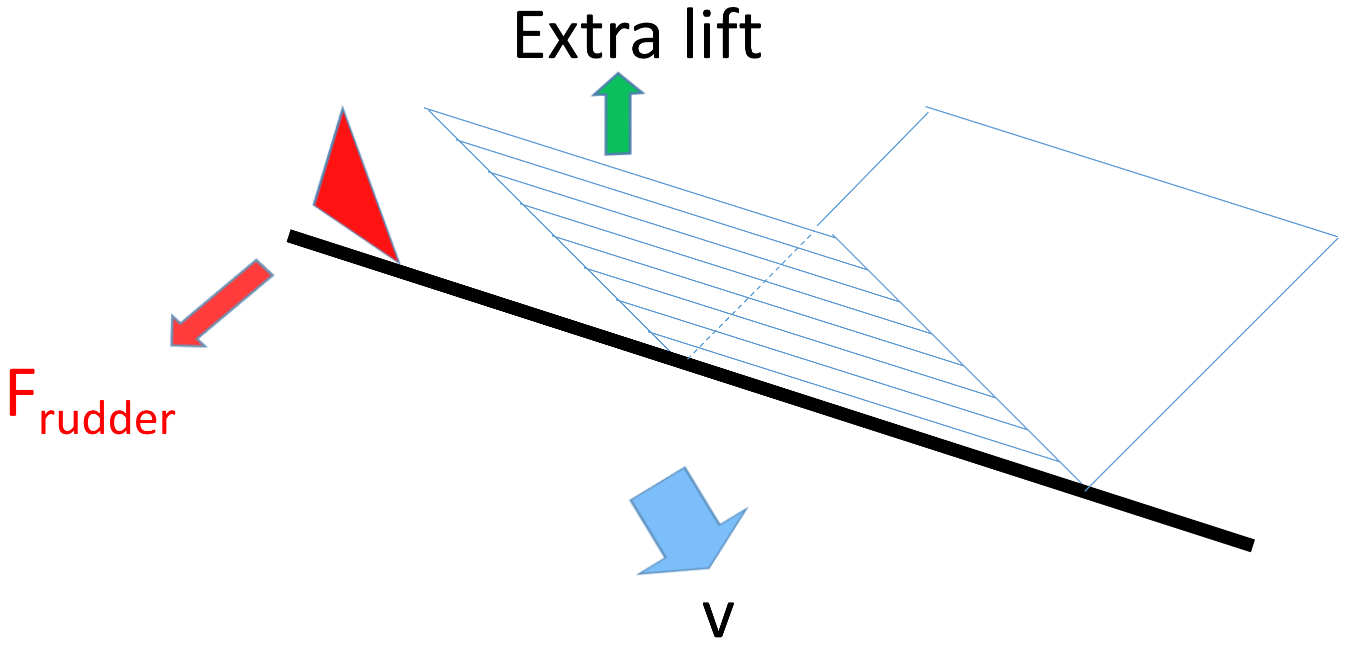




Lift on right wing less than on left wing AND mass of fuselage/motor tends to swing back to be centered on wing (like a pendulum)
→plane will roll back to level

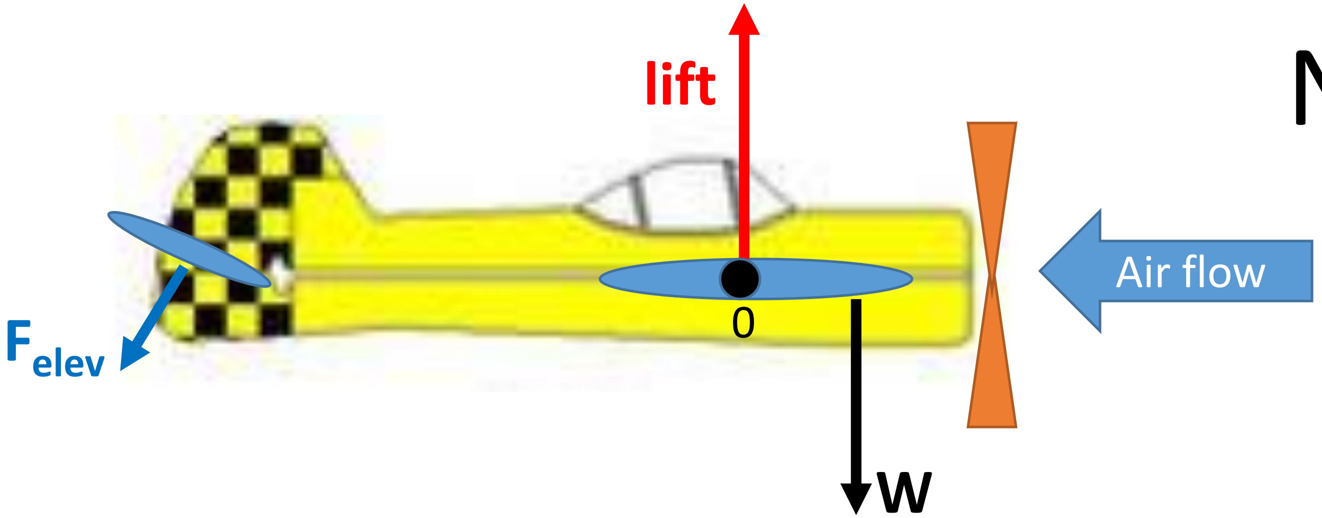
Advantages/Disadvantages of Dihedral: Yaw-Roll Coupling



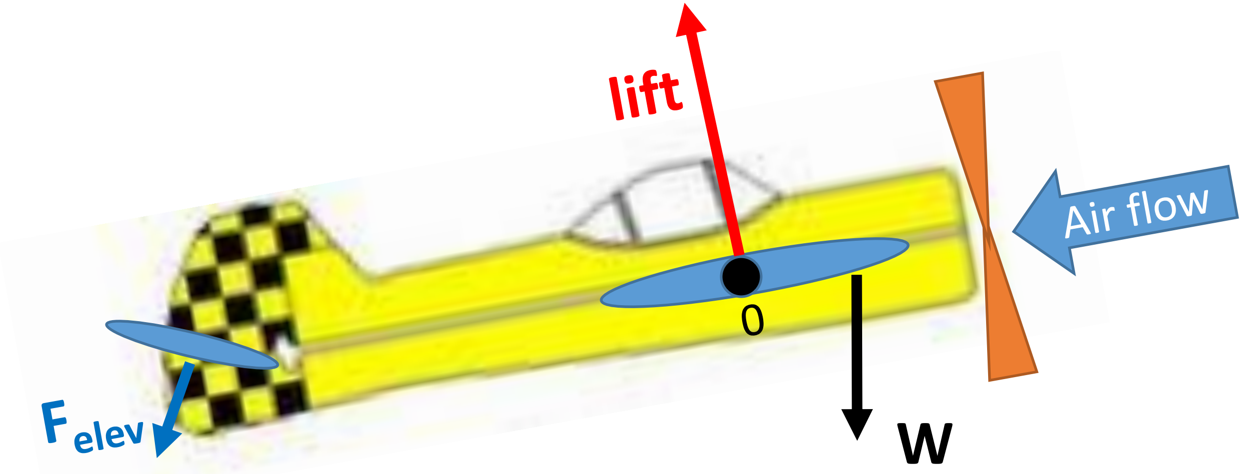


Demo 7: Yawing a folded card

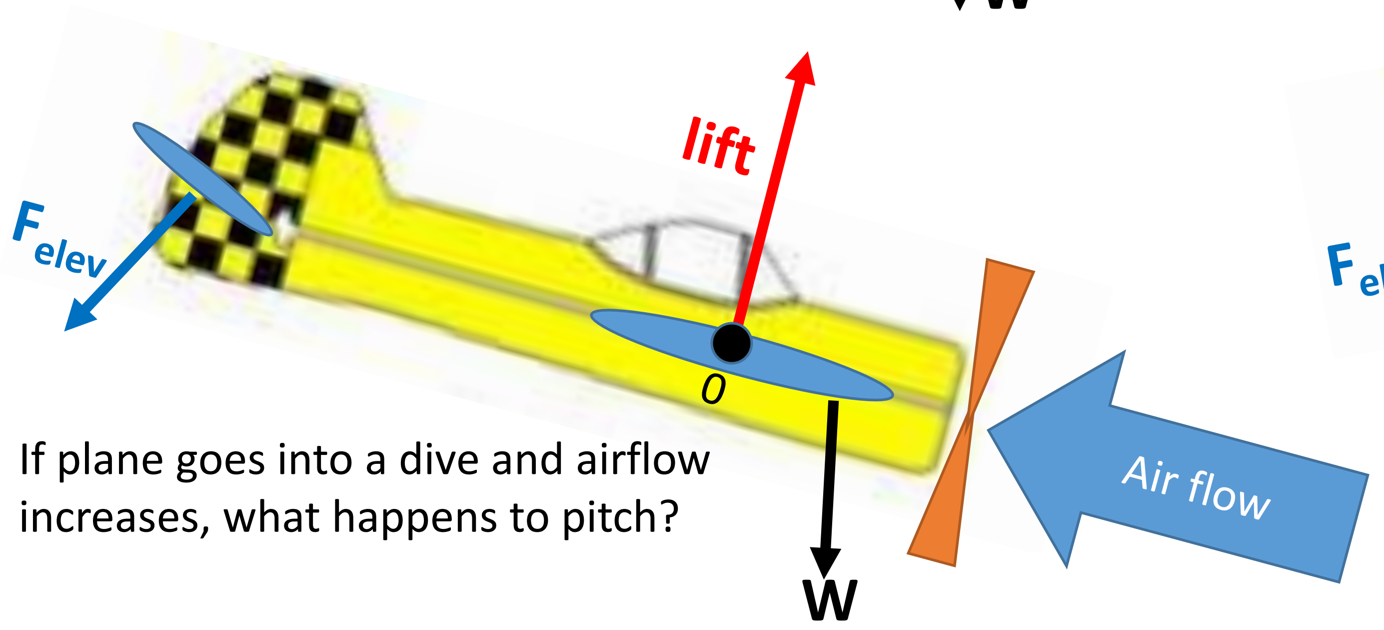
Inherent Airframe Stability: Pitch stability



Nose heavy airplane



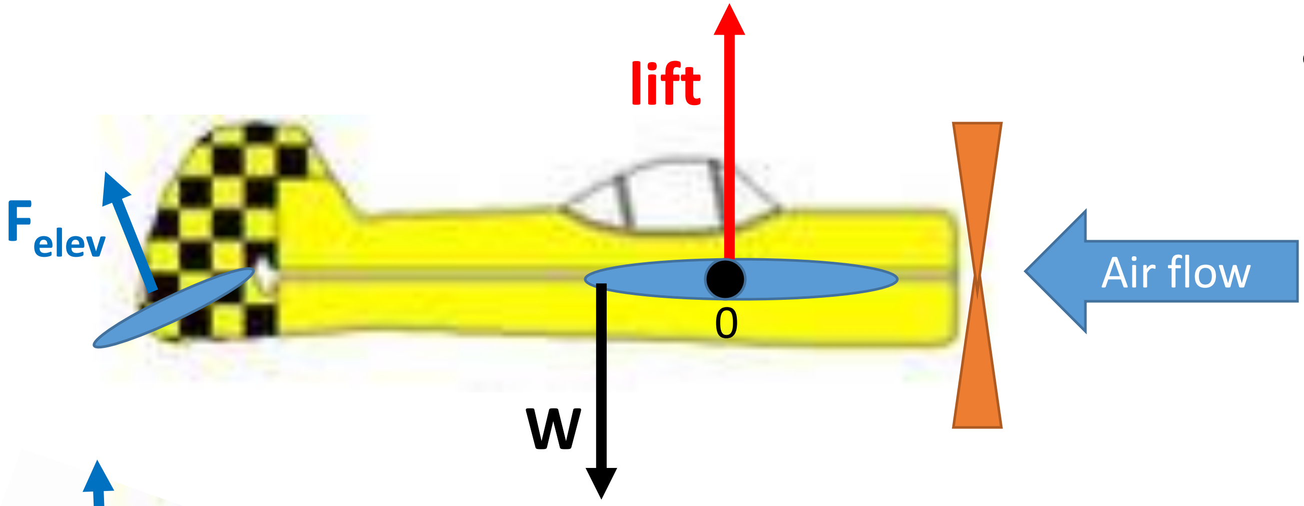
If plane pitches up and airflow decrease, what is the response?

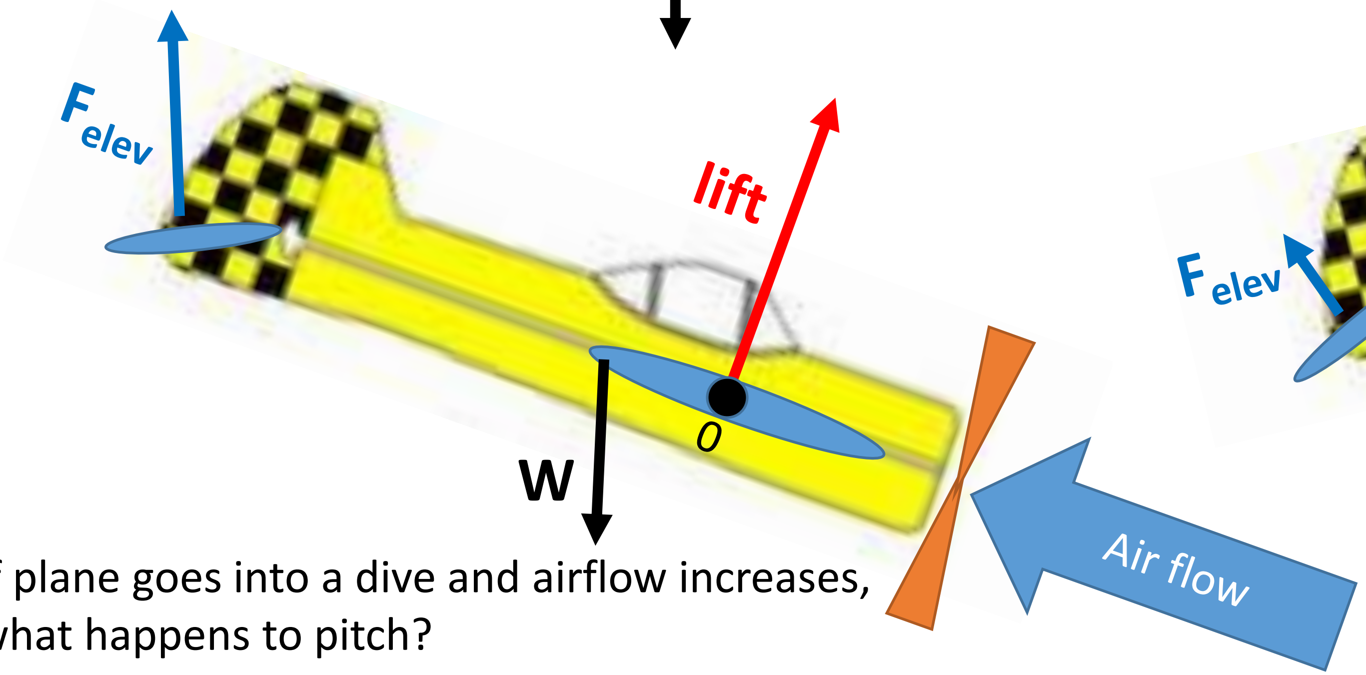


If plane goes into a dive and airflow increases, what happens to pitch?

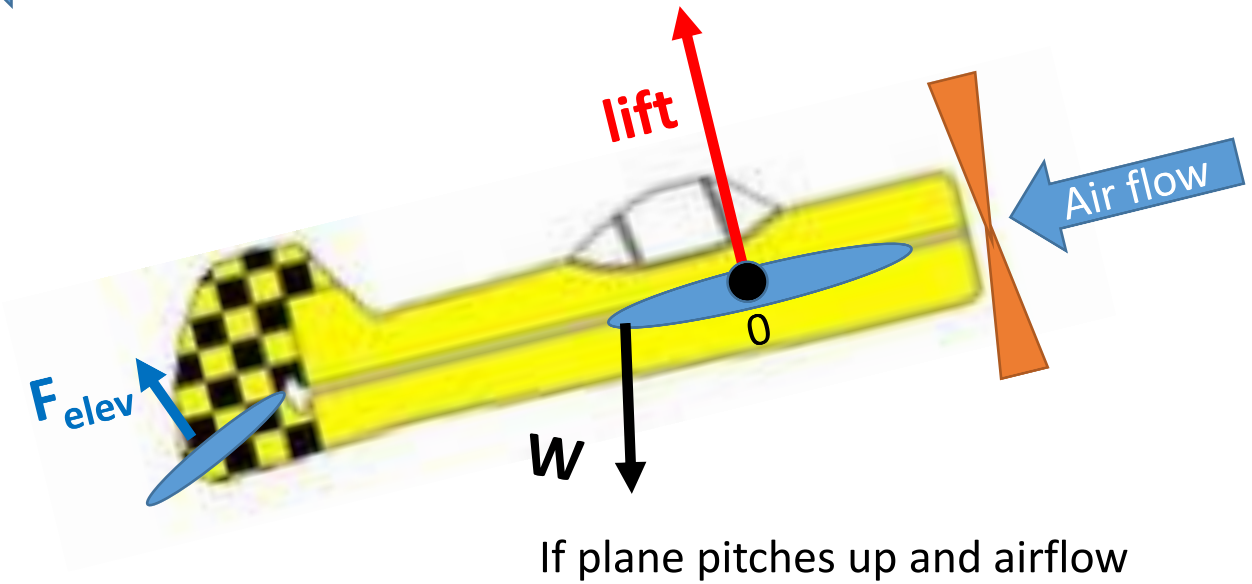
Inherent Airframe Stability: Pitch stability

Tail heavy airplane





If plane goes into a dive and airflow increases, what happens to pitch?



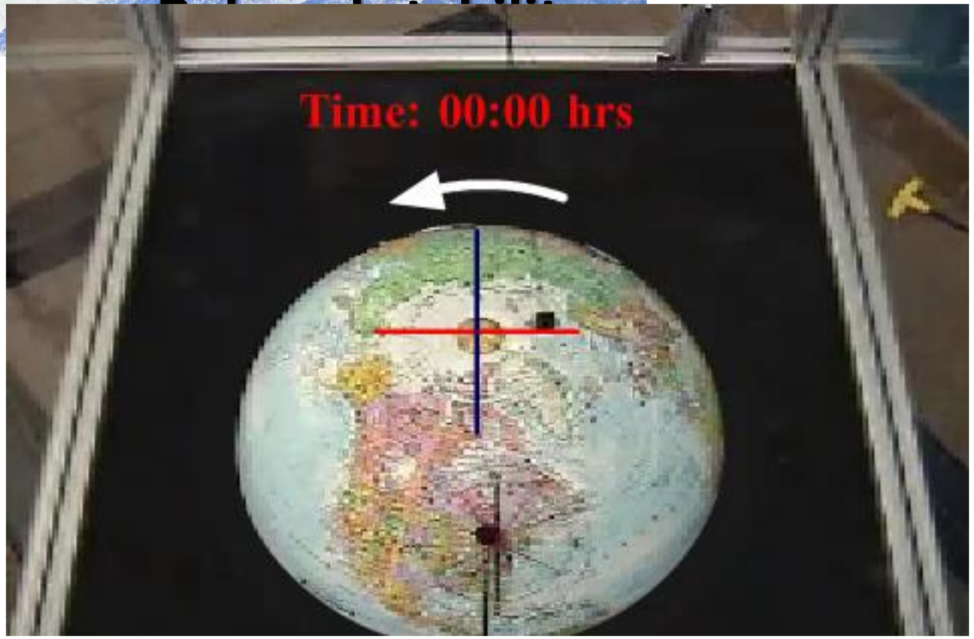
If plane pitches up and airflow decrease, what is the response?

How do we check if our plane is tail/nose heavy?

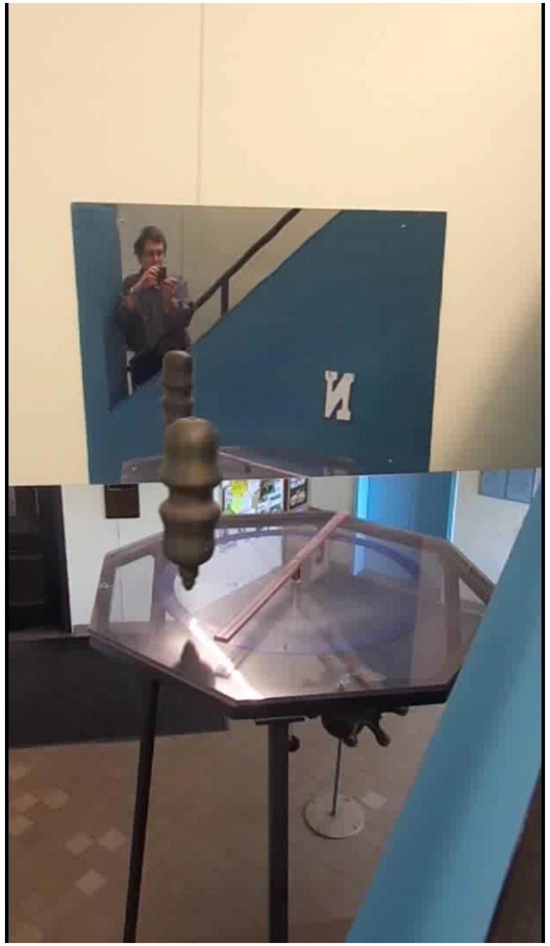
Electronic Stabilization

Inertial stabilization and the Foucault pendulum?!?!

Maneuverability
Unusual shape

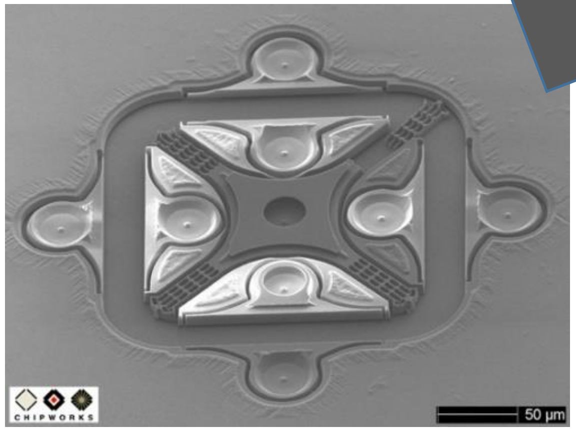


Demo 8: Foucault model



iphone MEMS gyro

Human hair



Demo 9: Drone stability

Putting electronic stabilization to work- helicopters/multi-copters

Demo 10: Quadcopter flight and first person view (FPV)

Drag and vortices

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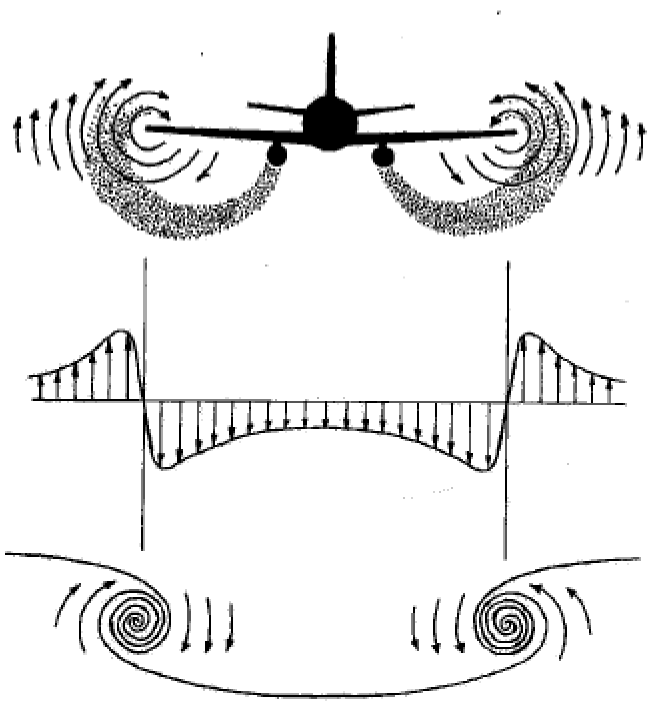
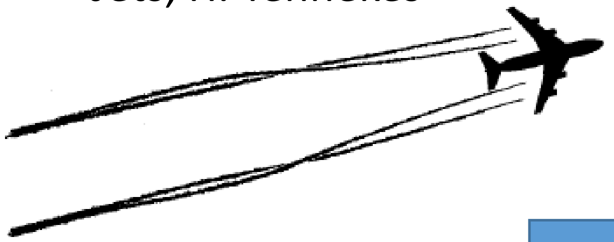
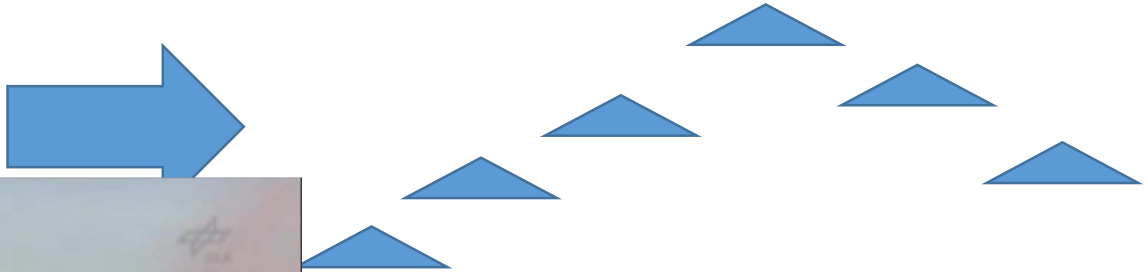


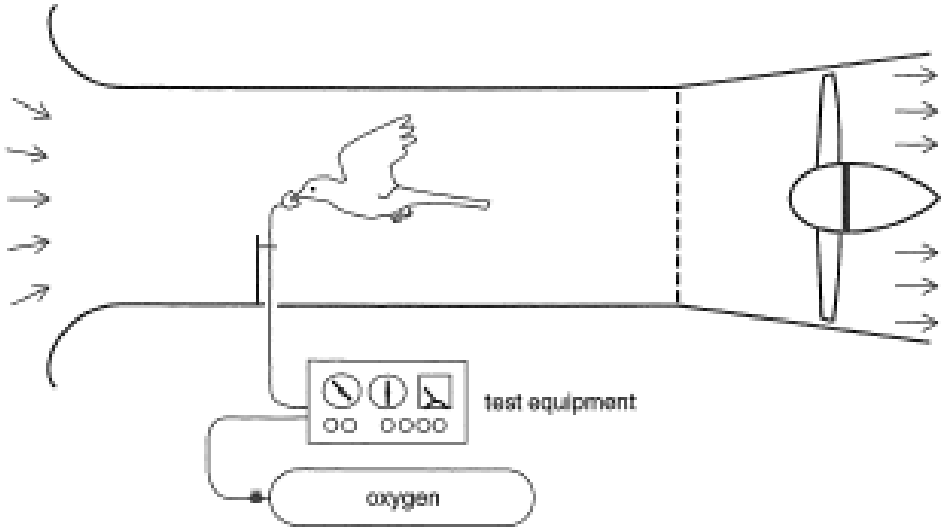




$D \propto V^2$ but induced drag (power lost to vortices) $D_i \propto \dfrac{W^2}{V^2 b^2}$

where $b = \dfrac{\text{wing length}}{\text{wing chord}}$ (skinniness of wings)

Most efficient flying speed



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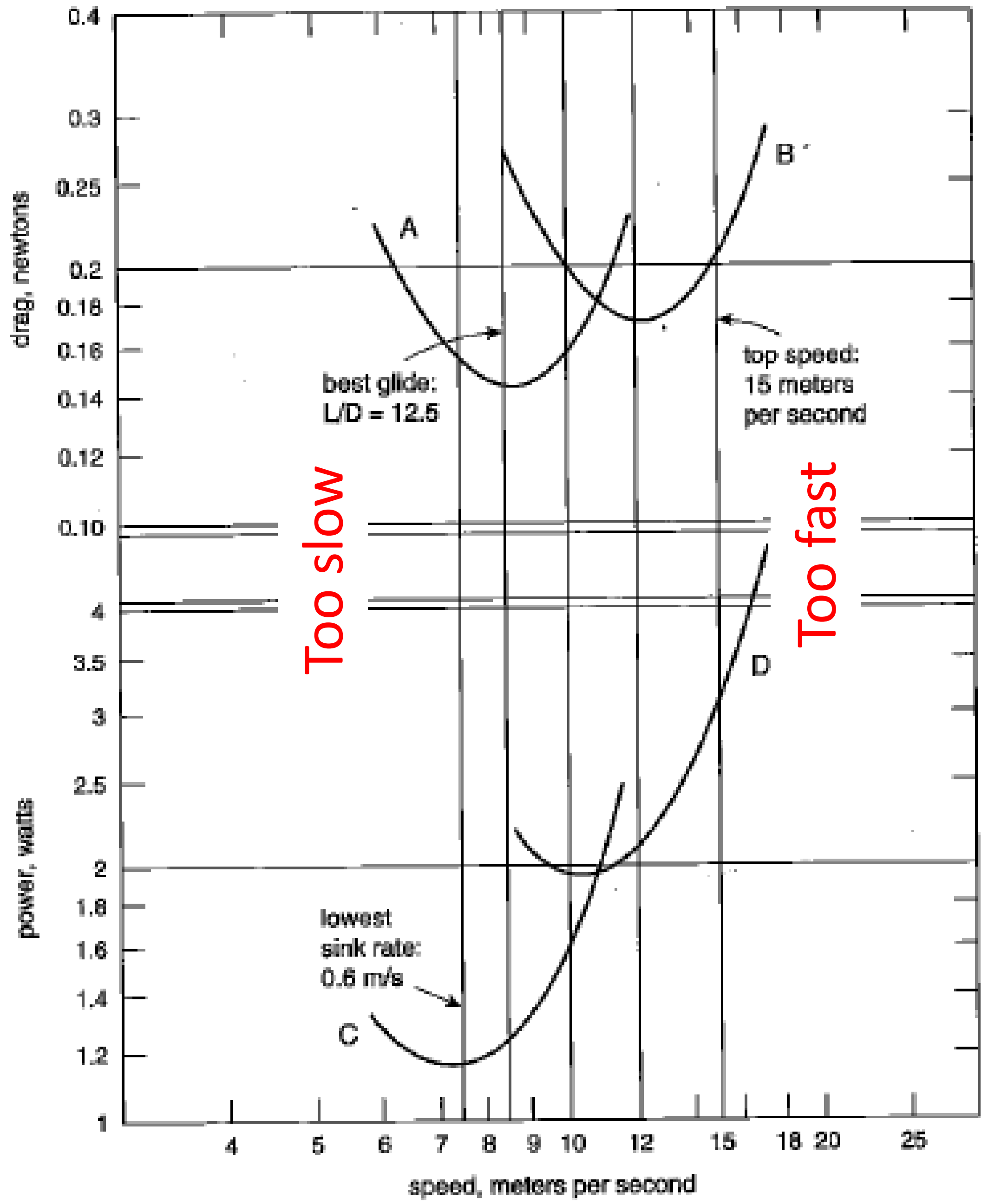
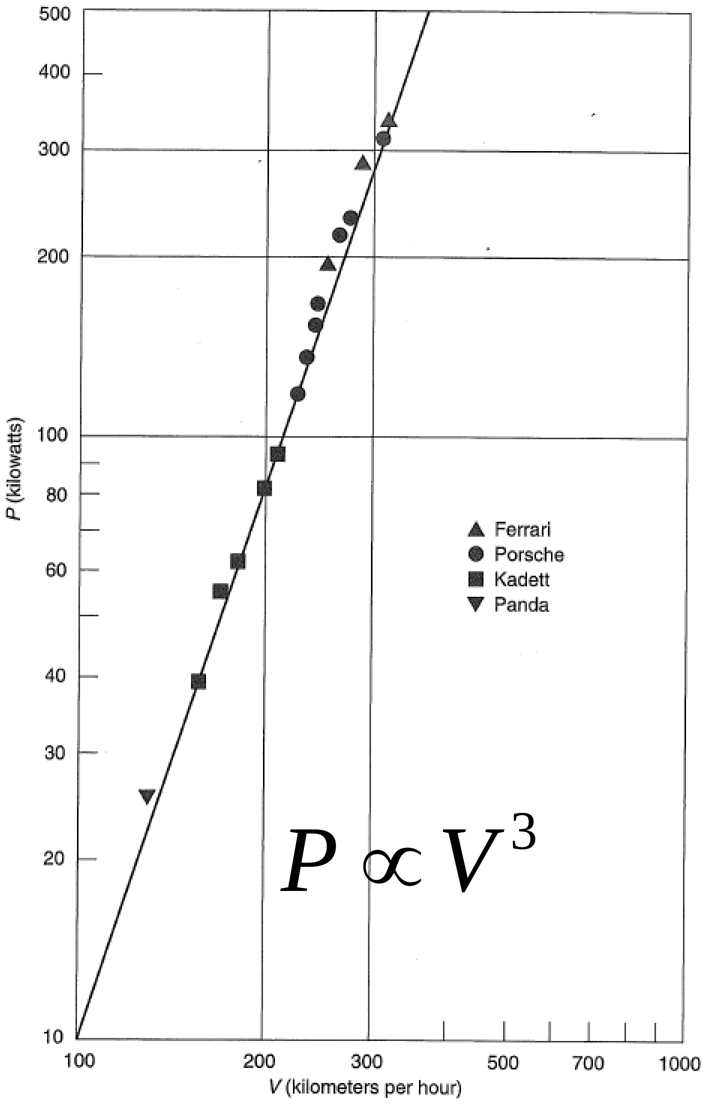


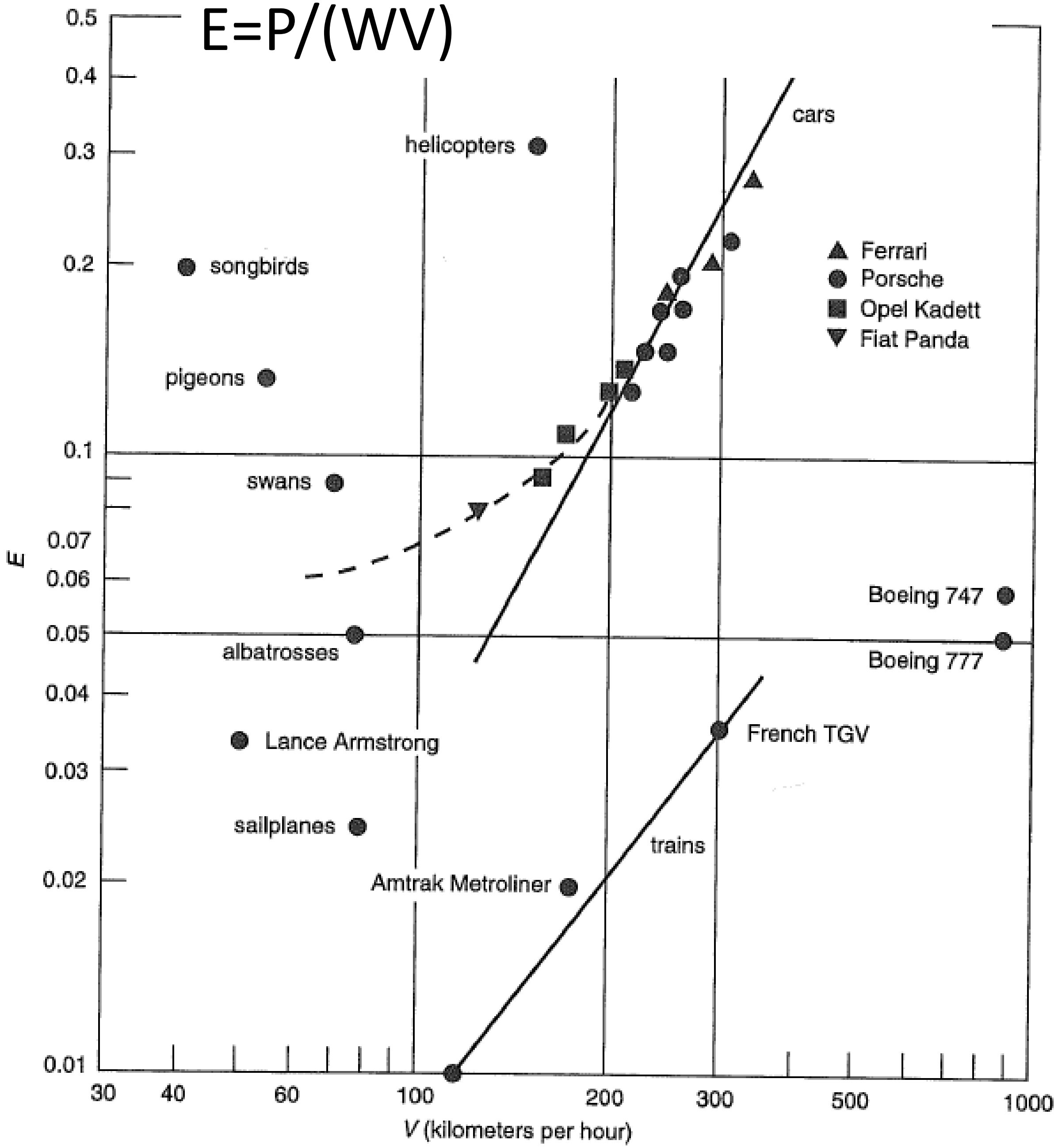
Demo 11: Yak Harrier (simulator and real model): what happens in slow flight

Transportation Efficiency



$$P \propto V^3$$

Specific energy consumption
$E = P/(WV)$



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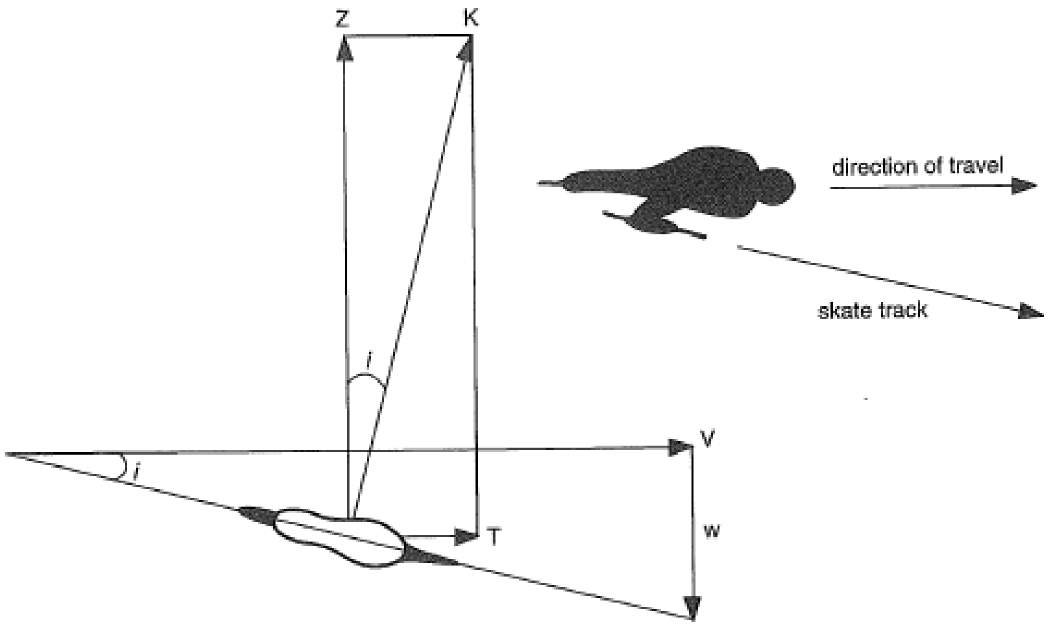
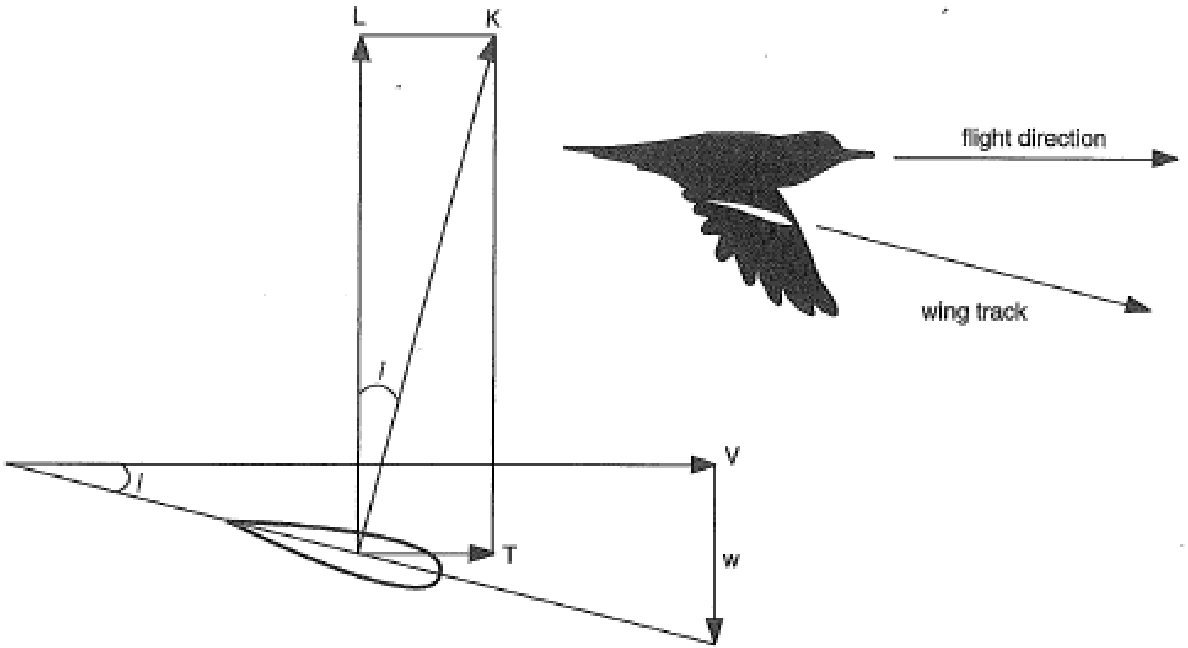
Flying and biology→BIRDS

1. Biomechanics-how they fly
2. Biochemistry-how they power their flying
3. Navigation
4. Time-keeping

Biomechanics-how they fly

Flapping wings is like paddling a canoe. True or False?





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Biochemistry-how they power their flying

What is the difference between energy and power?

Storage type	**Energy Density (MJ/kg)**	**Specific Power (W/kg)**	
Alkaline battery	0.28	39	
NiCd battery	0.18	150	
NiMH battery	0.27	200	
Lithium Polymer battery	**0.55**	**6000**	**RC Models**
Sugar	**15**		**muscles in humans**
Fat	**32**	**800***	**muscles in birds**
Gasoline	42		

*estimated from Tennekes p. 60, swan consuming 2g of fat per mile traveling at 45mi/h

Some comparisons

Bird 100W/kg muscle (better pulminary system) ⟷ Human 20W/kg muscle

Sugar energy density 14 MJ/kg (metabolized by humans) ⟷ Fat energy density 32 MJ/kg (metabolized by most birds)

Muscle efficiency 25% ⟷ Brushless motor efficiency 60% to over 90%

Premier athletes can maintain 5x base heart and 20x base metabolic rates for extended time ⟷ Birds can maintain 7x base heart and 14x base metabolic rates for extended time

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Navigation?

Photochemical reaction in retina produces short-lived chemical whose lifetime is sensitive to magnitude and direction of earth’s very weak magnetic field, Nature 2008

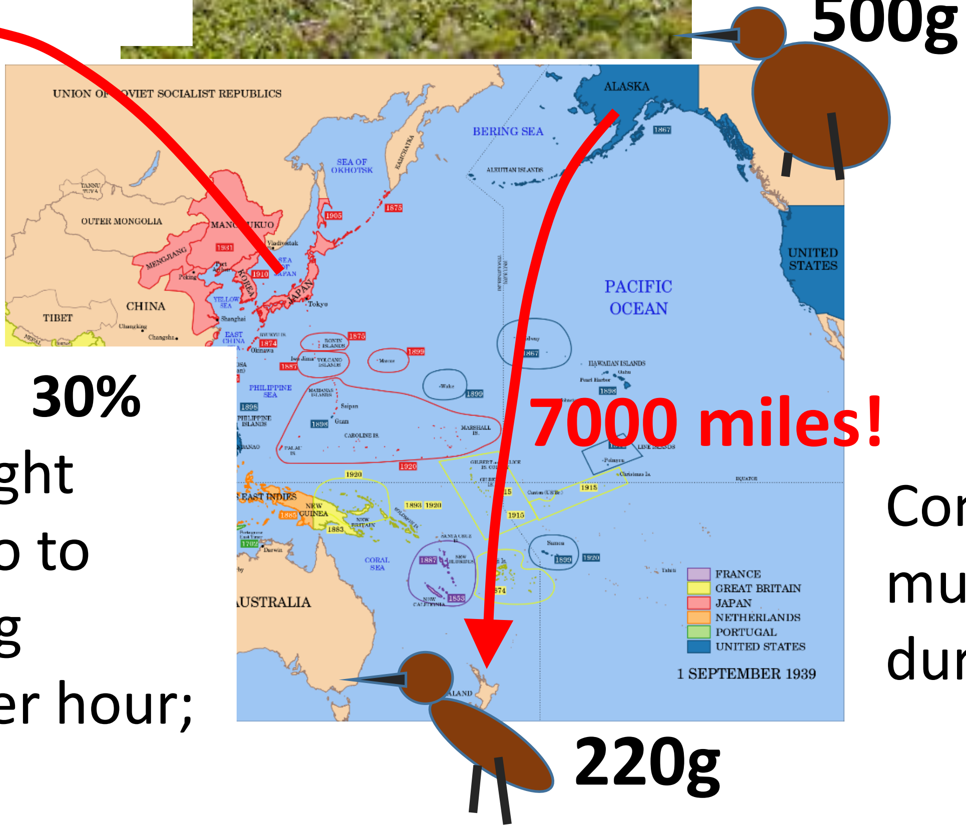
Grains of iron oxide (magnetite) in beak, but more recent studies found it in inner ear

Even if they know direction, how do they know location (high winds ~40 mph can easily carry them off course)?

Amazing examples of endurance and navigation

Bar-tailed godwit

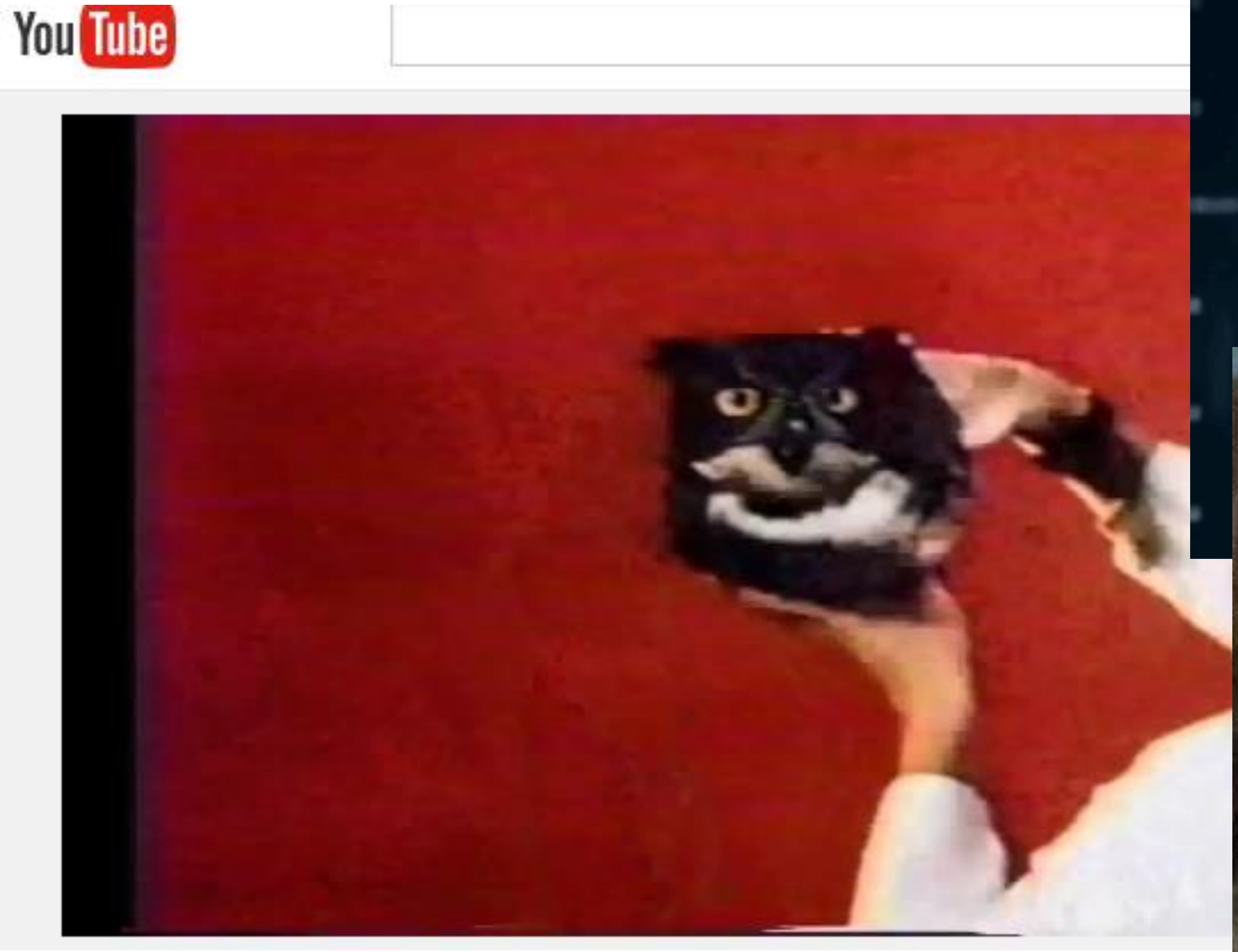
A Boeing 747 loses how much weight in fuel during a 13 hour, 9300 km flight?



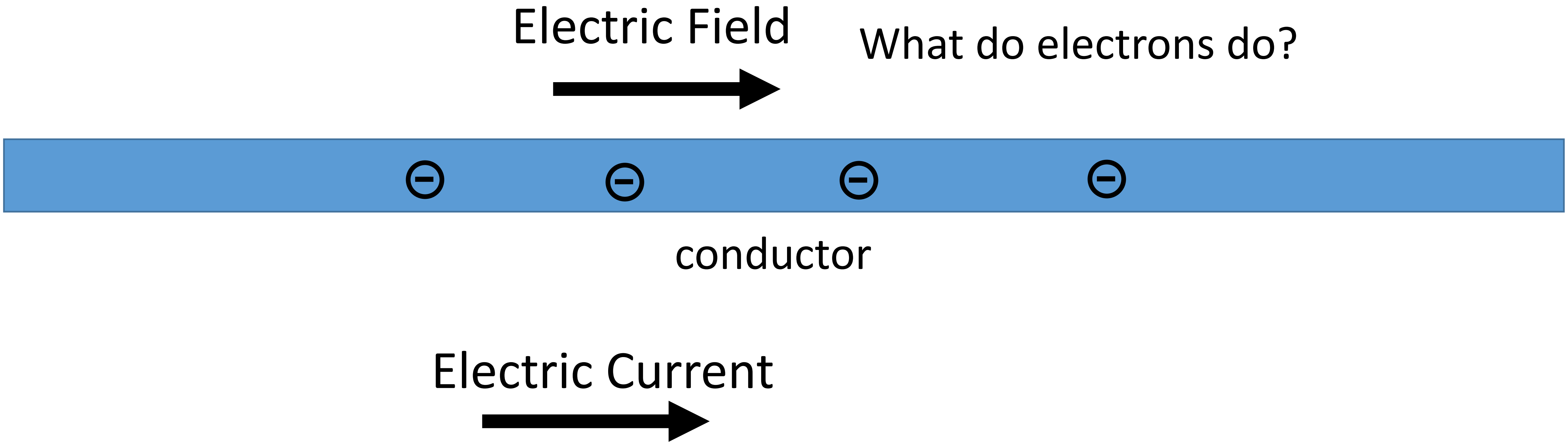
Note: A Boeing 747 loses **30%** (130 tons) of takeoff weight during a flight from Tokyo to Amsterdam→lighter wing loading→climbs 800 ft per hour; 30,000ft→ 40,000ft

Consumes 220g fat, 40g flight muscle, and 20g of other tissue during 9-day nonstop trip!

Keeping flight sensor/computer stable



Radio control: how does it work?



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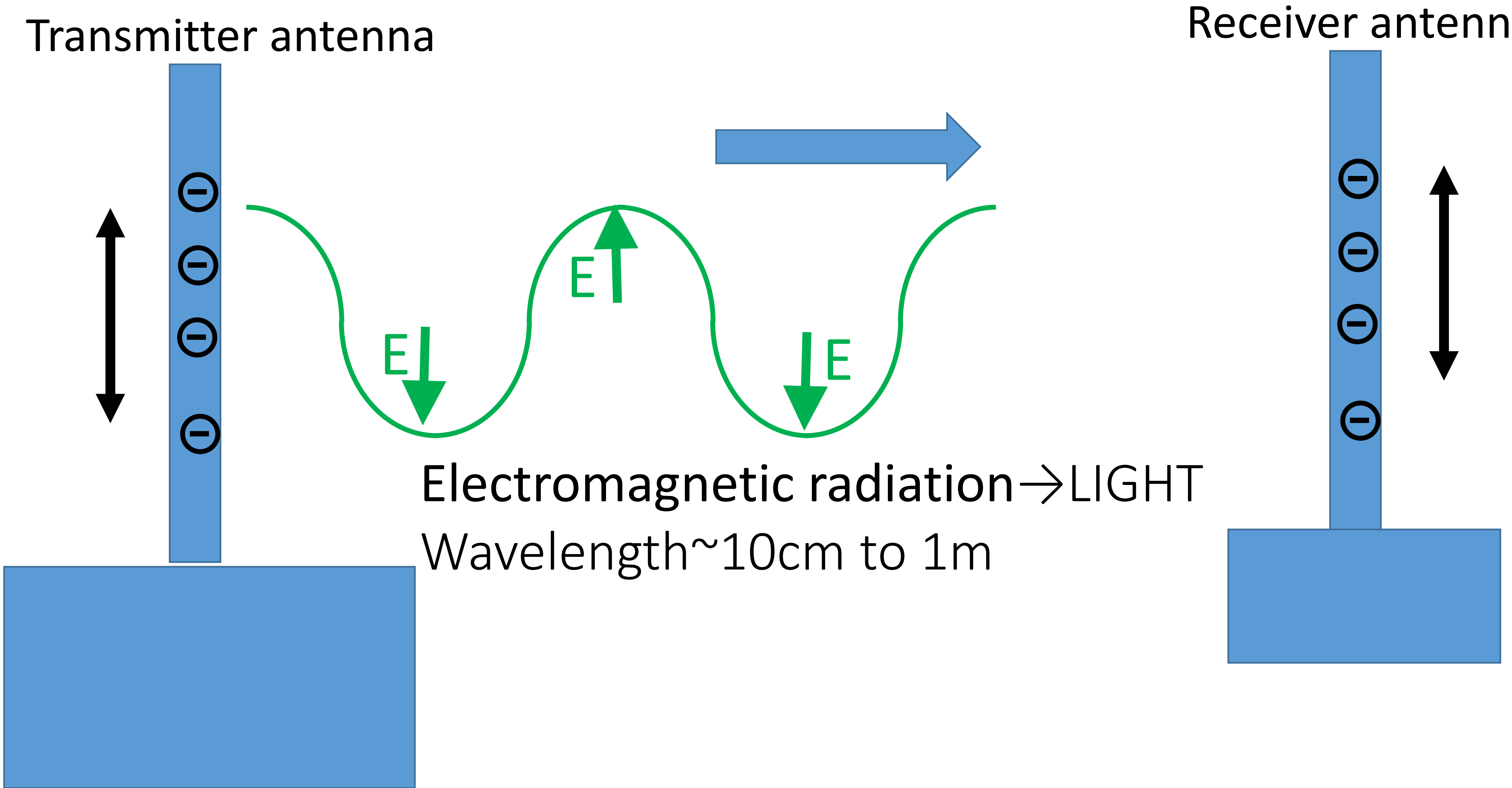
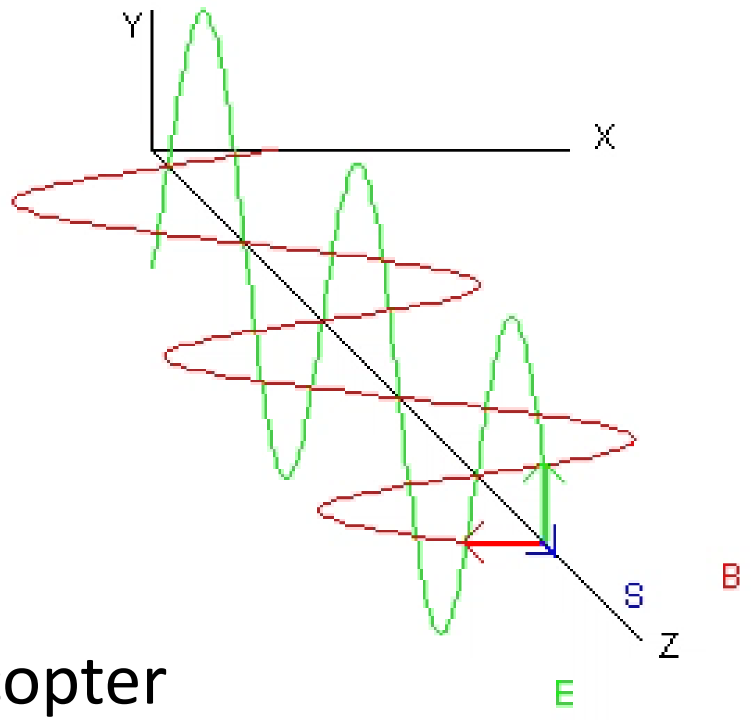


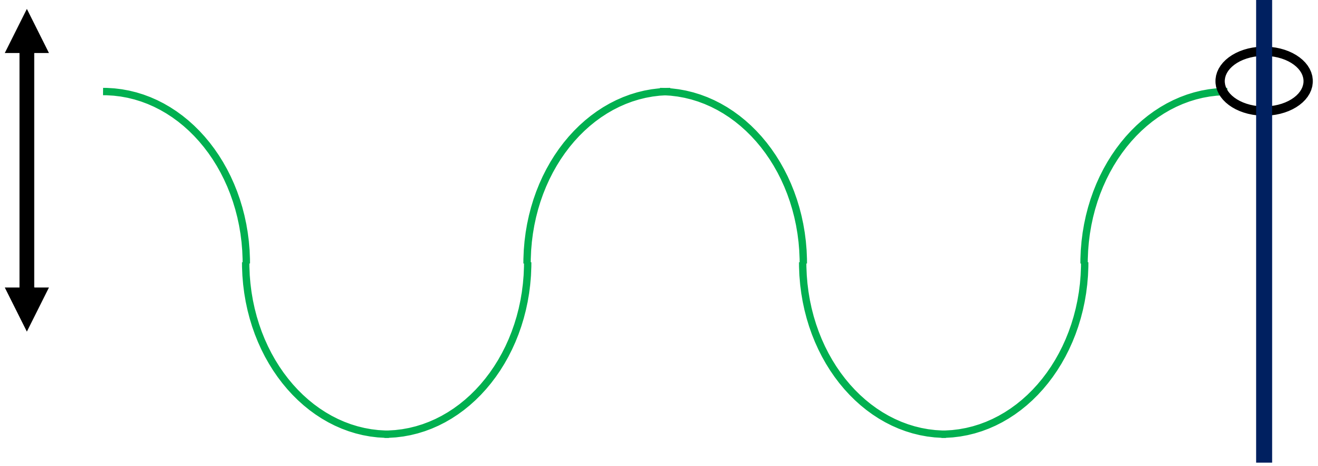
Polarization of light

claw.physics.buffalo.edu

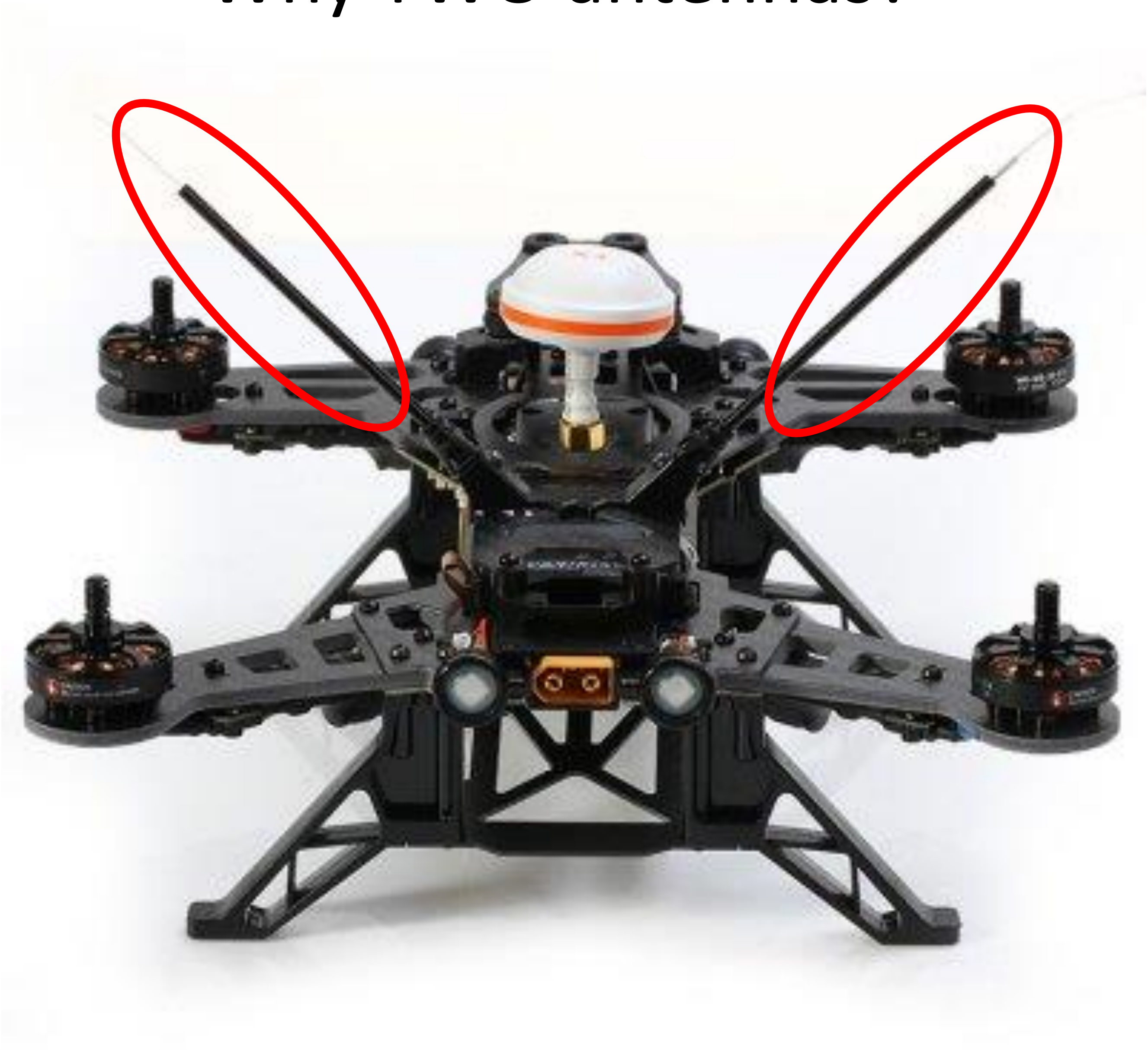


Demo 12: Polarized wave

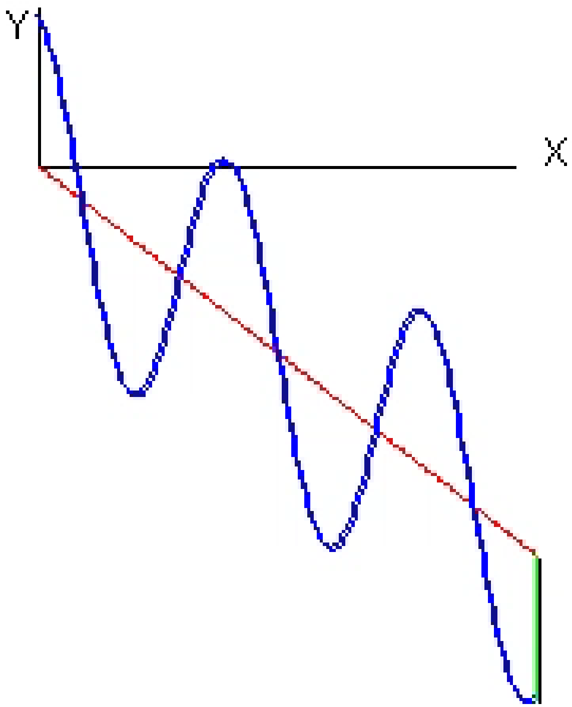
Look at receiver antennas on quadcopter



Why TWO antennas?

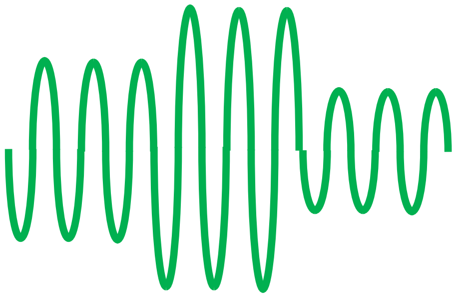


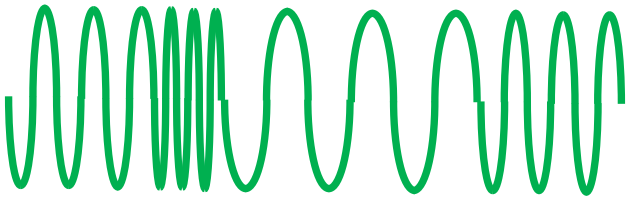
Polarization Physlet



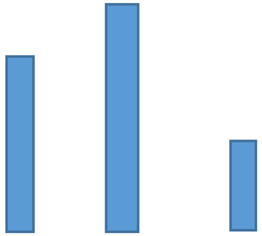
Antenna for left-circularly polarized light

Some Radio Control Concepts



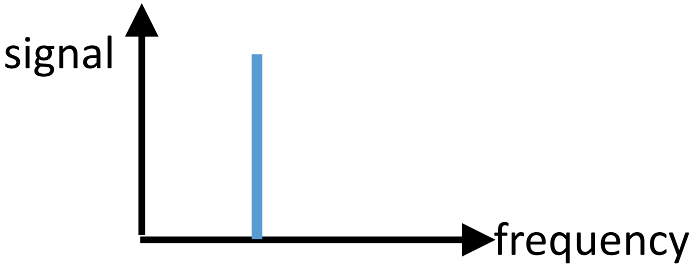


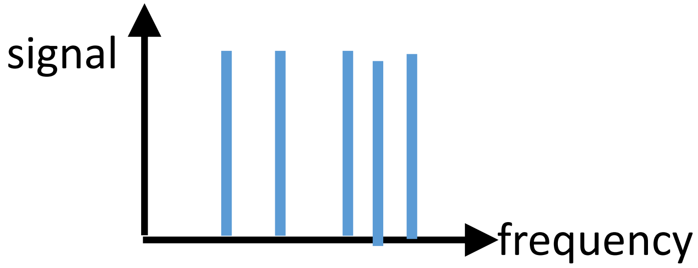
Amplitude Modulation vs Frequency Modulation



35 48 18

Analog vs digital





Single radio frequency vs Spread Spectrum

Equations (mathematical MODELS) are your friends!

Building a homemade ultralight…where to start?

What will we need?

What motor power, wing area, etc?

1. Estimate flying weight: 70kg person+ 40kg wings+30kg motor/prop+60kg frame, fuel, misc→200kg→2000N
2. Want to cruise at 60 km/h (17 m/s)→$W/S=0.38V^2$ →$S=19m^2$
3. Glide ratio of 8 is reasonable for such an airplane, descent w=2m/s→P=Ww=4000W to stay level, if want to climb at 3m/s need another 6000W→10000W (14 Hp) total
4. Best prop efficiency is around 50% →need a 28 Hp motor

Numbers matter!

Global warming, energy/economics policy, business→need reliable, quantitative estimates to make good decisions

The economics of flight:

Car with 4 people: 30 miles per gallon, 55 mph speed→0.008 gallon per passenger mile

Boeing 747 with 400 people and cargo (total=115,000 lbs)~520 people+luggage: 0.18 miles per gallon (burn 3000 gallons per hour!), 560 mph speed
→0.011 gallon per passenger mile

40% increase in fuel but 10 times the speed!

In transportation industry, time matters: ocean liner produces 200 million passenger miles per year, high speed train produces 250 million passenger miles per year, and Boeing 747 produces 750 million passenger miles per year

Take Home message: Radio control flying is exciting, interesting, fun and can teach us a lot about science and technology