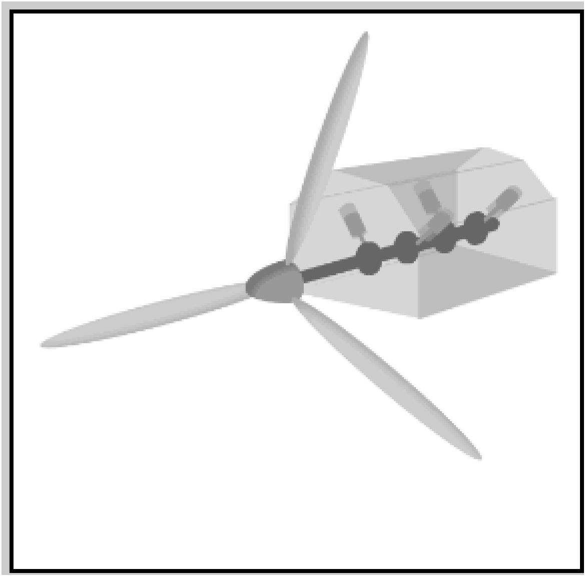
Propulsion

Unit –III	08 Hrs
Drones Propulsion Systems: Thrust Generation, Powered Lift, Sources of Power for UAVs- Piston, Rotary, Gas turbine engines, electric or battery powered UAVs.	

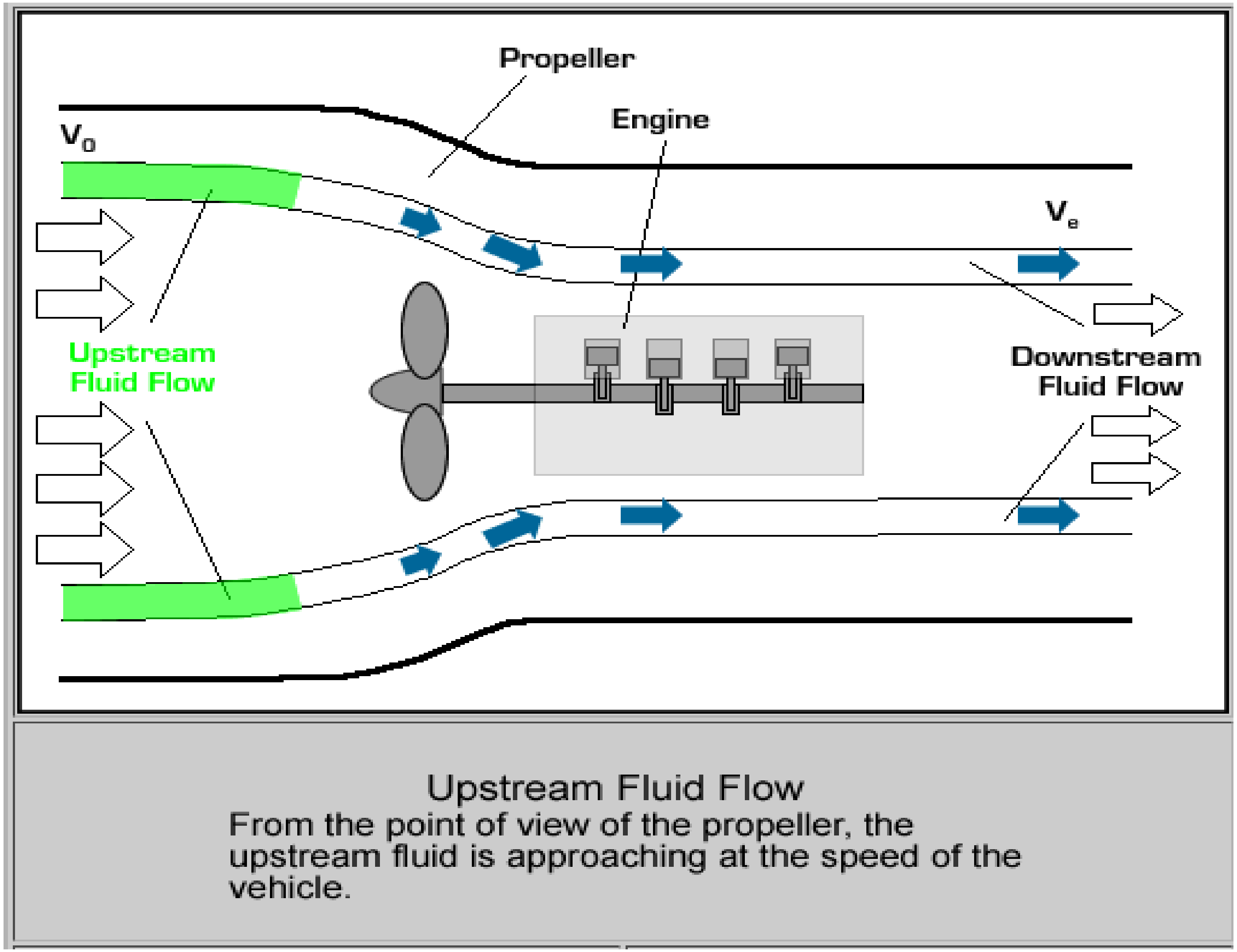
Thrust generation via propellers

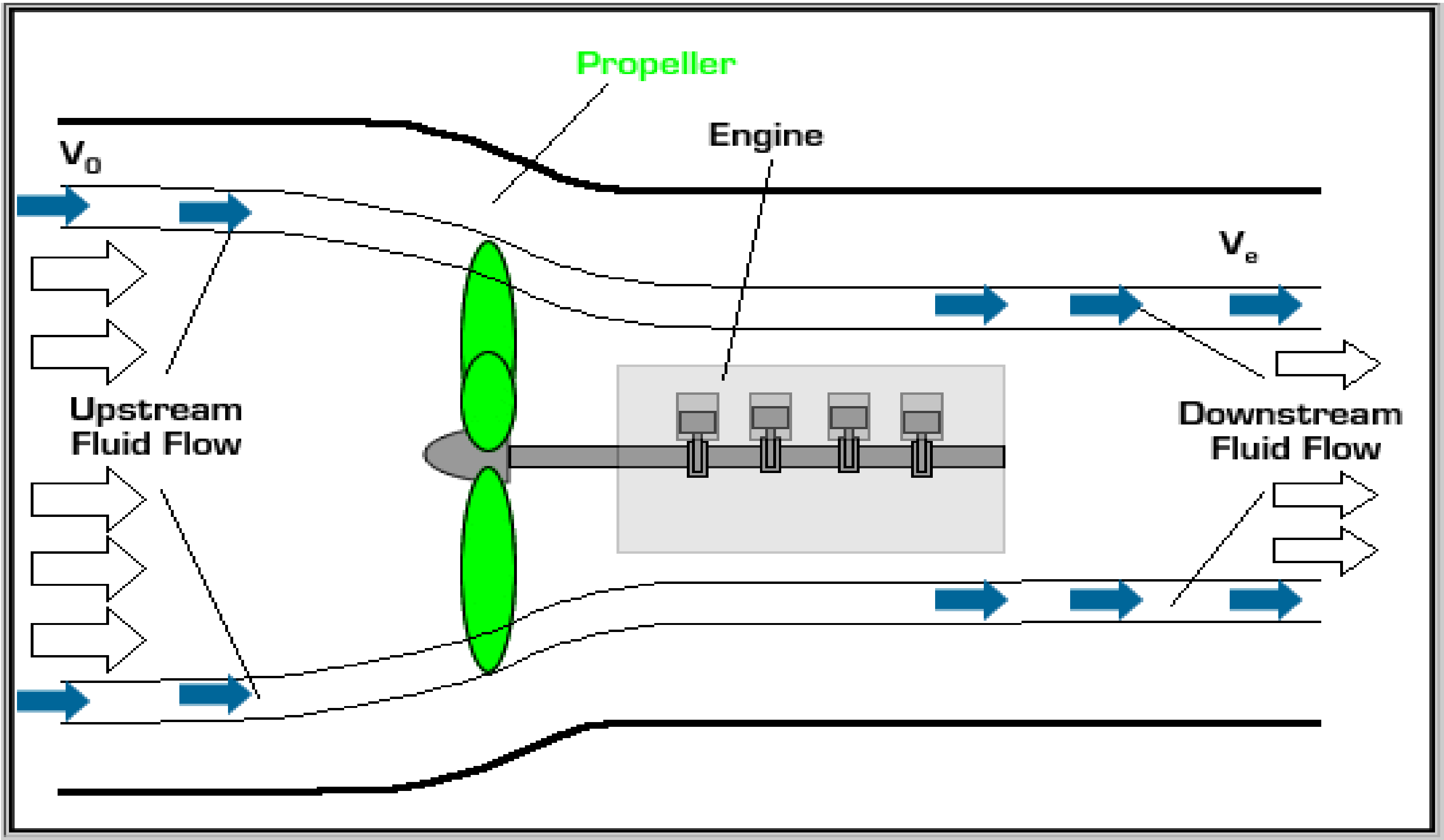
- Propellers are used on boats, submarines, and small aircraft. Propellers are simple, revolving hubs with blades placed evenly along the edges (usually 2 to 4 blades on a propeller, but more are possible).
- A mechanical engine attached to the propeller converts fuel or other stored energy into mechanical power which turns the propeller at a high rate of speed.



Different type of multi-cylinder engines and piston prop engines (video 2)

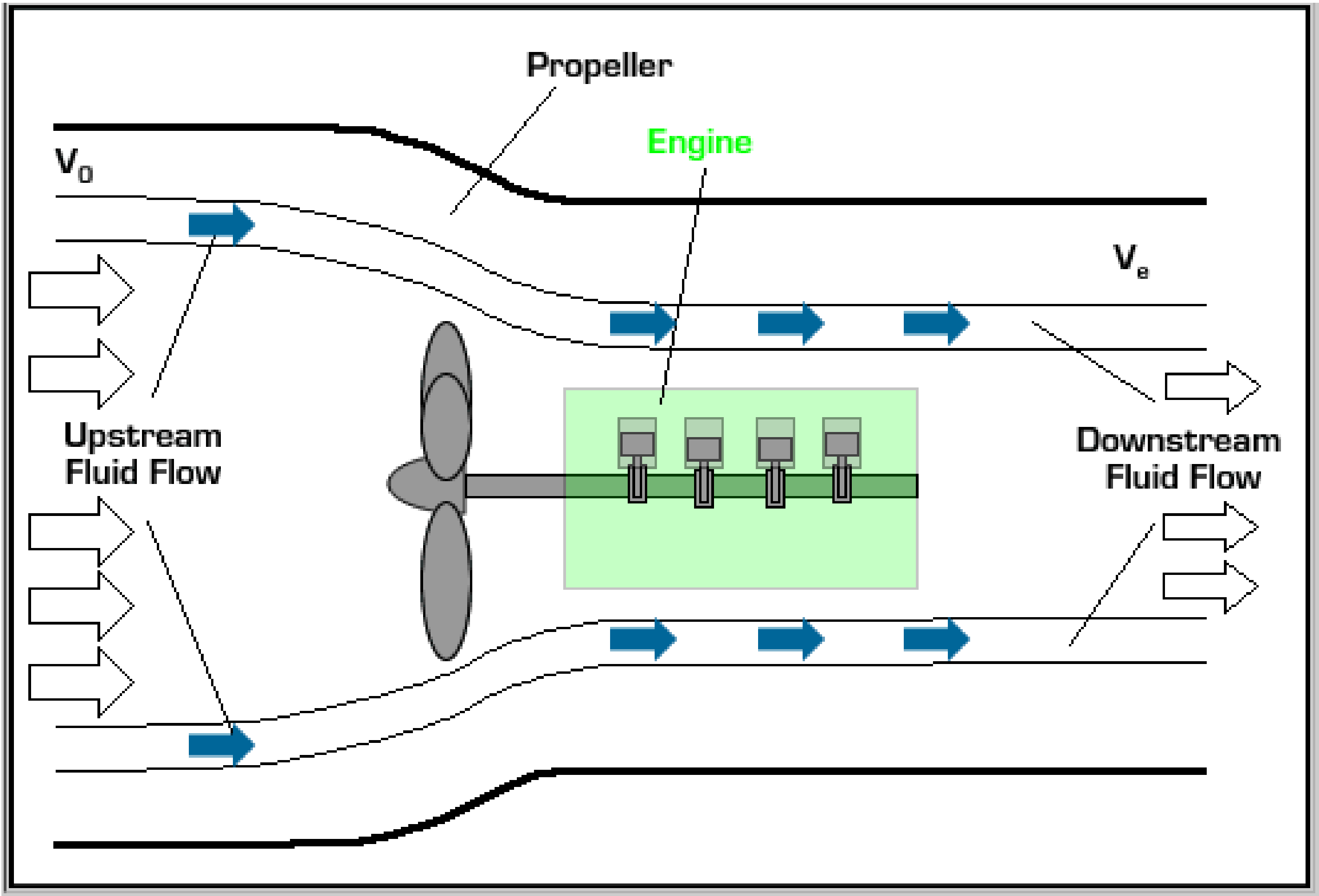
In small aircraft, the propeller is normally powered by a piston engine as shown above. In larger vessels like nuclear submarines, the propeller may be powered by a nuclear power plant. The basic operation of a propeller propulsion system is described in the interactive animation below.





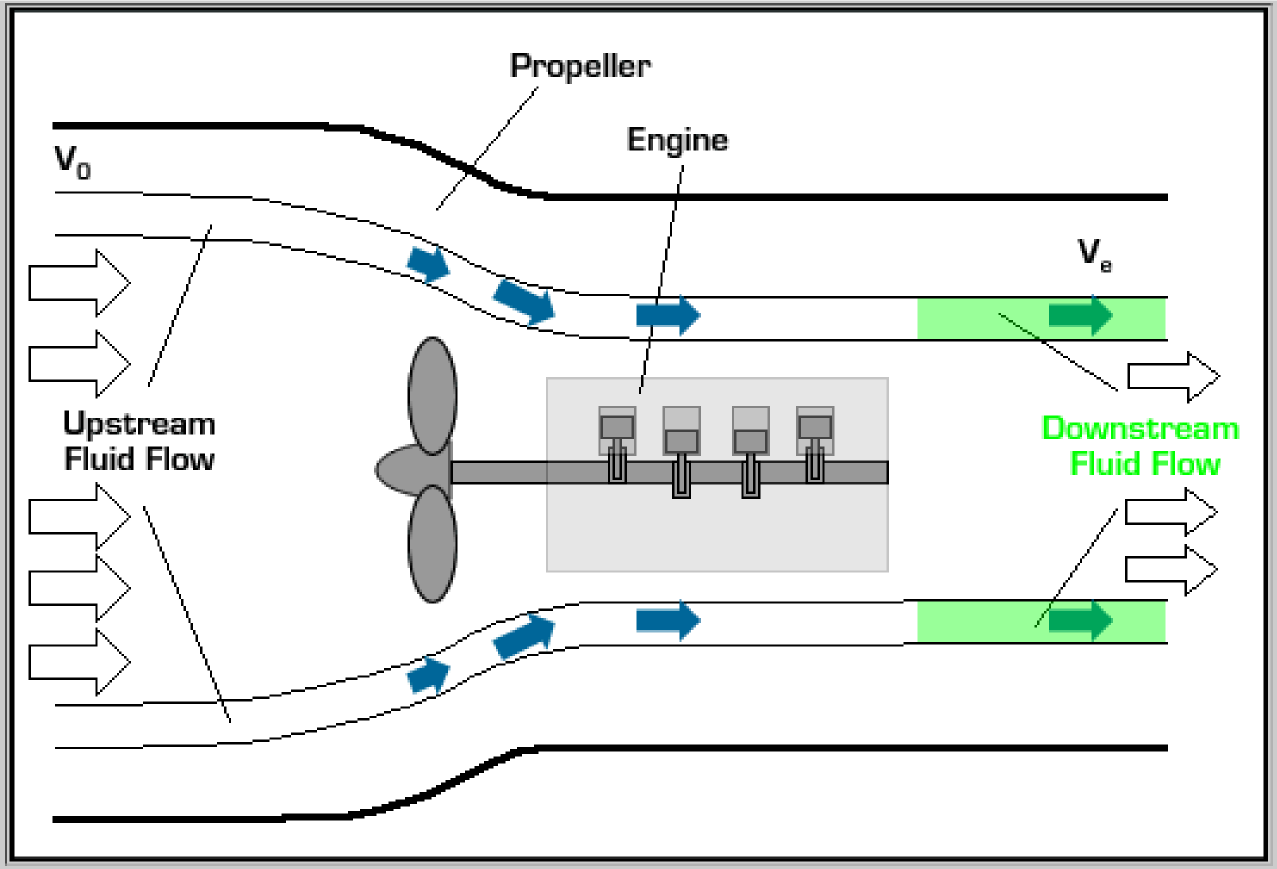
Propeller

The propeller is like a spinning wing. As the upstream fluid approaches, the blades accelerate the fluid creating thrust in the same manner that a wing creates lift as it moves through the air.



Engine

The engine is often an internal combustion engine that converts chemical fuel energy into mechanical power. The mechanical power turns a driveshaft and spins the propeller.



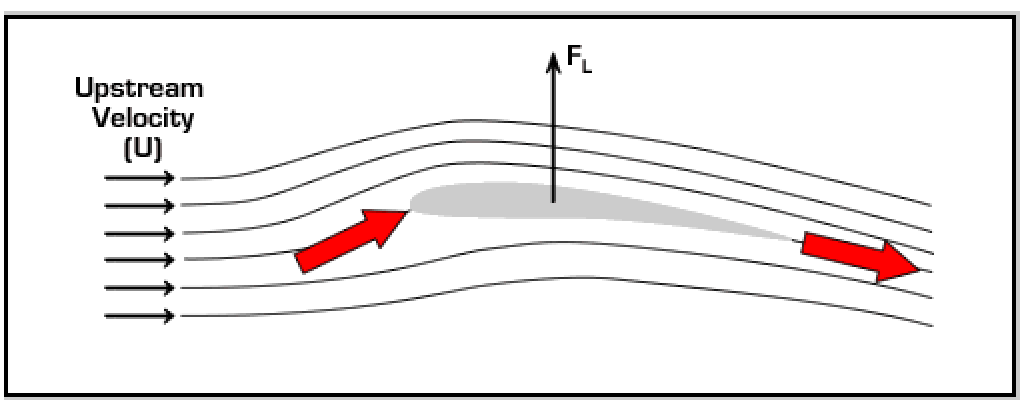
Downstream Fluid Flow

Downstream of the propeller, the air that has already passed through the blades of the propeller, has a much higher velocity than the ambient air. Higher downstream velocity translates into thrust according to the thrust equation.

The design of a propeller is crucial for this system to generate thrust efficiently. A propeller may be thought of as a **spinning wing.** Wings have a very special shape in order to direct the flow around them in a specific way.

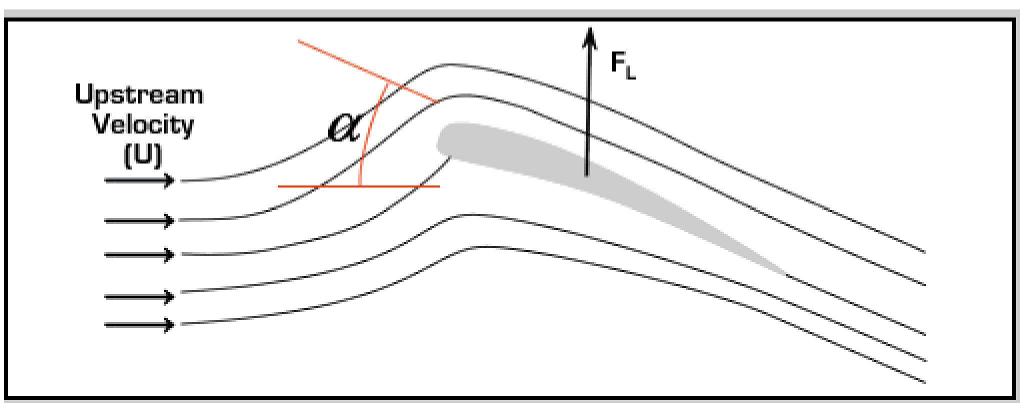
Lift production for an airfoil or wing

- In the figure below, it can be seen that **near the back a wing** has a **slightly steeper slope on the top as compared to the bottom**. As a result, the fluid flowing over the wing tends to flow down and away from the wing as it passes the end or "trailing edge" of the wing. Near the front of the wing, the curvature of the top of the wing adds to this effect because the flow must curve up as it approaches the wing in order to flow smoothly over the hump on the top of the wing. The net effect is a change in flow direction from upward to downward by the wing. **Because the flow is accelerated down** (the direction of the fluid velocity is changed to the downward direction), Newton's Third Law requires there be an upward reaction force on the wing..



Lift @ higher angle of attack

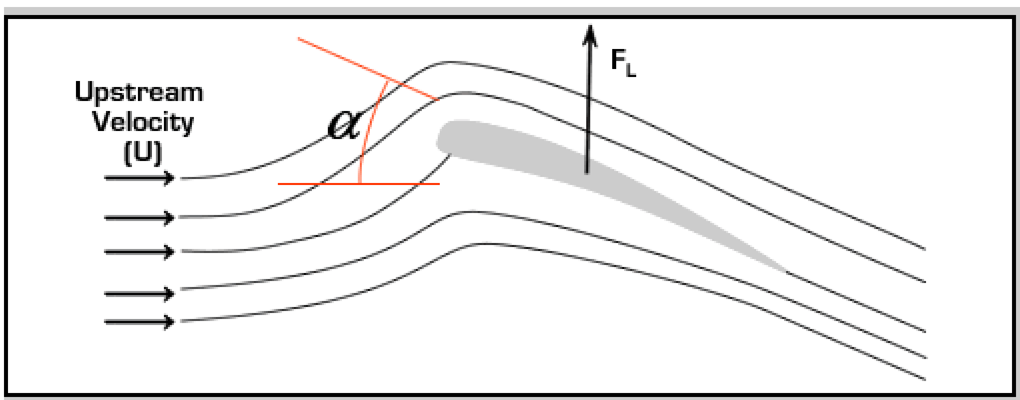
- The vertical force acting on the wing is called lift and it is what keeps airplanes aloft. If the angle of the wing relative to the oncoming flow (angle of attack, α) is increased, **the downward acceleration of the flow is enhanced and lift is increased** (as long as α is not too large).
- In general, the lift force can be computed from the equation where ρ is the fluid density, U is the upstream flow speed, and A is the wing area. C_L is called the lift coefficient and it depends on the wing geometry and α.

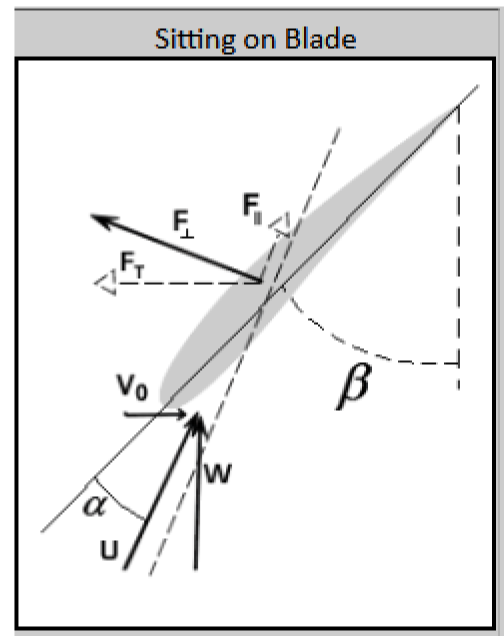


$$\boxed{F_L = \frac{1}{2} C_L \rho A U^2}$$

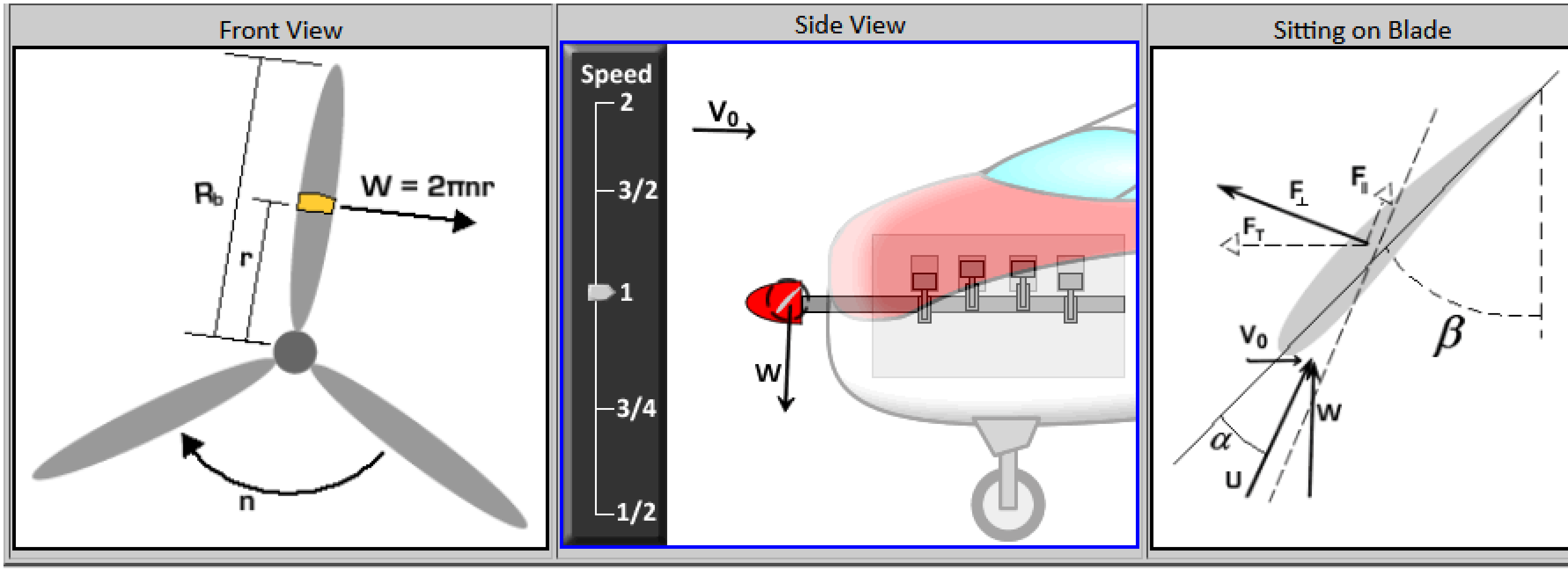
Thrust from propeller blade

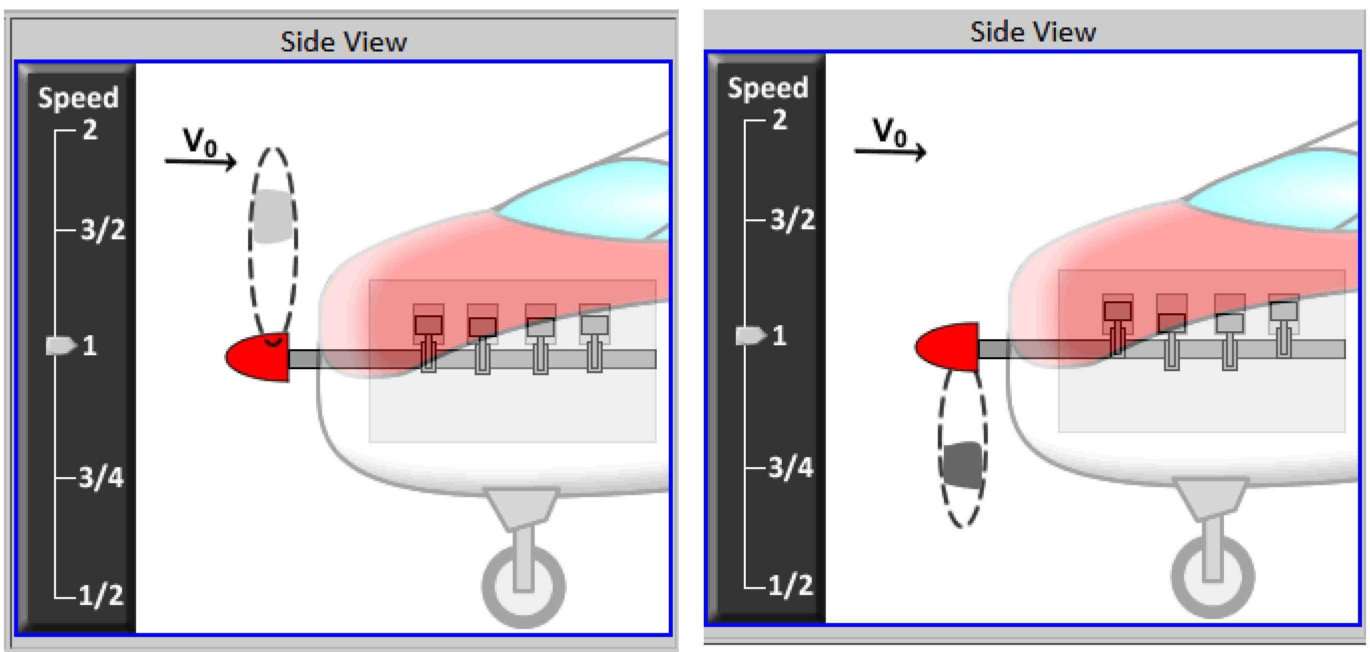
- Now, envision the above scenario rotated 90° counter clockwise so that the top of the wing is facing forward. The force on the wing is now pointed forward, creating thrust instead of lift. In this orientation, we call the wing a propeller "blade".





Vo—velocity of the vehicle or flight speed
W- velocity of the spinning wing or linear velocity
U- Velocity of the air as seen from the wing or relative air wing





- Source: Propeller: https://s2.smu.edu/propulsion/Pages/propeller.htm

- Just rotating the wing 90° **isn't enough to turn lift into thrust.**
- The propeller blade **must also be spun** around its axis.
- **Spinning the blade induces the fluid to flow over the blade in a manner similar to the flow over a wing, but rotated 90° to generate thrust.**
- In the center of the figure below is a side view of a spinning propeller blade. Only a slice of the blade is shown so you can see the wing-like shape of the propeller blade moving through the oncoming flow. **For future reference, let's say the chosen slice of the blade is a distance *r* from the hub (see the picture on the left in the figure).**
- On the right of the figure is the flow seen from the point of view of someone sitting on the propeller blade . In this view, the flow moves past the propeller blade in a manner similar to that illustrated for the wing above.
- **Notice that the angle of the oncoming flow (α) is determined by (a) the speed of the aircraft (V_0), and (b) the vertical speed of the propeller**, namely, $W = 2\pi nr$ where n is the rotation rate of the propeller in revolutions per minute (rpm).
- As with the wing, the propeller blade accelerates the oncoming flow away from it, generating **force ($F_\perp$)in a direction perpendicular to the oncoming flown** as shown. (Here we call the "lift" force generated by the blade $F_\perp$ instead of F_L because $F_\perp$ is not perpendicular to the motion of the airplane as is the case for lift on a wing.)

- **The horizontal component of $F_{\perp}$ points forward, giving the desired thrust (F_T).**
- Notice also that there is a vertical force component that resists the motion of the blade and must be overcome by the motor that spins the blade. That is, work must be done by the motor to generate thrust. There is also a "drag" force on the blade parallel to the oncoming flow ($F_{//}$). This parallel force tends to reduce thrust and increase the work required from the motor, but for a well-designed propeller, this effect is small.
- Thrust can be increased by increasing $F_{\perp}$, which can in turn be increased by increasing the oncoming flow speed (U) and α in the same way that lift on a wing is increased.
- Since U is the vector sum (addition) of V_0 and W, both U and α can be increased by increasing W, which increases with propeller rotation rate n . Thus, simply revving the engine to make the propeller spin faster will generate more thrust.
- Unfortunately, increasing W also increases the drag that resists propeller motion that requires more power from the motor to spin the propeller.
- From the point of view of the thrust equation introduced in the Principles section, as

$$F_T = \dot{m}_0 (V_e - V_0)$$

- Propeller: https://s2.smu.edu/propulsion/Pages/propeller.htm

1. Pressure Thrust:

OPTIONAL

Pressure thrust is the component of the total thrust generated by a jet engine due to the pressure differential across the engine. It arises from the acceleration of air through the engine, leading to an increase in pressure at the engine inlet and a decrease in pressure at the engine exhaust.

Formula for Pressure Thrust:

$$F_{\text{pressure}} = A_e(P_e - P_0)$$

Where:

- F_{pressure} = Pressure thrust (force)
- A_e = Cross-sectional area of the engine exhaust
- P_e = Pressure at the engine exhaust
- P_0 = Ambient (atmospheric) pressure

Pressure thrust is important only for supersonic jets and not for subsonic jets. Pressure thrust is small comparatively with momentum thrust. Also, Pe almost= Po, then pressure thrust is zero.

Case Study Application:

Let's consider a Boeing 737-800 aircraft with CFM56 engines. In this case, we'll use typical values for pressure at the engine exhaust and atmospheric pressure:

- P_e = 3 atm (hypothetical)
- P_0 = 1 atm

Assuming a cross-sectional area of the engine exhaust (A_e) of 2 square meters, we can calculate pressure thrust:

$$F_{\text{pressure}} = 2\,\text{m}^2 \times (3\,\text{atm} - 1\,\text{atm}) = 4\,\text{atm}\,\text{m}^2$$

2. Momentum Thrust:

OPTIONAL

Momentum thrust is the thrust generated by the change in momentum of the air passing through the engine. According to Newton's third law, for every action, there is an equal and opposite reaction. Thus, as the engine expels a mass of air rearward at high velocity, it experiences an equal and opposite force forward, resulting in momentum thrust.

Formula for Momentum Thrust:

$$F_{\text{momentum}} = \dot{m} \times \Delta V$$

Where:

- F_{momentum} = Momentum thrust (force)
- $\dot{m}$ = Mass flow rate of air through the engine
- ΔV = Change in velocity of the exhaust gases

Case Study Application:

For the Boeing 737-800 equipped with CFM56 engines, let's assume a mass flow rate ($\dot{m}$) of 250 kg/s and a change in velocity (ΔV) of 200 m/s for the exhaust gases.

$$F_{\text{momentum}} = 250\,\mathrm{kg/s} \times 200\,\mathrm{m/s} = 50,000\,\mathrm{N}$$

Comparison:

- Pressure thrust depends on pressure differentials ($P_e - P_0$) and engine geometry.
- Momentum thrust depends on the mass flow rate ($\dot{m}$) and change in velocity (ΔV) of the exhaust gases.

OPTIONAL

The complete thrust equation for a jet engine considers both the pressure thrust and momentum thrust components, along with any losses due to inefficiencies in the engine. The total thrust (F_{total}) generated by the engine can be expressed as:

$$F_{\text{total}} = F_{\text{pressure}} + F_{\text{momentum}} - F_{\text{losses}}$$

Where:

- F_{pressure} is the pressure thrust generated by the engine.
- F_{momentum} is the momentum thrust generated by the engine.
- F_{losses} represents any losses due to inefficiencies in the engine, such as friction, heat losses, and exhaust nozzle inefficiencies.

The pressure thrust (F_{pressure}) is given by:

$$F_{\text{pressure}} = A_e(P_e - P_0)$$

OPTIONAL

- A_e is the cross-sectional area of the engine exhaust.
- P_e is the pressure at the engine exhaust.
- P_0 is the ambient (atmospheric) pressure.

The momentum thrust (F_{momentum}) is given by:

$$F_{\text{momentum}} = \dot{m}\Delta V$$

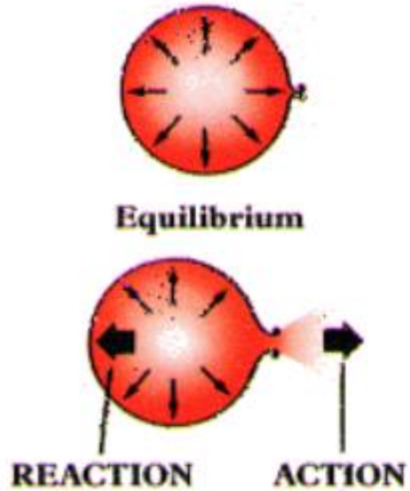
Where:

- $\dot{m}$ is the mass flow rate of air through the engine.
- ΔV is the change in velocity of the exhaust gases.

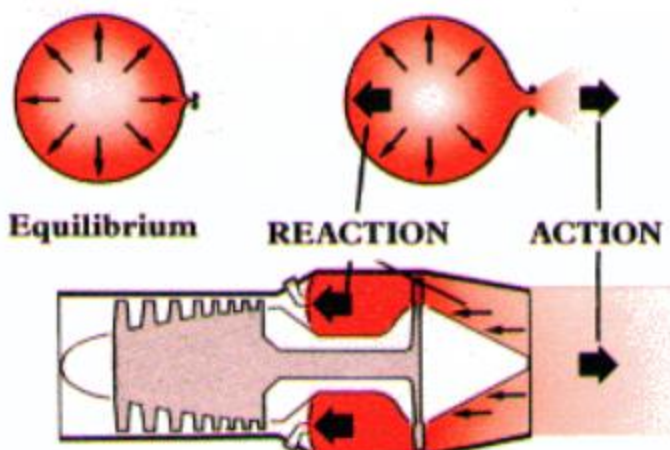
The losses (F_{losses}) can vary depending on engine design and operating conditions but are generally accounted for in engine performance calculations.

Combining these components provides a comprehensive model for calculating the total thrust produced by a jet engine. This equation is essential for analyzing engine performance, optimizing aircraft design, and conducting performance evaluations during flight testing and operation.

"For every action, there is an equal and opposite reaction."

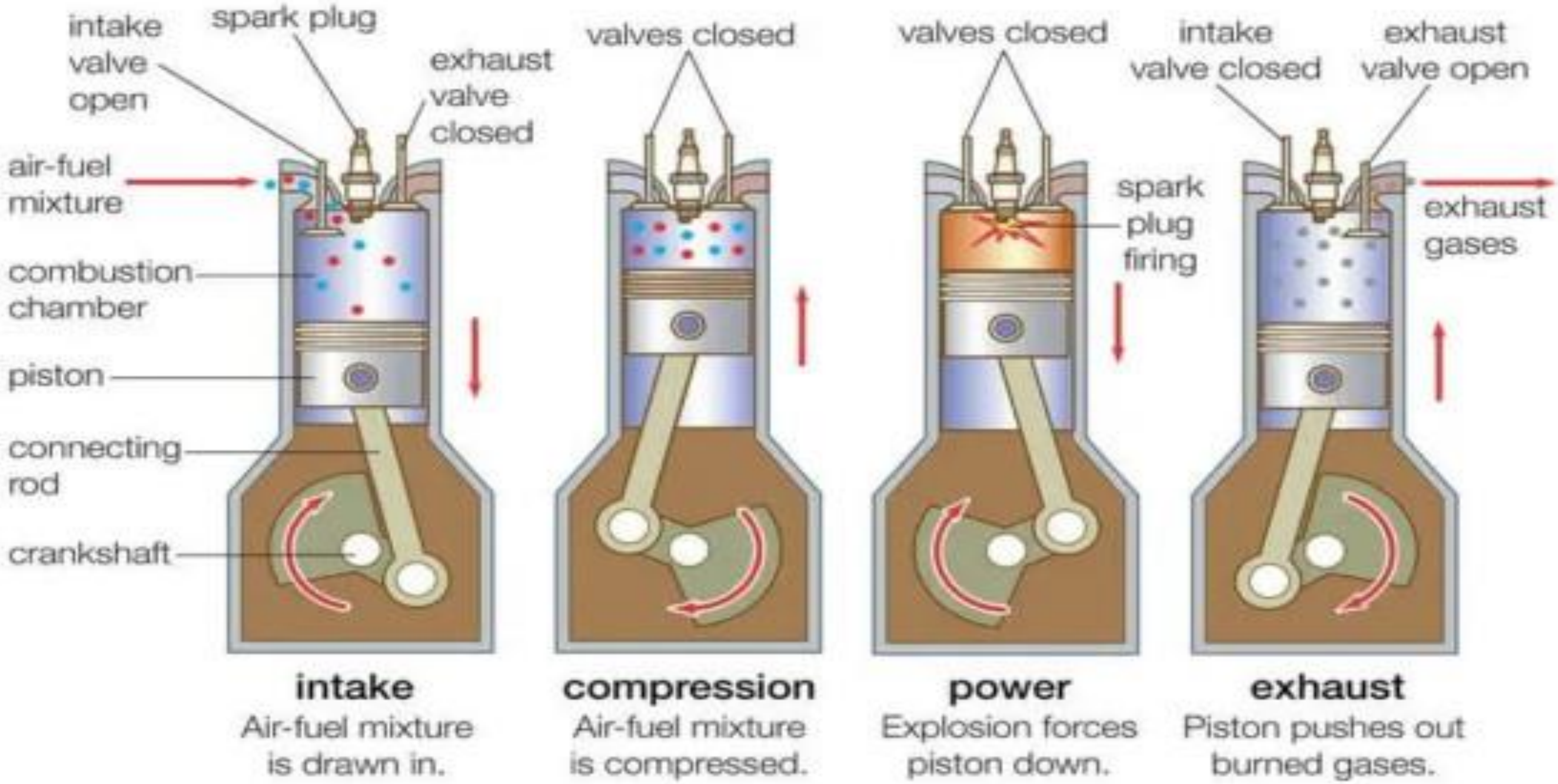


Rocket Propulsion:
Thrust = Mass Flow x Velocity



Jet Propulsion:
Thrust = (Mass Flow x Velocity) + (Pressure x Exit Area)

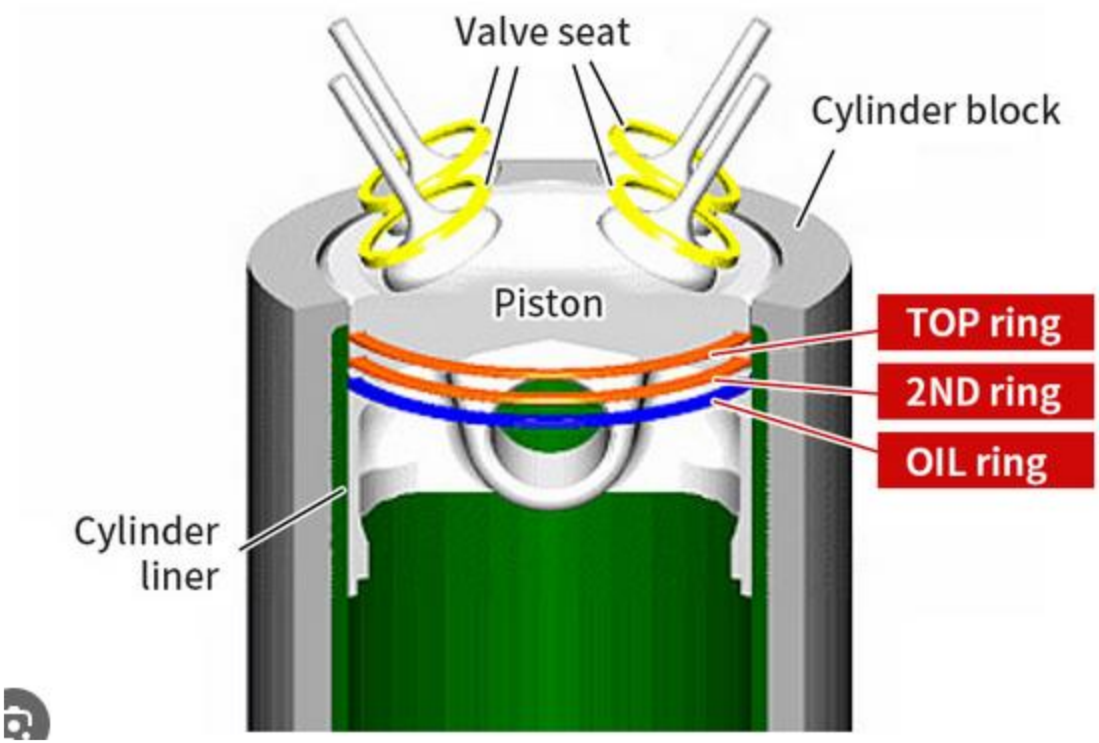
Source of power for UAVs
4 stroke piston engine(Video 1)



Construction

- Four-stroke engines consist of the following parts:
- **Cylinder**: It is the heart of the engine. The piston reciprocates in the cylinder.
- **Cylinder head:** It is the top cover of the cylinder, towards TDC, which is called the cylinder head.
- **Piston**: It is the reciprocating member of the engine. It reciprocates in the cylinder.
- **Piston rings**: Two or three piston rings are provided on the piston. It seals the gap between the cylinder liner and piston.
- **Crank**: It is a rotating member. It makes a circular motion inside the crankcase.
- **Crankcase**: It is the housing of crank and other engine parts. It is also used as the sump of lubricating oil.
- **Connecting rod**: It is used to convert the reciprocating motion of the piston to rotary motion of the crankshaft.
- **Crankshaft**: It is the rotating member, which connects the crank.
- **Cooling fins or Water jackets:** It is used for cooling purposes.
- **Cam and Camshaft:** It is provided to operate the **opening and closing** of the Inlet and Exhaust valve and also operate the fuel injection pump in the Diesel engine.
- **Inlet valve:** This valve controlled the admission of charge or air inside the engine cylinder.
- **Exhaust valve**: This valve controls the removal of burnt gas after combustion.
- **Intake manifold**: This is a passage that carries the fresh charge or air.
- **Exhaust manifold**: This a passage through which the exhaust gas goes out of the engine cylinder.
- **Spark plug**: It is used in a Petrol engine or SI engine to ignite the fuel.
- **Fuel injector**: It is used in a Diesel engine or CI engine to sprayed the fuel inside the cylinder. engine
- **Carburetor**: It is used in a Petrol engine to mix the air-fuel properly.

Piston rings



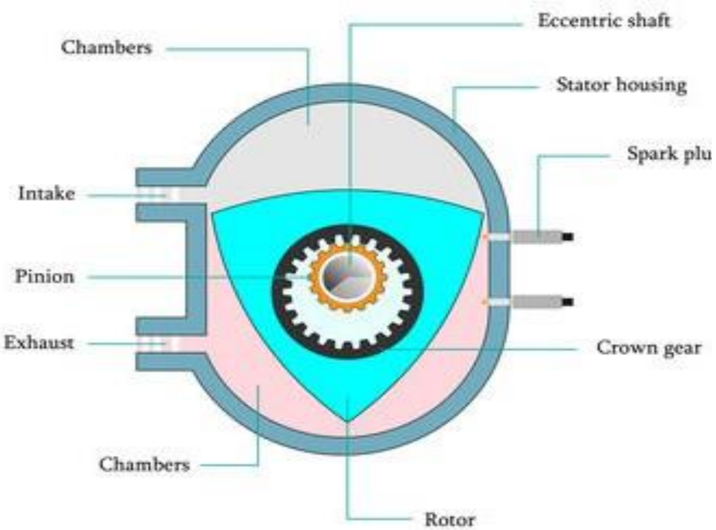
- The piston rings **act to carry heat away from the hot piston into the cooled cylinder wall/block of the engine**. Heat energy flows from the piston groove into the piston ring and then into the cylinder wall, where it eventually will be transferred into the engine coolant.

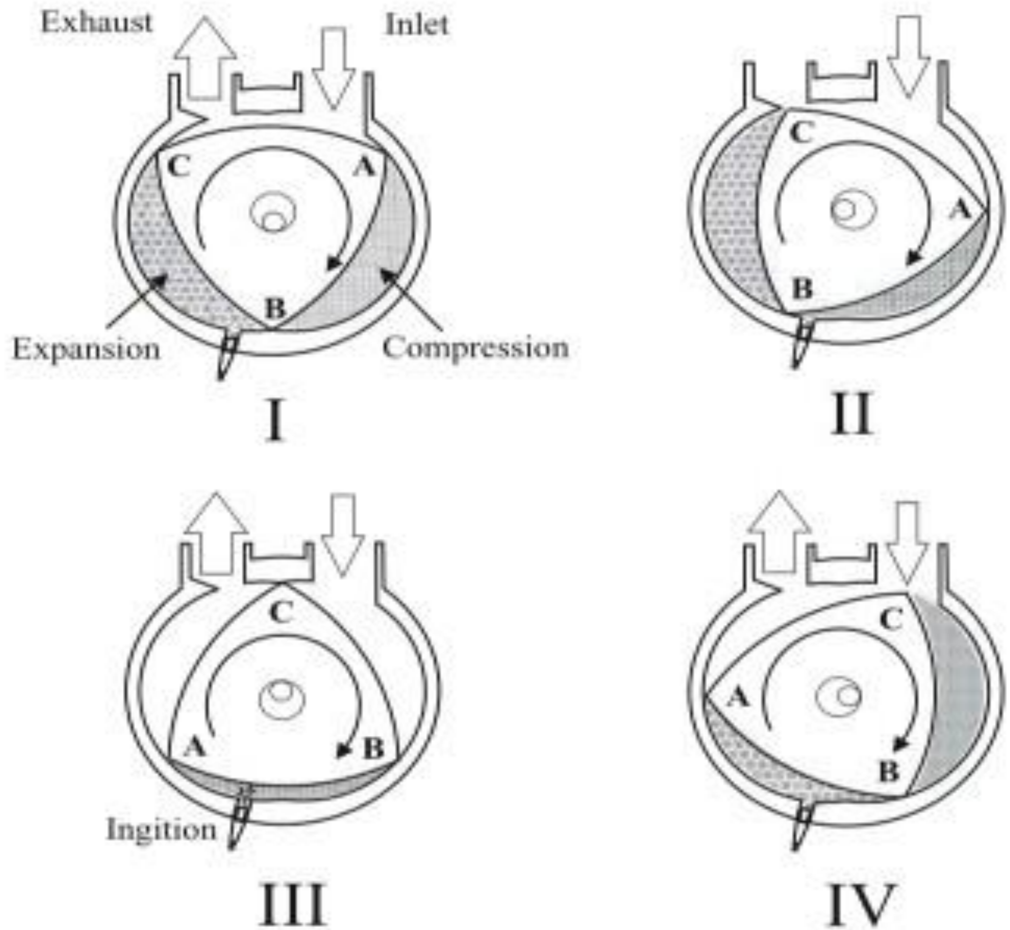
Working

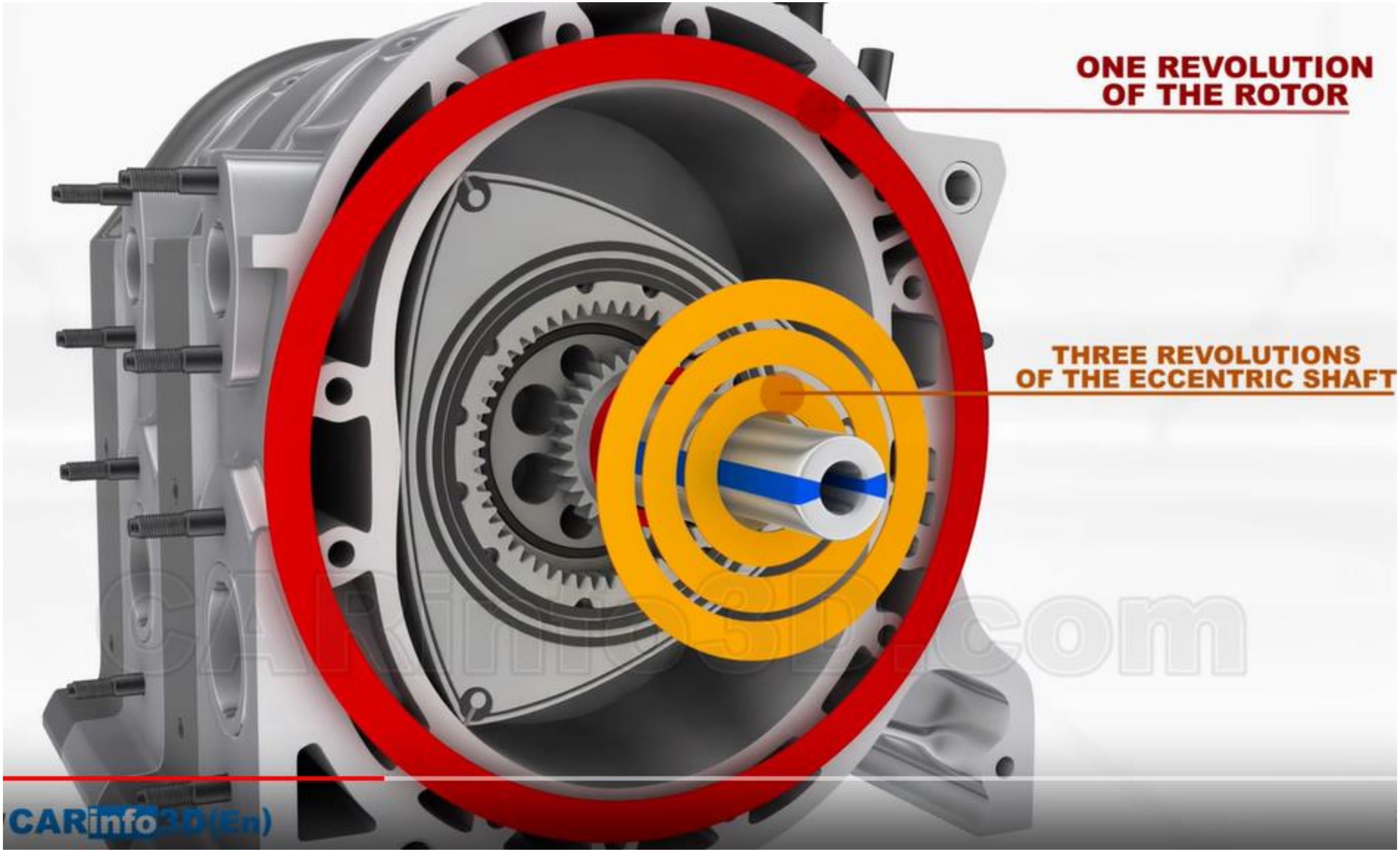
- A four-stroke engine delivers one power stroke for every two cycles of the piston (or four-piston strokes). Intake stroke: The piston moves downward to the bottom; this increases the volume to allow a fuel-air mixture to enter the chamber.
- Compression stroke: The intake valve is closed, and the piston moves up the chamber to the top. This compresses the fuel-air mixture. At the end of this stroke, a spark plug provides the compressed fuel with the activation energy required to begin combustion.
- Power Stroke: As the fuel reaches the end of its combustion, the heat released from combusting hydrocarbons increases the pressure which causes the gas to push down on the piston and create the power output.
- Exhaust stroke: As the piston reaches the bottom, the exhaust valve opens. The remaining exhaust gas is pushed out by the piston as it moves back upwards.

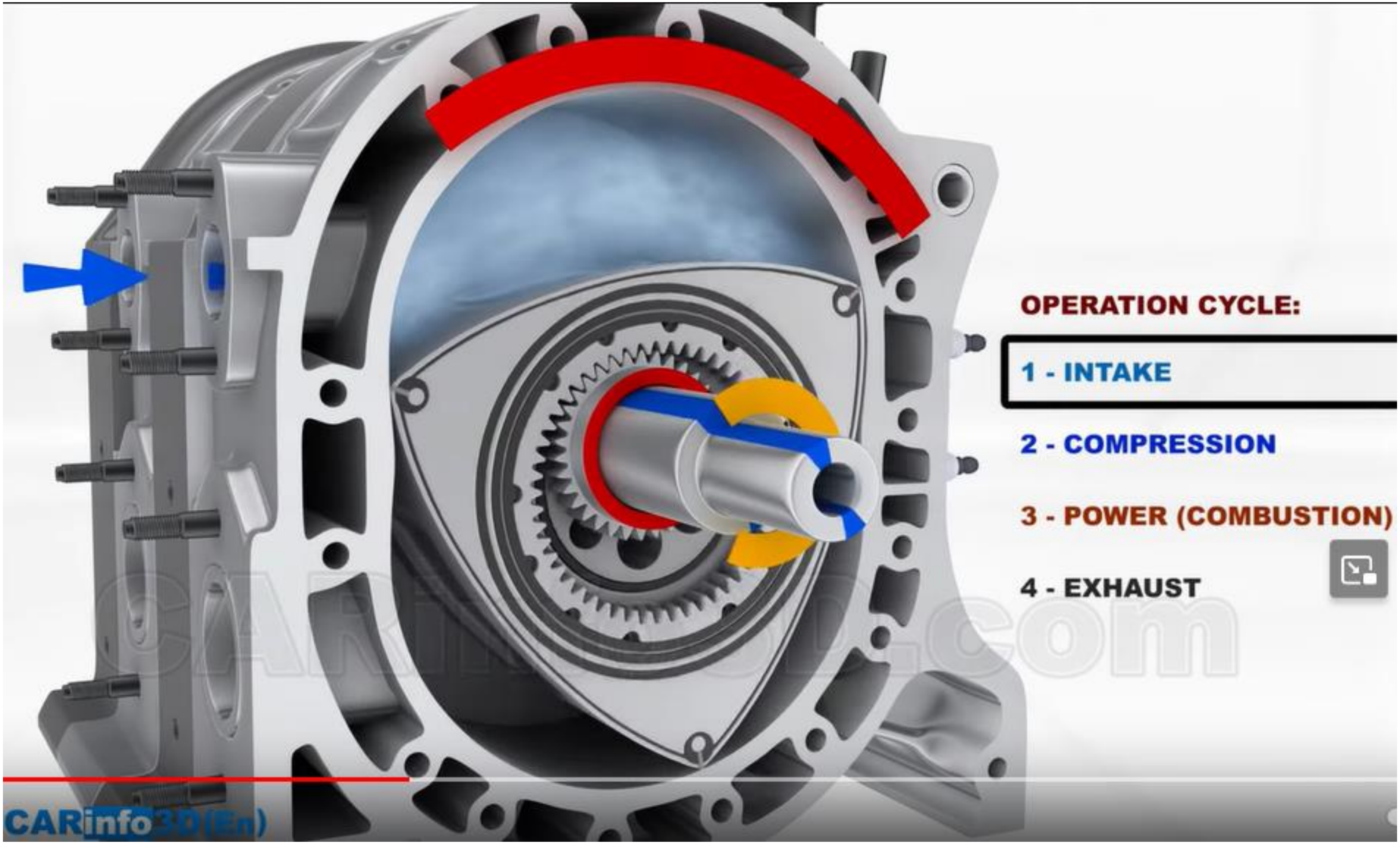
- **Different type of multi-cylinder engines(video 2)**

Rotary engine: Working animated video 3

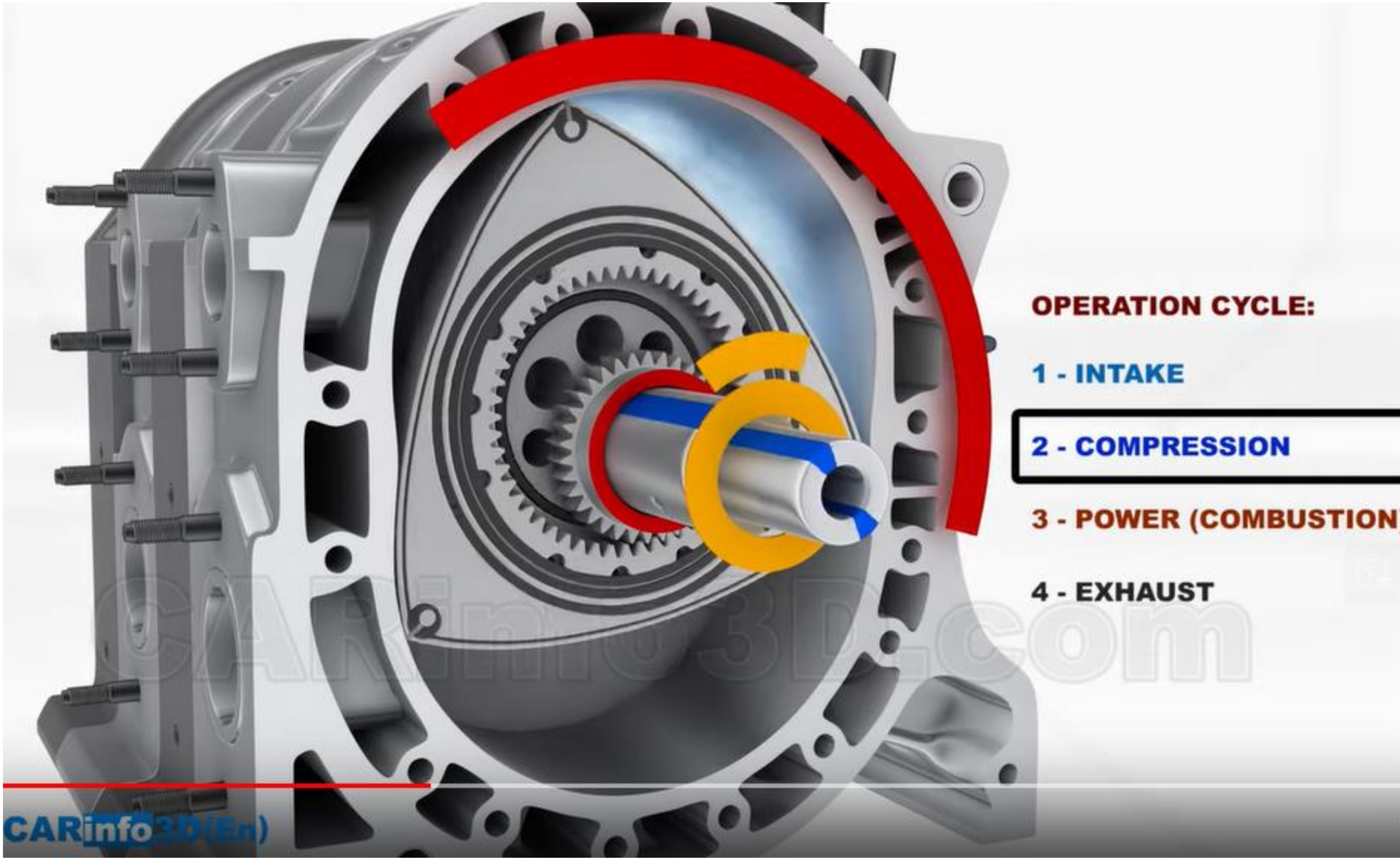





ONE REVOLUTION
OF THE ROTOR
THREE REVOLUTIONS
OF THE ECCENTRIC SHAFT
CARinfo3D.com
CARinfo3D(En)



OPERATION CYCLE:
1 - INTAKE
2 - COMPRESSION
3 - POWER (COMBUSTION)
4 - EXHAUST
CARinfo3D(En)


OPERATION CYCLE:
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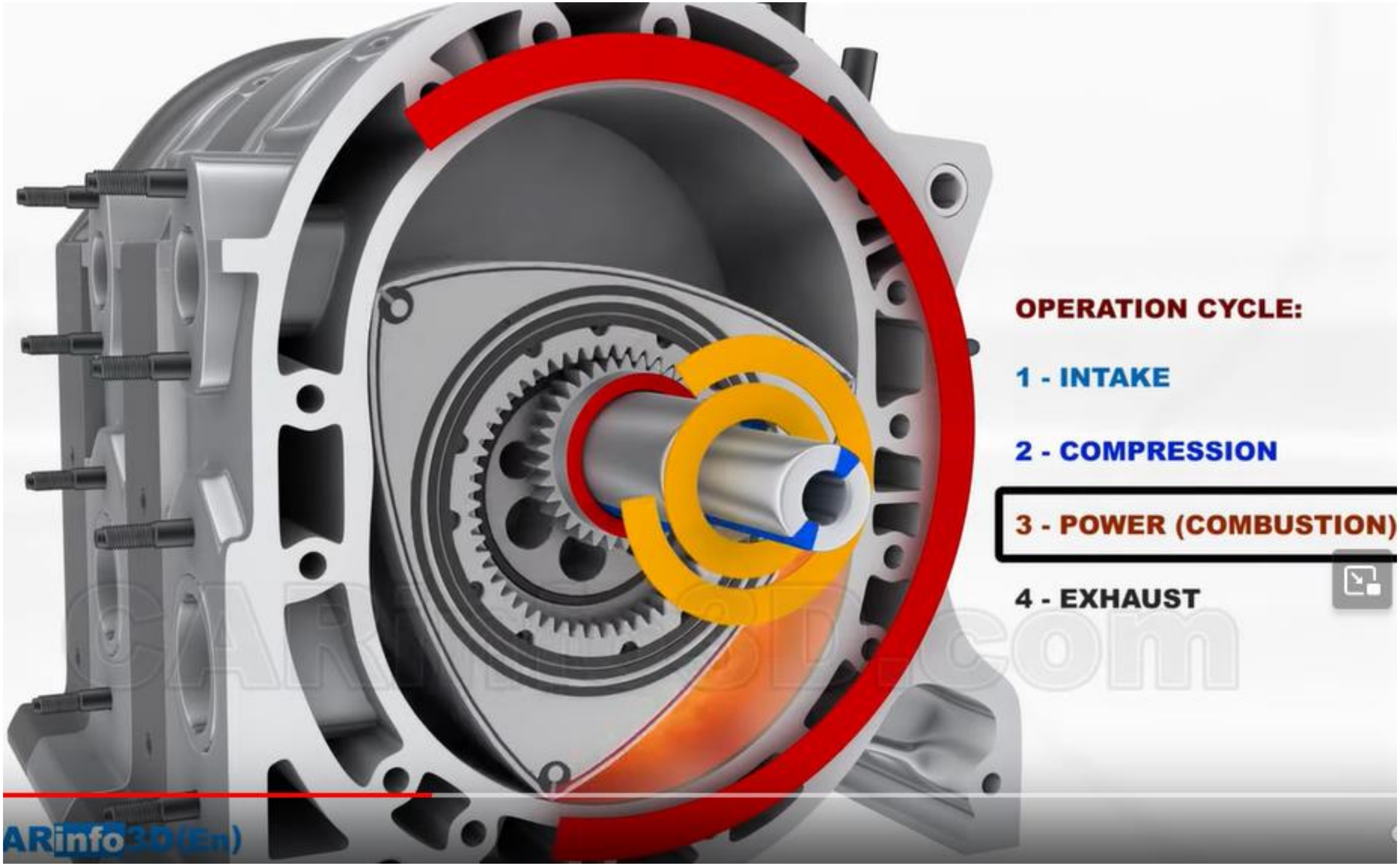
OPERATION CYCLE:
1 - INTAKE
2 - COMPRESSION
3 - POWER (COMBUSTION)
4 - EXHAUST
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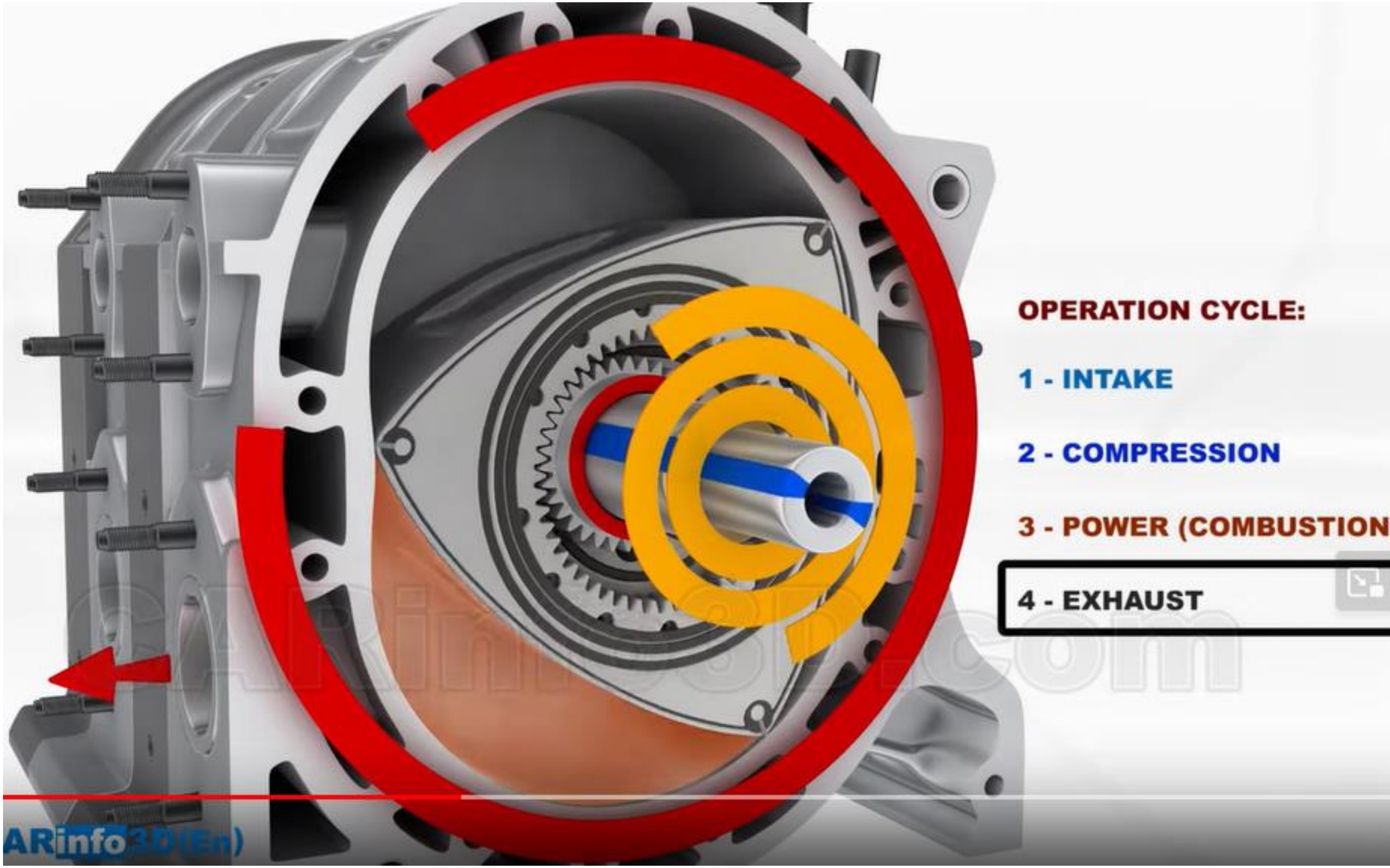
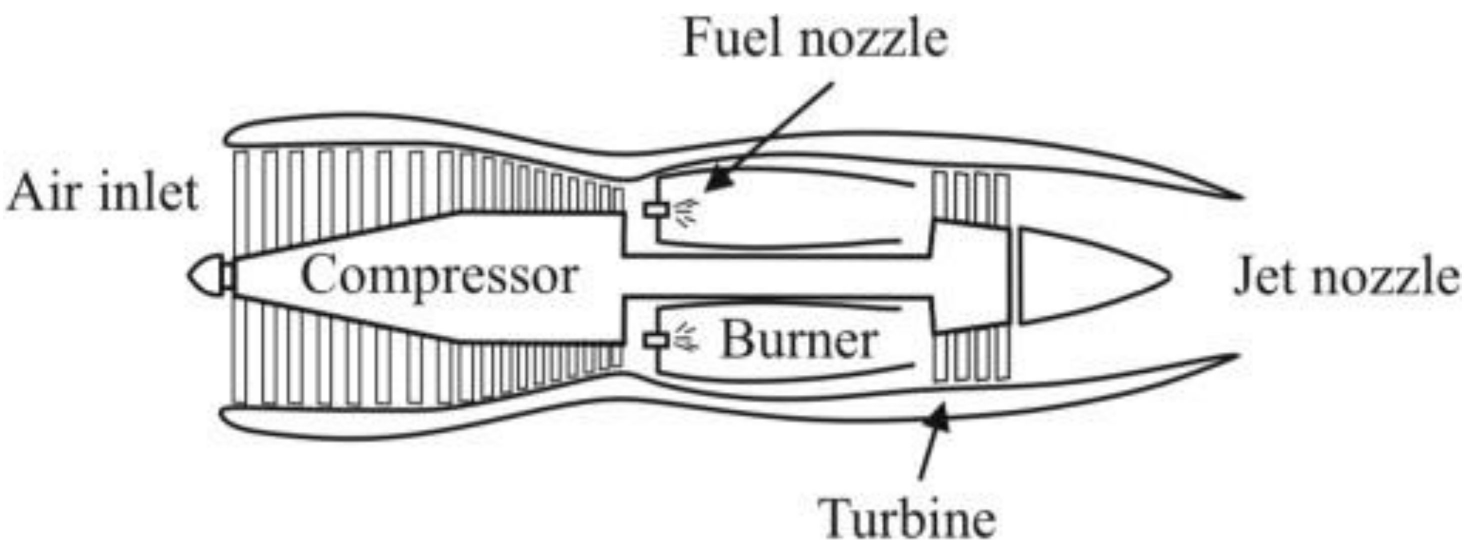
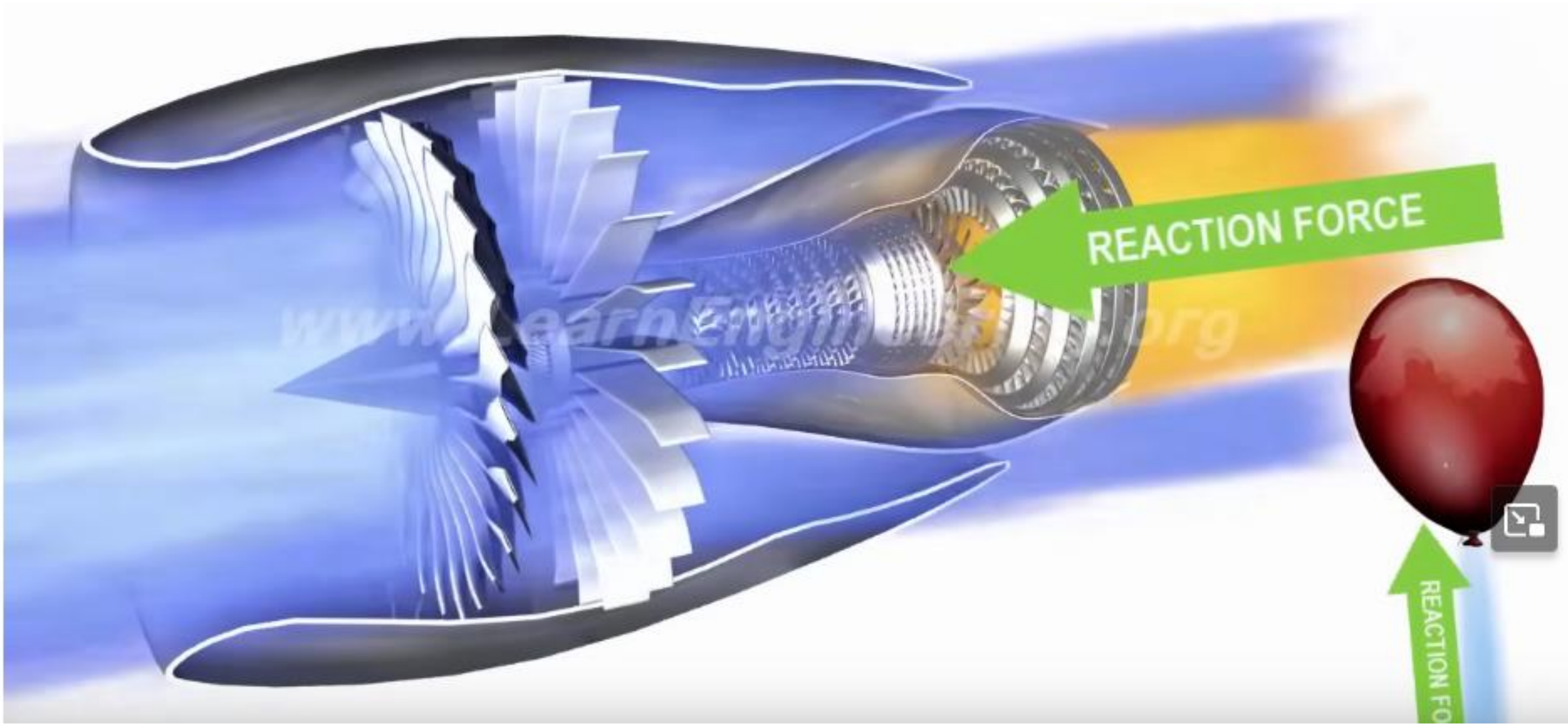

OPERATION CYCLE:
1 - INTAKE
2 - COMPRESSION
3 - POWER (COMBUSTION)
4 - EXHAUST
CARinfo3D(En)

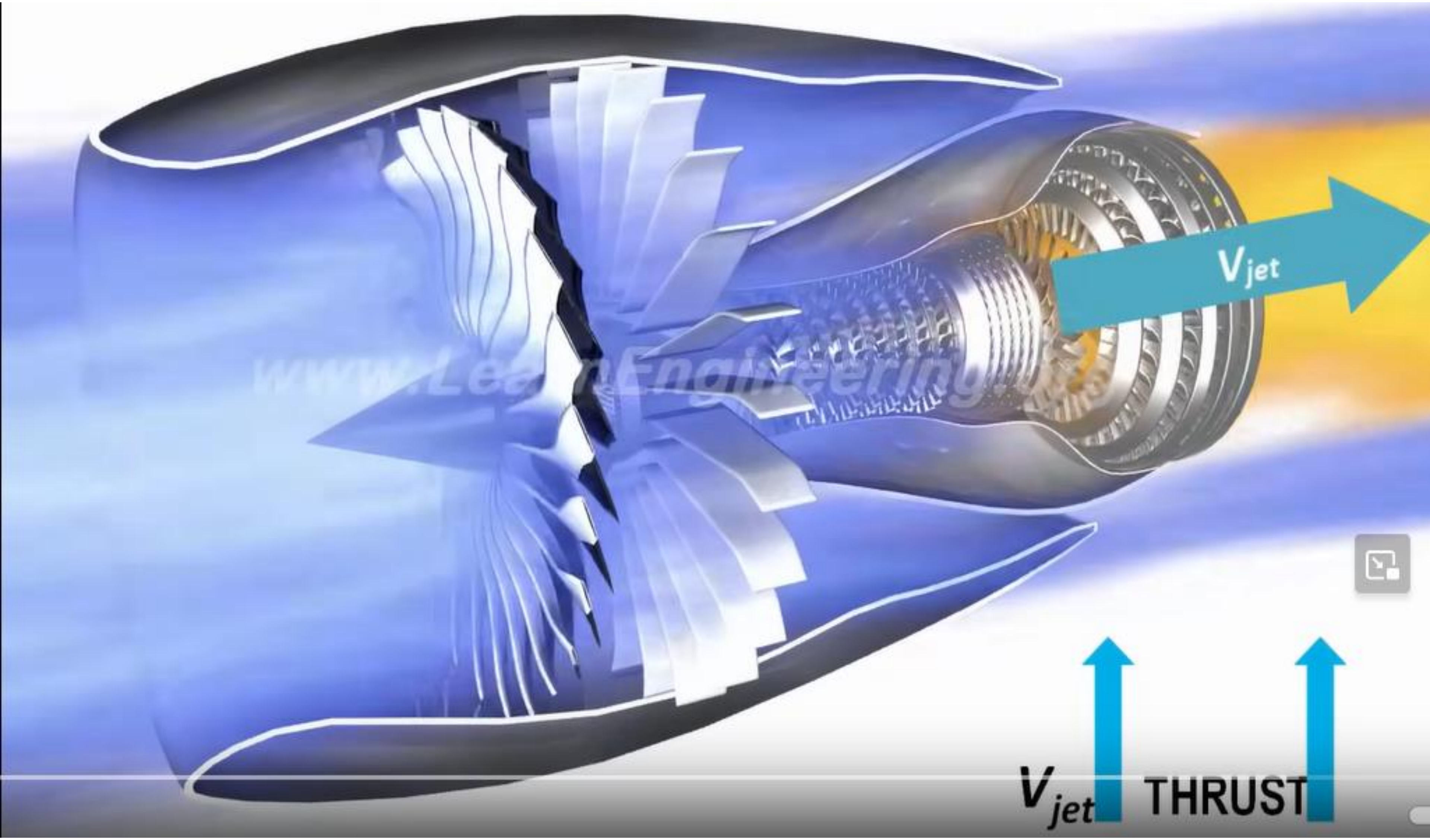
- The principle of operation of the rotary engine is based on the rotation of a three-sided geometrical shape within a two-lobe geometrical stator. The rotor revolves within this stator such that its three apices make continuous contact with the stator. The stator is an epitrochoid curve based on the path of a point on the radius of a circle that rolls on the outside of a fixed circle.
- Each face of the rotor completes a four-cycle process identical to the four-cycle engine:intake, compression, combustion, and exhaust.
- The cycle takes place during one rotation of the rotor, so one can consider a single bank rotary engine as a three-cylinder engine. As we shall see there is no reciprocating motion, so vibration can be very low. The end of the rotor is usually provided with an internal gear, concentric with its center, that rotates around a smaller fixed pinion gear mounted on the side cover of the casing

- In diagram I, the exhaust and inlet ports are shown to be open, just ending one cycle of exhaust and starting input of a fresh fuel–air mixture to the segment adjacent to side C–A, while the mixture previously drawn into the segment adjacent to side A–B is starting to be compressed. This process continues in diagram II. In diagram III, the mixture adjacent to side A–B has reached its maximum compression and is ignited by a spark. At the same time, the segment adjacent to side B–C, which has been expanding and driving the rotor, is opened to the exhaust port.
- The burning mixture in the segment adjacent to side A–B now expands and drives the rotor, while the fresh mixture that has been drawn into the segment adjacent to side C–A begins tobe compressed, and the combustion products in the segment adjacent to side B–C are expelled through the exhaust port and replaced by a fresh fuel–air mixture entering through the inlet port.
- Thus, in one revolution three, four-cycle Otto cycles have been completed, one in each segment

The Gas Turbine Engine(Video 4_1or 2)




REACTION FORCE



V_{jet}
www.LearnEngineering.org
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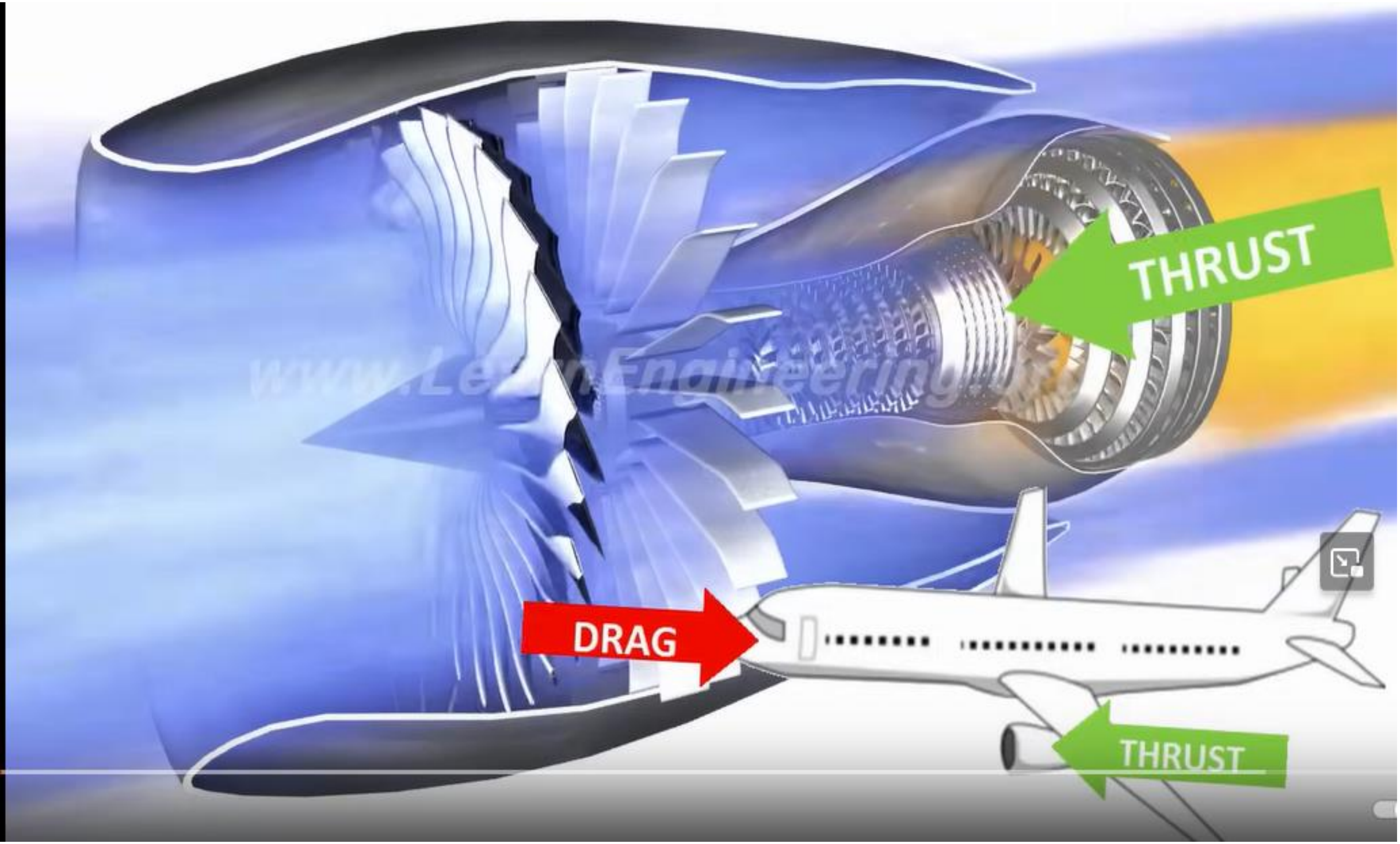
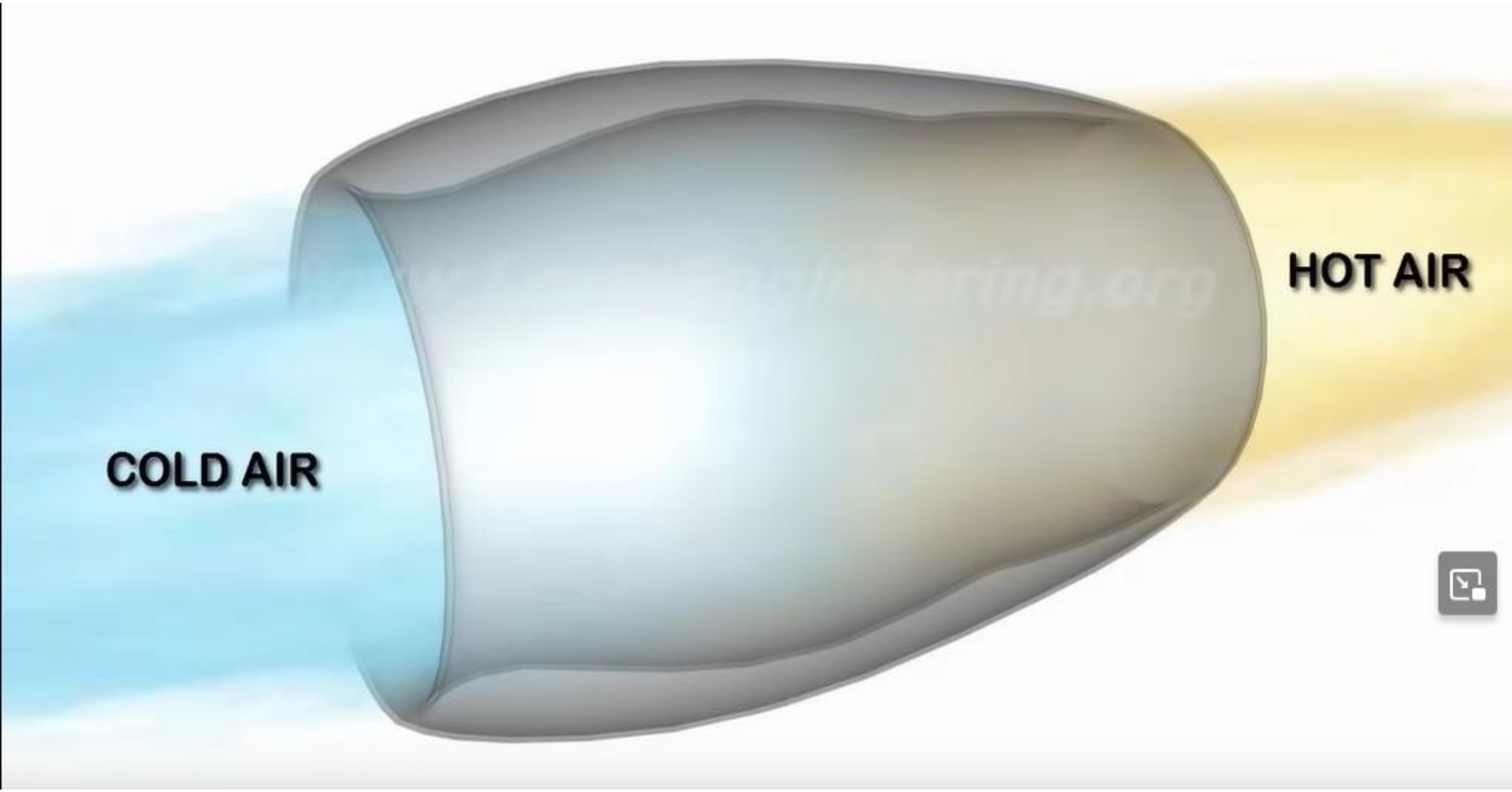
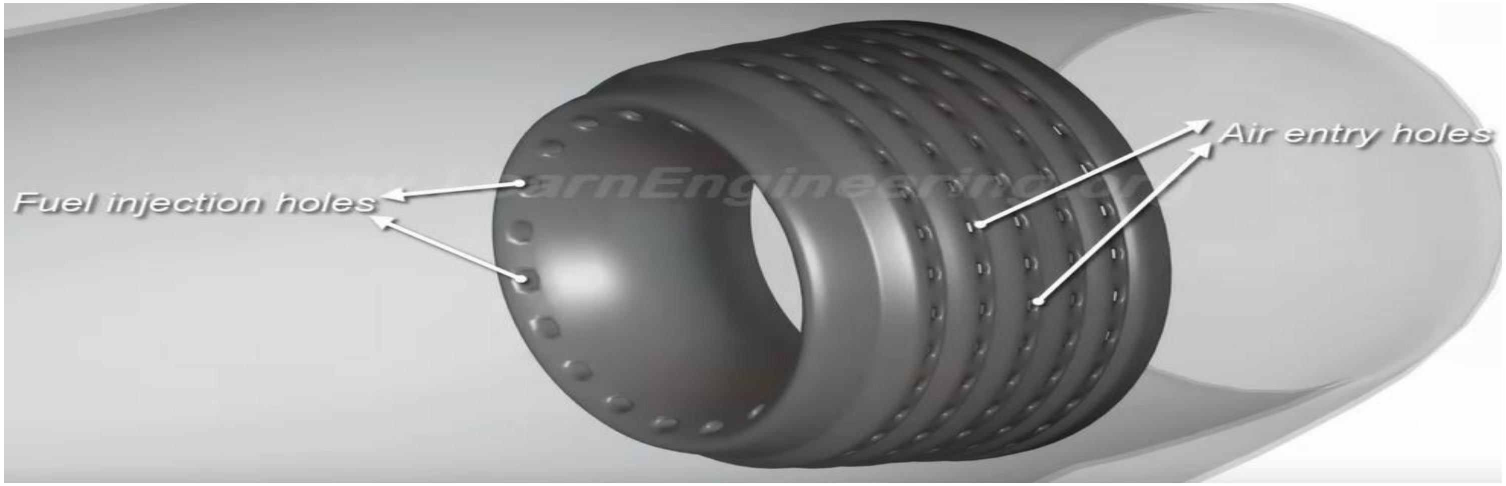
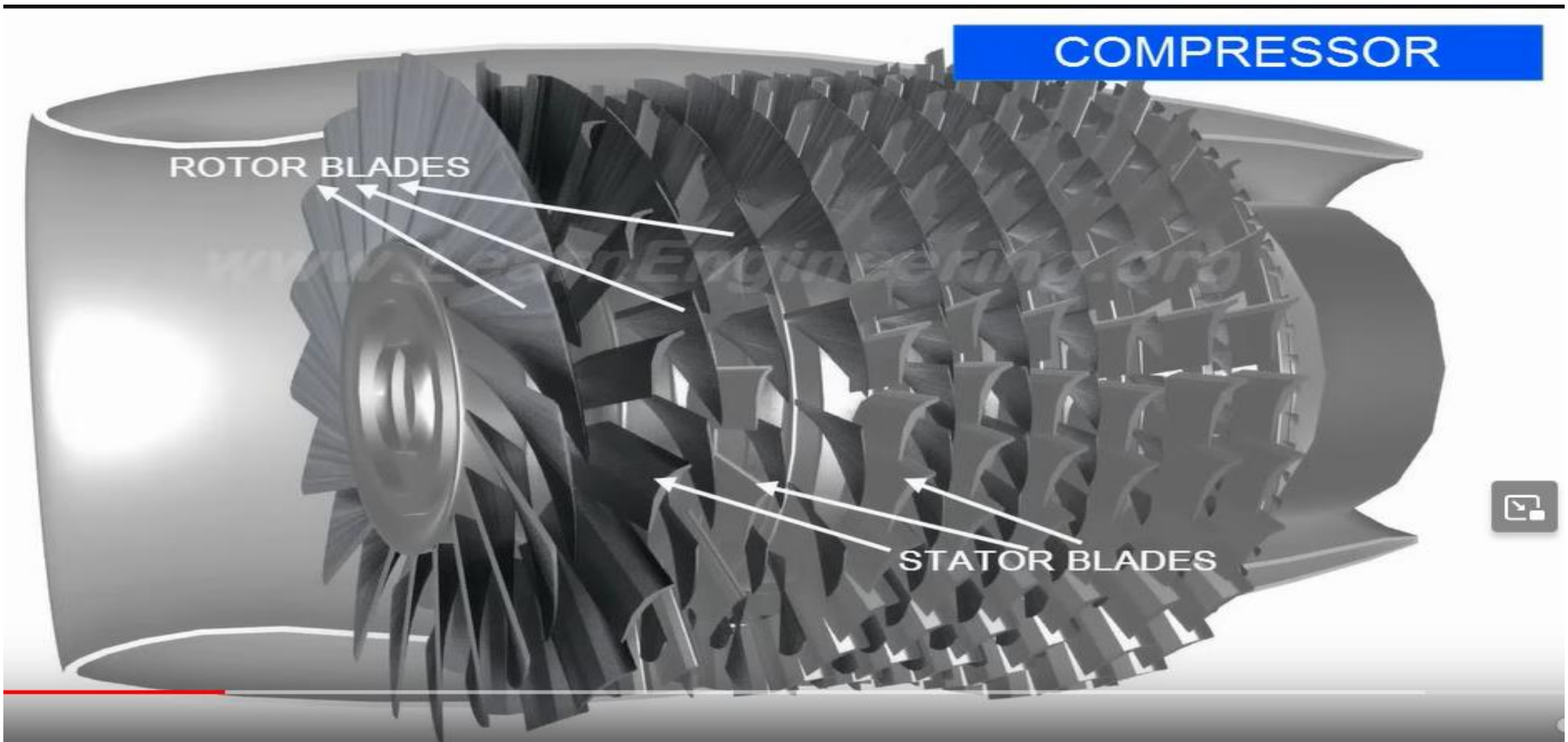
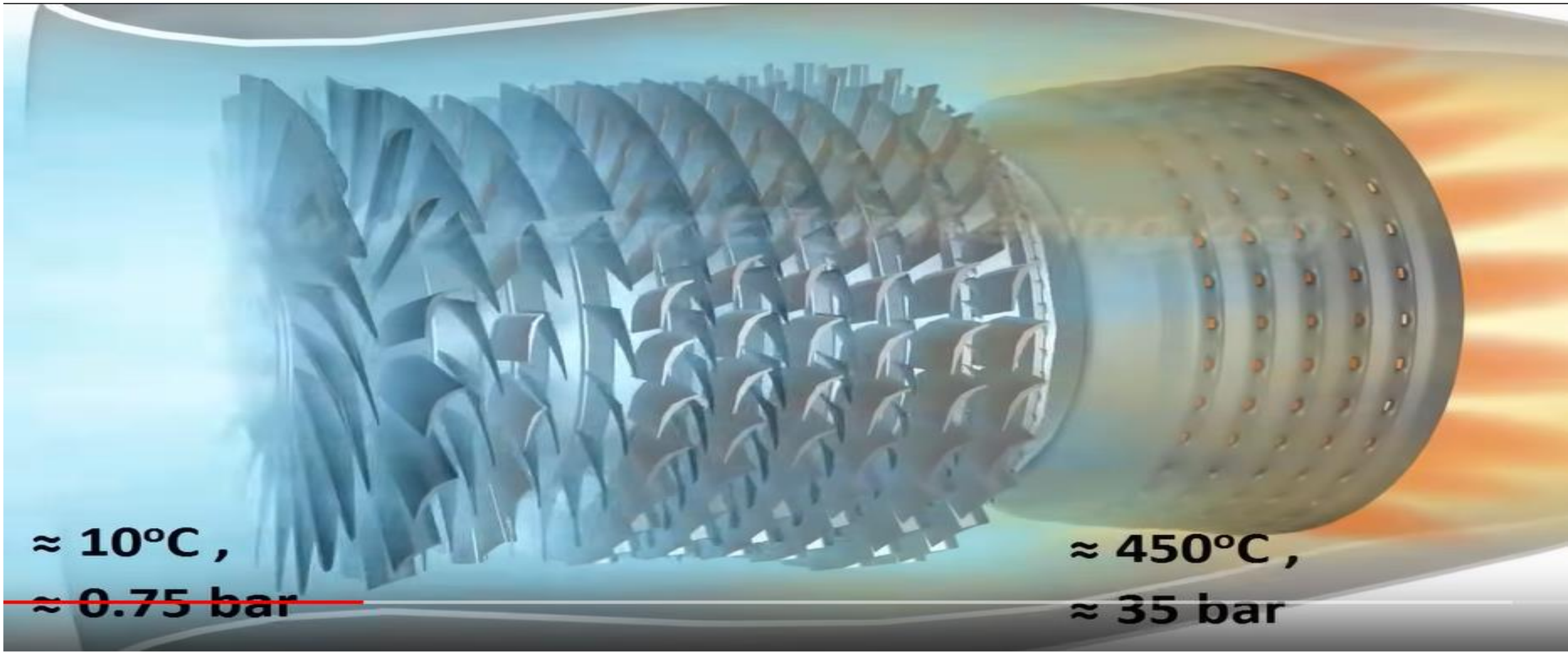
THRUST

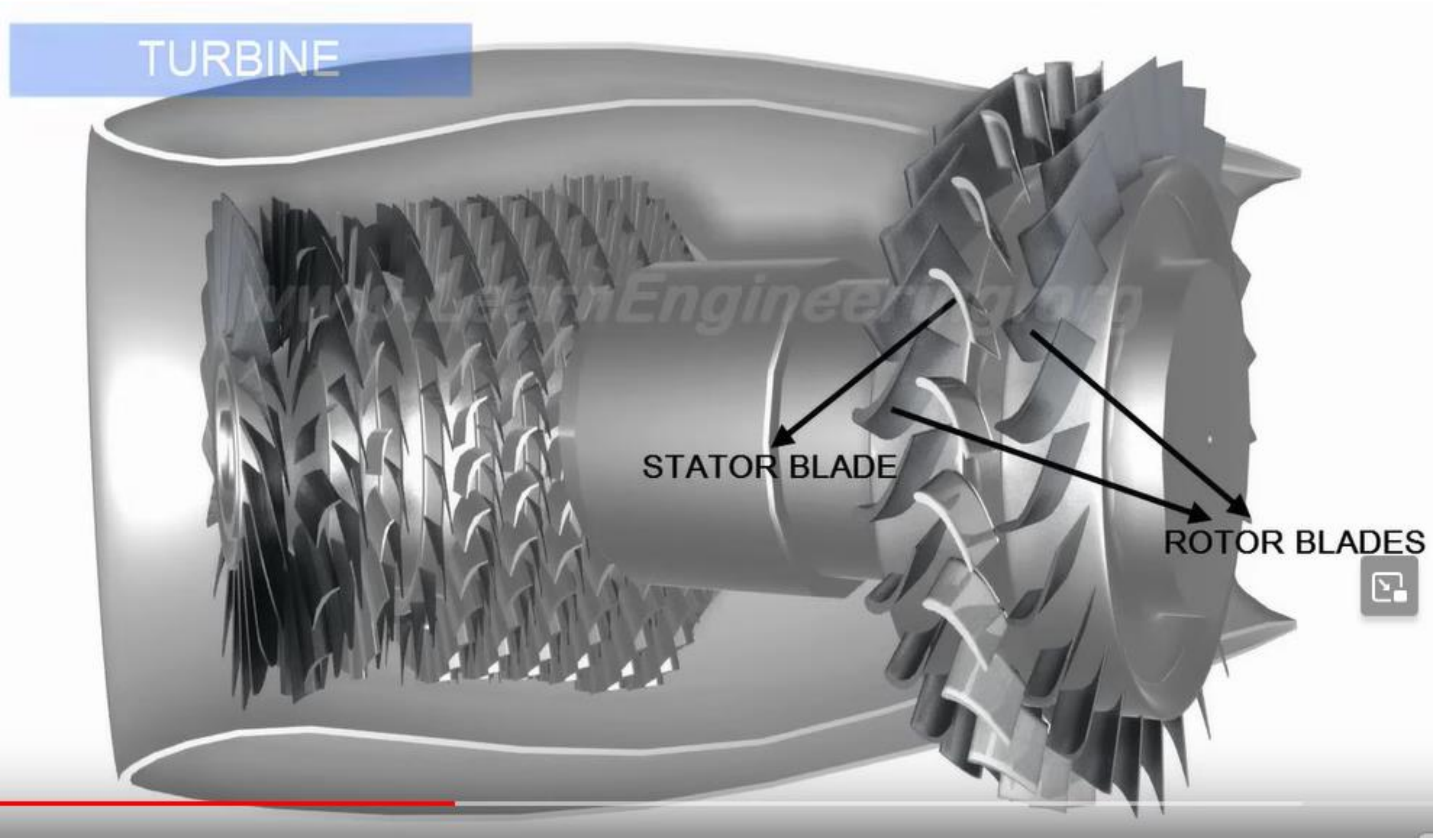

THRUST
DRAG
THRUST

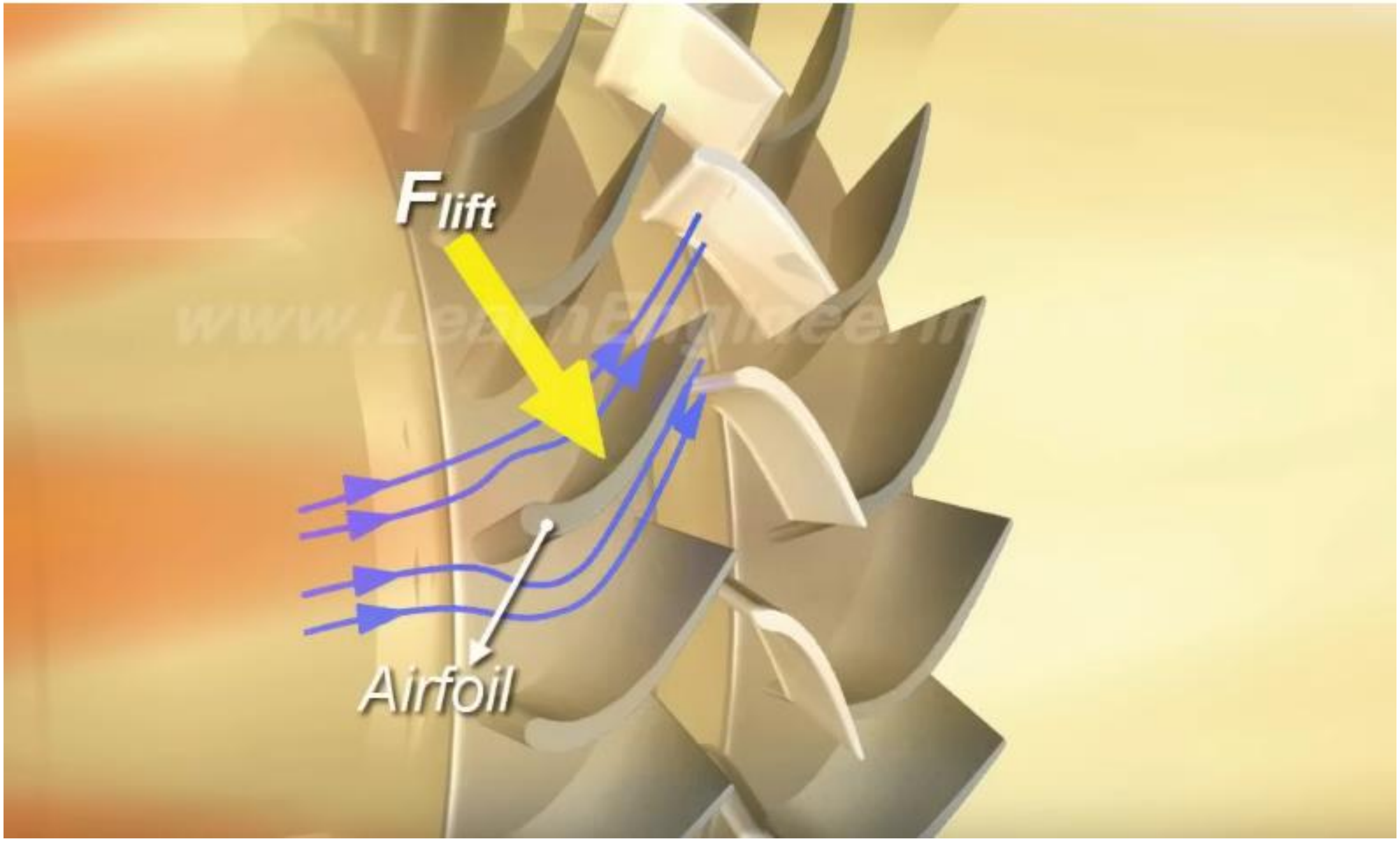

HOT AIR
COLD AIR

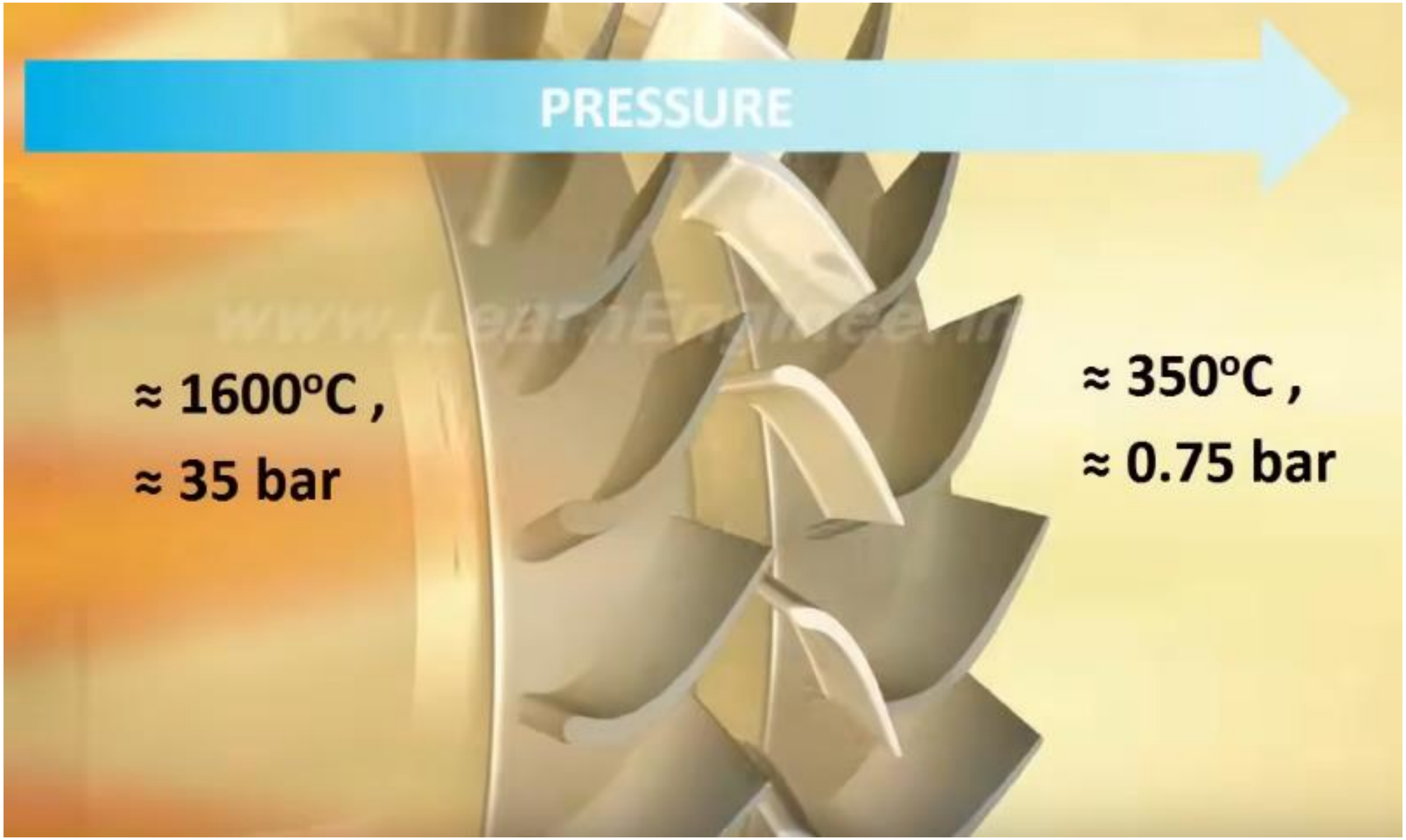

Fuel injection holes
Air entry holes

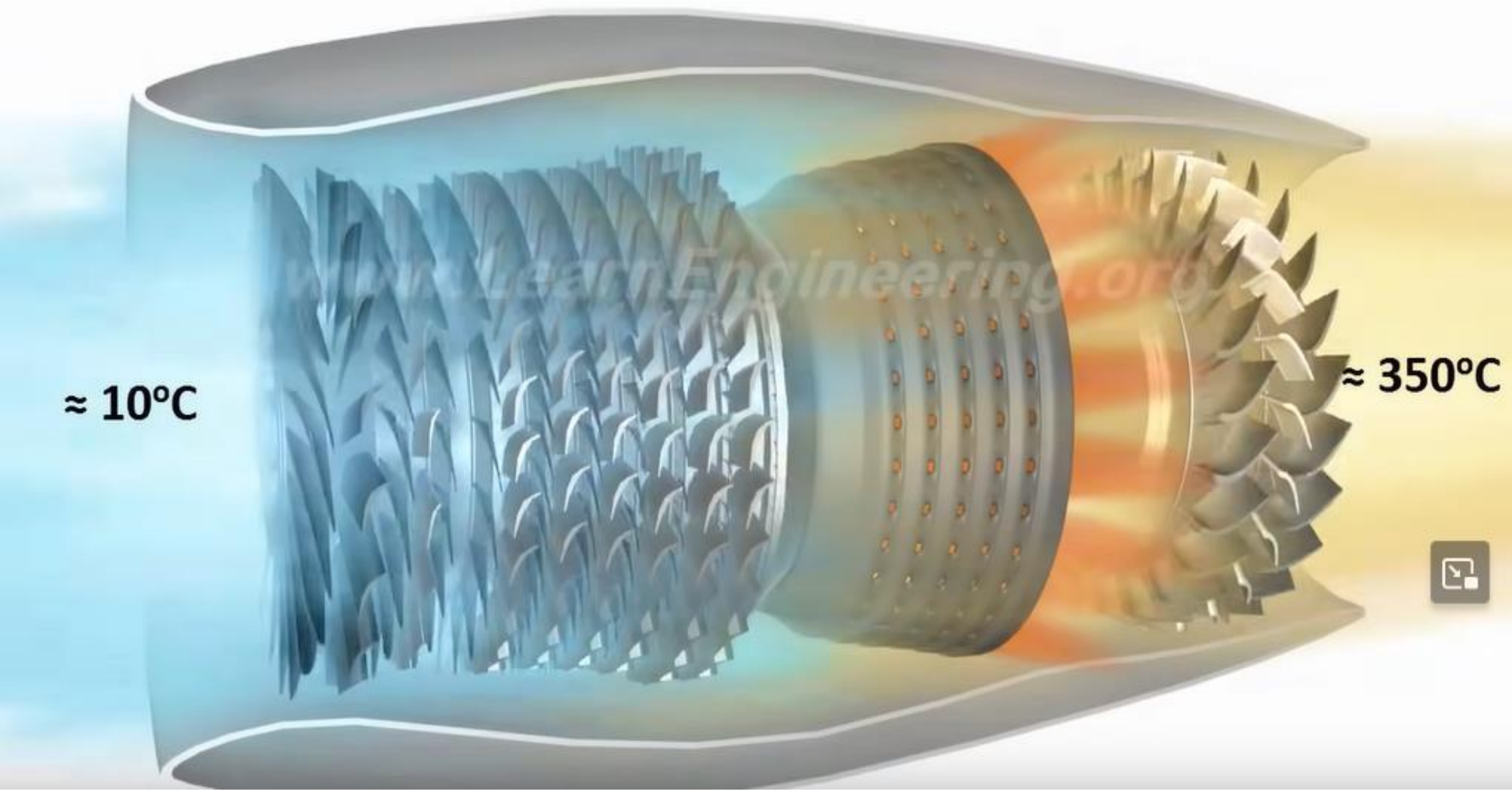

COMPRESSOR
ROTOR BLADES
STATOR BLADES

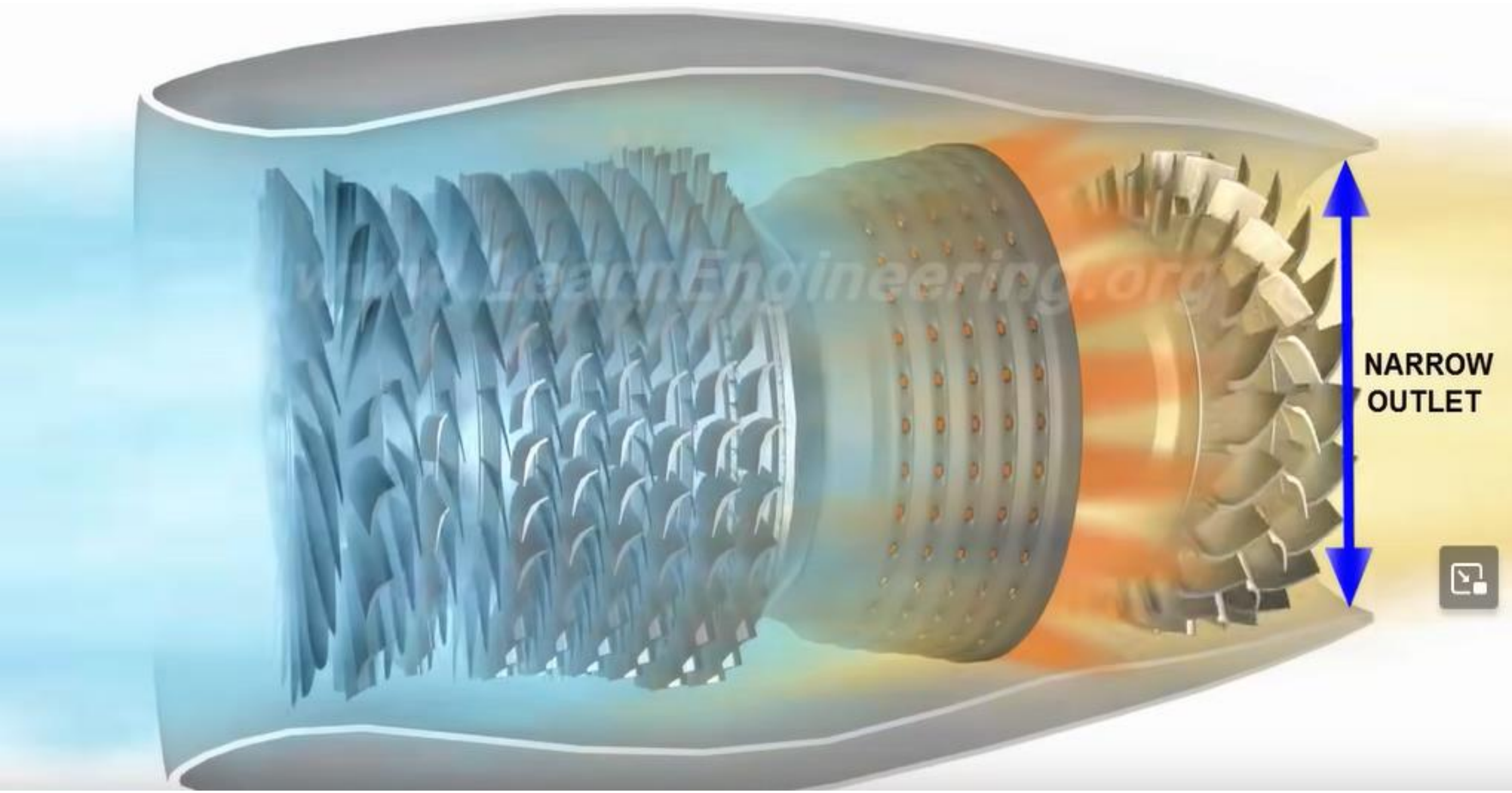

≈ 10°C ,
≈ 0.75 bar
≈ 450°C ,
≈ 35 bar


TURBINE
STATOR BLADE
ROTOR BLADES


F_{lift}
Airfoil


PRESSURE
≈ 1600ºC ,
≈ 35 bar
≈ 350ºC ,
≈ 0.75 bar


≈ 10°C
www.LearnEngineering.org
≈ 350°C


NARROW
OUTLET

Air inlet: The air inlet duct must provide clean and unrestricted airflow to the engine. Clean and undisturbed inlet airflow extends engine life by preventing erosion, corrosion, and foreign object damage (FOD).

Compressor: The compressor is responsible for providing the turbine with all the air it needs in an efficient manner. In addition, it must supply this air at high static pressures.In an axial flow compressor, each stage incrementally boosts the pressure from the previous stage. A single stage of compression consists of a set of rotor blades attached to a rotating disk, followed by stator vanes attached to a stationary ring. The flow area between the compressor blades is slightly divergent.

Combustion chamber :combustion section has the difficult task of controlling the burning of large amounts of fuel and air. It must release the heat in a manner that the air is expanded and accelerated to give a smooth and stable stream of uniformly-heated gas at all starting and operating conditions.Maximum combustion section outlet temperature (turbine inlet temperature) in this engine is about 1070 degree Celsius.

Turbine :The turbine converts the gaseous energy of the air/burned fuel mixture out of the combustor into mechanical energy to drive the compressor, driven accessories, and, through a reduction gear, the propeller. The turbine converts gaseous energy into mechanical energy by expanding the hot, high-pressure gases to a lower temperature and pressure

Nozzle: It is a device that is used to accelerate the hot gas from the turbine.it expands the gas to higher velocity and generates a jet thrust. It is found at the rear of the engine.

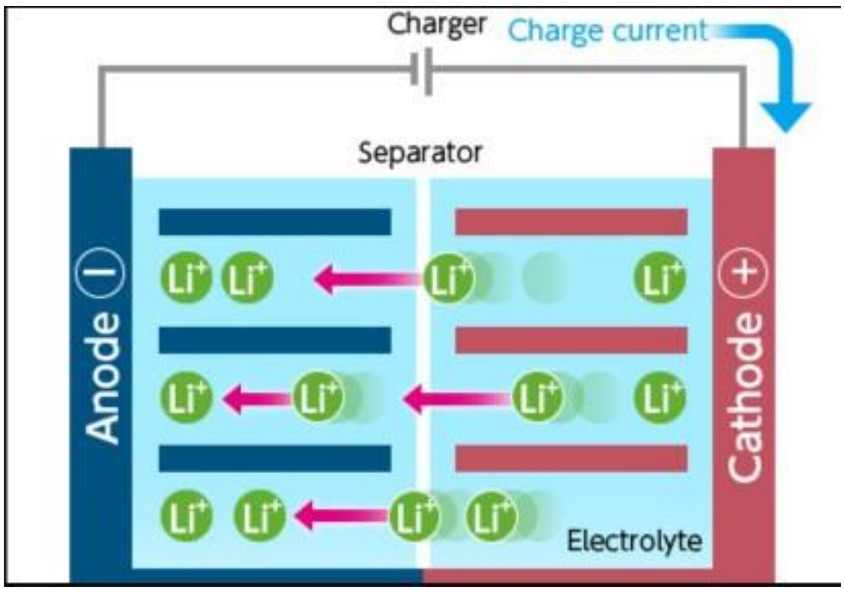
Fan : The turbojet engine fitted with fan at the front end of engine is called as turbofan engine.The rotation of fan pushes a incoming air rearward resulting in forward Fan thrust. This design is not suitable for supersonic flight.

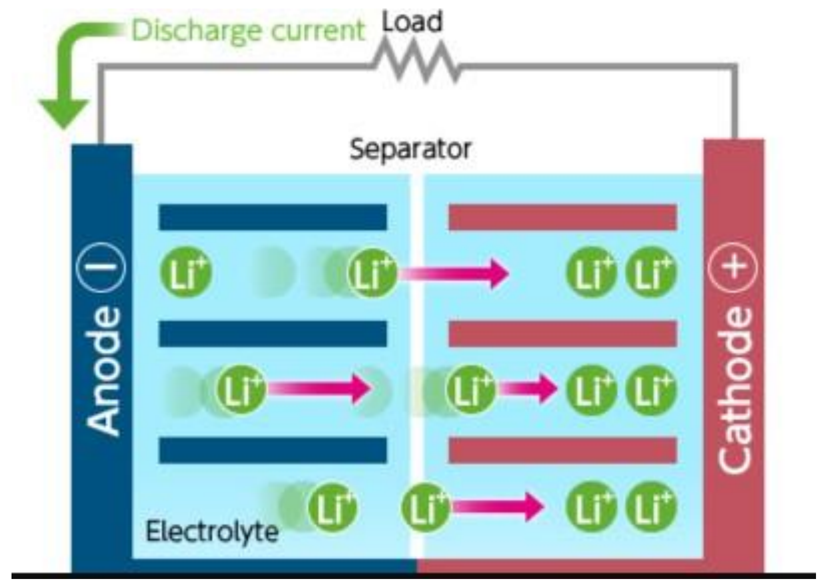
Turbofan thrust = Fan thrust +Jet thrust

Basics of electrochemistry(optional)

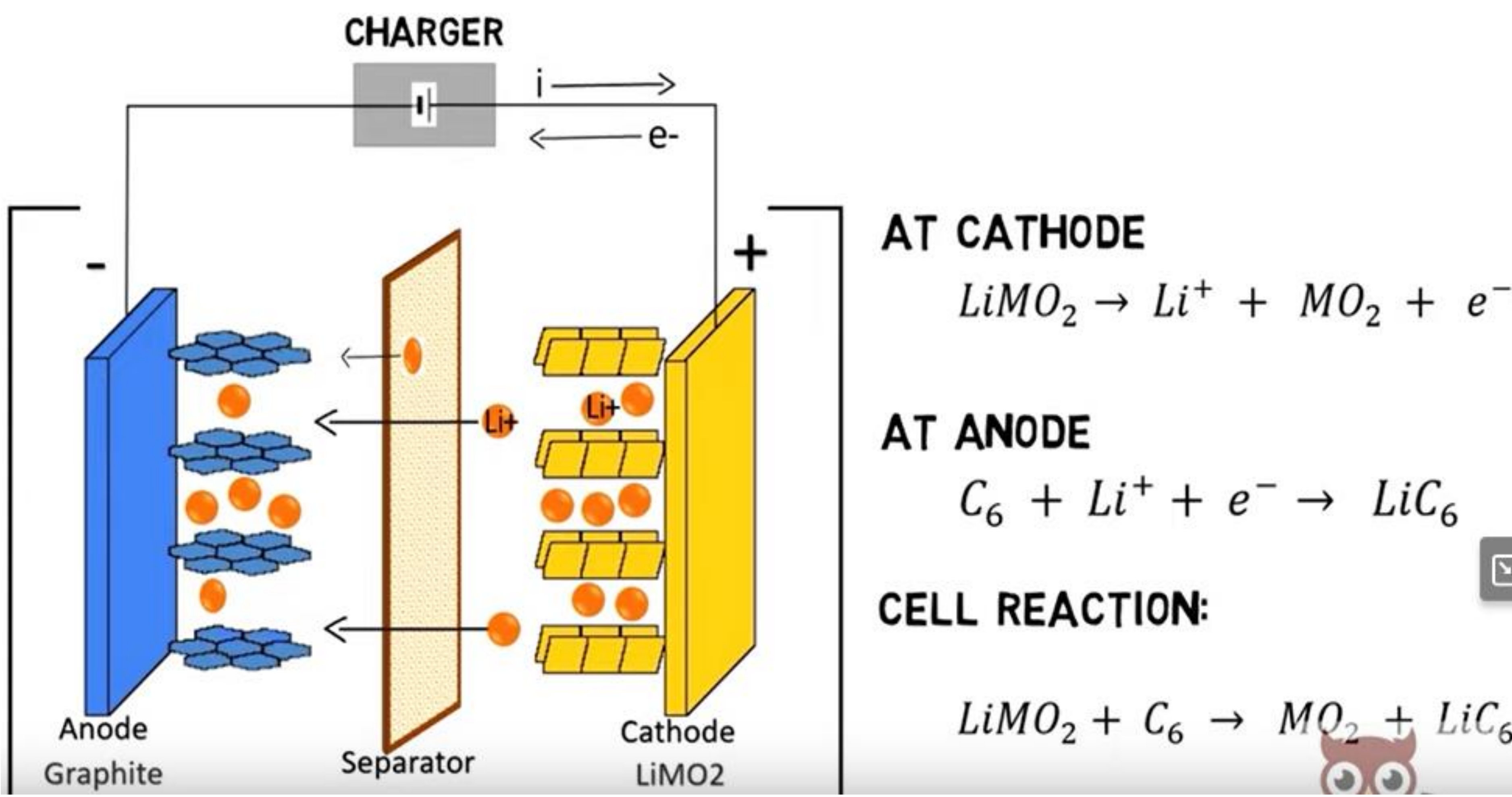
- **A stable atom has a net charge of 0**. In other words, it has an equal number of protons and electrons. The positive protons cancel out the negative electrons. When the number of electrons does not equal the number of protons, the atom is ionized.
- **On the basis of reactivity of different metals with oxygen, water and acids as well as displacement reactions, the metals have been arranged in the decreasing order of their reactivities. This arrangement is known as activity series or reactivity series of metals.The basis of reactivity is the tendency of metals to lose electrons. If a metal can lose electrons easily to form positive ions, it will react readily with other substances. Therefore, it will be a reactive metal. On the other hand, if a meal loses electrons less rapidly to form a positive ion, it will react slowly with other substances. Therefore, such a metal will be less reactive.**
- **Which of the following represents the correct order of reactivity for the given metals?**
- **(a), Na > Mg > Al > Cu**
- **Atomic hydrogen is very reactive**. It combines with most elements to form hydrides (e.g., sodium hydride, NaH), and it reduces metallic oxides, a reaction that produces the metal in its elemental state.

Lithium ion battery (video 5)

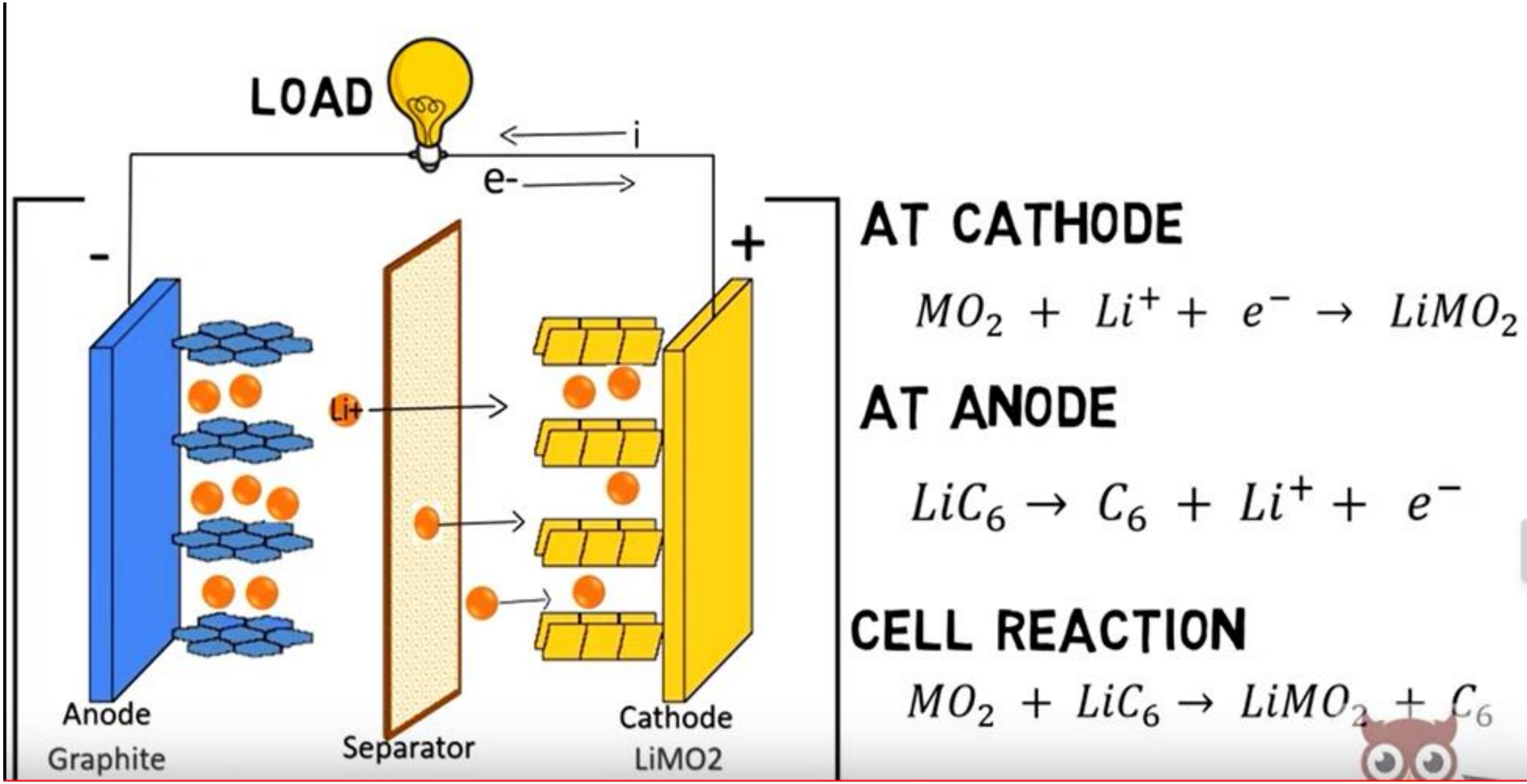




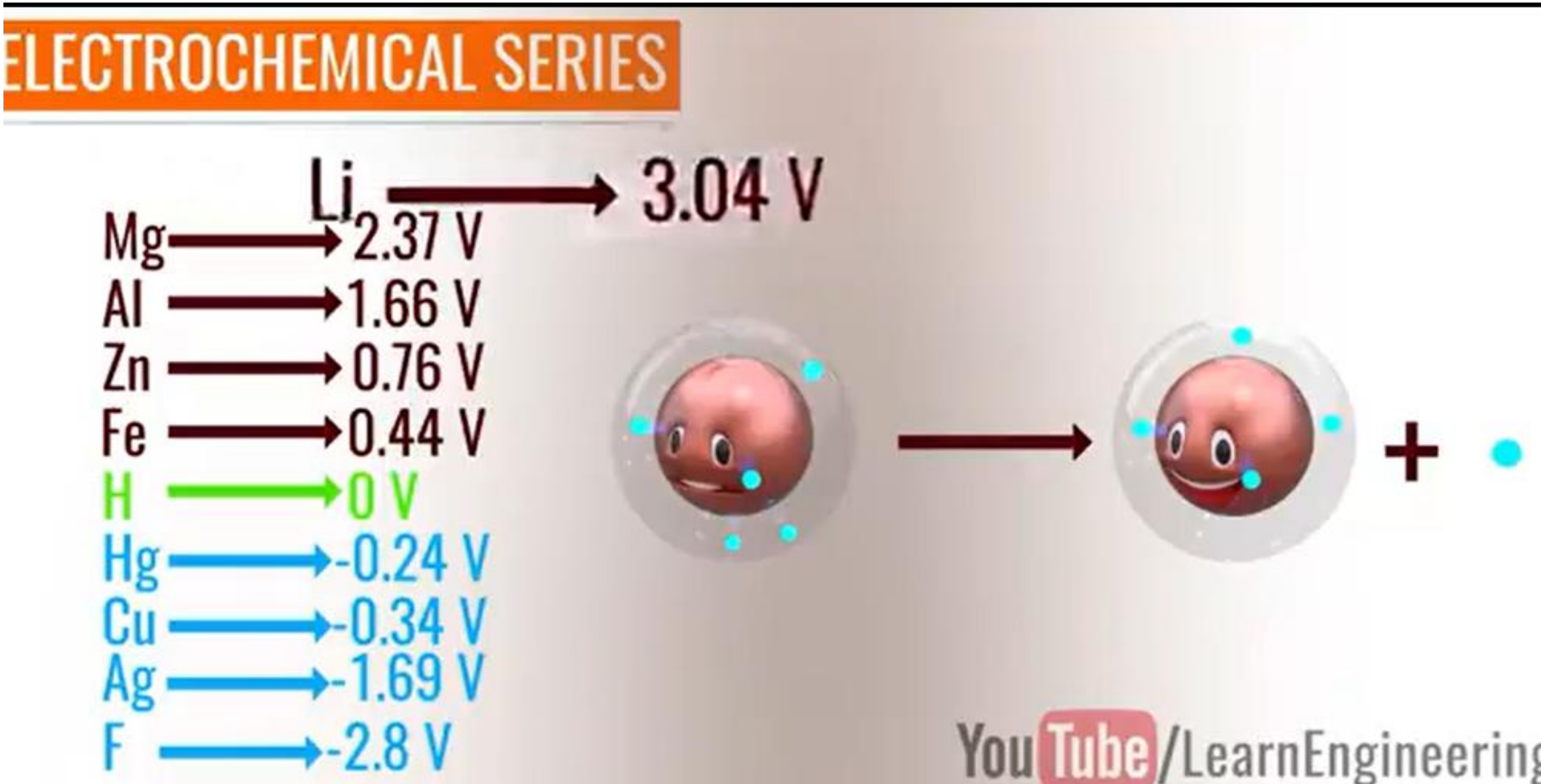
The most common electrolyte in lithium batteries is a lithium salt solution such as **lithium hexafluorophosphate (LiPF6) Ref: https://www.energy.gov/energysaver/articles /how-lithium-ion-batteries-work**



LiC6—litheated carbon and LiMO2—Lithium metal oxide
and **mobile battery is 100% if lithium is loaded at anode between graphite(carbon) layers. Electric current is used to drive the non-spontaneous redox reaction through this electrolytic cell**
For reference: to know electrochemical cell and electrolytic cell working and how spontaneours redox reaction drive electric current and how electric current drives non-spontaneous redox reaction: https://www.youtube.com/watch?v=1tvvSUySfls

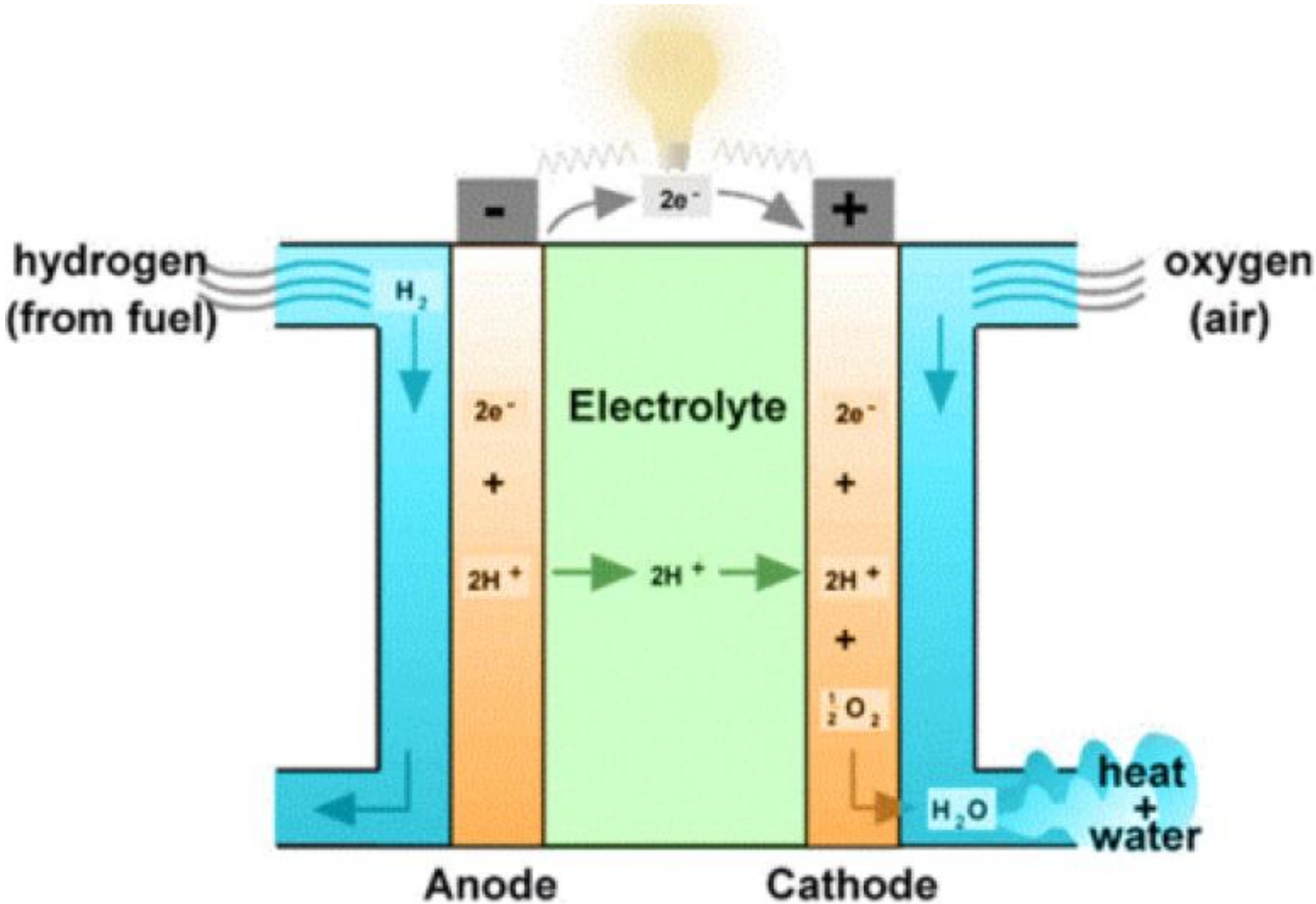


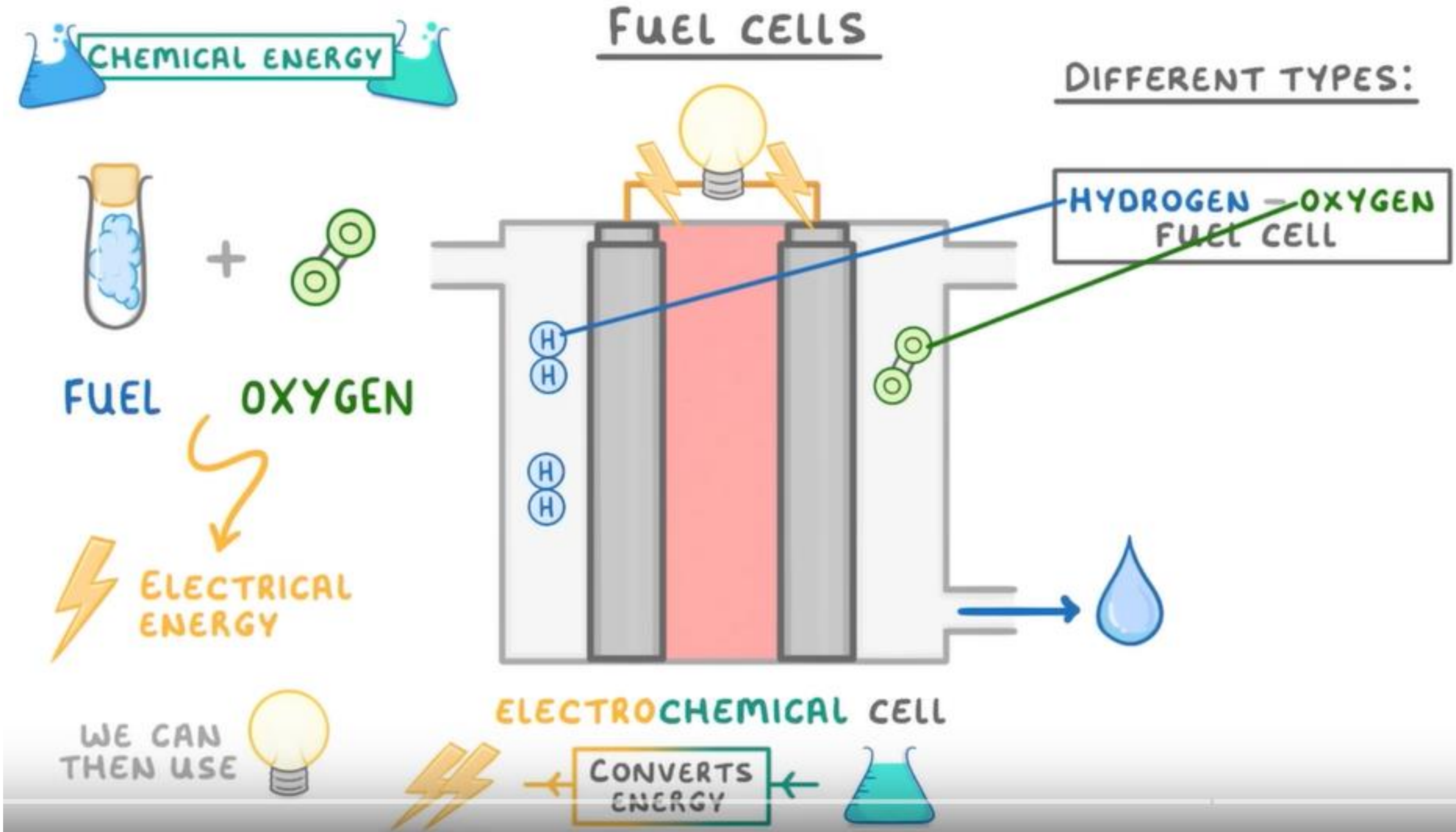
- Mobile battery is **empty(0%)** if there is no lithium ions at the anode to move.
- Lithium is a reactive metal and thus **spontaneous redox reaction** takes place to loose electrons at the anode while discharging.
- Lithium ion will transfer through separator where electron will drive and electric current.


ELECTROCHEMICAL SERIES
Li → 3.04 V
Mg → 2.37 V
Al → 1.66 V
Zn → 0.76 V
Fe → 0.44 V
H → 0 V
Hg → -0.24 V
Cu → -0.34 V
Ag → -1.69 V
F → -2.8 V
+
YouTube/LearnEngineering

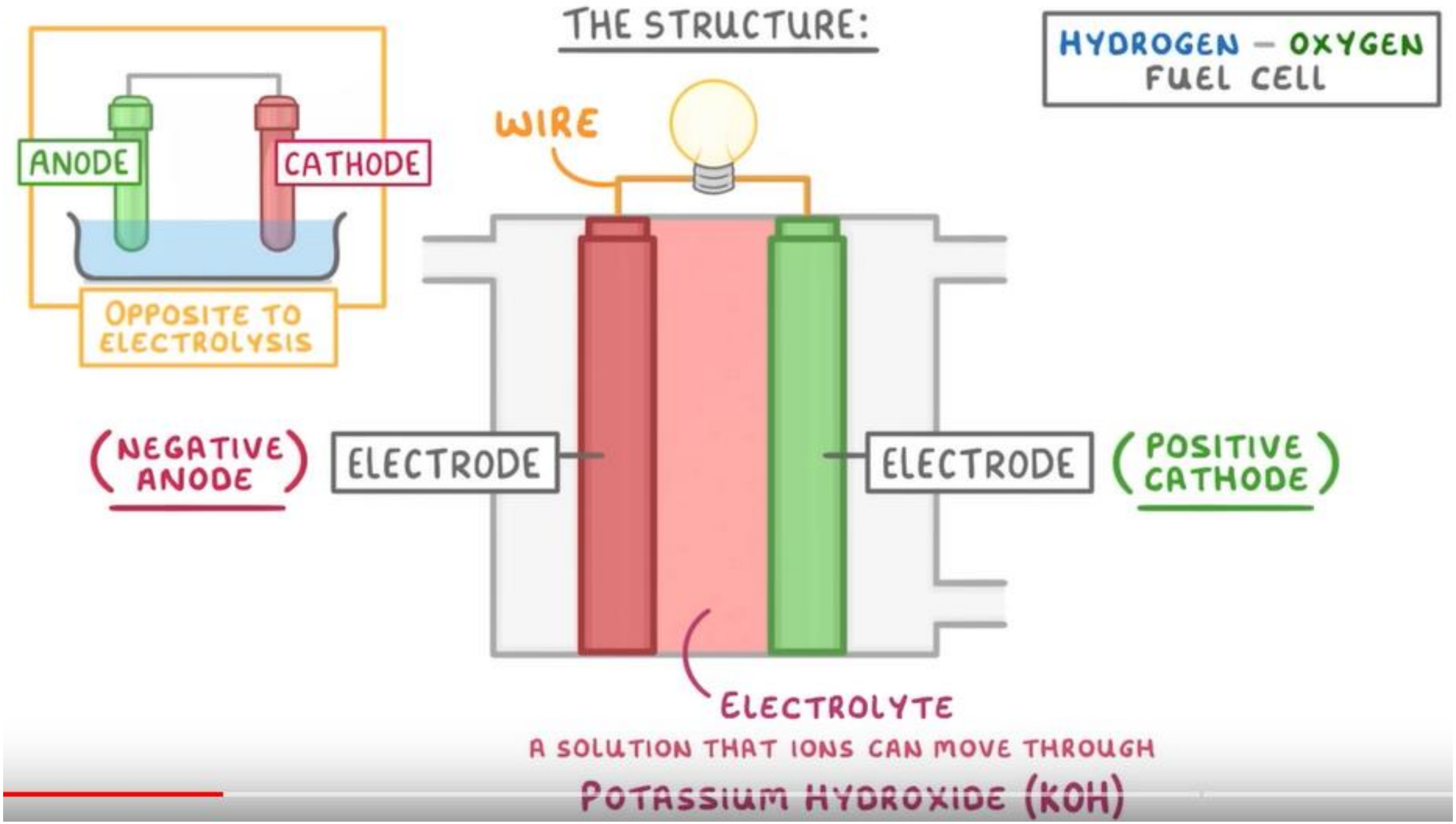
- The rechargeable lithium-ion battery is made of one or more power-generating compartments called cells. Each cell has essentially three components.- positive electrode, negative electrode and electrolyte.
- A positive electrode connects to the battery's positive or + terminal. A negative electrode connects to the negative or − terminal. And a chemical called an electrolyte in between them.
- The positive electrode is typically made from a chemical compound called lithium-cobalt oxide ($LiCoO_2$) or lithium iron phosphate ($LiFePO_4$). The negative electrode is generally made from carbon (graphite). The electrolyte varies from one type of battery to another.
- The electrolyte carries positively charged lithium ions from the anode to the cathode.The movement of the lithium ions creates free electrons in the anode which creates a charge at the positive current collector. The electrical current then flows from the current collector through a device being powered (cell phone, computer, etc.) to the negative current collector. The separator blocks the flow of electrons inside the battery.
- While the battery is discharging and providing an electric current, the anode releases lithium ions to the cathode, generating a flow of electrons from one side to the other. When plugging in the device, the opposite reaction happens, the cathode releases lithium ions and anode receives them. This is how the Lithium-ion battery works

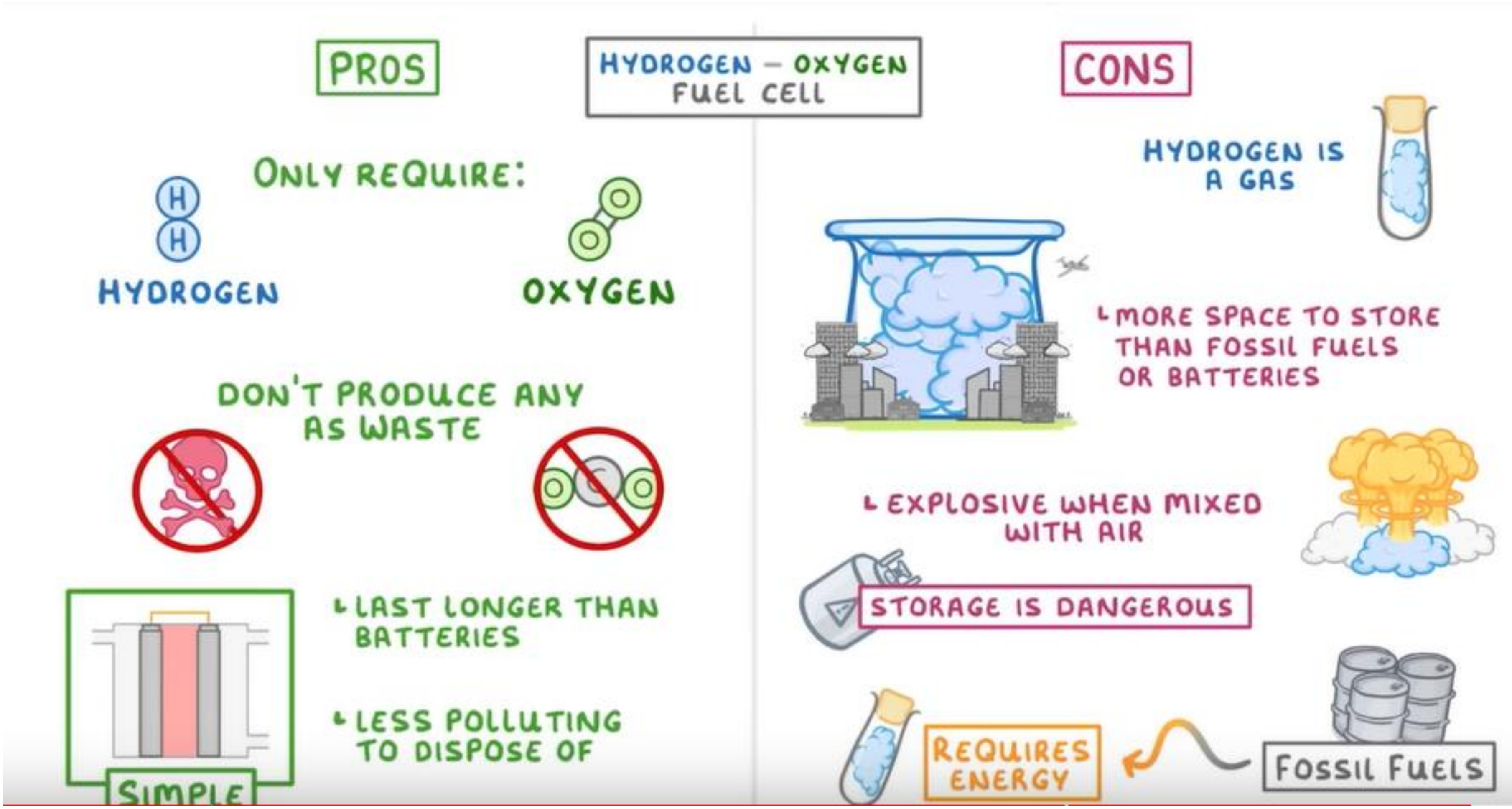
Fuel cells: Play video 6

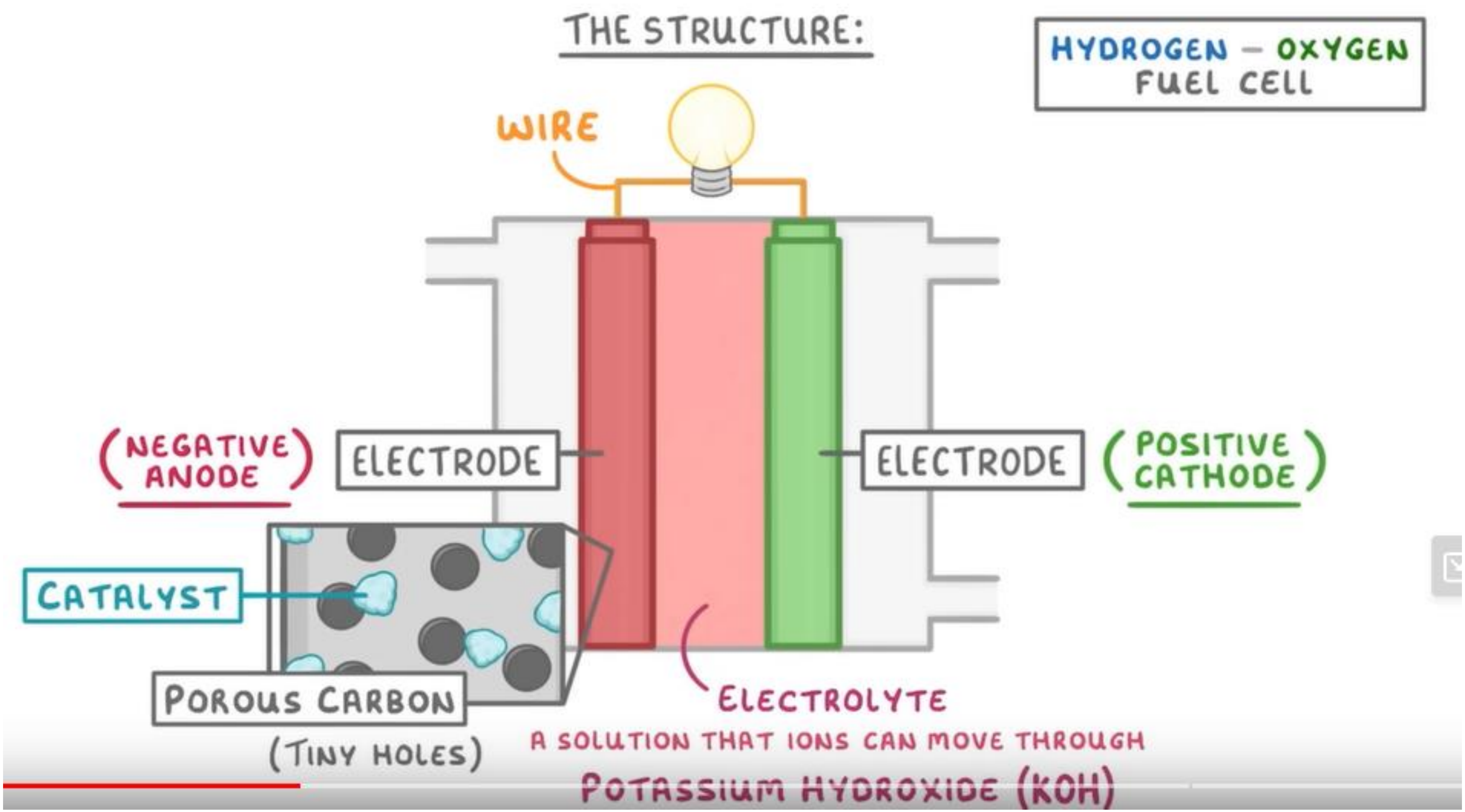


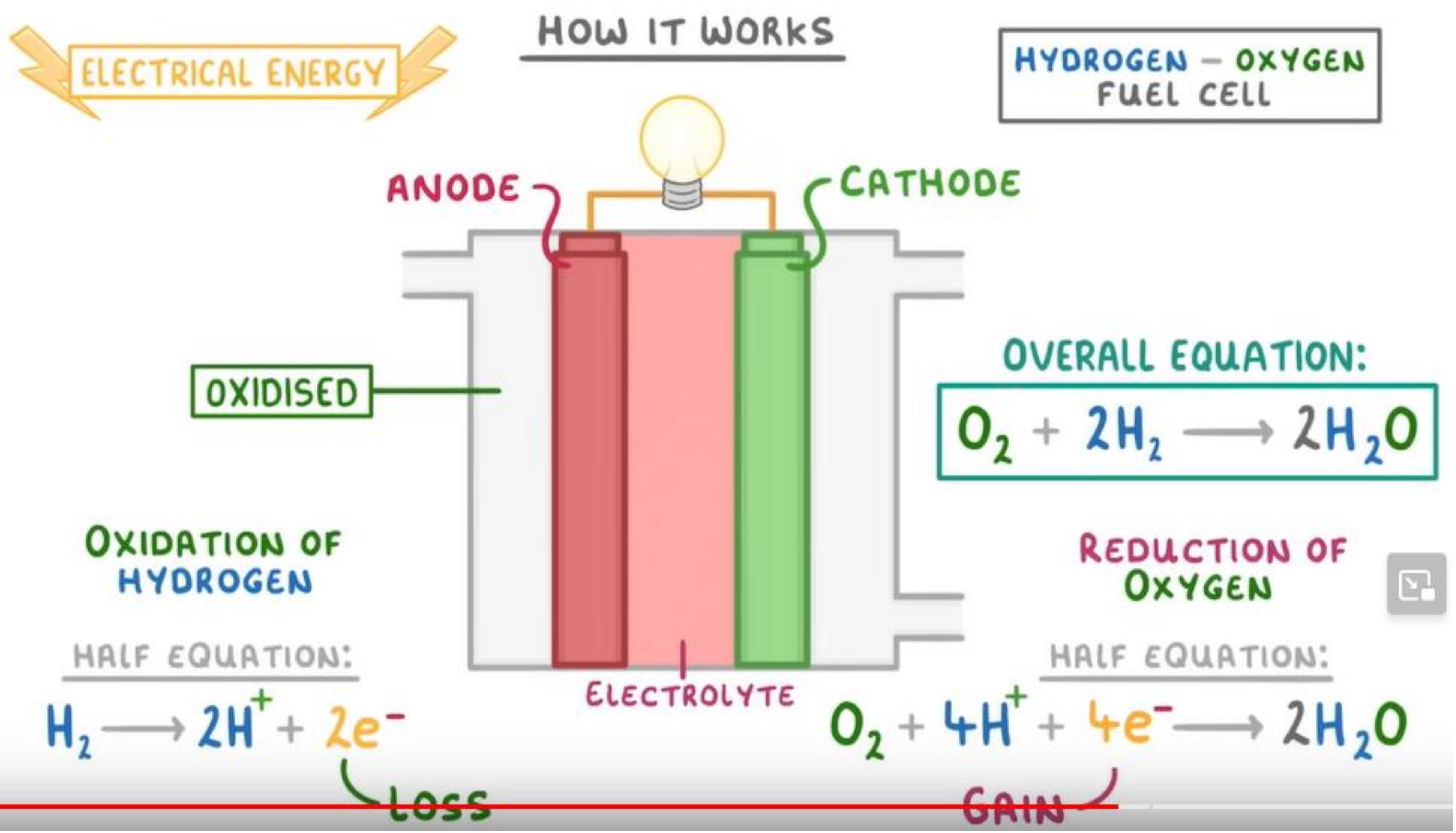


FUEL CELLS
CHEMICAL ENERGY
DIFFERENT TYPES:
HYDROGEN - OXYGEN
FUEL CELL
H
H
H
H
FUEL
OXYGEN
ELECTRICAL
ENERGY
ELECTROCHEMICAL CELL
WE CAN
THEN USE
CONVERTS
ENERGY

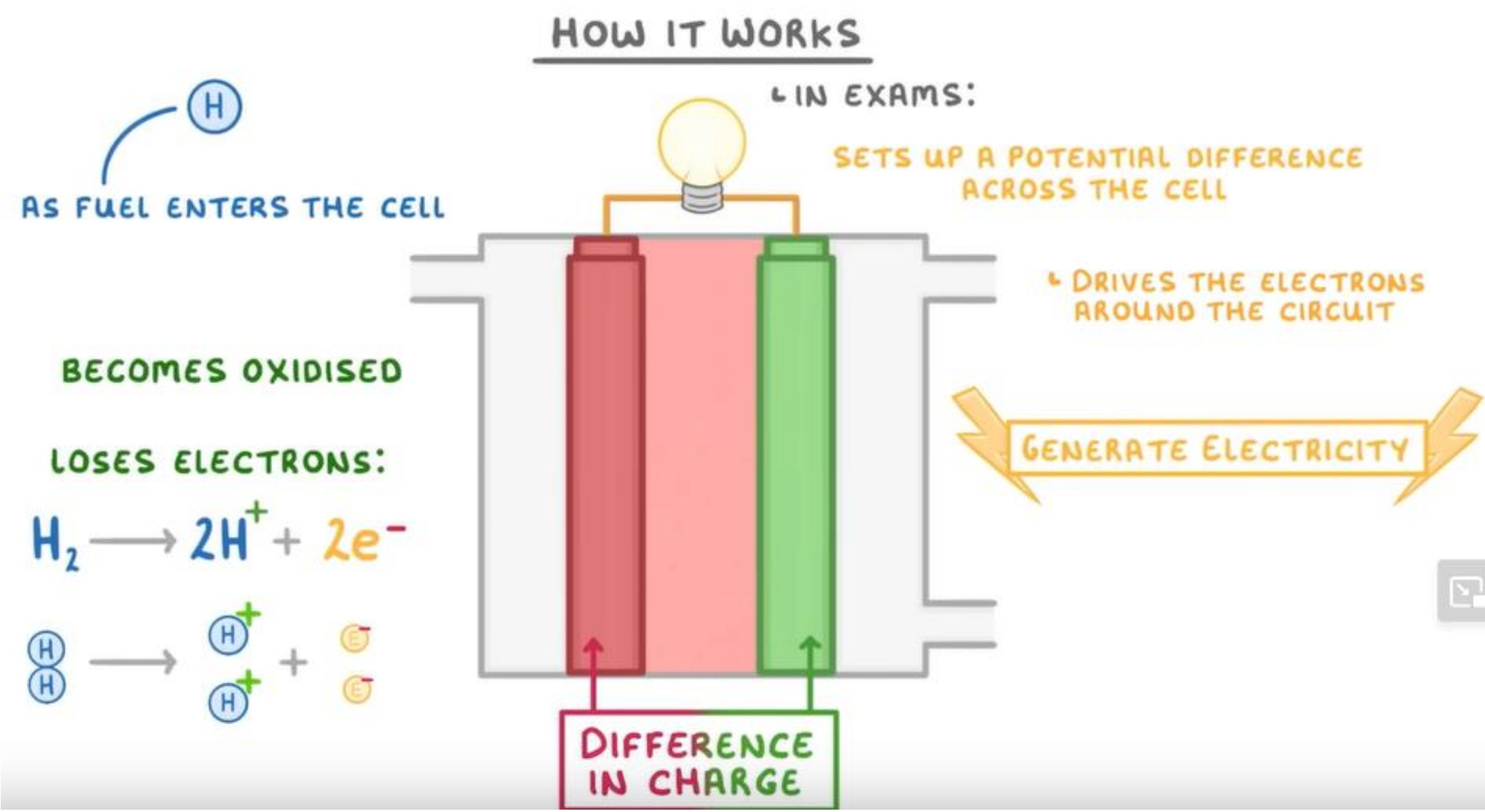

THE STRUCTURE:
HYDROGEN – OXYGEN
FUEL CELL
ANODE
CATHODE
OPPOSITE TO
ELECTROLYSIS
WIRE
(NEGATIVE
ANODE)
ELECTRODE
ELECTRODE
(POSITIVE
CATHODE)
ELECTROLYTE
A SOLUTION THAT IONS CAN MOVE THROUGH
POTASSIUM HYDROXIDE (KOH)


PROS
HYDROGEN – OXYGEN FUEL CELL
CONS
ONLY REQUIRE:
H
H
HYDROGEN
OXYGEN
DON'T PRODUCE ANY AS WASTE
LAST LONGER THAN BATTERIES
LESS POLLUTING TO DISPOSE OF
SIMPLE
HYDROGEN IS A GAS
MORE SPACE TO STORE THAN FOSSIL FUELS OR BATTERIES
EXPLOSIVE WHEN MIXED WITH AIR
STORAGE IS DANGEROUS
REQUIRES ENERGY
FOSSIL FUELS


THE STRUCTURE:
HYDROGEN – OXYGEN
FUEL CELL
WIRE
(NEGATIVE
ANODE)
ELECTRODE
ELECTRODE
(POSITIVE
CATHODE)
CATALYST
POROUS CARBON
(TINY HOLES)
ELECTROLYTE
A SOLUTION THAT IONS CAN MOVE THROUGH
POTASSIUM HYDROXIDE (KOH)



ELECTRICAL ENERGY
HOW IT WORKS
HYDROGEN – OXYGEN FUEL CELL
ANODE
CATHODE
OXIDISED
OVERALL EQUATION:
$O_2 + 2H_2 \longrightarrow 2H_2O$
OXIDATION OF HYDROGEN
REDUCTION OF OXYGEN
HALF EQUATION:
$H_2 \longrightarrow 2H^+ + 2e^-$
LOSS
ELECTROLYTE
HALF EQUATION:
$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$
GAIN

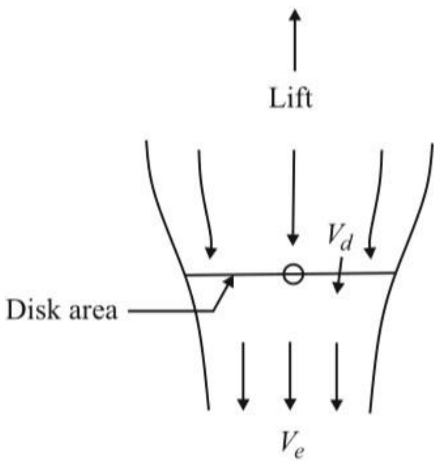


HOW IT WORKS
IN EXAMS:
SETS UP A POTENTIAL DIFFERENCE ACROSS THE CELL
DRIVES THE ELECTRONS AROUND THE CIRCUIT
GENERATE ELECTRICITY
AS FUEL ENTERS THE CELL
BECOMES OXIDISED
LOSES ELECTRONS:
$H_2 \longrightarrow 2H^+ + 2e^-$
DIFFERENCE IN CHARGE

- In fuel cell the chemical energy is converted into electrical energy in a reaction that eliminates the combustion of the fuel.
- Fuel cells allow the direct conversion of energy stored in a fuel into electricity.
- Instead of combining the hydrogen with oxygen from the air, the fuel cell uses a catalyst to facilitate the ionization of the hydrogen at the anode, creating positively charged hydrogen ions and free electrons. It then uses an electrolyte to pass the hydrogen ions to a cathode that is in contact with oxygen gas. This gives the anode a positive charge and creates a voltage potential between the cathode and anode that drives the free electrons through an external circuit. When the electrons get to the cathode, they combine with the oxygen atoms to form water molecules.
- The choice of the electrolyte is very important. Some of the electrolytes that work well in fuel cells need to operate at temperatures as high as 1,000 C. This clearly requires signif i cant packaging to insulate the cell from its surroundings. For use in a UAS, the more attractive electrolytes are solid organic polymers and solutions of potassium hydroxide in a “matrix.”
- In this context, one could think of the matrix as a layer of some absorbing material that can be permeated by the liquid electrolyte and avoids the issues related to an unrestrained liquid electrolyte.
- A fuel cell is not a battery and cannot directly be “recharged.” However, if it uses hydrogen as a fuel, the resulting water can be saved and electrolyzed to turn it back into oxygen and hydrogen gas. This makes a fuel cell an attractive way to store and recover energy on an electrically propelled UAV that uses solar cells to provide power during the day but must store energy to remain aloft at night

Powered Lift

Lift or thrust is directly generated by rotor or fan, is called powered lift



For an un-ducted rotor, ambient air is sucked into the disk defined by the spinning fan, and passes through it with a velocity v_d and continues to accelerate to a final exit velocity v_e. It is well known and easily proved that:

$$v_d = \frac{v_e}{2} \tag{6.7}$$

and the mass flow is:

$$\frac{\mathrm{d}m}{\mathrm{d}t} = \rho A v_d = \frac{1}{2}\rho A v_e \tag{6.8}$$

where A is the area of the disk, so the lift of the disk is:

$$L = \frac{\mathrm{d}m}{\mathrm{d}t} v_e = \frac{\rho A v_e^2}{2} \tag{6.9}$$

The induced power is:

$$P = \frac{1}{2}\frac{\mathrm{d}m}{\mathrm{d}t} v_e^2 \tag{6.10}$$

and by substituting for $\mathrm{d}m/\mathrm{d}t$ from Equation (6.8) and for v_e^3 from Equation (6.9), we find that:

$$P = \frac{L^{3/2}}{\sqrt{2\rho A}} \tag{6.11}$$

February 2

Powered lift — Thrust generation

25 Tuesday

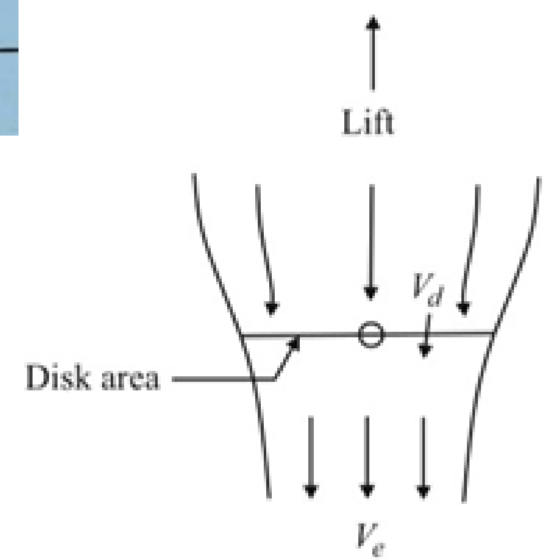
$F = T =$ rate of change of momentum (momentum generator) $(\dot{m}[V_e - V_i])$

$= \frac{dm}{dt}(V_{in} - V_{out})$.

w.r.t $\dot{m} = \rho V A \rightarrow$ disk area,

26 Wednesday rate at which air mass flows past a wing or propeller can be calculated as.

$$\frac{dm}{dt} = \rho V \frac{\pi b^2}{4} \quad (1)$$



Powered lift.

$V_d = \frac{V_e}{2}$

mass flow $\frac{dm}{dt} = \rho A V_d = \rho A \frac{V_e}{2}$ — (1)

$A \rightarrow$ area of the disk.

$\therefore$ Lift of the disk $= L = \frac{dm}{dt} V_e$ — (2)

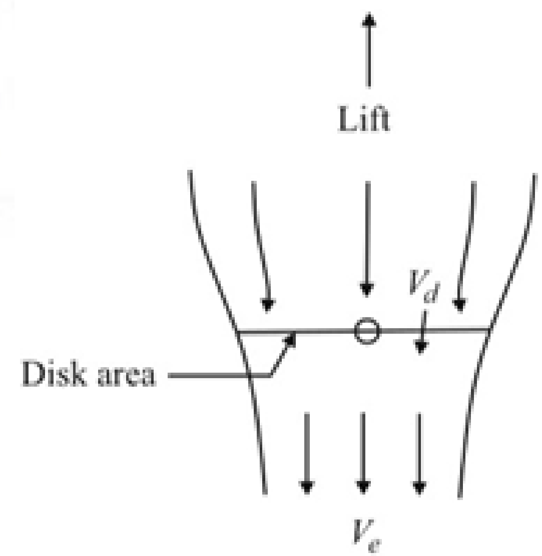
sub (1) in (2) for $\frac{dm}{dt}$

$\therefore L = \rho A \frac{V_e}{2} \cdot V_e = \frac{\rho A V_e^2}{2}$ — (3) a

$\boxed{V_e = \sqrt{\frac{2L}{\rho A}}}$ — (3) b

induced power is the power req to generate lift or thrust i.e, change in KE of fluid across the disk. ie

$P = \frac{1}{2} \frac{dm}{dt} V_e^2$ — (4)



$$P = \frac{1}{2} \frac{dm}{dt} V_e^2 \quad \text{—— (4)}$$

Sub for $\frac{dm}{dt}$ from eq (1)

$$P = \frac{1}{2} \rho A \frac{V_e}{2} V_e^2 \quad \text{—— (5)}$$

Sub for V_e from eq (3b) & V_e^2 from eq (3a) in eq (5)

09
Monday

$$\therefore P = \frac{1}{\cancel{2}} \cdot \frac{\cancel{\rho A}}{\cancel{2}\sqrt{2}} \sqrt{\frac{2L}{\rho A}} \cdot \frac{\cancel{2}L}{\cancel{\rho A}}$$

$$= \frac{L^{1/2} \cdot L^1}{\sqrt{2\rho A}} \qquad \therefore \boxed{P = \frac{L^{3/2}}{\sqrt{2\rho A}}}$$

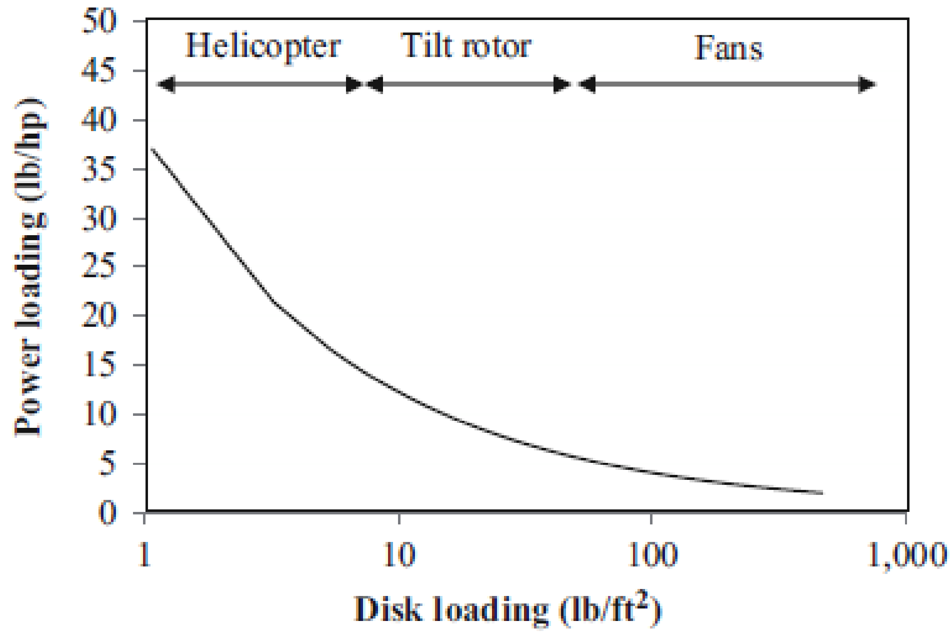


Figure 6.3 Disk loading versus power loading

a slight rearrangement leads to:

$$\frac{L}{P} = \sqrt{\frac{2\rho}{L/A}} \tag{6.12}$$

which tells us that the lift per unit power is inversely proportional to the square root of the disk loading (L/A) and directly proportional to the square root of the density. Plotting power loading against disk loading for helicopters, tilt rotor/wing, and fans (Figure 6.3) shows the relative efficiency of each. While the units of power in Equation (6.12) are N or ft·lb/s, we plot the results of the calculation in the commonly used units of horsepower.

Consider eqv (3a) $\quad L = \frac{\rho A V_e^2}{2}$ — (3a) 10

~~Consider~~ Consider induced power, i.e rate of change of kinetic energy of air across the disk
or
power required to generate the upward thrust.

$$\therefore P = \Delta k.e = \frac{1}{2}\frac{dm}{dt}(V_e - \cancel{V_i}^{\,0})^2$$ 11

$$P = \frac{1}{2}\frac{dm}{dt}V_e^2 \quad \text{— (2)}$$

W.K.T $\quad \frac{dm}{dt} = \frac{\rho A V_e}{2}$ — (1)

Sub (1) in (2) for $\frac{dm}{dt}$

$$\therefore P = \frac{1}{2}\,\frac{\rho A V_e}{2}\,V_e^2 \quad \text{— (6)}$$ 12

Consider $\frac{L}{P}$ i.e $\frac{\text{eqv (3a)}}{\text{eqv (6)}}$

$$\frac{L}{P} = \frac{\frac{\cancel{\rho A} V_e^{\cancel{2}}}{\cancel{2}}}{\frac{1}{\cancel{2}}\cancel{\rho A}\frac{V_e}{2}\cancel{V_e^2}} = \frac{2}{V_e}$$

$$\boxed{\frac{L}{P} = \frac{2}{V_e}}$$

Combining the expressions for lift and power in terms of exit velocity in Equations (6.9) and (6.10), we find that:

$$\frac{L}{P} = \frac{2}{V_e} \tag{6.13}$$

This indicates that lift per unit power is inversely proportional to exit velocity. From this, it is clear that the most efficient powered lift is generated by using a large mass of air at a low velocity.

Figure 6.4 shows momentum generators classified as a function of lift-to-power ratio or exit velocity. Rotors, with large disk areas and large amounts of air flowing rather slowly, are the most efficient for hovering. Fans are at a disadvantage compared to rotors, and turbojets at a disadvantage compared to fans, all the way down to rockets, which have the highest exit velocities.

Use of fixed wings with a propeller or turbojet engine producing thrust is a more efficient way to achieve forward horizontal flight than use of rotary wings that produce only lift. The power used to produce thrust in a fixed-wing configuration directly produces forward motion and indirectly produces lift due to the forward motion of the fixed wings. On the other hand, the power applied to a rotor moves a blade to the rear at the same time that it moves another blade forward, so it does not directly produce any forward motion of the aircraft. The rotor produces only lift and wastes the fraction of the power that is used to overcome the parasitic

A vertically-oriented ducted fan can be equipped with wings to aid in the horizontal flight mode. In this case, the fan exit flow is deflected via vanes to provide a horizontal propulsive force. There is a loss, of course, in turning the flow that can range from 10% to 40% depending on the turning angle.

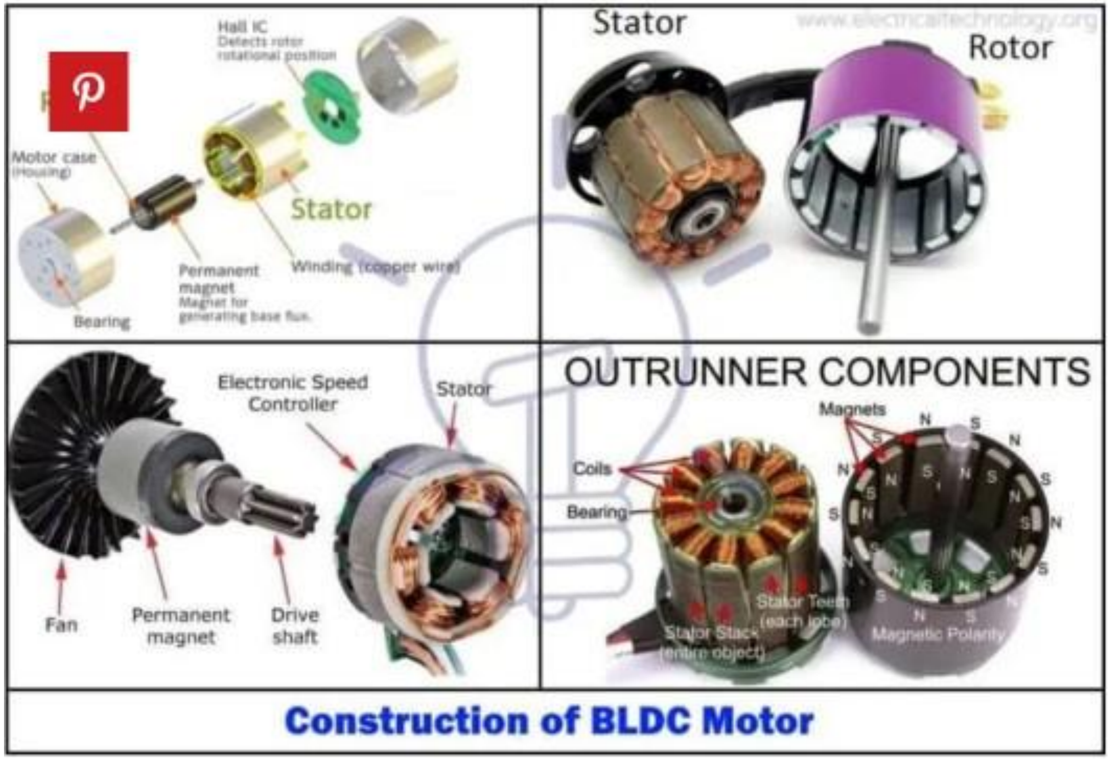
A similar approach that has been used on some fast helicopters is to have short wings that can contribute to lift when the helicopter is in forward flight, reducing the need to increase the total aerodynamic force on the rotors to compensate for using some of the lift as thrust. For this to work, the wings must be set or adjustable to the correct angle to achieve a desired angle of attack when the helicopter is tilted nose downward while in forward flight.

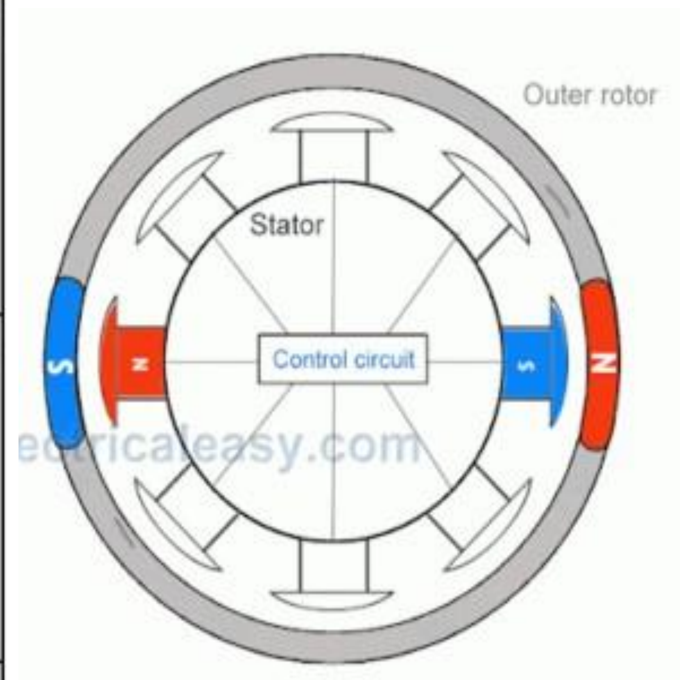
Vertical-lift UAVs have other disadvantages. They are difficult to control in a hover and they are more mechanically complex, both of which will add to the cost. In addition, engine failure is probably a more serious problem with a VTOL than a fixed-wing air vehicle that can glide or parachute to safety. To minimize this possibility, rotary-wing designers opt for the more reliable, and also more costly, gas turbine power plant. Having said all of this, there are many missions where the VTOL UAV is superior to fixed-wing UAVs. Without the need for launch and recovery equipment, they can attain battlefield mobility that is difficult if not impossible to realize with a fixed-wing vehicle, especially the larger-sized vehicles.

In addition to battlefield mobility, there is the question of transportability or strategic mobility. It is probably more important to the Marine Corps that they can transport extra ammunition or perhaps a tank or two than to have to transport two 5-ton trucks carrying a launcher and a recovery net.

There is also the problem of accomplishing landings in small areas. Even with flaps, which add weight, cost, and complexity, the typical fixed-wing UAV cannot attain a steep enough glide angle to land in very small fields surrounded by trees or other obstacles and be caught by a net. Small ships cannot afford the luxury of a net system; there simply is not space available. The larger ships cannot tolerate nets if they interfere with helicopter operations. A VTOL UAV offers a great deal of flexibility for combined UAV and helicopter operations. All of these advantages and disadvantages must be carefully weighed when deciding whether the mission is worth the cost of a VTOL vehicle.

Brushless DC motor Video 7_1 d_2)





Construction:BLDC motor consists of two main parts a stator and a rotor. Permanent magnets are mounted on the rotor of a BLDC motor, and the stator is wound for a specific number of poles. Also, a control circuit is connected to the stator winding. Most of the times, the inverter/control circuit or controller is integrated into the stator assembly.

Working: Stator windings of a BLDC motor are connected to a control circuit (an integrated switching circuit or inverter circuit). The control circuit energizes proper winding at the proper time, in a pattern which rotates around the stator. Permanent magnets on the rotor try to align with the energized electromagnets of the stator, and as soon as it aligns, the next electromagnets are energized. Thus, the rotor keeps running.

Batteries

The key characteristics of a battery are as follows:

- Capacity—The electrical charge effectively stored in a battery and available for transfer during discharge. Expressed in ampere-hours (Ah) or milliampere-hours (mAh).
- Energy Density—Capacity/Weight or Ah/weight.
- Power Density—Maximum Power/Weight in Watts/weight.
- Charging/Discharging rate (C rate)—The maximum rate at which the battery can be charged or discharged, expressed in terms of its total storage capacity in Ah or mAh. A rate of 1C means transfer of all of the stored energy in 1 h; 0.1C means 10% transfer in 1 h, or full transfer in 10 h.

Battery types

6.4.5.1.1 Nickel–Cadmium Battery

The nickel–cadmium (NiCd) battery uses nickel hydroxide as the positive electrode (anode) and cadmium/cadmium hydroxide as the negative electrode (cathode). Potassium hydroxide is used as the electrolyte. Among rechargeable batteries, NiCd is a popular choice but contains toxic metals. NiCd batteries have generally been used where long life and a high discharge rate is important.

6.4.5.1.2 Nickel–Metal Hydride Battery

The nickel–metal hydride (NiMH) battery uses a hydrogen-absorbing alloy for the negative electrode (cathode) instead of cadmium. As in NiCd cells, the positive electrode (anode) is nickel hydroxide.

The NiMH has a high-energy density and uses environmentally friendly metals. The NiMH battery offers up to 40% higher energy density compared to NiCd. The NiMH has been replacing the NiCd in recent years. This is due both to environmental concerns about the disposal of used batteries and the desirability of the higher energy density.

6.4.5.1.3 *Lithium-Ion Battery*

The lithium-ion (Li-ion) battery is a fast growing battery technology because it offers high-energy density and low weight. Although slightly lower in energy density than lithium metal, the energy density of the Li-ion is typically higher than that of the standard NiCd. Li-ion batteries are environmentally friendly for disposal.

Li-ion batteries typically use a graphite (carbon) anode and an anode made of $LiCoO_2$ or $LiMn_2O_4$. $LiFePO_4$ also is used. The electrolyte is a lithium salt in an organic solvent. These materials are all relatively environmentally friendly.

Li-ion is the presently used technology for most electric and hybrid ground vehicles and its maturity and cost are likely to be driven by the large commercial demand.

6.4.5.1.4 *Lithium-Polymer Battery*

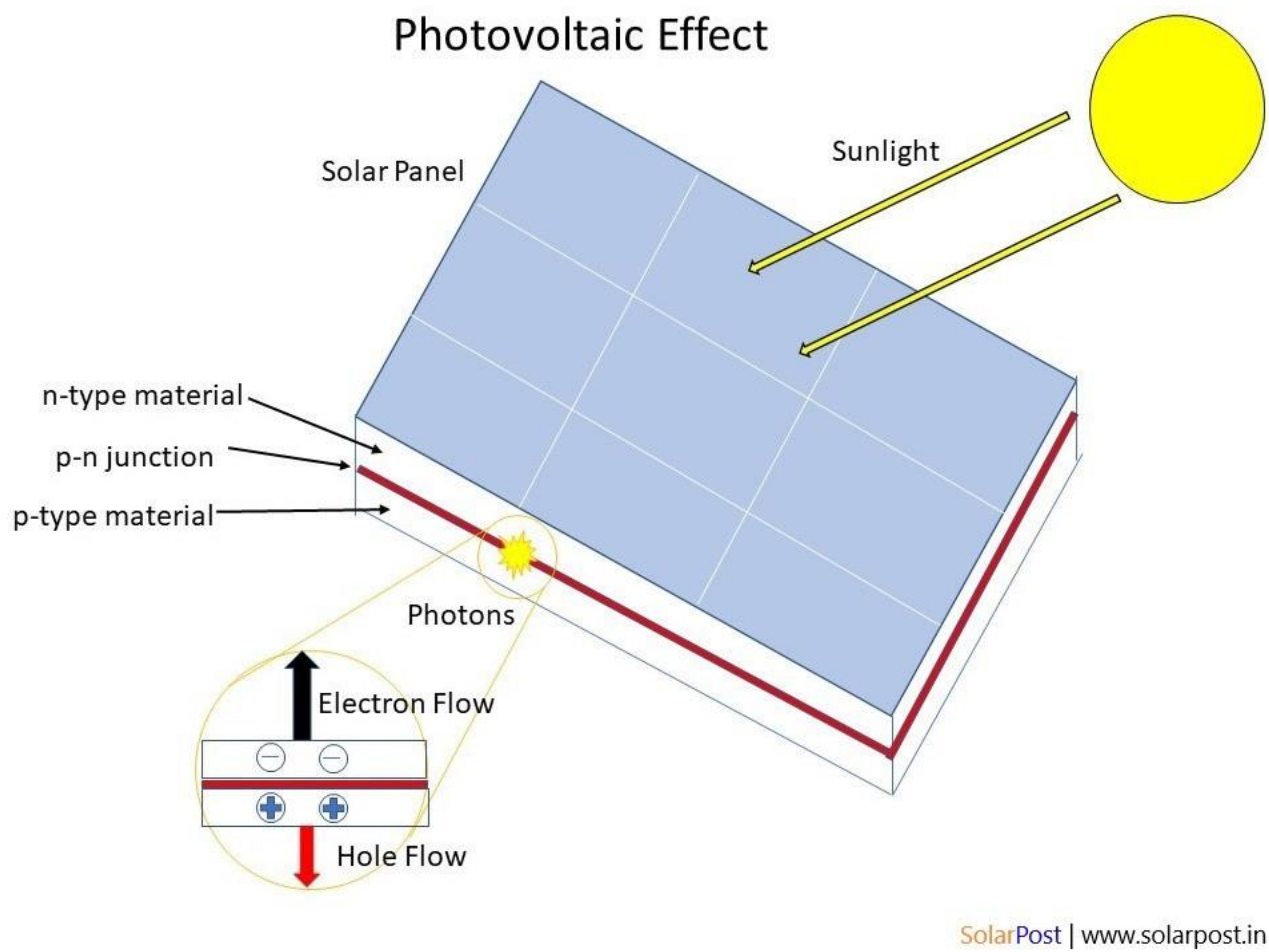
The lithium-polymer (Li-poly) battery uses $LiCoO_2$ or $LiMn_2O_4$ for the cathode and carbon or lithium for the anode.

The Li-poly battery is different than other batteries because of the type of electrolyte used. The polymer electrolyte replaces the traditional porous separator, which is soaked with a liquid electrolyte.

The dry polymer design offers simplifications with respect to fabrication, ruggedness, safety and thin-profile geometry. The major reason for switching to the Li-ion polymer is form factor. It allows great freedom to choose the shape of the battery, including wafer-thin geometries.

Solar Cells(Video 8)

- **The basic principle of a solar cell is that a photon from the sun (or any other light source) is absorbed by an atom in the valence band of semiconductor material and an electron is excited into the conduction band of the material. In order for this to happen, the photon must have enough energy to allow the electron to jump through an “energy gap” that separates the conduction band from the valence band and is due to quantum mechanical effects that create “forbidden” energy states in a crystalline material.**


Photovoltaic Effect
Sunlight
Solar Panel
n-type material
p-n junction
p-type material
Photons
Electron Flow
Hole Flow
SolarPost | www.solarpost.in

- The most common type of solar cell is a silicon positive-intrinsic-negative (PIN) diode.
- This is created by doping small amounts of selected impurities into a silicon crystal so that it has somewhat higher energy bands than pure silicon (positive doped or “P” material) and then adding additional doping to the surface of the crystal that lowers the energy bands near the surface relative to the undoped material (negative doped or N material). In the region where the doping is intermediate, the energy bands pass through the levels of pure silicon,
  and the crystal is neither positive nor negative, but “intrinsic” or “I” material
- The doping of the junction creates a potential difference in the crystal that causes the electron to move toward the surface and contact on the “N” side and the hole to move to the surface and contact on the P side, so that if these two contacts are connected through a load, a current will f l ow through that load

References

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- https://www.youtube.com/watch?v=8xeB_O_fyzM
- to know elctrochemical cell and electrolytic cell working and how spontaneours redox reaction drive electric current and how electric current drives non-spontaneous redox reaction: https://www.youtube.com/watch?v=1tvvSUySfls
- Brushless DC Motor working https://www.youtube.com/watch?v=bCEiOnuODac
- DC Motor working: https://www.youtube.com/watch?v=CWulQ1ZSE3c
- Solar cell: https://www.youtube.com/watch?v=L_q6LRgKpTw&t=234s and
- Solar cell khan academy: https://www.youtube.com/watch?v=YSRs3PuYT_k
- https://www.youtube.com/watch?v=yXF6B7RB7LA Aircraft Propulsion Efficiency| GATE Previous Paper Solution | GATE Aerospace 2021 | Your Engineer
- https://www.youtube.com/watch?v=U5SAttn-e4E **Piston Aircraft Engines**
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