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4th D-ERDW PhD Retreat

May 26 - 29, 2016
Black Forest, Germany

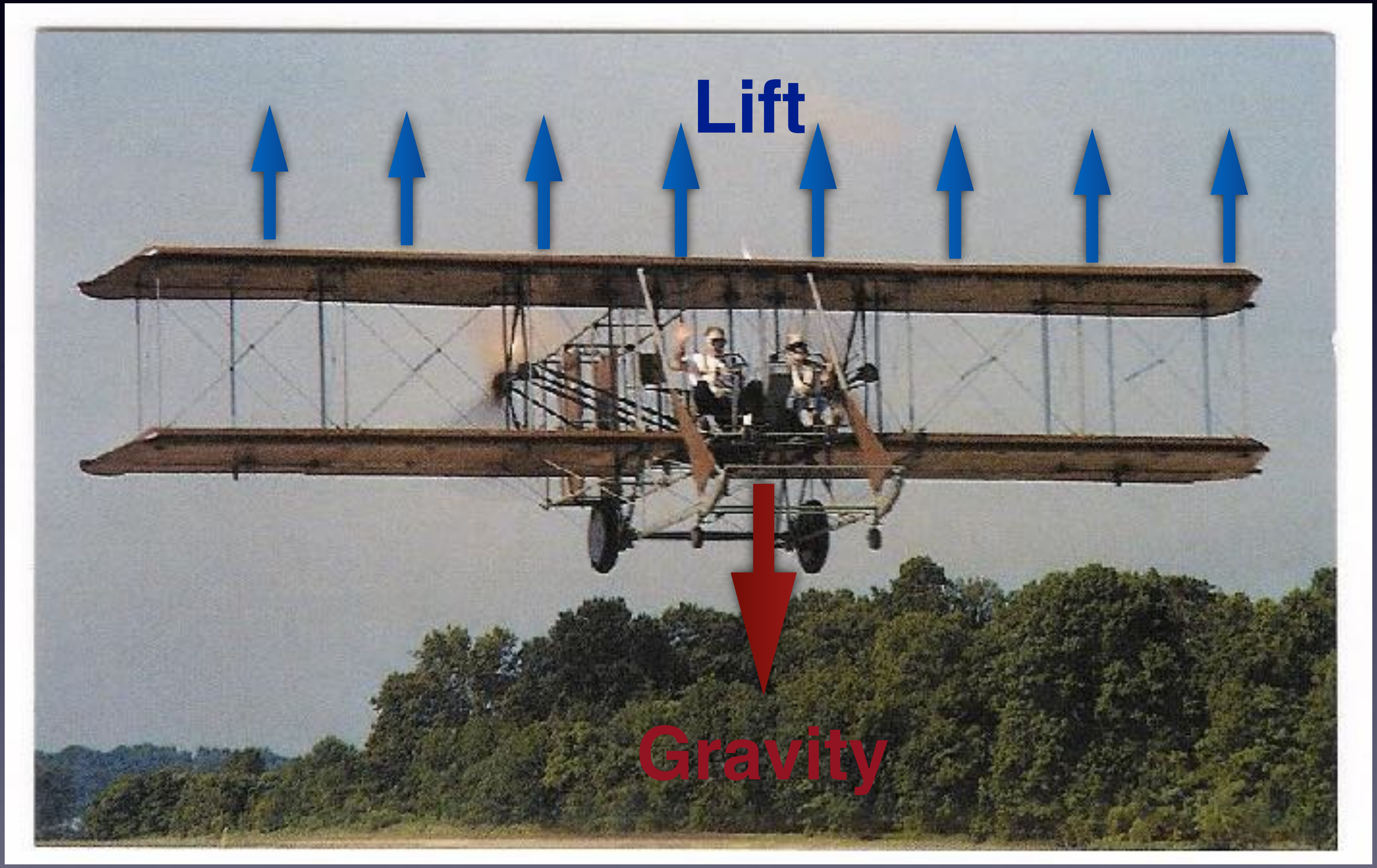
talks and posters by fellow PhD students
guest speakers
geological and adventurous excursions
sports, games... and much more!

Are you in!?

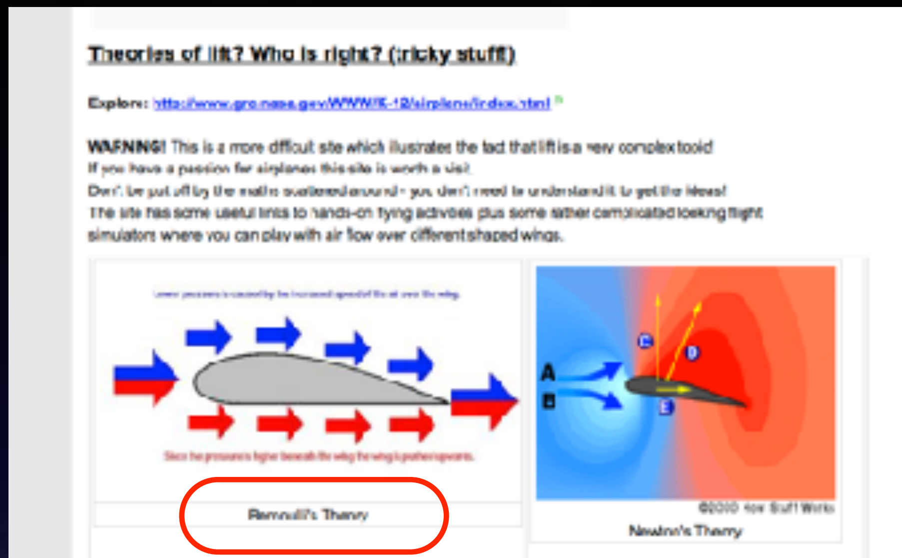
Register by January 30, 2016
http://www.erdw-retreat.ethz.ch/

The art of Flying…

The lift from the wing



The lift from the wing



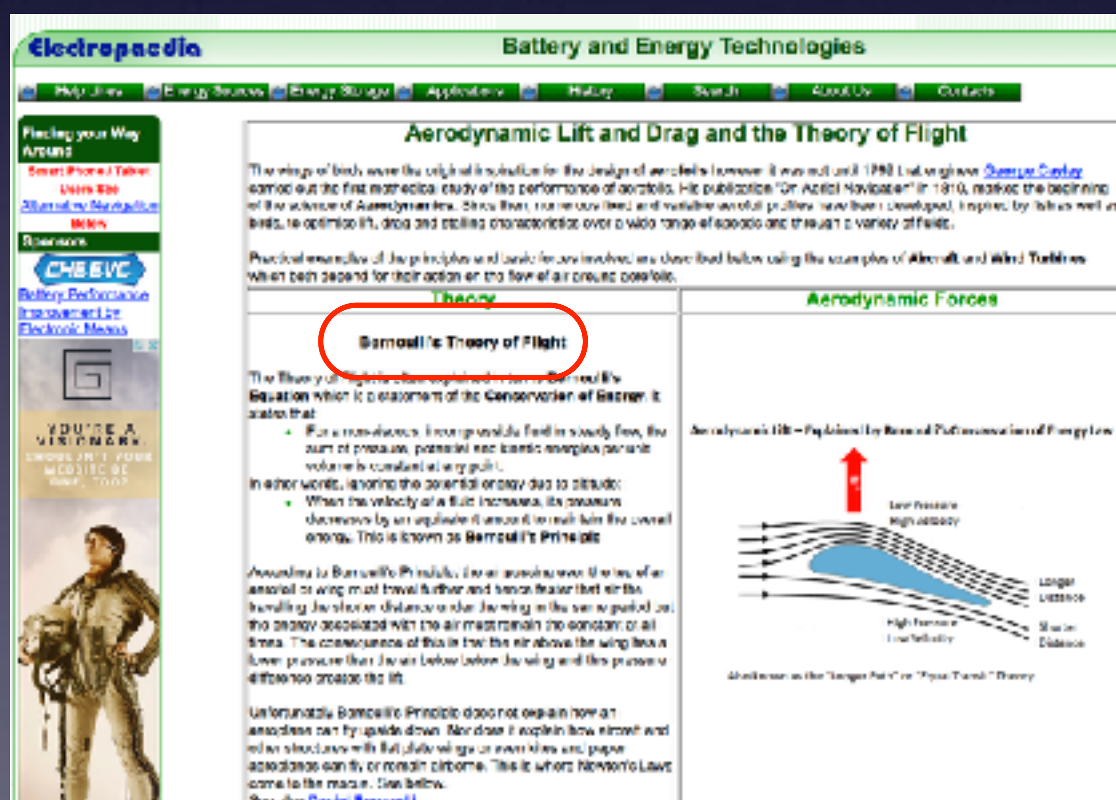
Theories of lift? Who is right? (tricky stuff)

Explore: http://www.grc.nasa.gov/WWW/K-12/airplane/index.html

WARNING! This is a more difficult site which illustrates the fact that lift is a very complex topic!
If you have a passion for airplanes this site is worth a visit.
Don't be put off by the maths scattered around - you don't need to understand it to get the ideas!
The site has some useful links to hands-on flying activities plus some rather complicated looking flight simulators where you can play with air flow over different shaped wings.

Bernoulli's Theory

Newton's Theory



Electropaedia

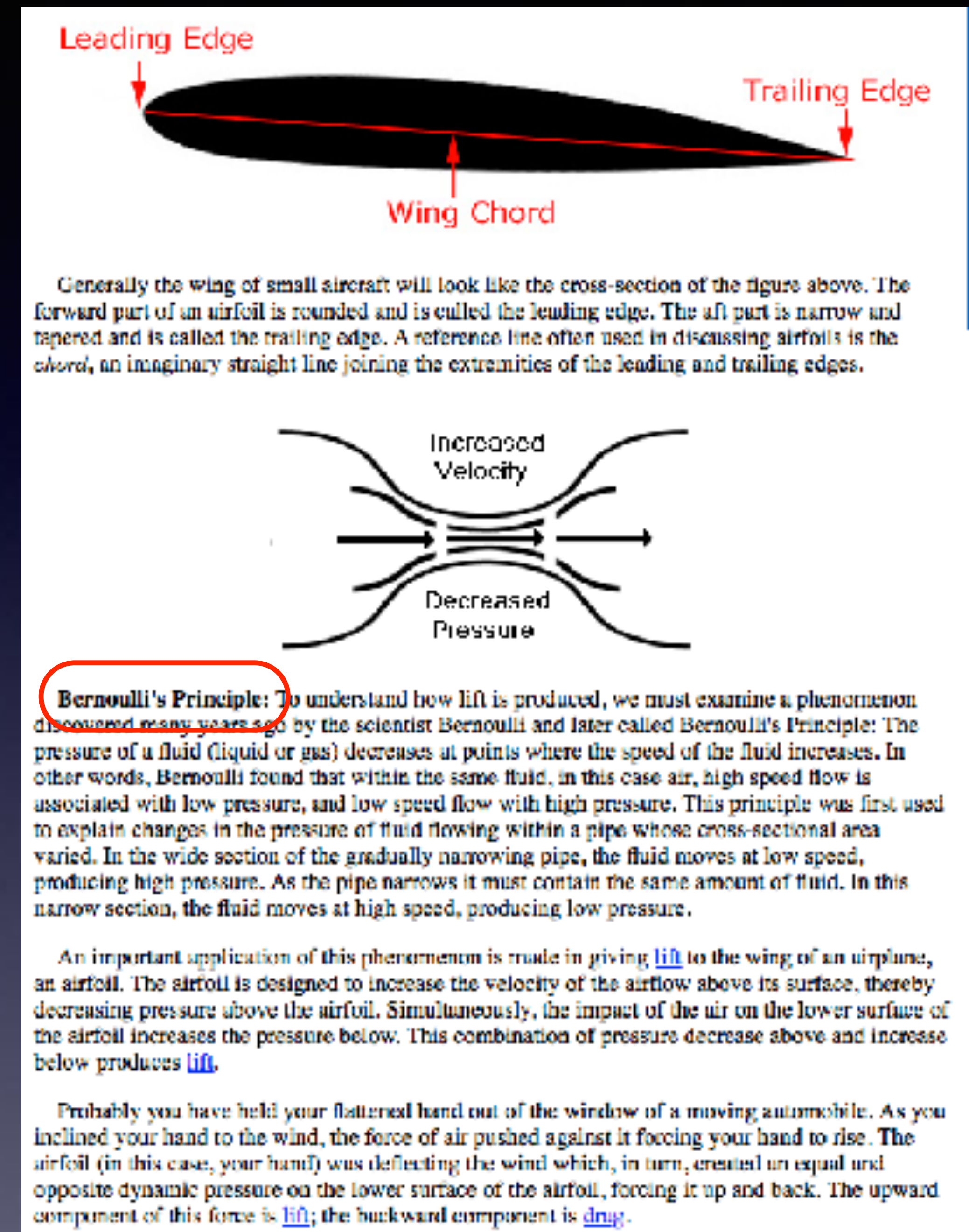
Battery and Energy Technologies

Aerodynamic Lift and Drag and the Theory of Flight

Theory

Aerodynamic Forces

Bernoulli's Theory of Flight



Generally the wing of small aircraft will look like the cross-section of the figure above. The forward part of an airfoil is rounded and is called the leading edge. The aft part is narrow and tapered and is called the trailing edge. A reference line often used in discussing airfoils is the *chord*, an imaginary straight line joining the extremities of the leading and trailing edges.

Bernoulli's Principle: To understand how lift is produced, we must examine a phenomenon discovered many years ago by the scientist Bernoulli and later called Bernoulli's Principle: The pressure of a fluid (liquid or gas) decreases at points where the speed of the fluid increases. In other words, Bernoulli found that within the same fluid, in this case air, high speed flow is associated with low pressure, and low speed flow with high pressure. This principle was first used to explain changes in the pressure of fluid flowing within a pipe whose cross-sectional area varied. In the wide section of the gradually narrowing pipe, the fluid moves at low speed, producing high pressure. As the pipe narrows it must contain the same amount of fluid. In this narrow section, the fluid moves at high speed, producing low pressure.

An important application of this phenomenon is made in giving lift to the wing of an airplane, an airfoil. The airfoil is designed to increase the velocity of the airflow above its surface, thereby decreasing pressure above the airfoil. Simultaneously, the impact of the air on the lower surface of the airfoil increases the pressure below. This combination of pressure decrease above and increase below produces lift.

Probably you have held your flattened hand out of the window of a moving automobile. As you inclined your hand to the wind, the force of air pushed against it forcing your hand to rise. The airfoil (in this case, your hand) was deflecting the wind which, in turn, created an equal and opposite dynamic pressure on the lower surface of the airfoil, forcing it up and back. The upward component of this force is lift; the backward component is drag.

Flow around a wing

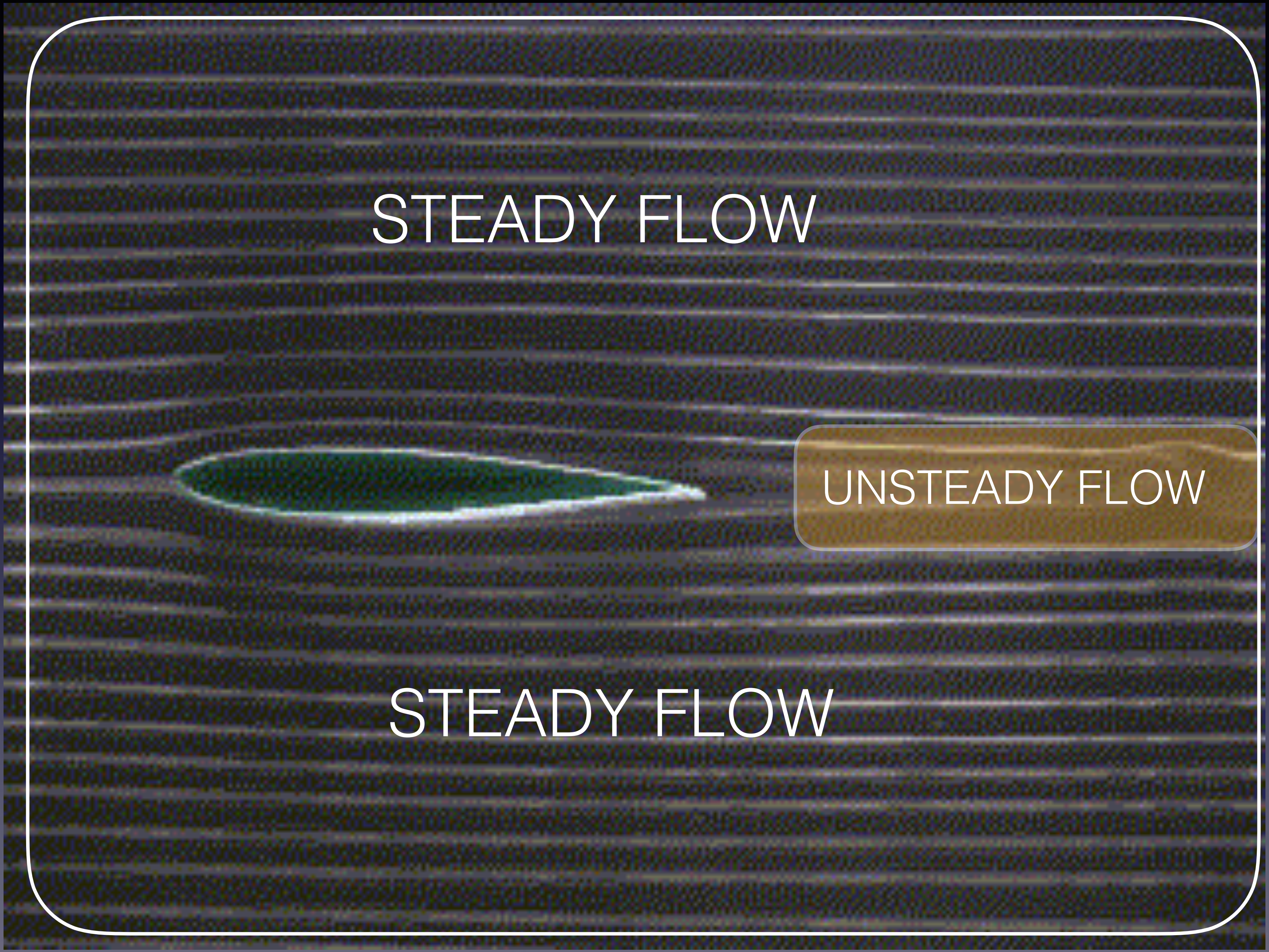
<u>The fluid:</u>

- Homogeneous.
- Incompressible.

<u>The flow:</u>

- Speed is large enough to neglect viscous effects.
- Speed is low enough to neglect turbulence.

Flow around a wing



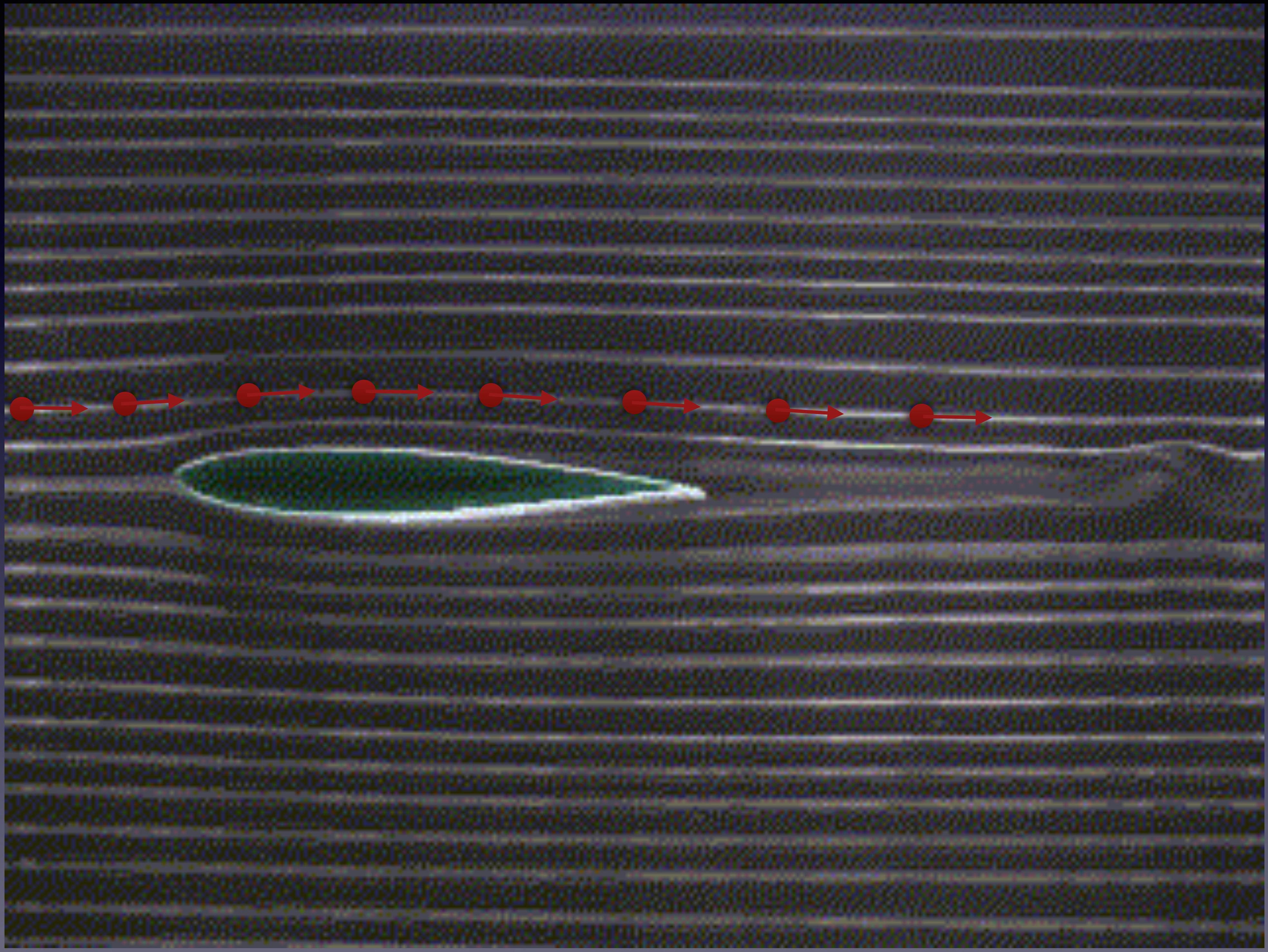
Flow around a wing

The flow is governed by the Navier-Stokes equation:

$$\rho[\frac{\partial \vec{U}}{\partial t} + \vec{U} \cdot \nabla \vec{U}] = -\vec{\nabla}(p + p_{atm}) + \mu \nabla^2 \vec{U}$$

$$\rho \vec{U} \cdot \nabla \vec{U} = -\vec{\nabla}(p + p_{atm})$$

Flow around a wing



Flow around a wing

$$\rho\vec{U}\cdot\nabla\vec{U} = -\vec{\nabla}(p + p_{atm})$$

Along a streamline, i.e. a trajectory:

$$\rho U\frac{\partial U}{\partial s} = \frac{\partial(p + p_{atm})}{\partial s}$$

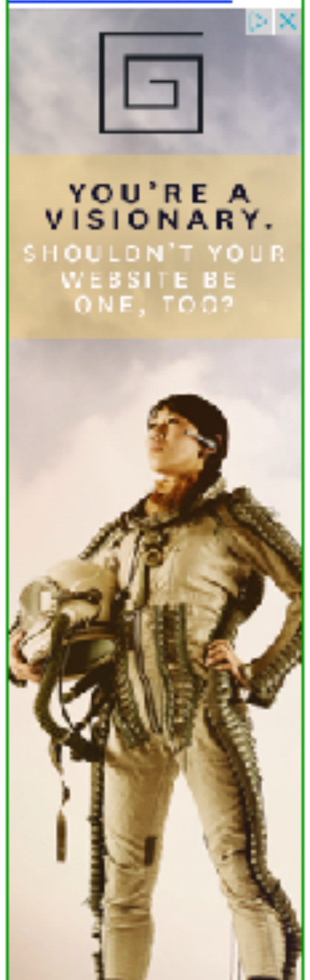
Bernoulli equation or energy conservation

$$\frac{1}{2}\rho U^2 + p = cst$$

Flow around a wing

Electropaedia — **Battery and Energy Technologies**

Finding your Way Around
Smart Phone / Tablet Users See
Alternative Navigation
Below



Aerodynamic Lift and Drag and the Theory of Flight

The wings of birds were the original inspiration for the design of **aerofoils** however it was not until 1799 that engineer George Cayley carried out the first methodical study of the performance of aerofoils. His publication "On Aerial Navigation" in 1810, marked the beginning of the science of **Aerodynamics**. Since then, numerous fixed and variable aerofoil profiles have been developed, inspired by fish as well as birds, to optimise lift, drag and stalling characteristics over a wide range of speeds and through a variety of fluids.

Practical examples of the principles and basic forces involved are described below using the examples of **Aircraft** and **Wind Turbines** which both depend for their action on the flow of air around aerofoils.

Theory	Aerodynamic Forces

Bernoulli's Theory of Flight

The Theory of Flight is often explained in terms **Bernoulli's Equation** which is a statement of the **Conservation of Energy**. It states that:

- For a non-viscous, incompressible fluid in steady flow, the sum of pressure, potential and kinetic energies per unit volume is constant at any point.

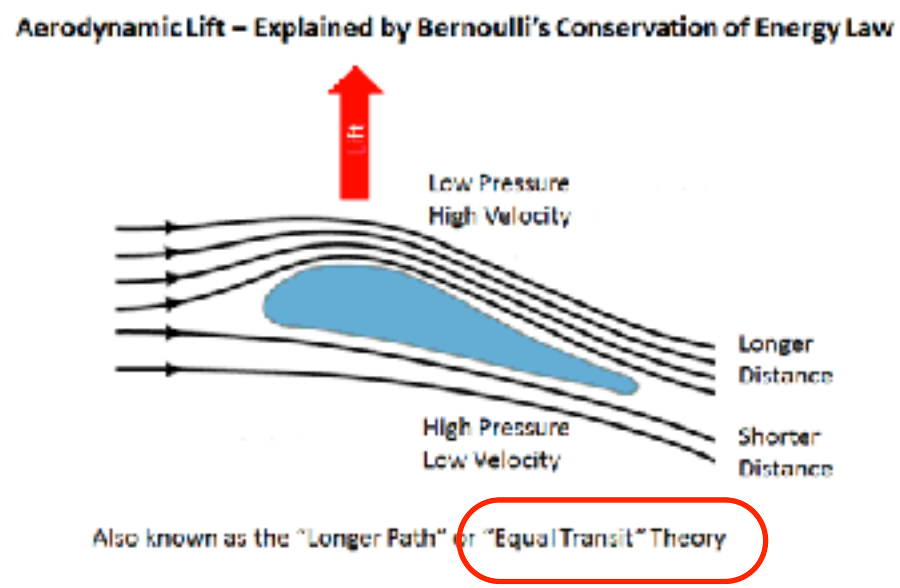
In other words, ignoring the potential energy due to altitude:

- When the velocity of a fluid increases, its pressure decreases by an equivalent amount to maintain the overall energy. This is known as **Bernoulli's Principle**

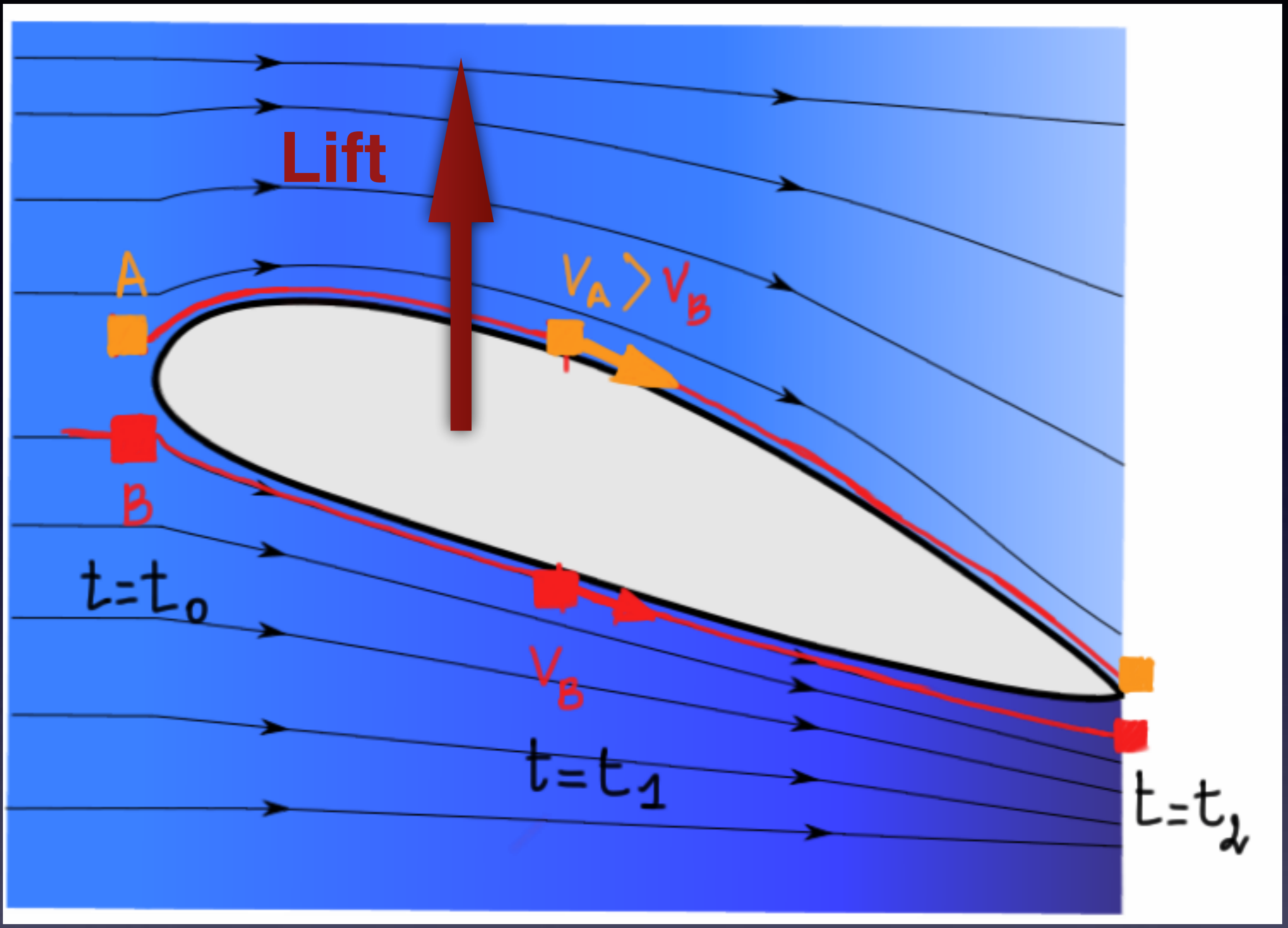
According to Bernoulli's Principle, the air passing over the top of an aerofoil or wing must travel further and hence faster that air the travelling the shorter distance under the wing in the same period but the energy associated with the air must remain the constant at all times. The consequence of this is that the air above the wing has a lower pressure than the air below below the wing and this pressure difference creates the lift.

Unfortunately Bernoulli's Principle does not explain how an aeroplane can fly upside down. Nor does it explain how aircraft and other structures with flat plate wings or even kites and paper aeroplanes can fly or remain airborne. This is where Newton's Laws come to the rescue. See below.

See also **Daniel Bernoulli**



Flow around a wing



$$\frac{1}{2}\rho U^2 + p = cst$$

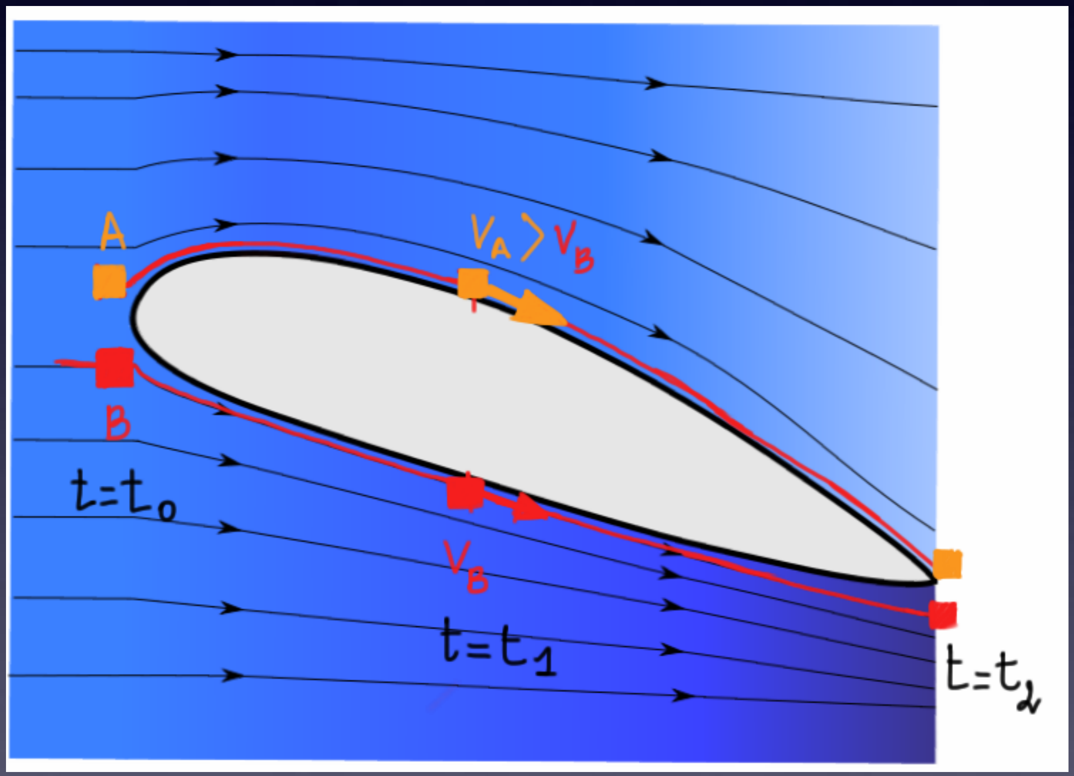
$$V_A > V_B$$

$$P_A < P_B$$

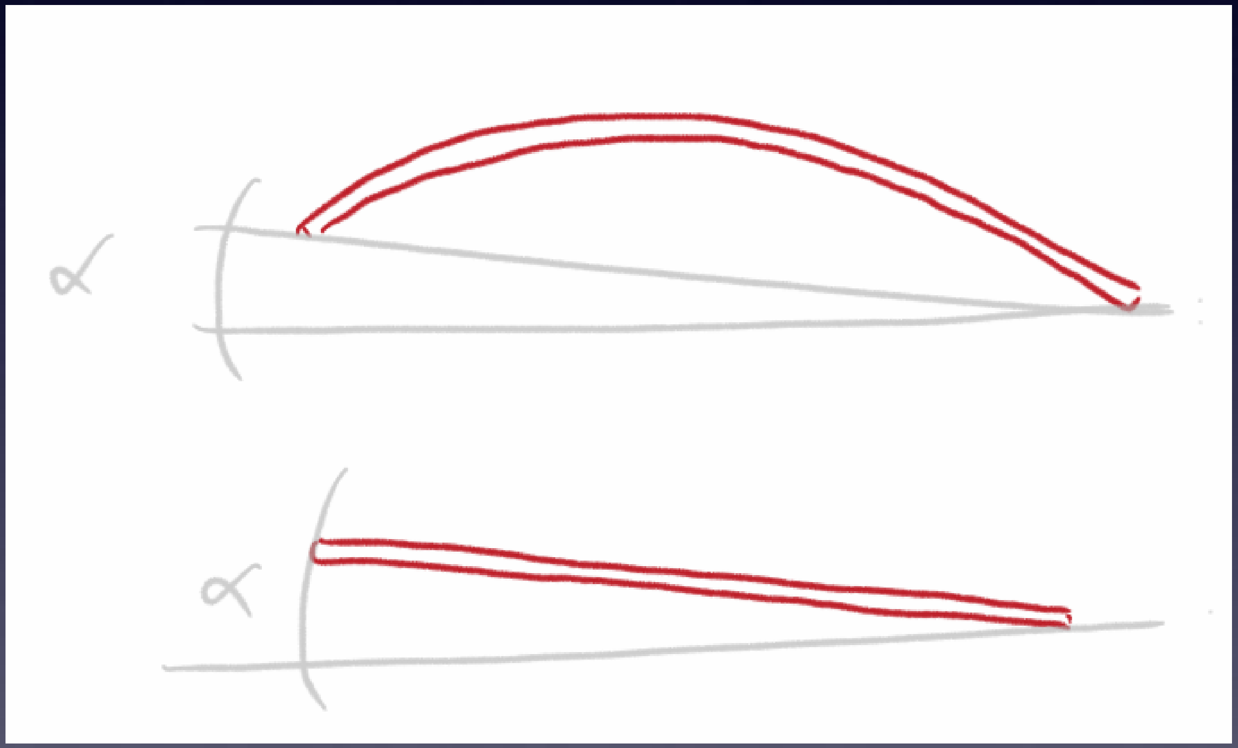
The flow results in a net force acting on the wing pointing upward

Flow around a wing

$$\frac{1}{2}\rho U^2 + p = cst$$



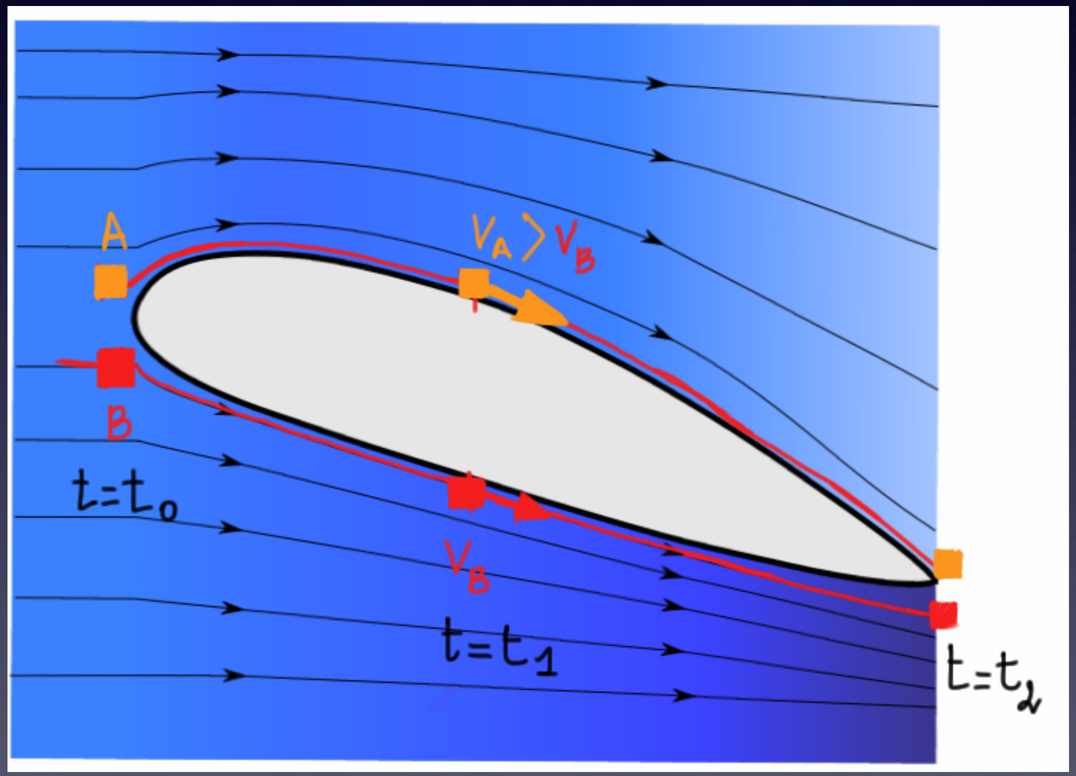
This wing produces lift



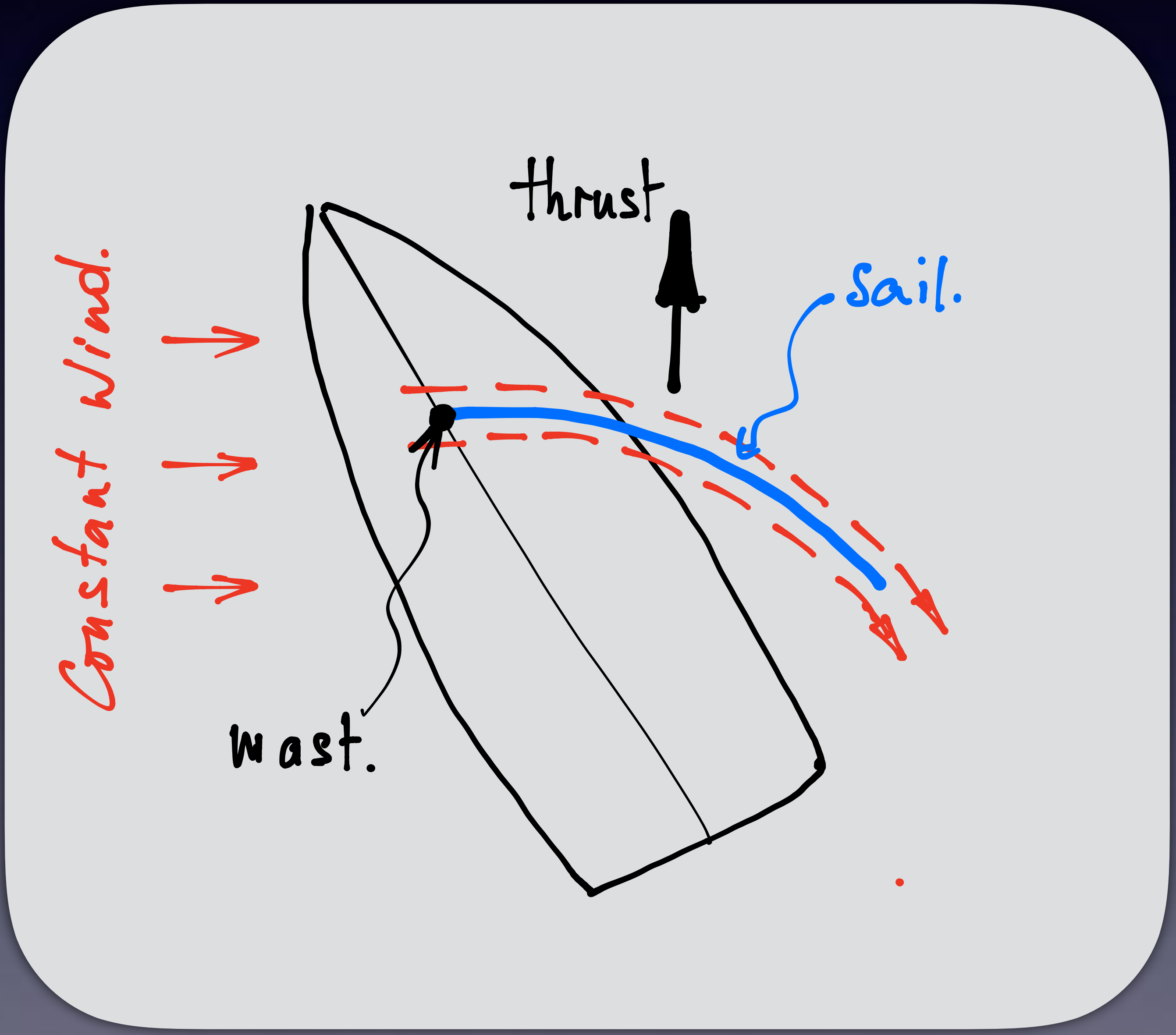
These wings should not produce lift, they should both be equally bad.

Flow around a wing

$$\frac{1}{2}\rho U^2 + p = cst$$

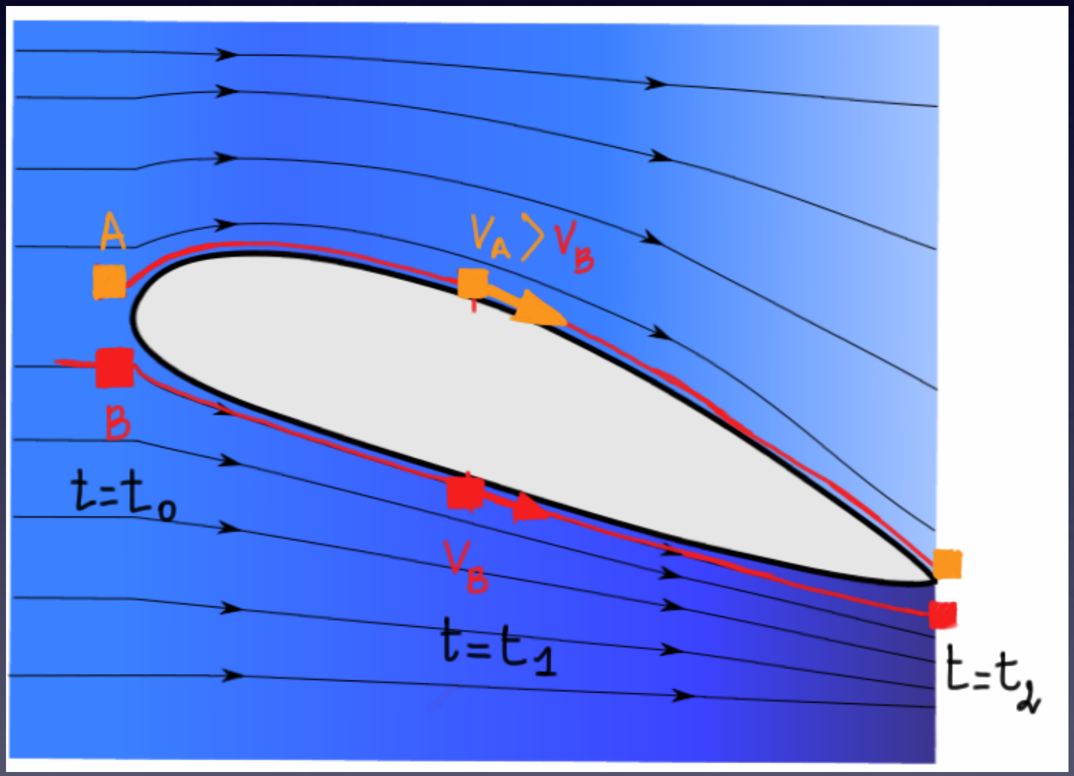


This wing produces lift

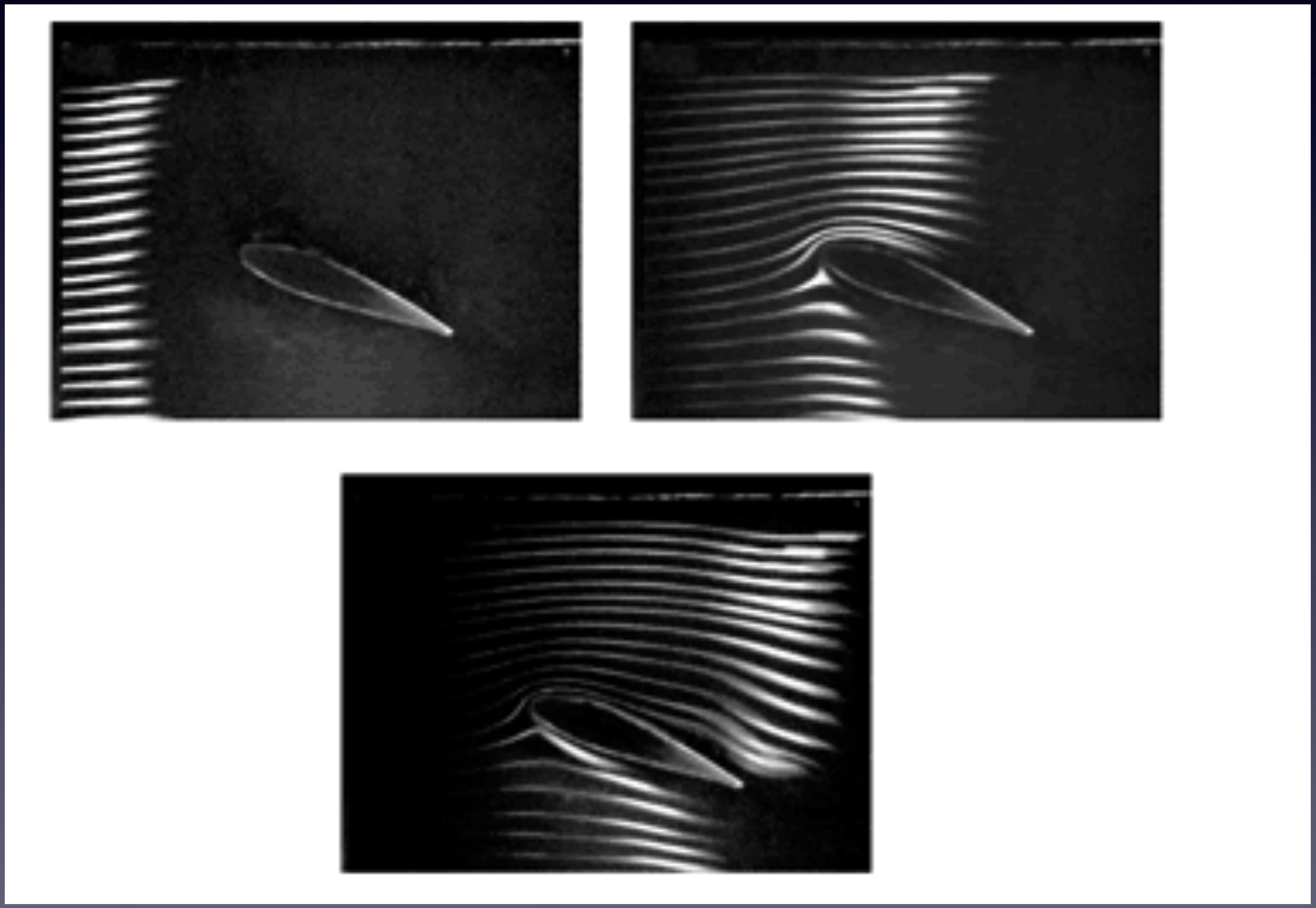


Flow around a wing

$$\frac{1}{2}\rho U^2 + p = cst$$

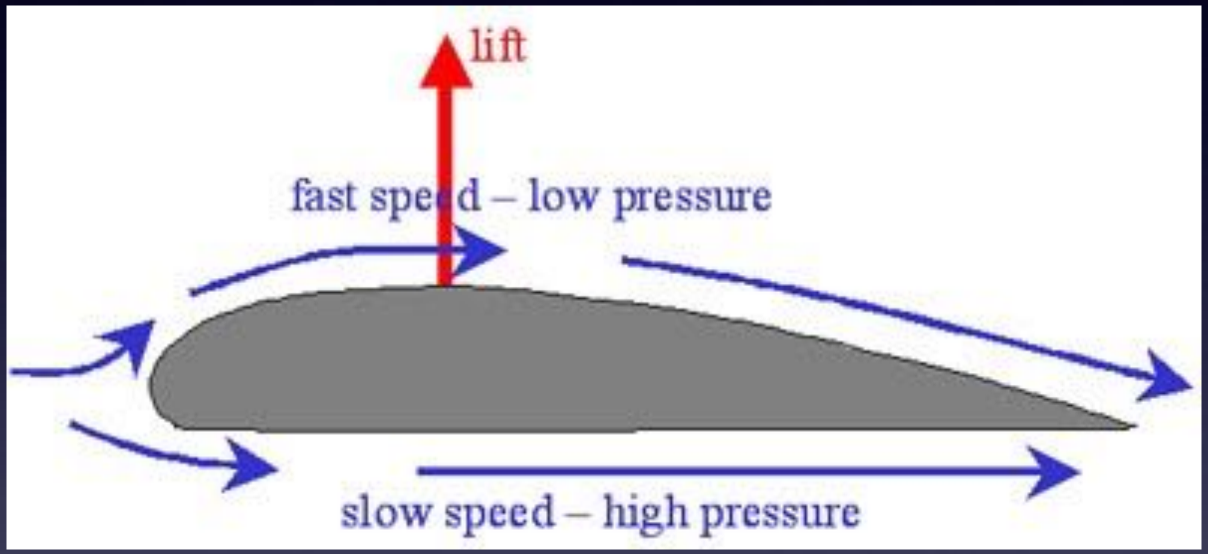


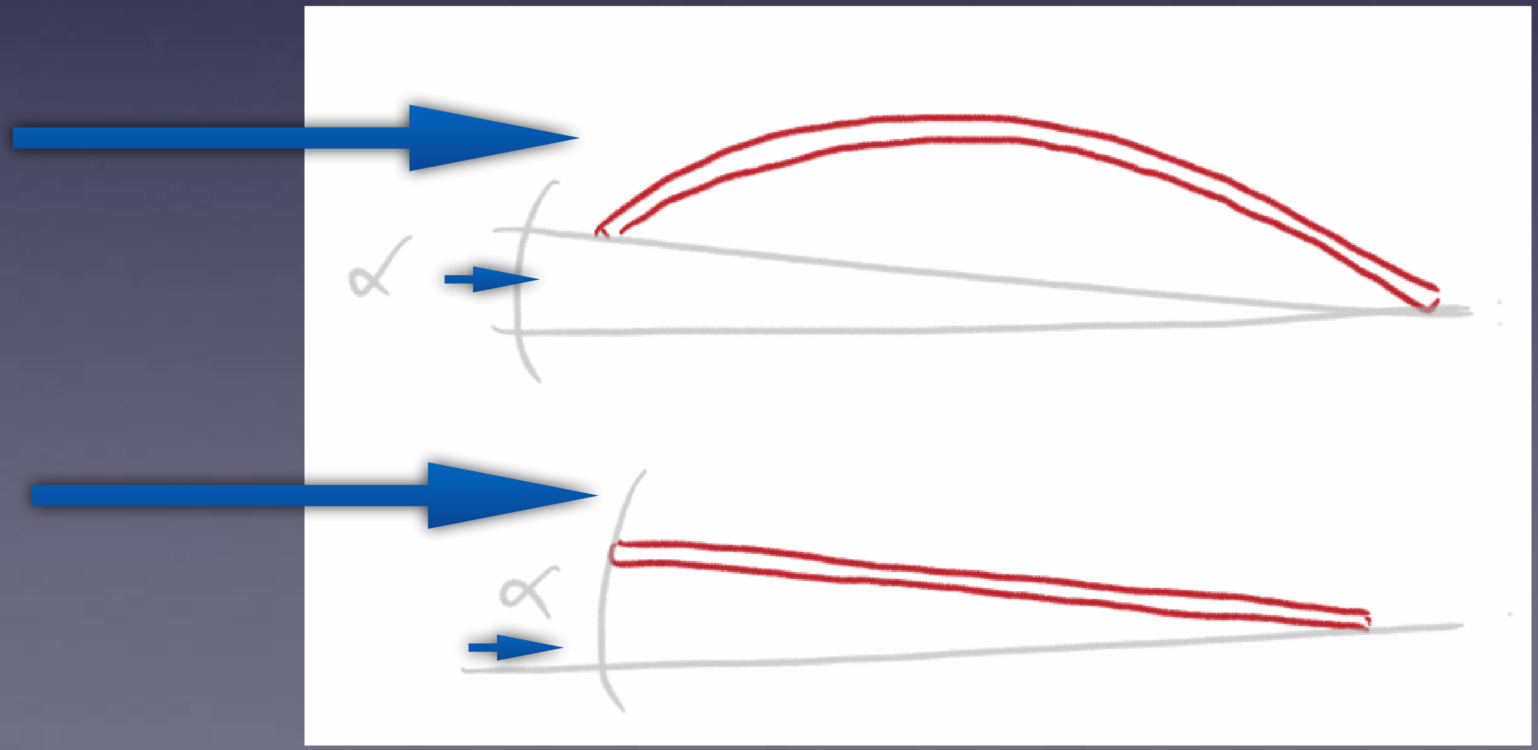
This wing produces lift



Flow around a wing

$$\frac{1}{2}\rho U^2 + p = cst$$





Flow around a wing

$$\rho\vec{U}\cdot\nabla\vec{U} = -\vec{\nabla}(p + p_{atm})$$

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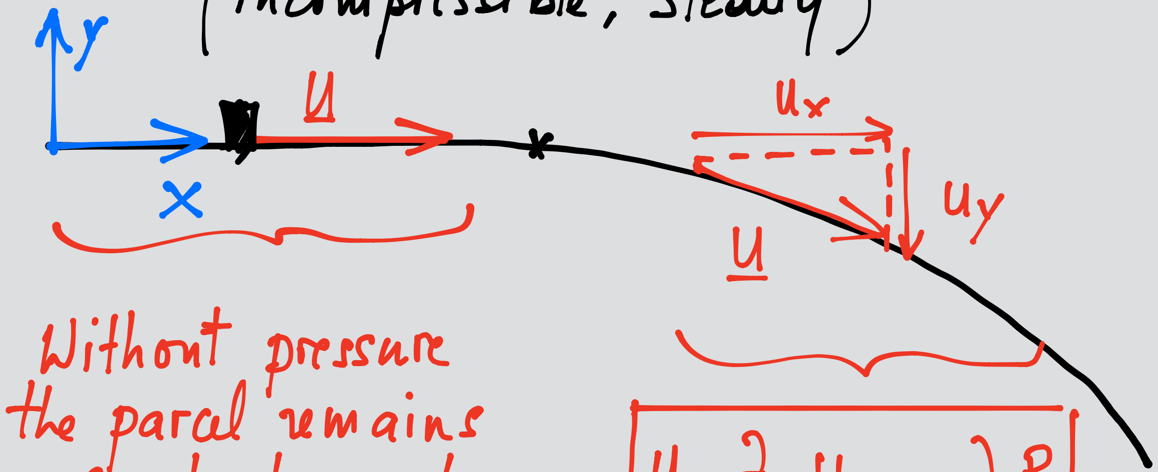
(incompressible, steady)



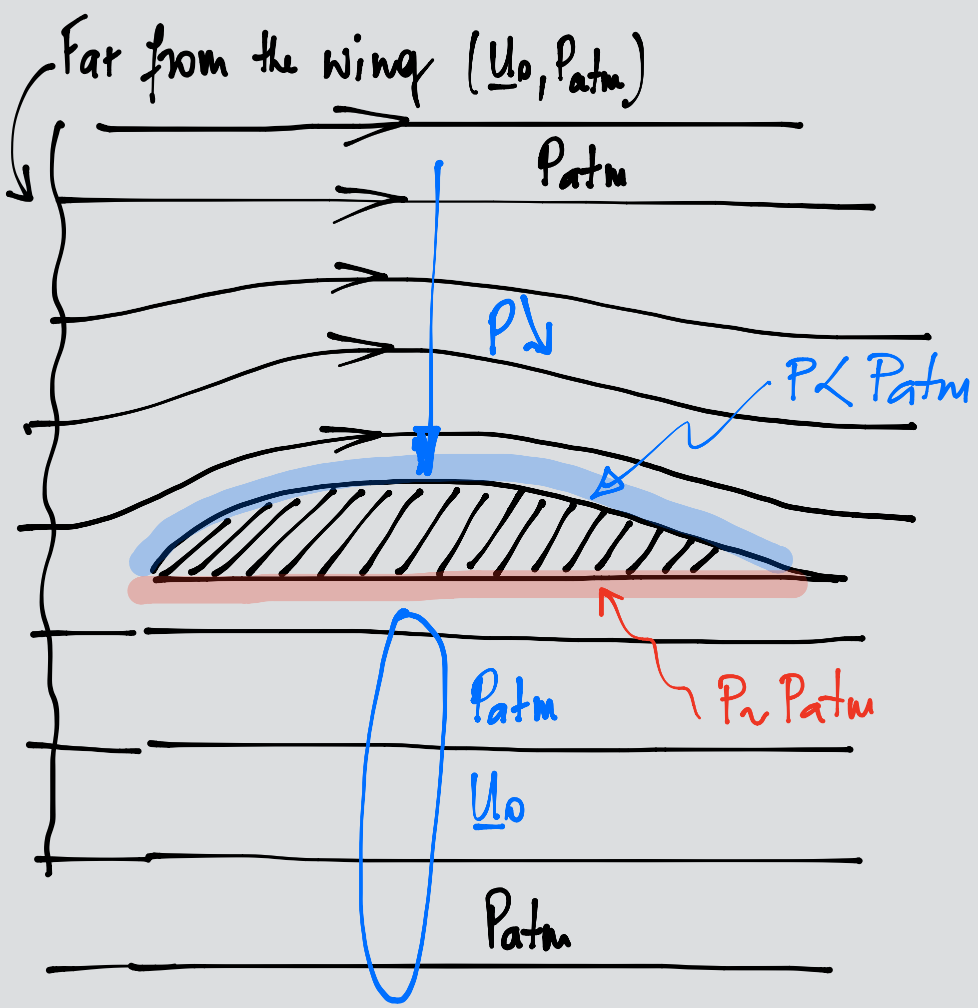
Without pressure the parcel remains a constant speed U_0

$$\boxed{u_x \frac{\partial}{\partial x} u_y = -\frac{\partial}{\partial y} p}$$

Curvature implies pressure gradient.

Flow around a wing

$$\rho\vec{U}\cdot\nabla\vec{U} = -\vec{\nabla}(p+p_{atm})$$



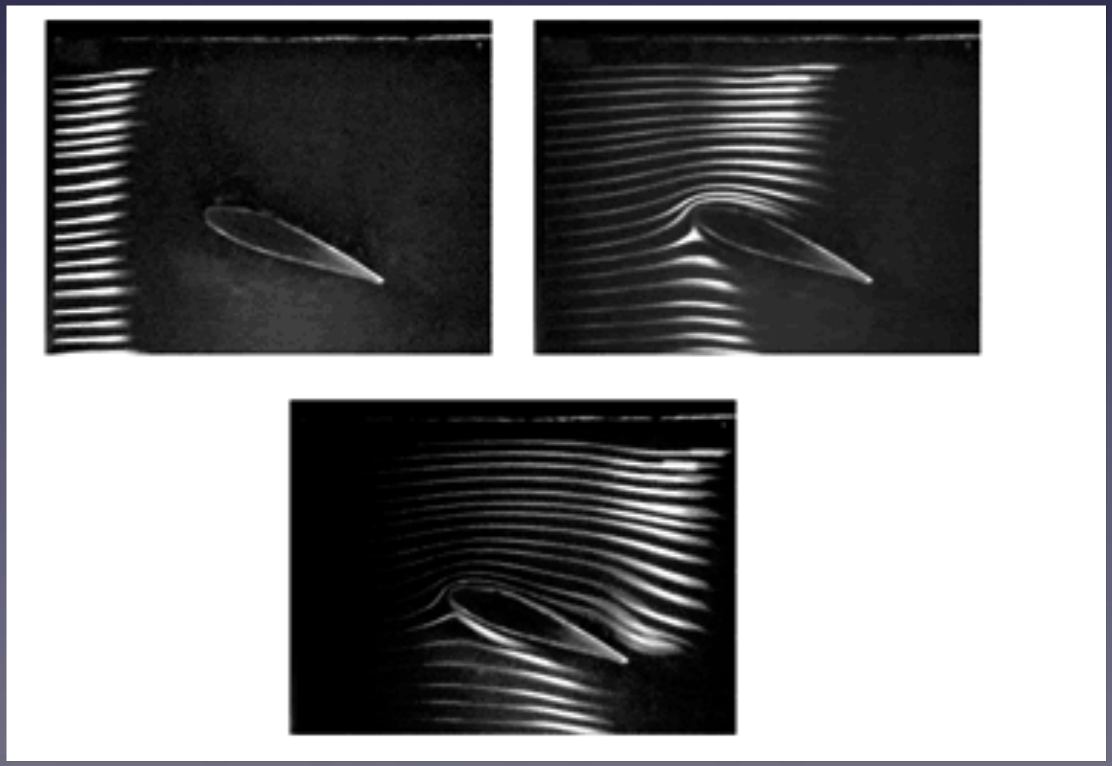
Pressure drop along the streamline results from curvature of the flow.

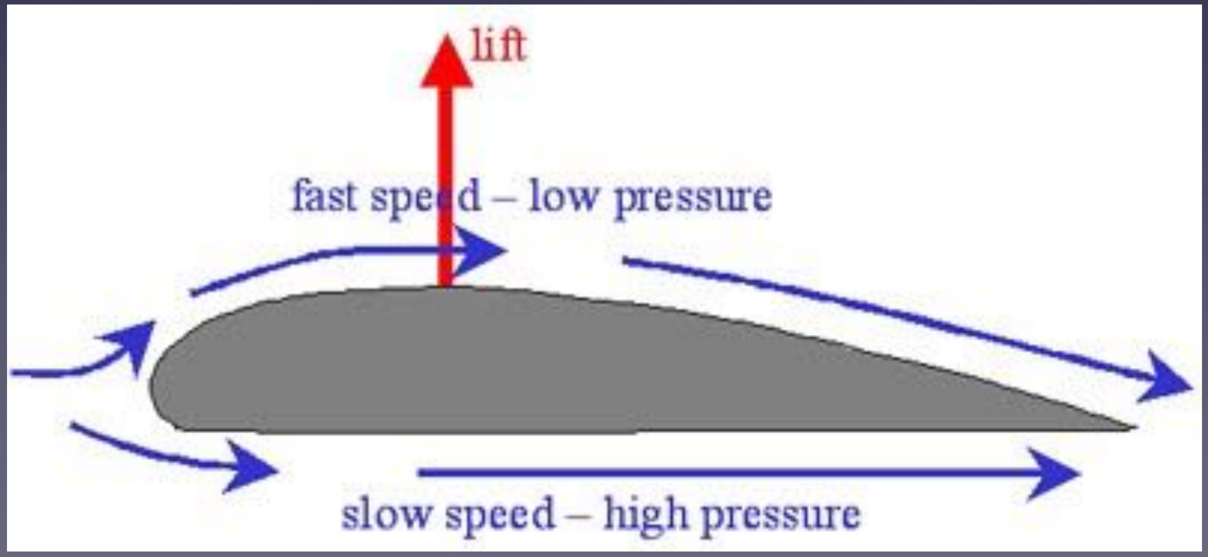
Flow around a wing

$$\frac{1}{2}\rho U^2 + p = cst$$

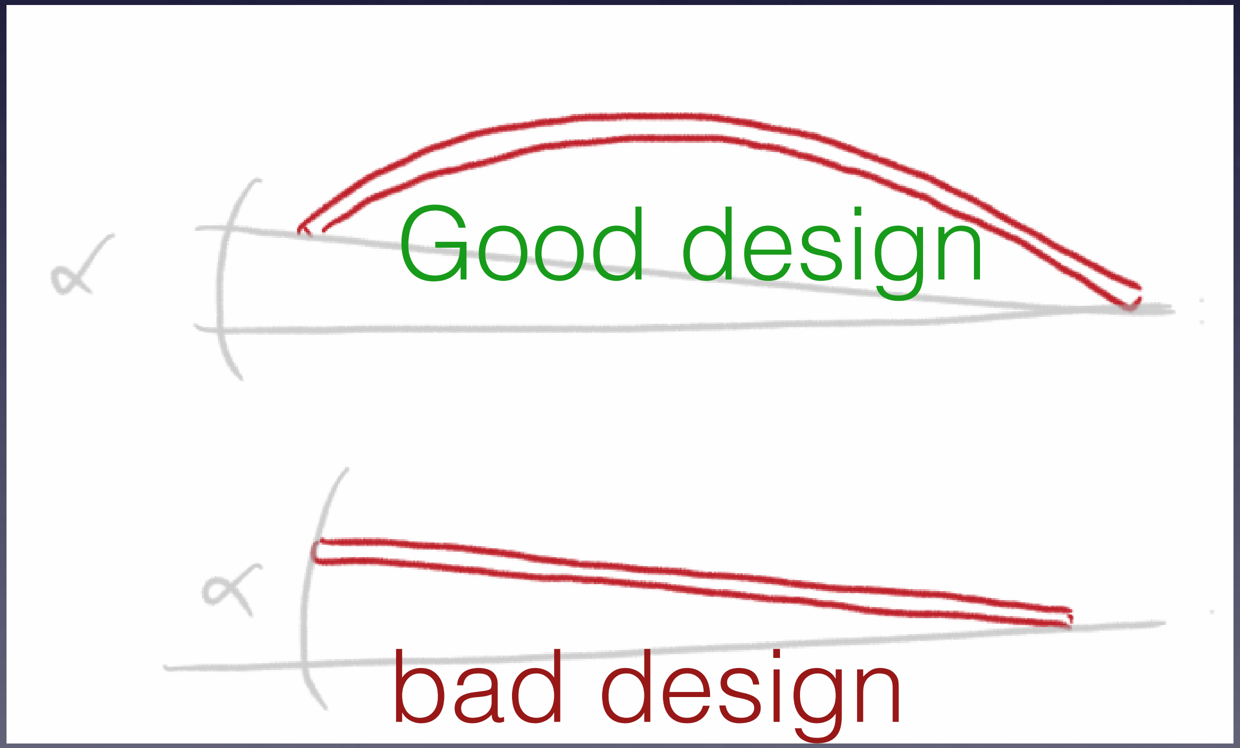
Is Bernoulli wrong ? No, it is correct but…

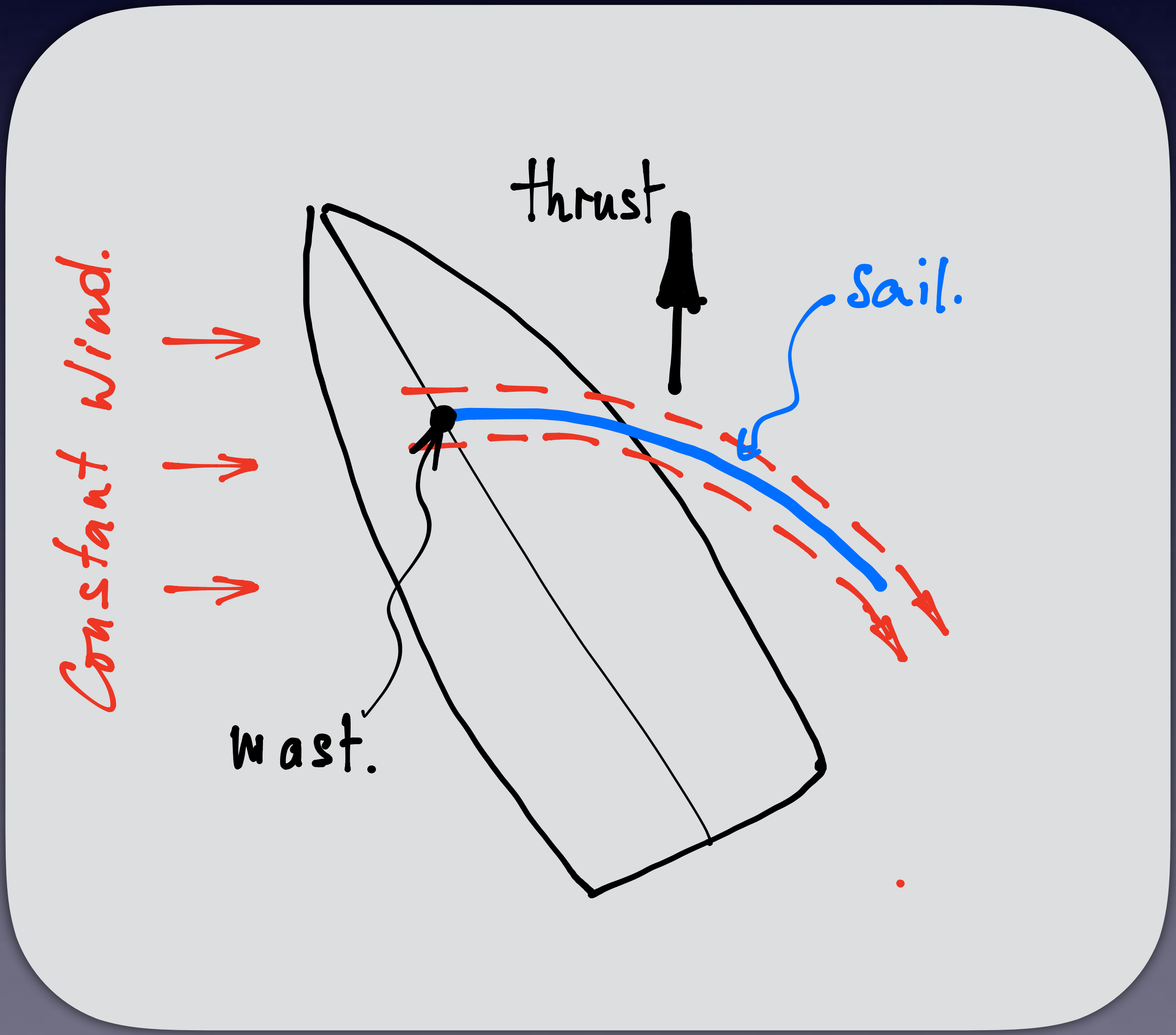
Low pressure implies higher velocity !!!

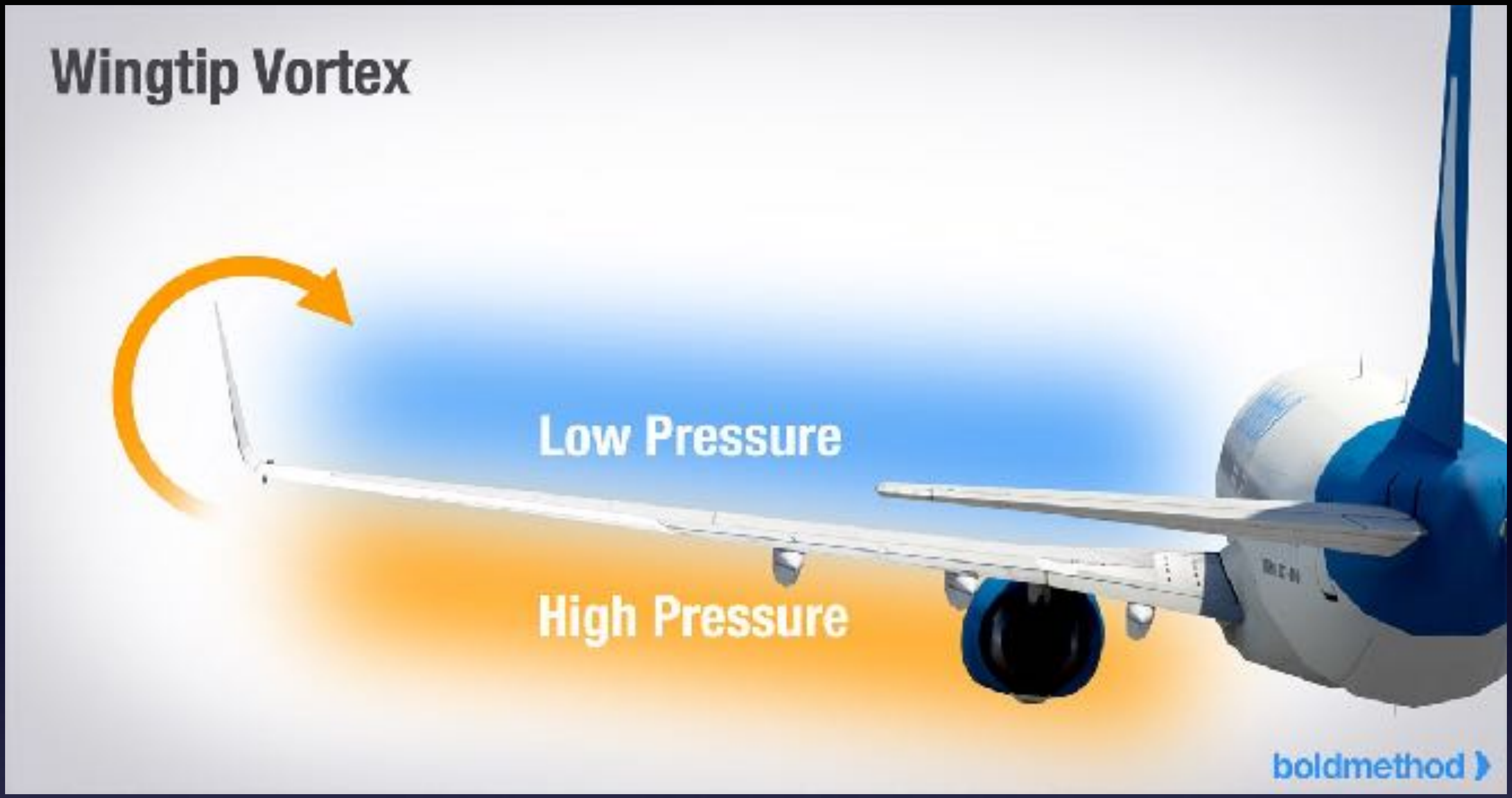


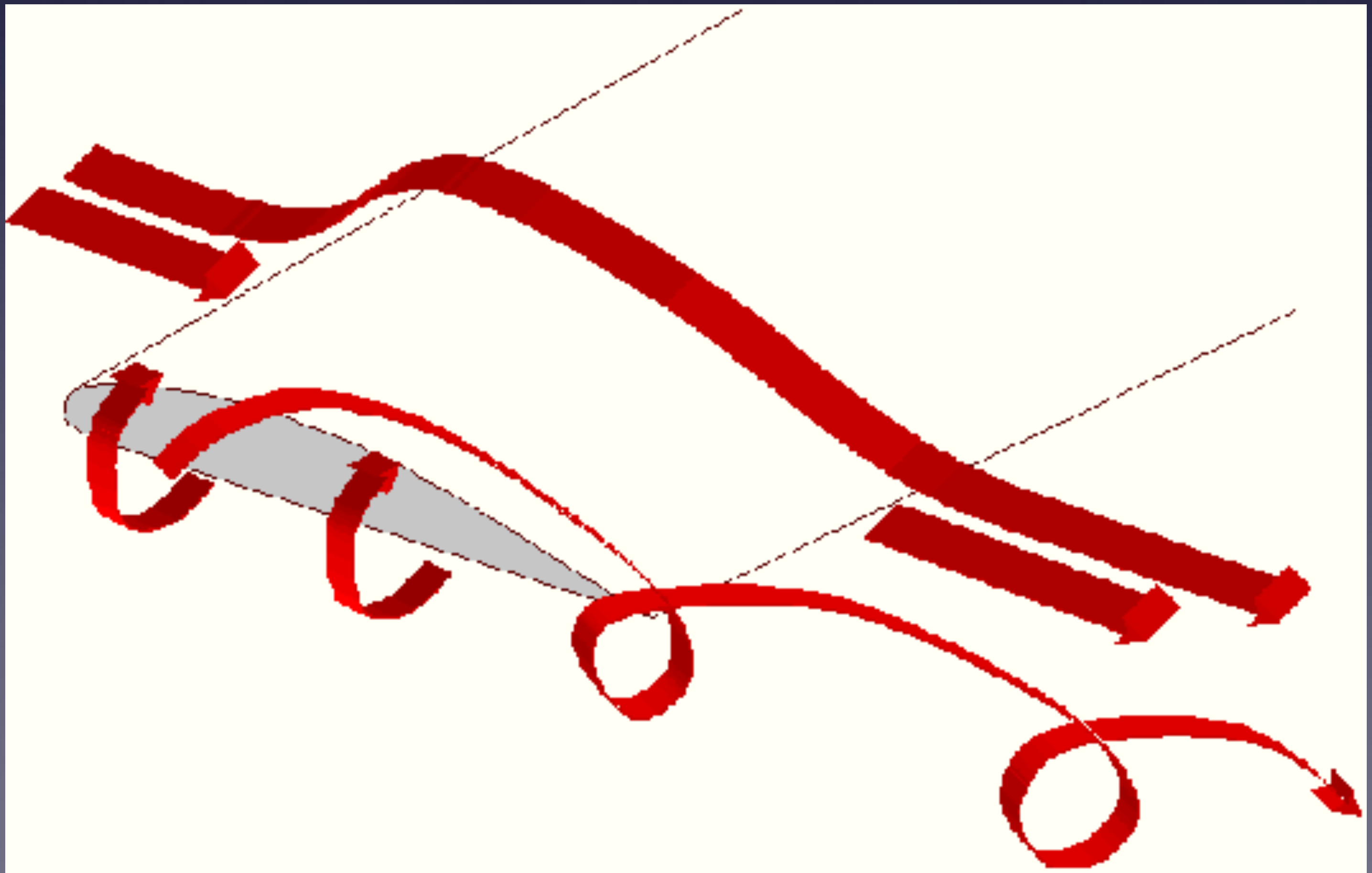


Curvature implies pressure gradient






Wingtip Vortex
Low Pressure
High Pressure
boldmethod

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