Introduction to Aerospace Engineering

Lecture slides

Introduction to Aerospace Engineering

AE1101ab - Propulsion

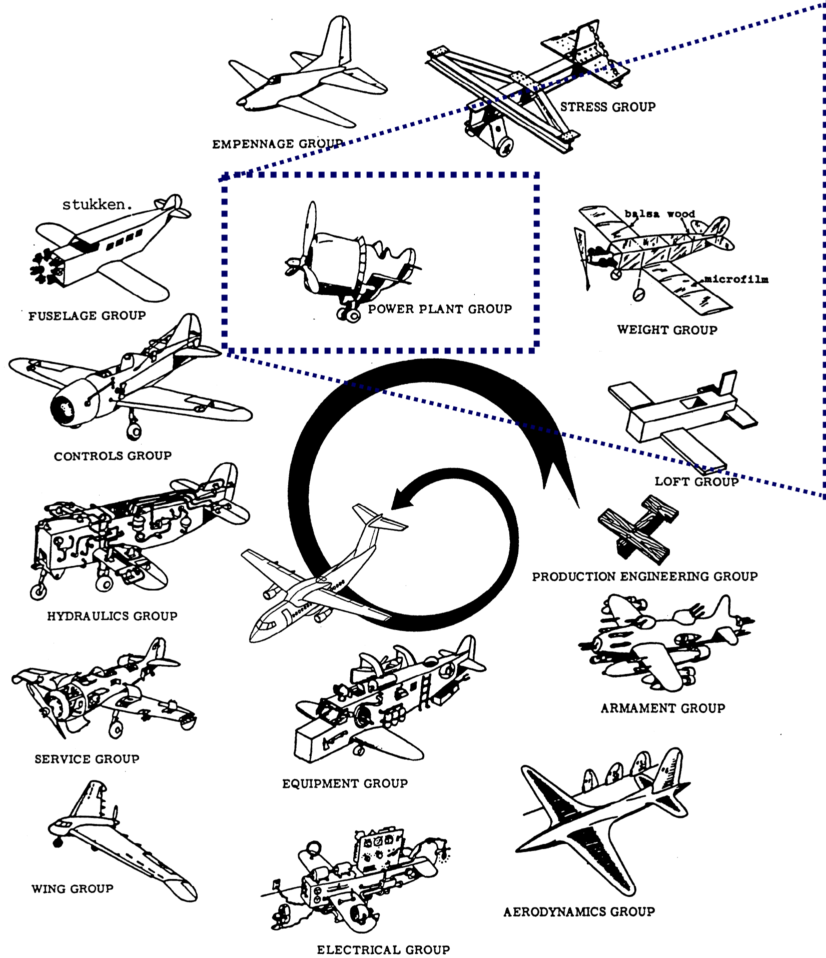
Prof.dr.ir. Jacco Hoekstra

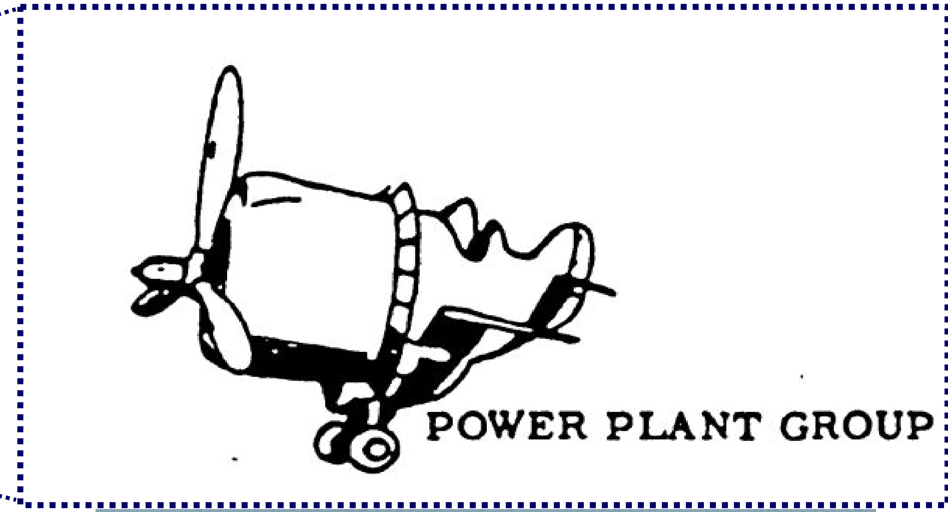
11

Propulsion

We do not use Anderson's ch 9 (too difficult for now), but these slides for 1101ab

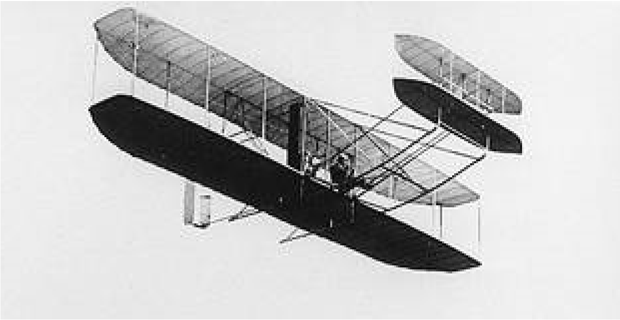
The propulsion perspective…



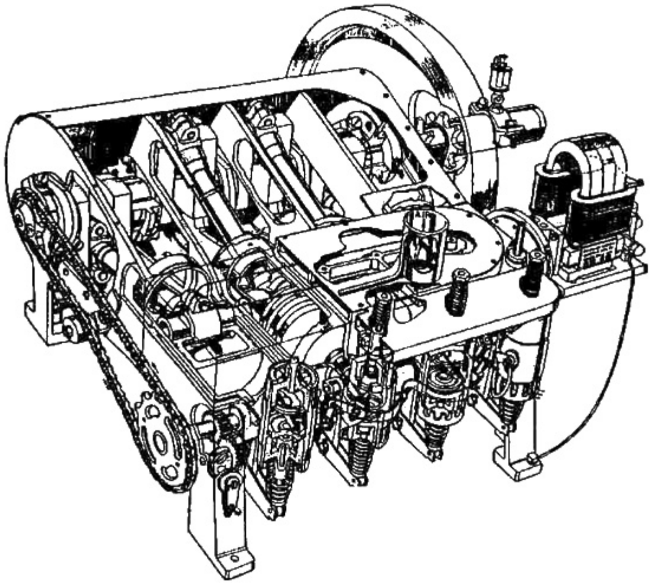


Gee Bee model ‘R’ Sportster

Wright Flyer required an engine that did not exist



- Engine: Wright 4-cylinder 12 - 20 hp water-cooled inline
- Weight 150 lbs, 200 lbs with fuel

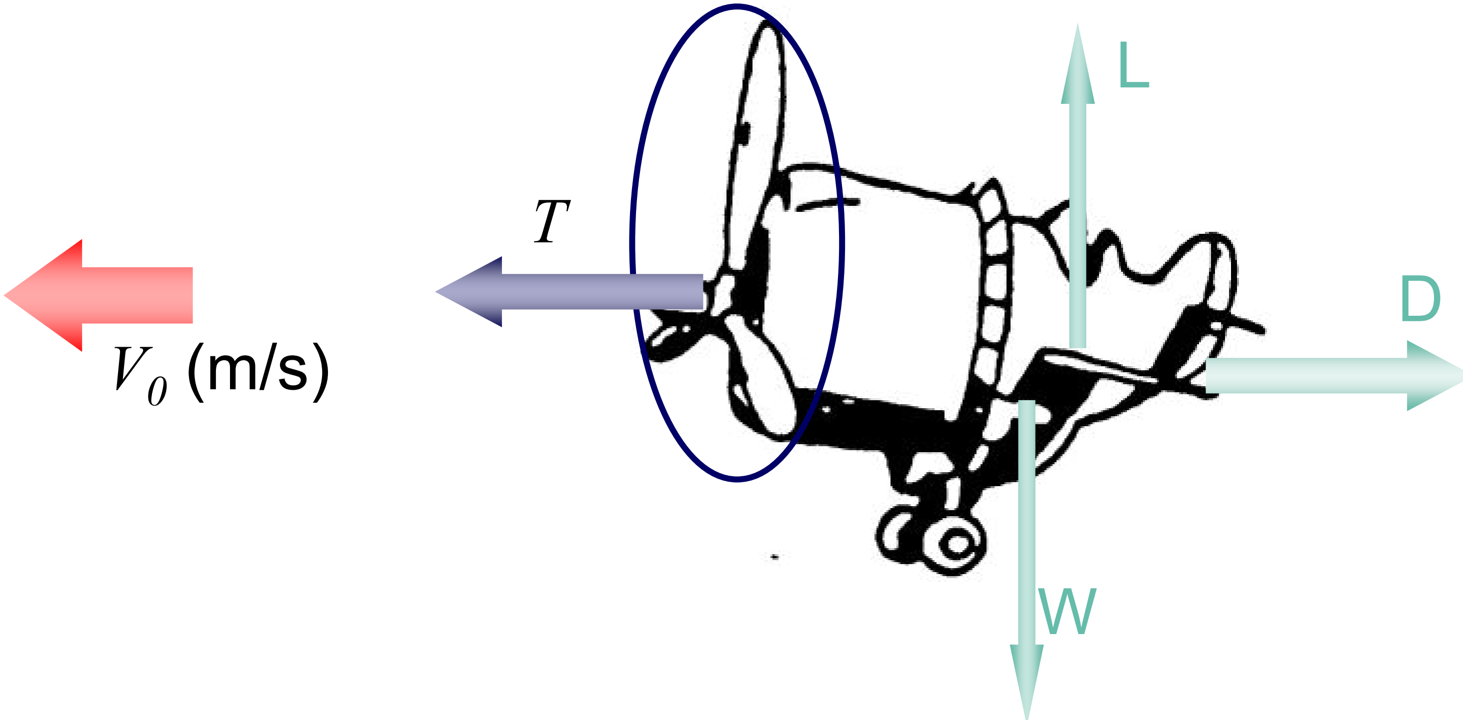


"Even considering the improvements possible …… the gas turbine could hardly be considered a feasible application to airplanes, mainly because of the difficulty with the stringent weight requirements."

Gas turbine committee, US National Academy of Sciences (1940)

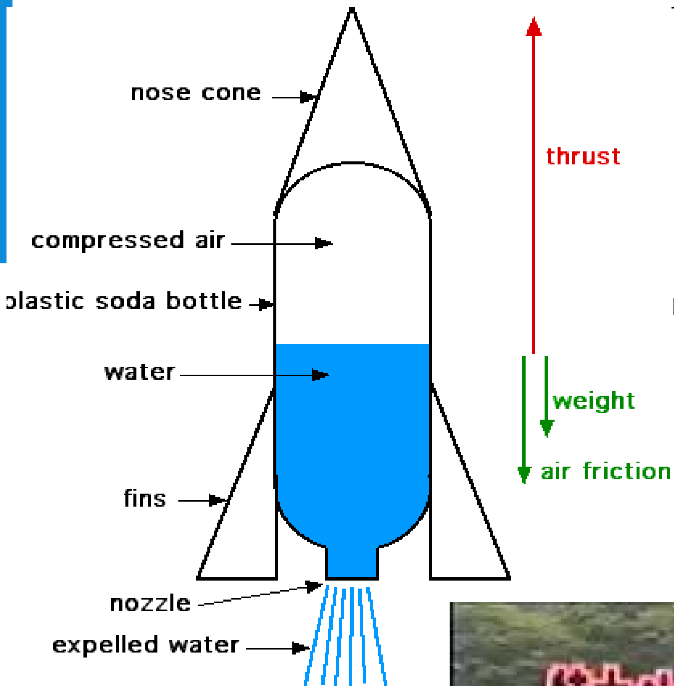
Same statement is currently often heard for electrical propulsion!

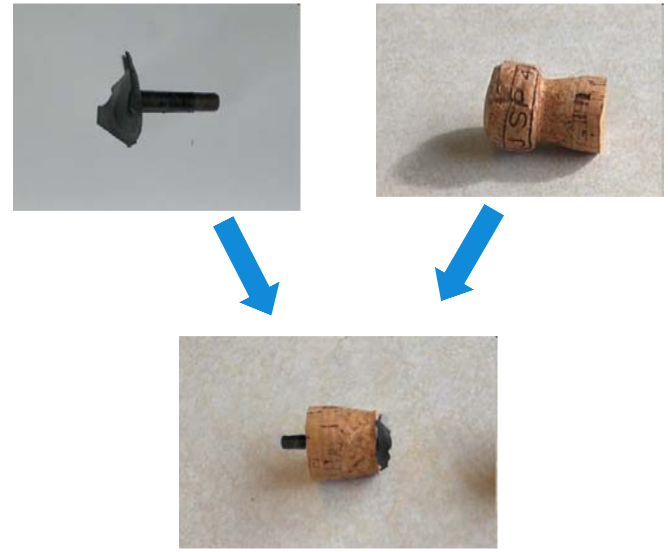
Theory



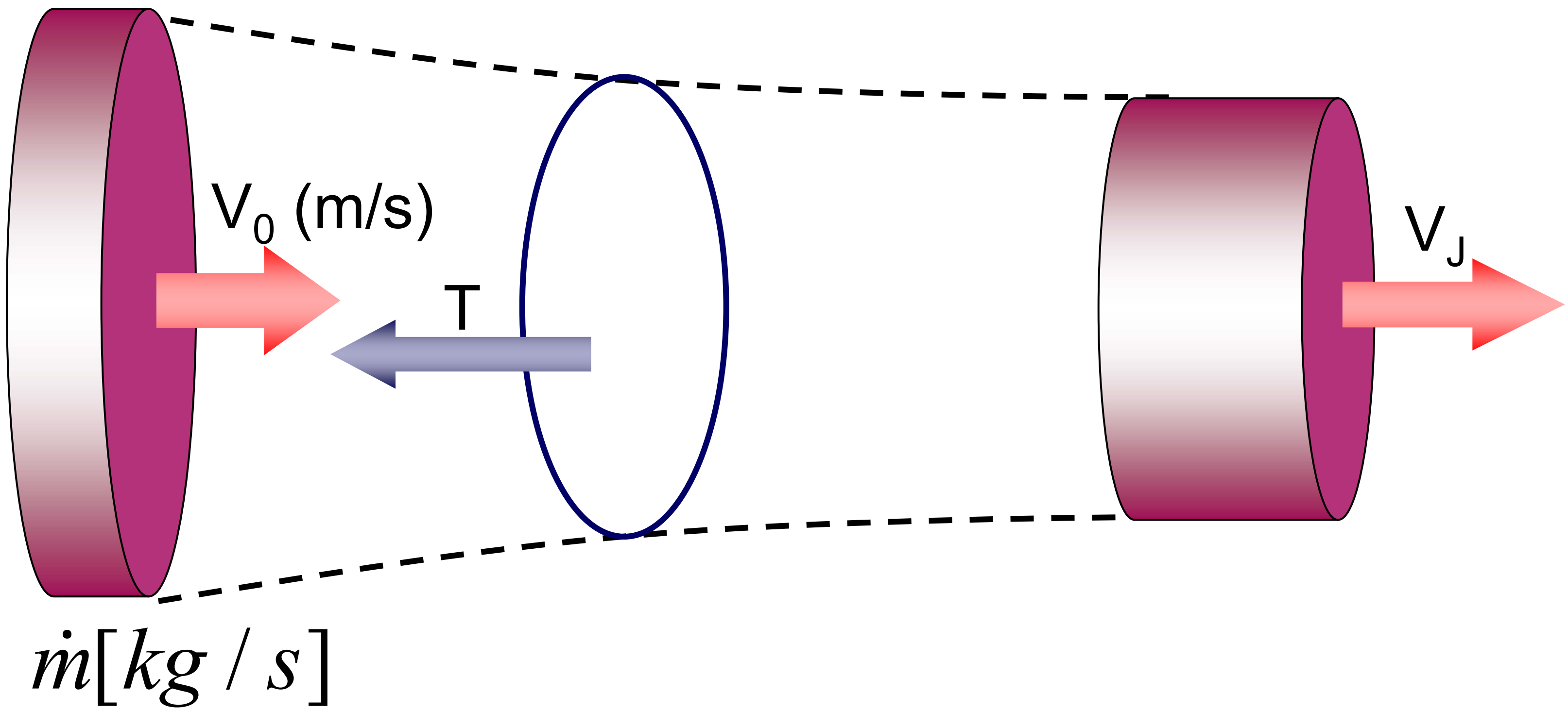
aircraft- and rocket propulsion
≡ reaction propulsion

You can see this principle in the water rocket.





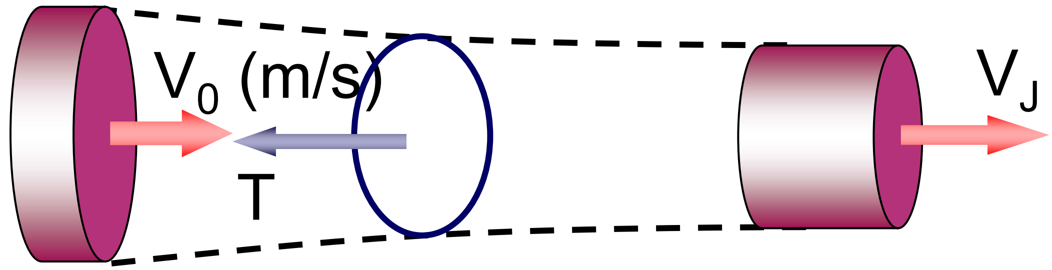
Theory of air breathing engines



For rocket propulsion we use Tsjolkovski's rocket equation (covered 1101cd)!

Theory

Momentum Equation:



$$I = m \cdot V$$

(En: linear momentum, NL: impuls)

$$F = \frac{dI}{dt}$$

(Newton's second law) [kg m/s²](=N)

$$\rightarrow F = m \cdot \frac{dV}{dt} = m \cdot a$$

$$\rightarrow T = \dot{m}(V_j - V_0)$$

[kg/s · m/s] (=N)

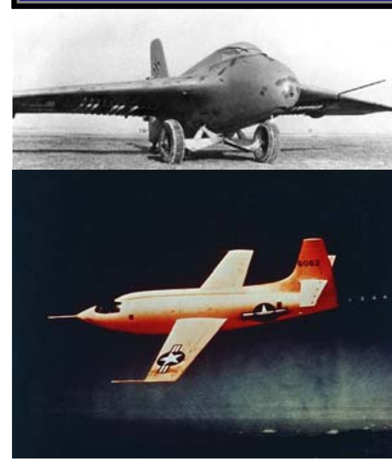
What Flew or Is Flying Around?

Propeller Propulsion | **Jet Propulsion**

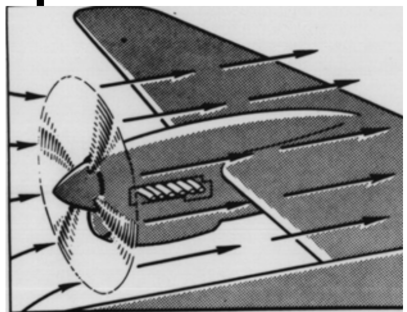
- **Human Powered**

- **Electrical Engine**

- **Airbreathing Engine**
- **Rocket Engine**



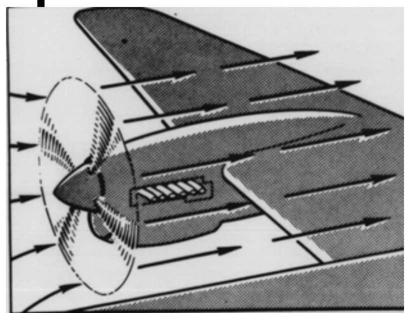
Propeller Propulsion



Counter Rotating

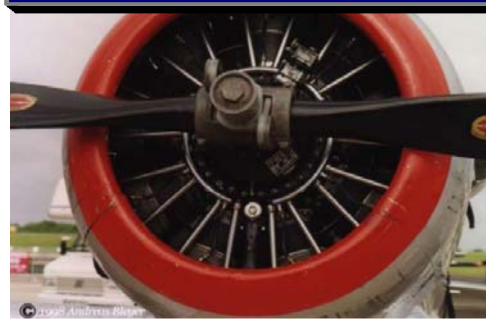
Rotating

Propeller Propulsion

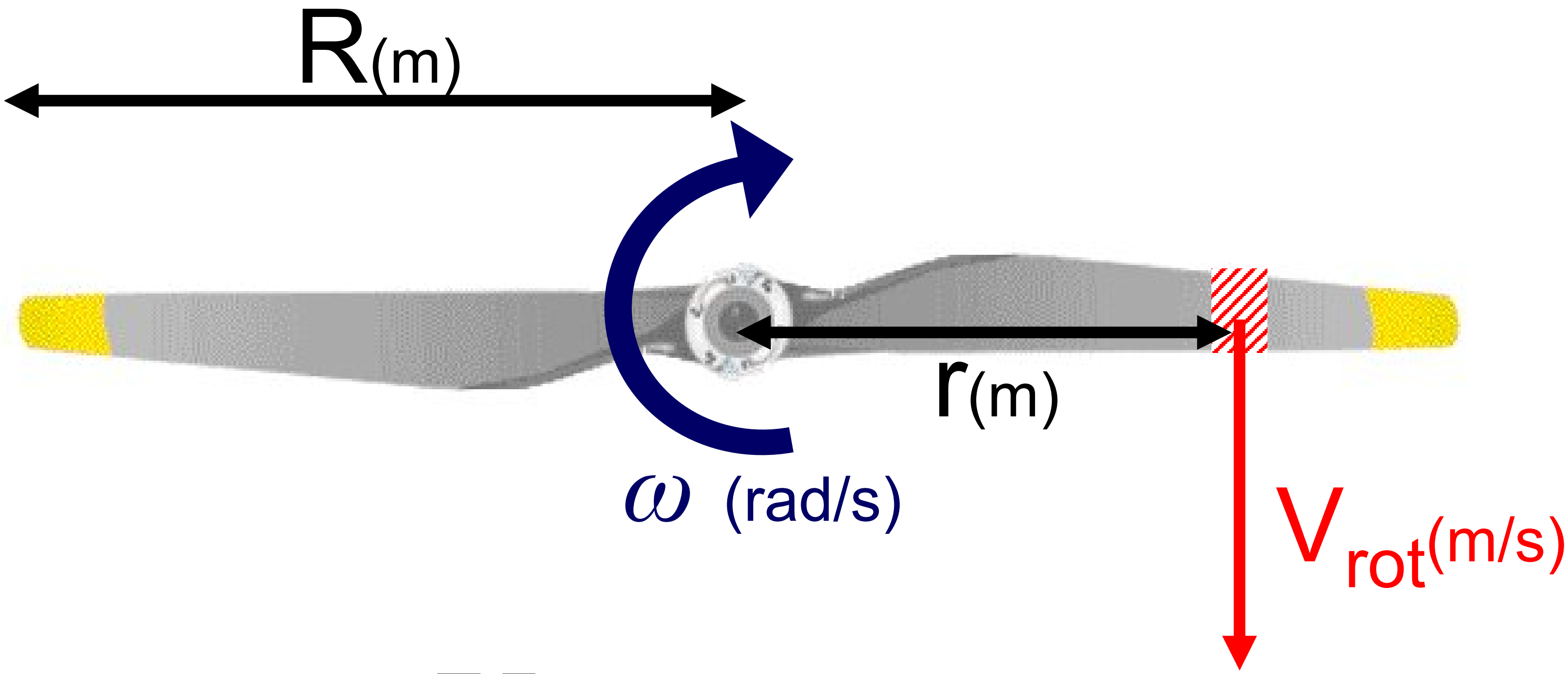


Counter Rotating | **Rotating**

Fixed Pitch | **Variable Pitch** | **Ducted Fan**

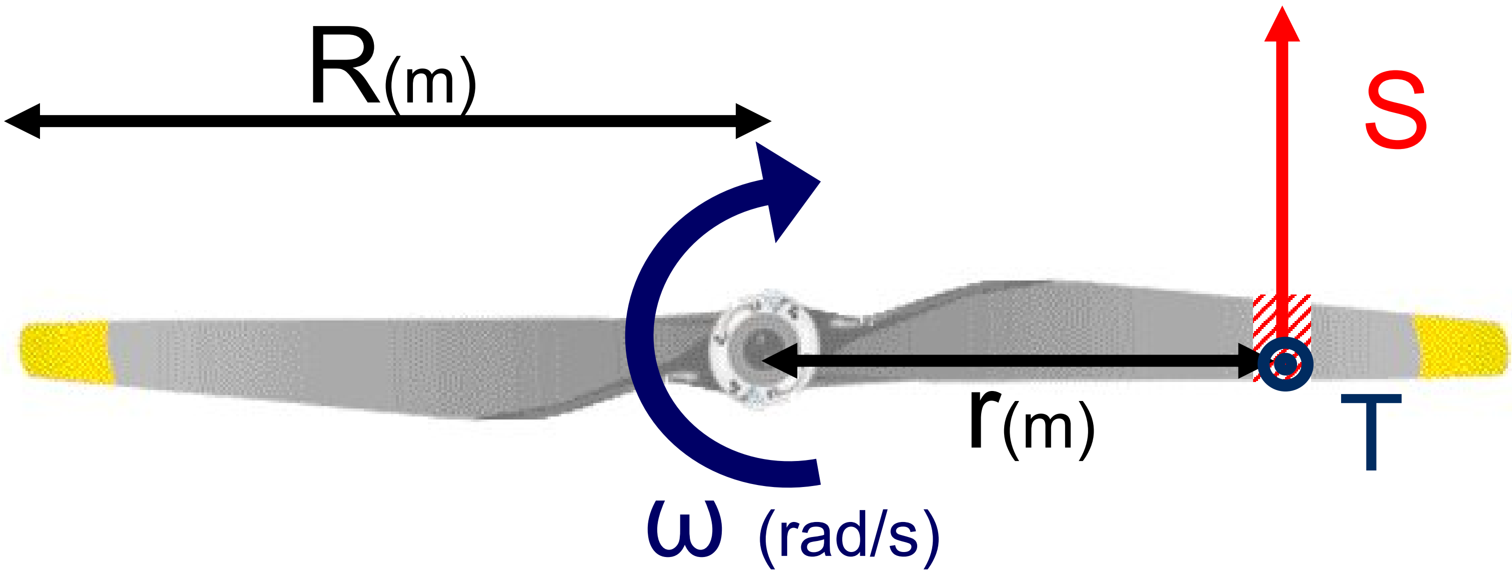


Propeller Theory



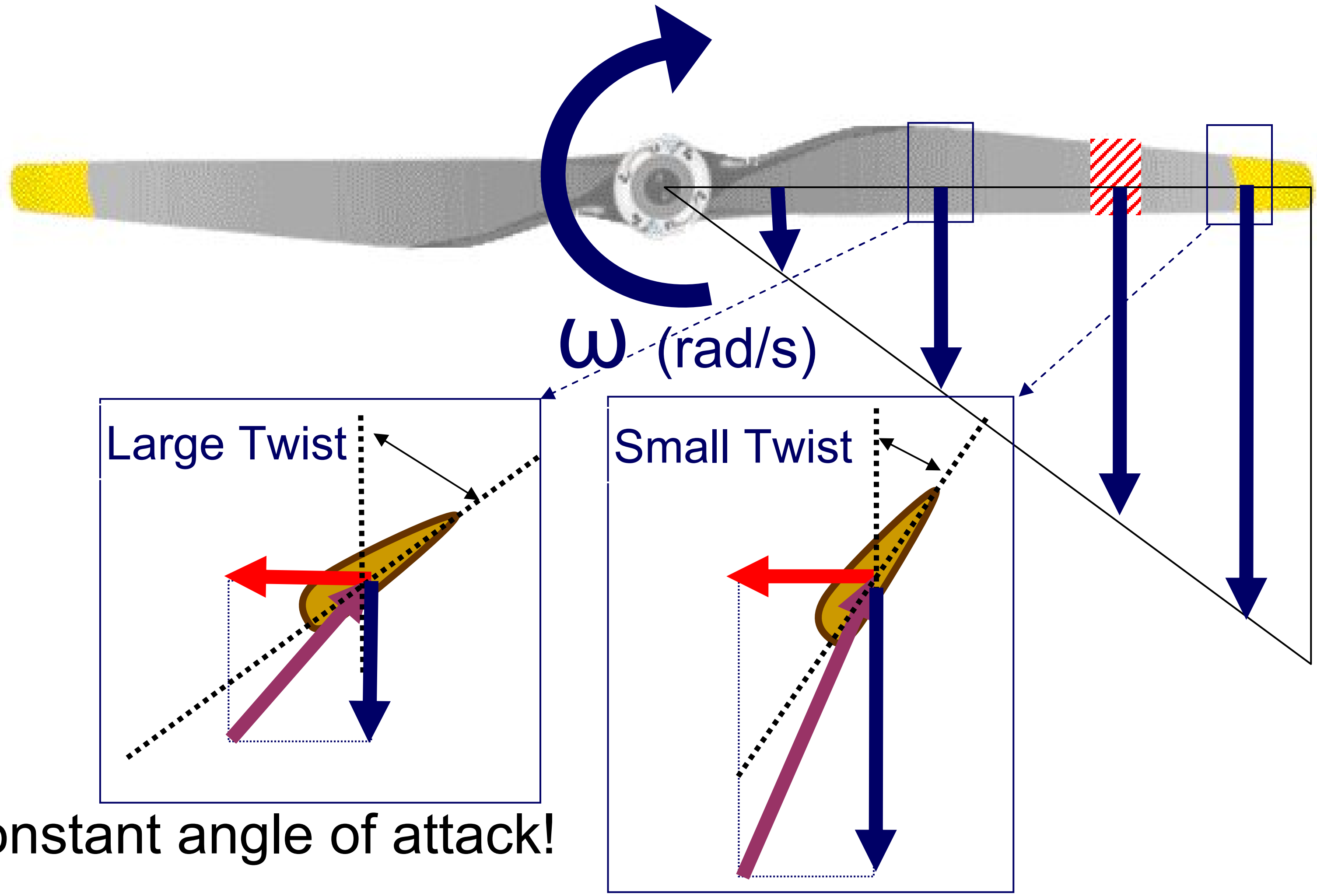
$$V_{rot} = \omega \cdot r$$

Propeller Theory: Blade is like a wing



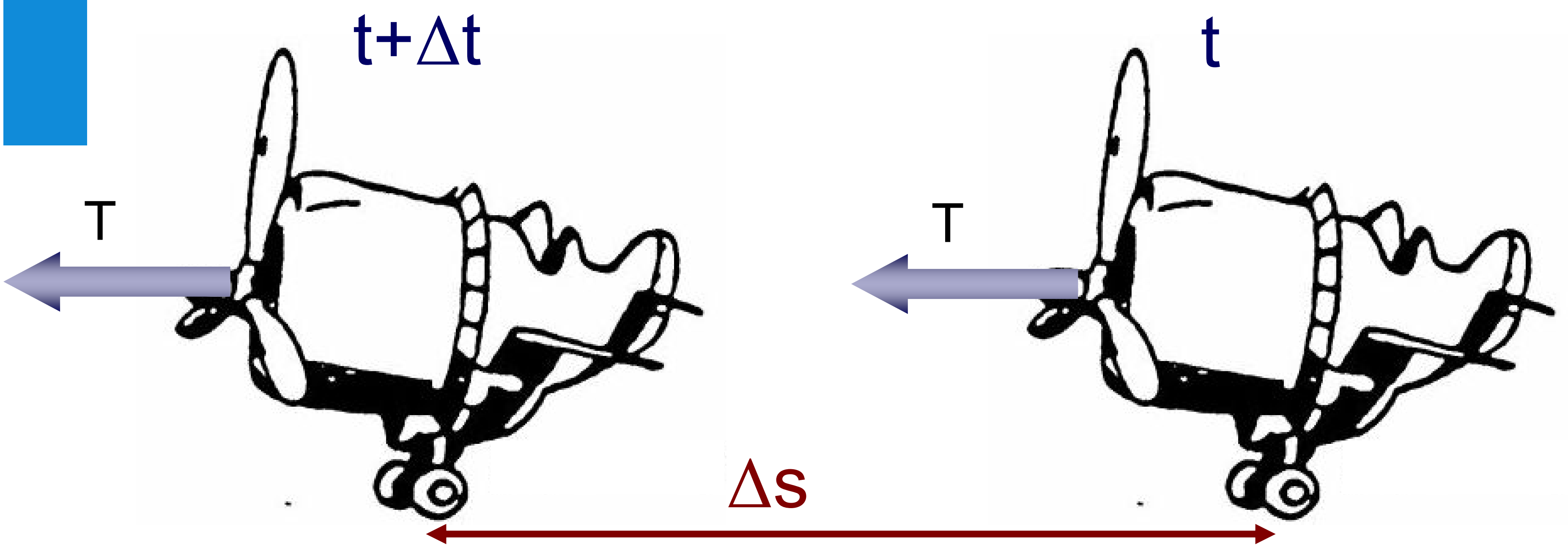
Useful force:	T	Thrust (pointing at us)
Loss:	S	Side force (like drag for wing)

Twisted for constant angle of attack



Constant angle of attack!

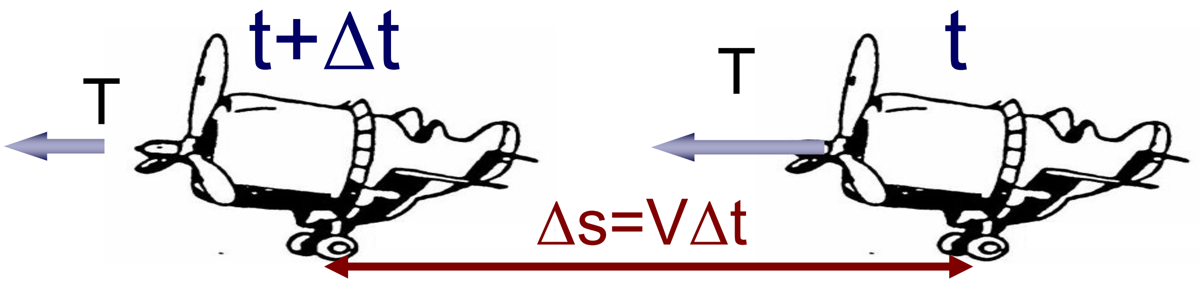
Available Power for thrust



Work Performed: $W = T \cdot \Delta s$ [Nm or J]

Available Power: $P_a = \dfrac{T \cdot \Delta s}{\Delta t} = T \cdot V$ [Nm/s, J/s or W]

Available Power



Speed is V

Net available Power for thrust: $P_a = T\,V$

Brake (shaft) Power: P_{br}

Propulsive Efficiency: $\eta = \dfrac{P_a}{P_{br}} = \dfrac{T\,V}{P_{br}}$

Airbreathing Engines

They all work the same way..........in principle
Only the details differ.

They all have 4 stages:

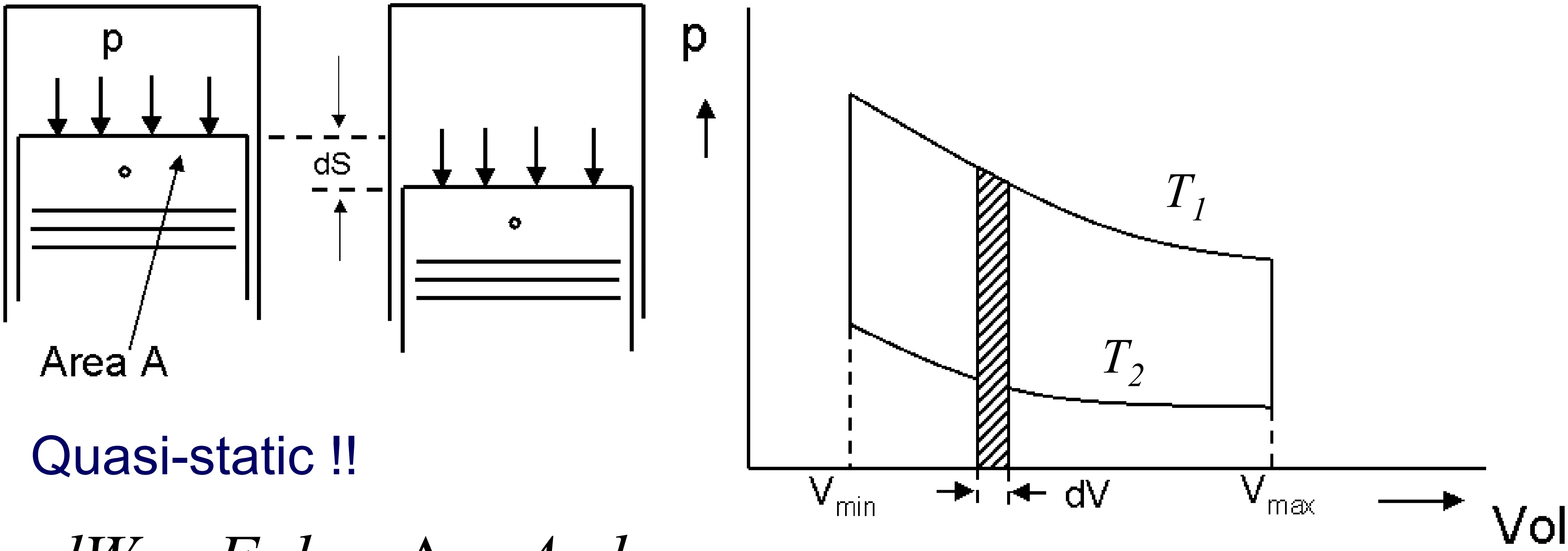
1. Intake
2. Compression
3. Work
4. Exhaust

Piston Engines

What is used in Aviation ?

• 2 Stroke Engine	Obsolete
• 4 Stroke Engine	Common
• Wankel Engine	‘New’
• Diesel Engine	Expected

Combustion Cycle (Otto Cycle)

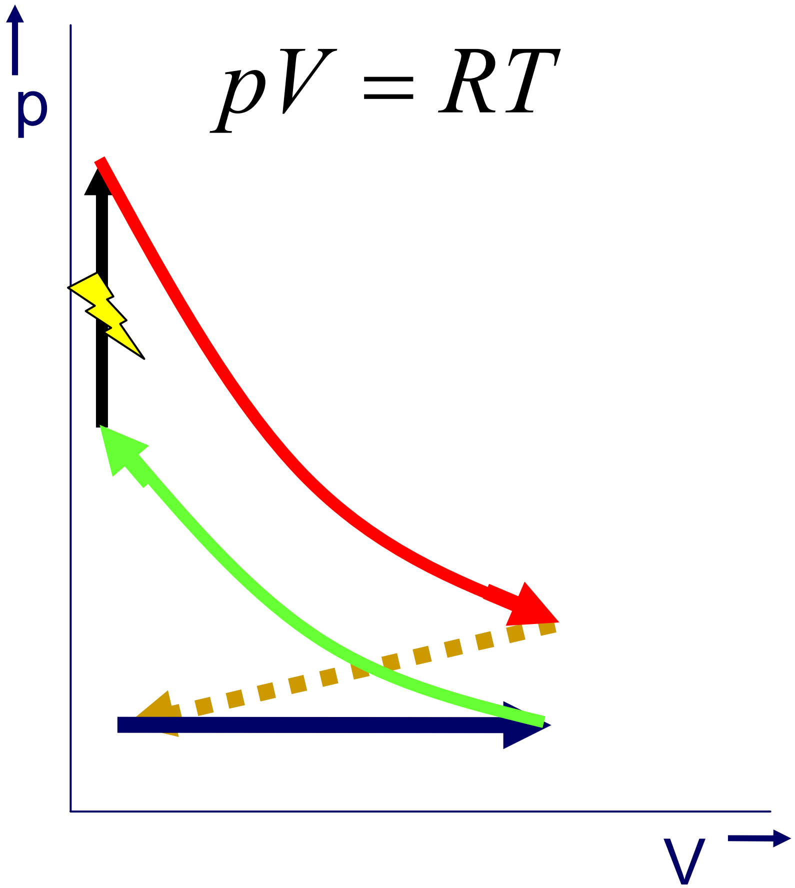


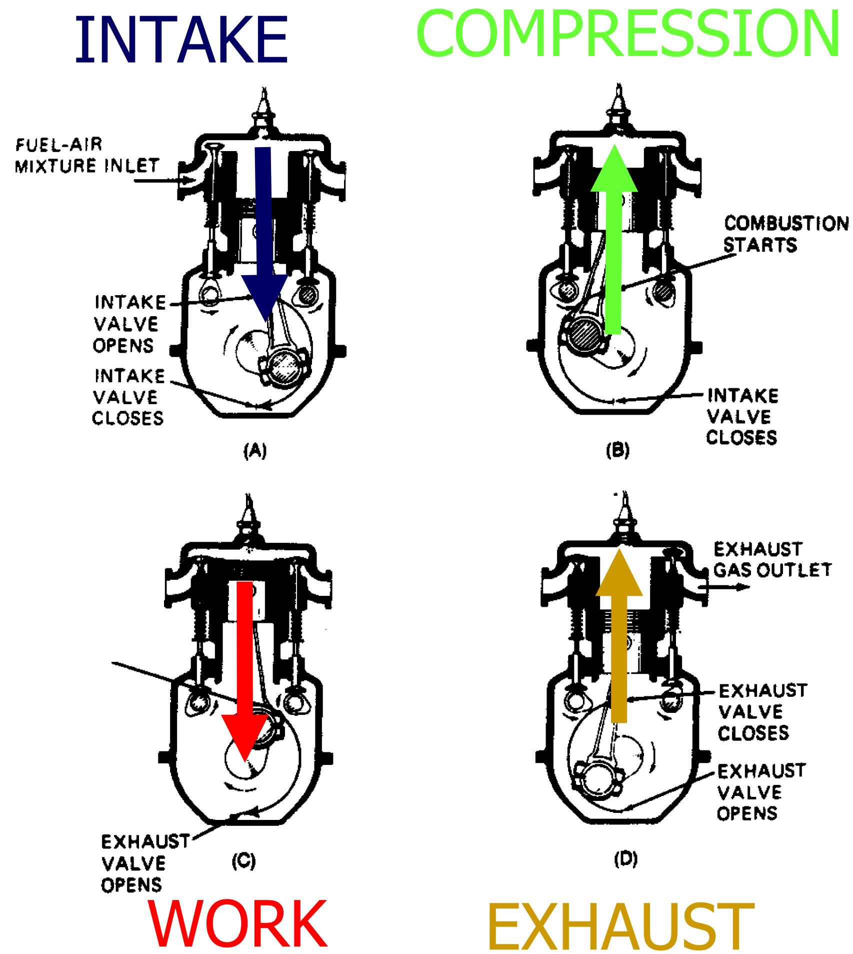
Quasi-static !!

$$dW = F.ds = \Delta p \cdot A \cdot ds$$

$$dW = (p_{upper} - p_{lower})dV \Rightarrow W = \int_{V_{\min}}^{V_{\max}} (p_{upper} - p_{lower})dV$$

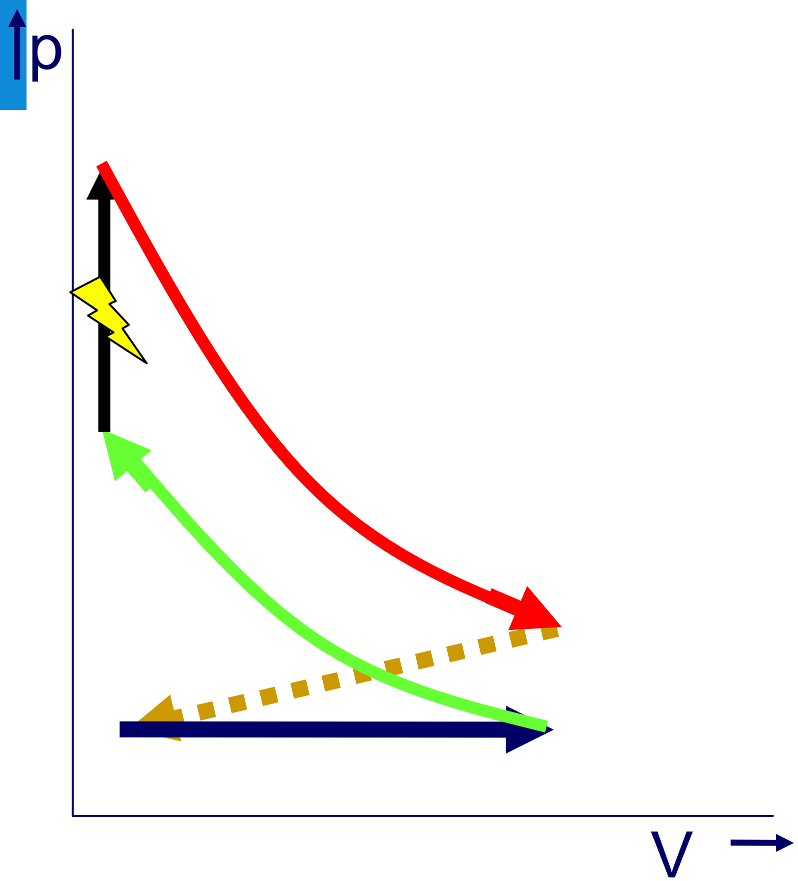
Working Cycle (4 stroke engine)

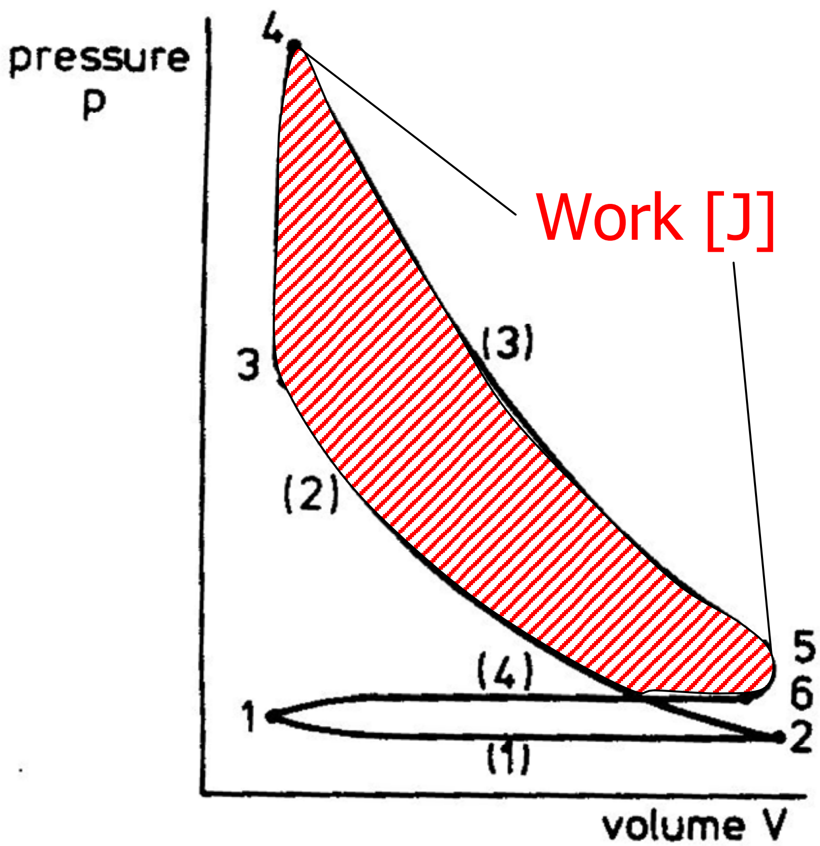




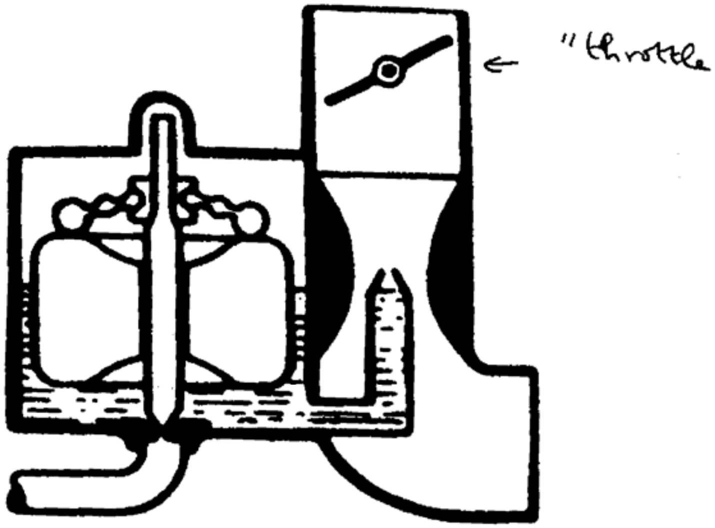
Working Cycle (4 stroke engine)

INTAKE COMPRESSION WORK EXHAUST

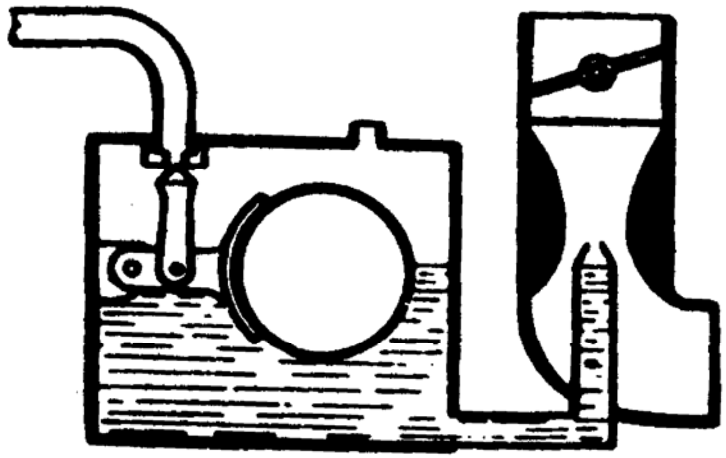




Throttle control

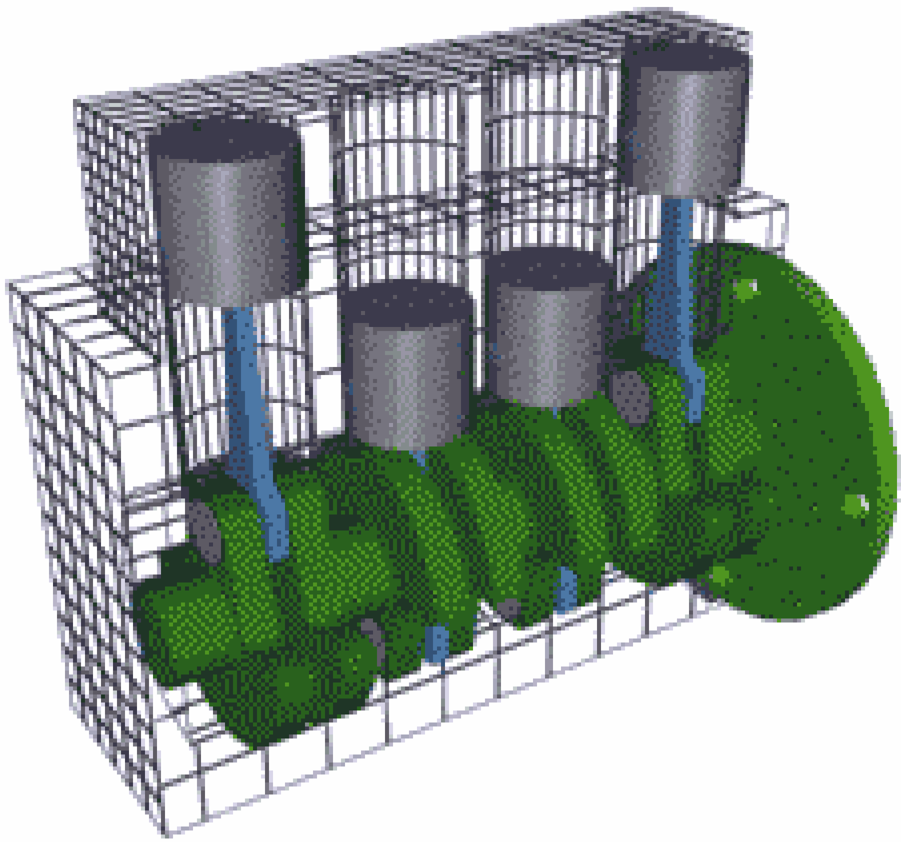


CONCENTRIC FLOAT AND VALVE

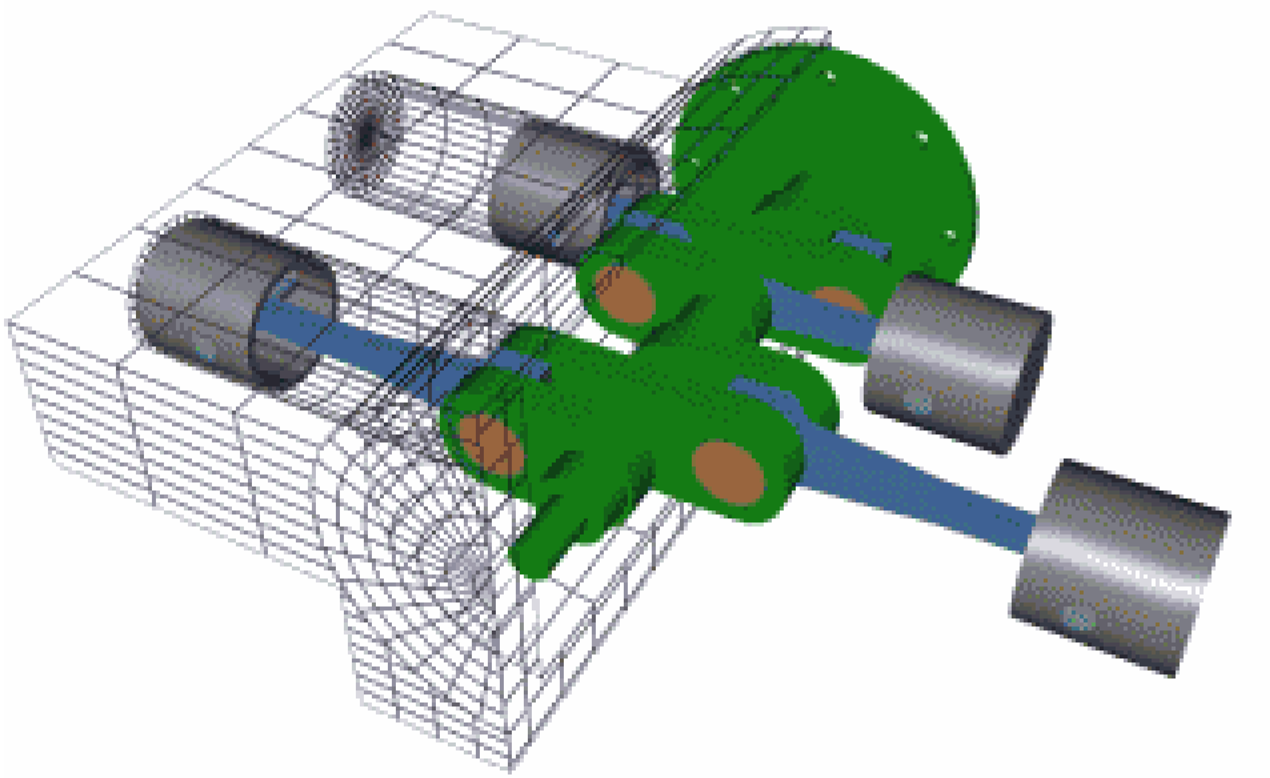


ECCENTRIC FLOAT AND VALVE

Piston Engines: In-Line

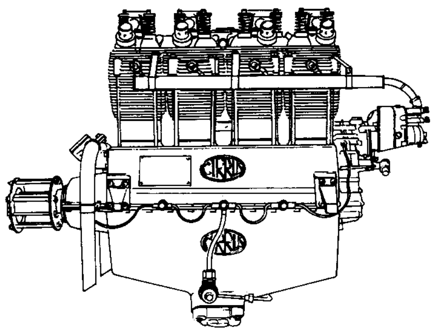


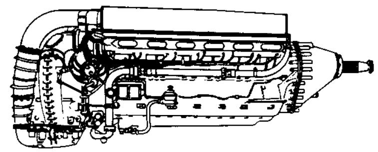
Piston Engines: Boxer



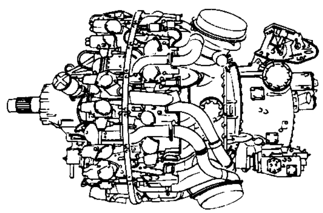
Piston Engines

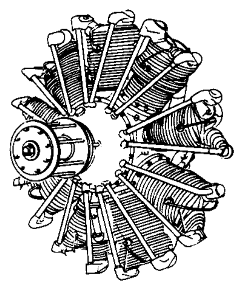
In-Line

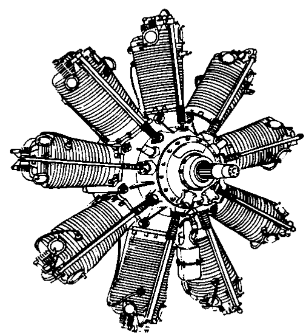




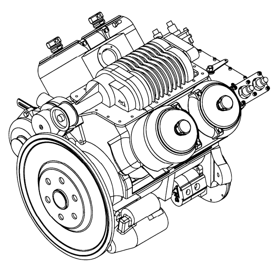
Radial



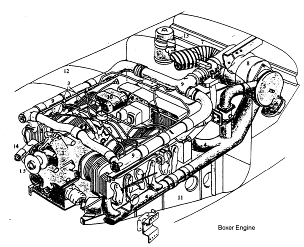




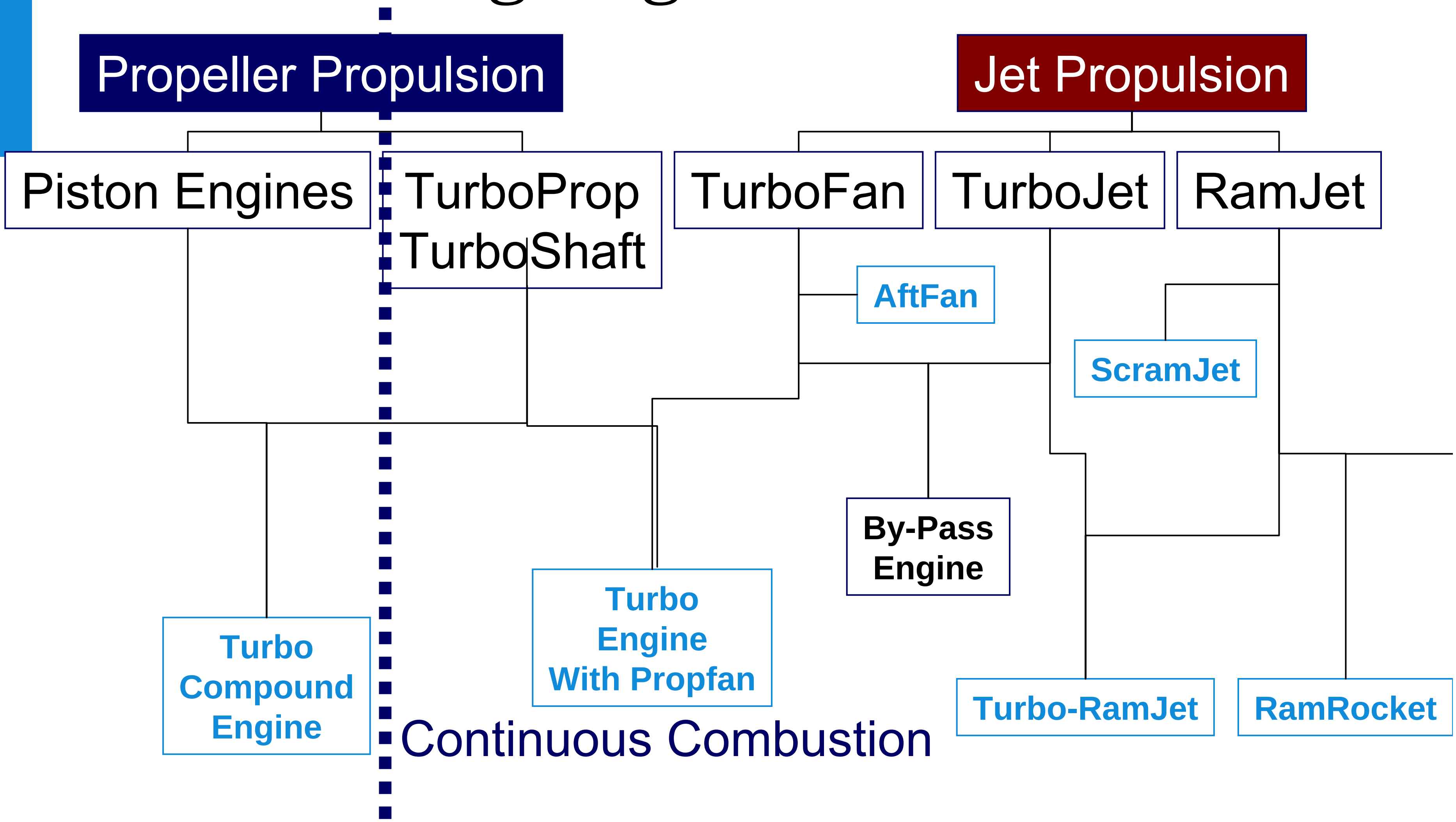
V



Boxer

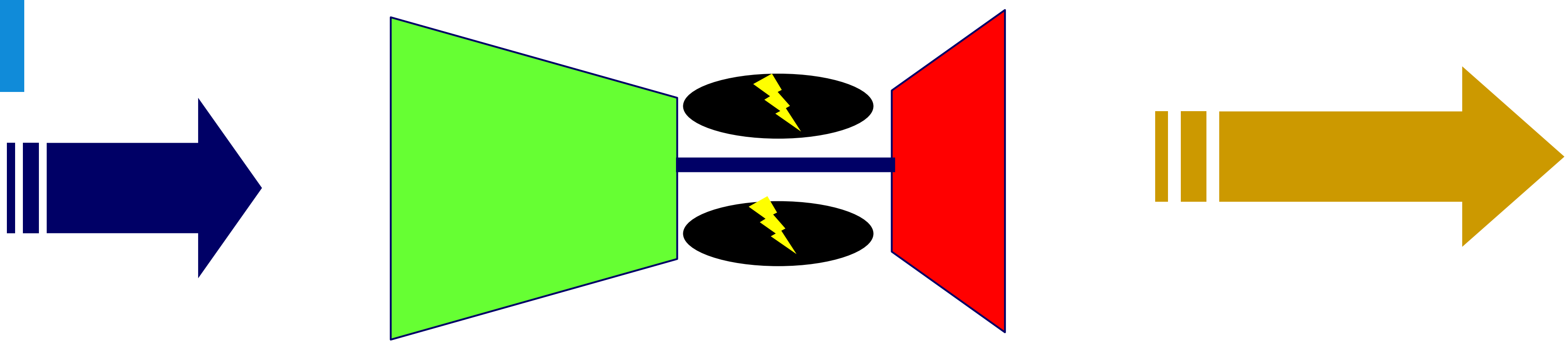


Airbreathing Engines



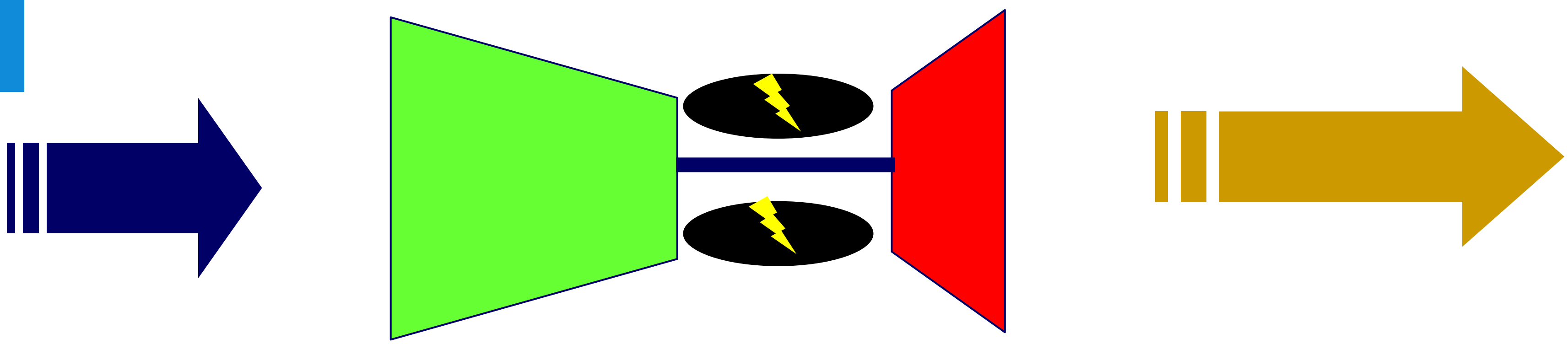
Continuous Combustion

INTAKE COMPRESSION WORK EXHAUST

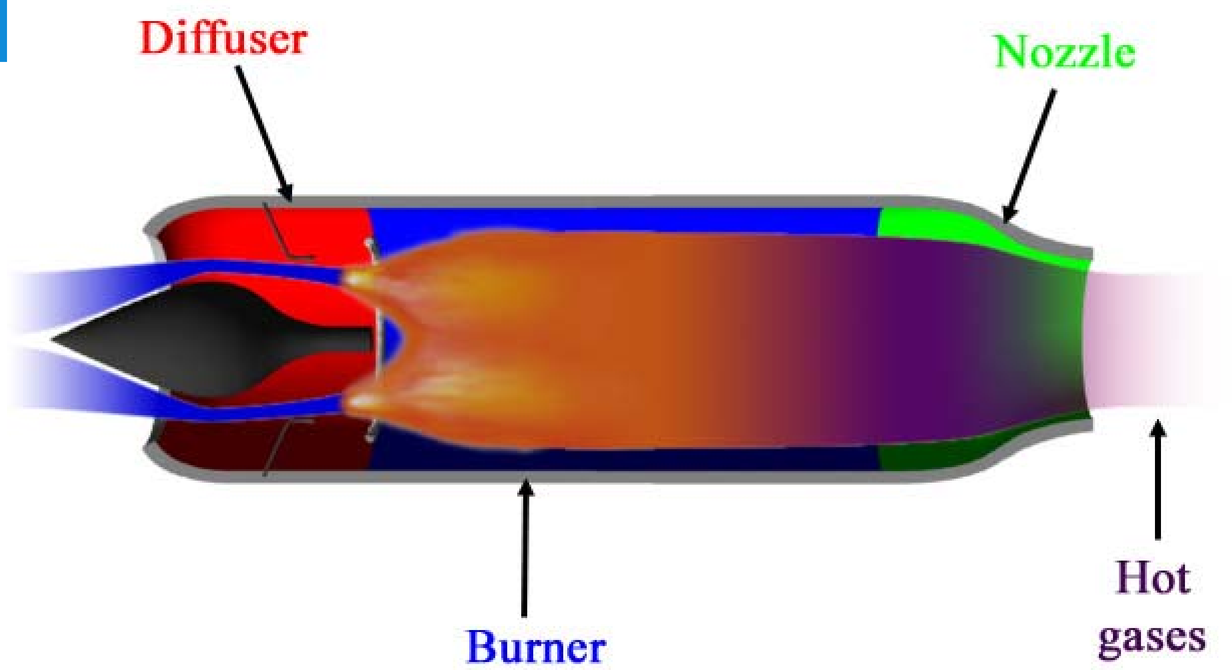


Continuous Combustion

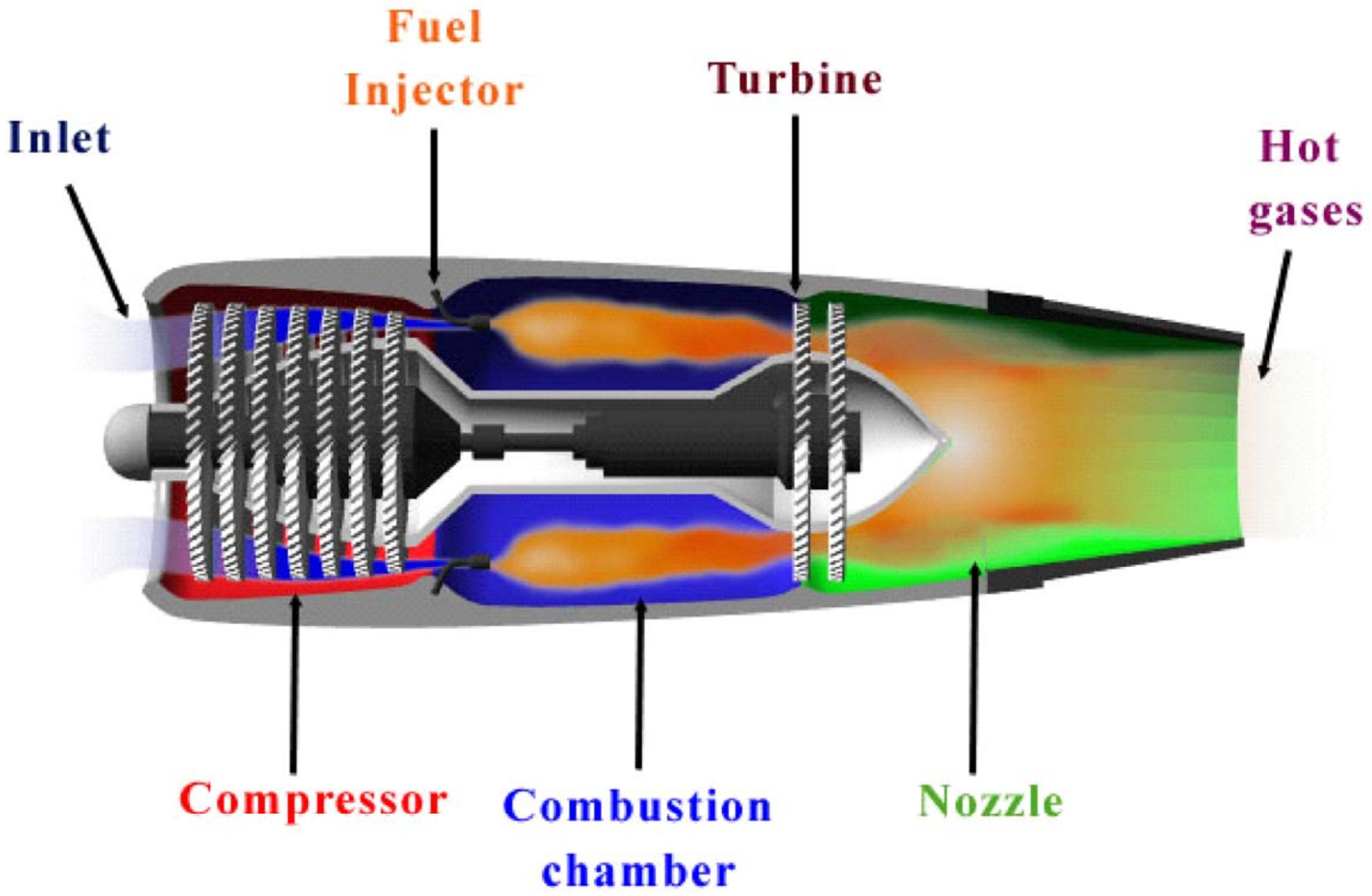
INTAKE COMPRESSION WORK EXHAUST



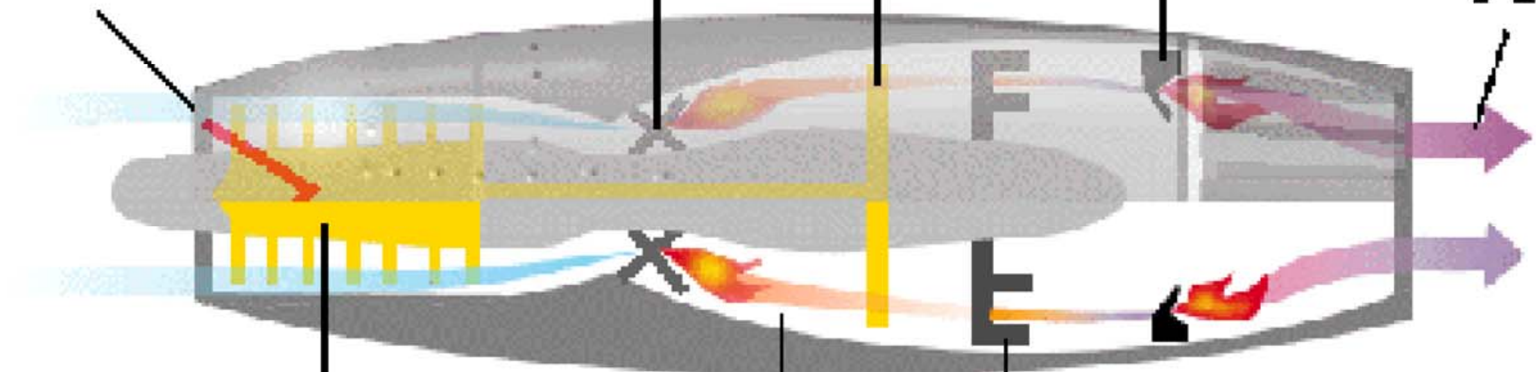
Ramjet



Pure Jet Engine

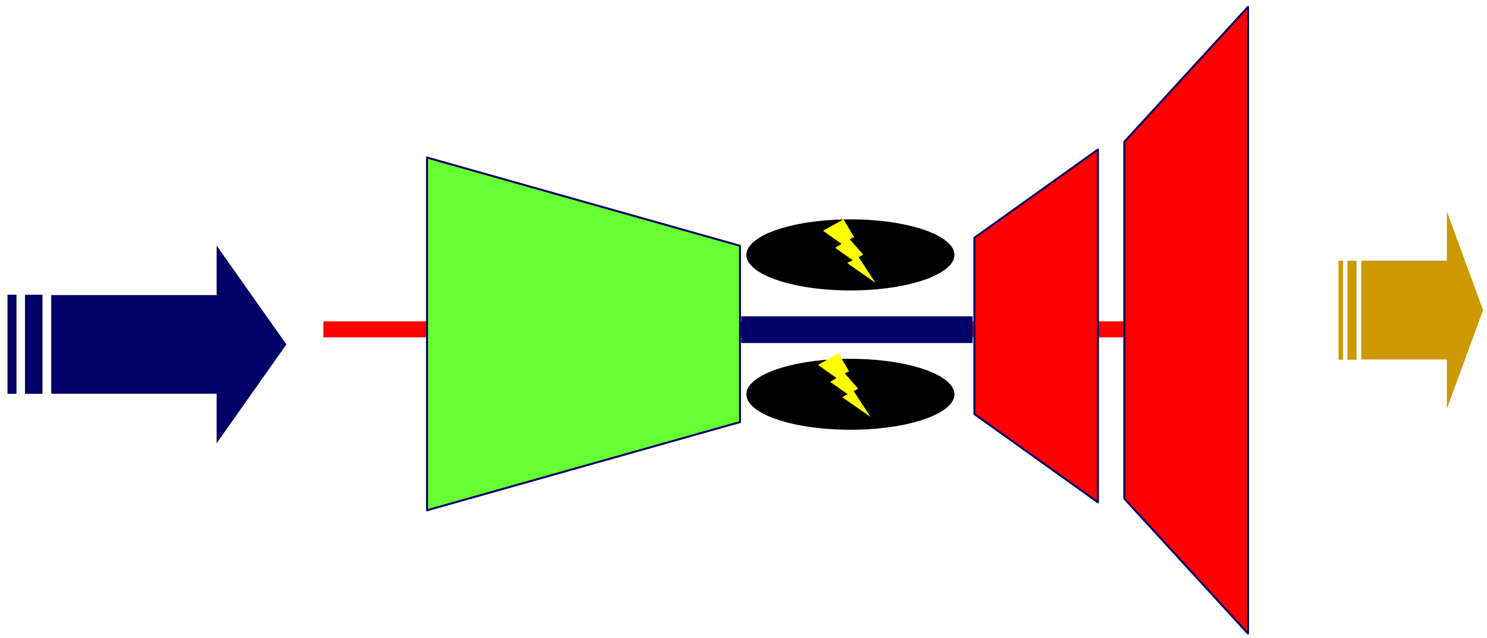


Jet Engine With Afterburner

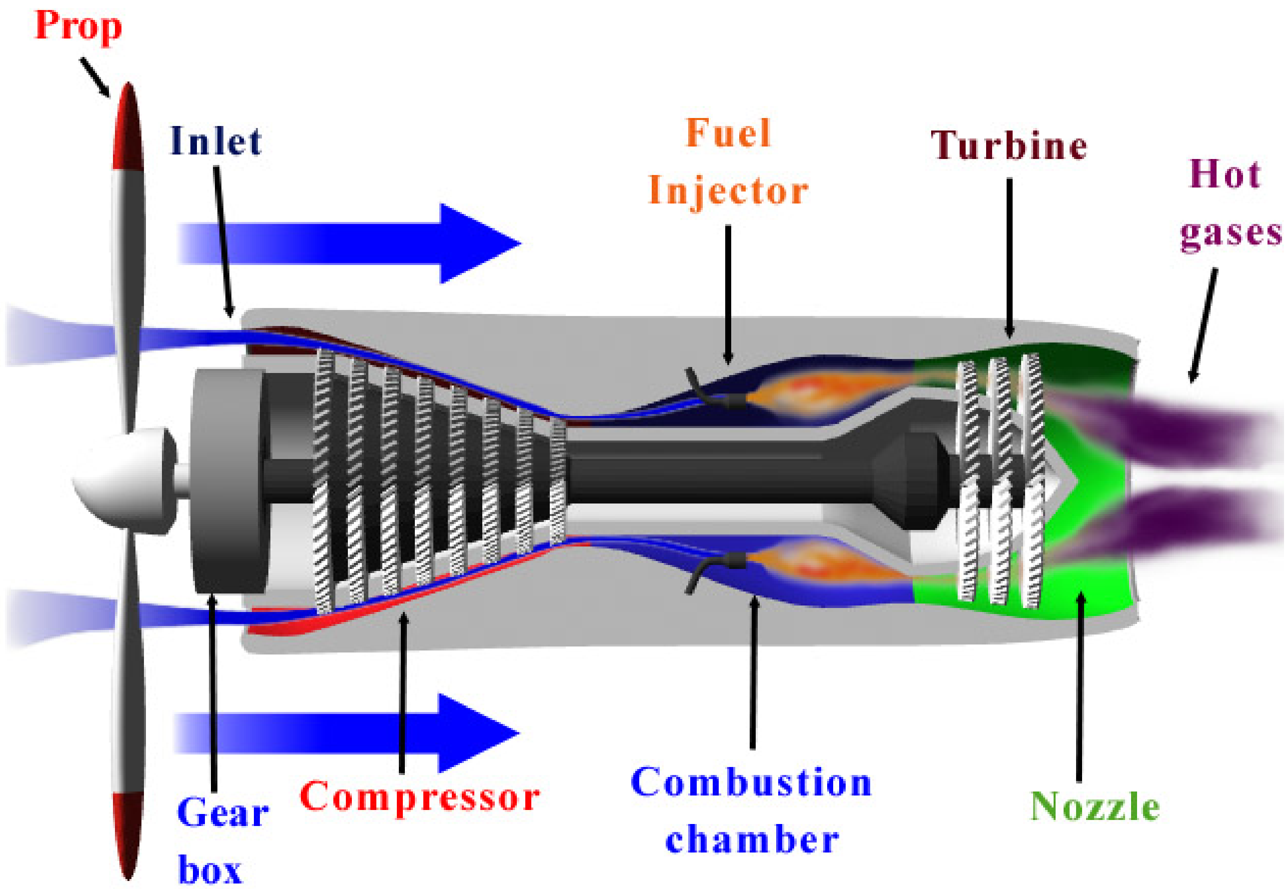


Trading Exhaust Power for Shaft Power

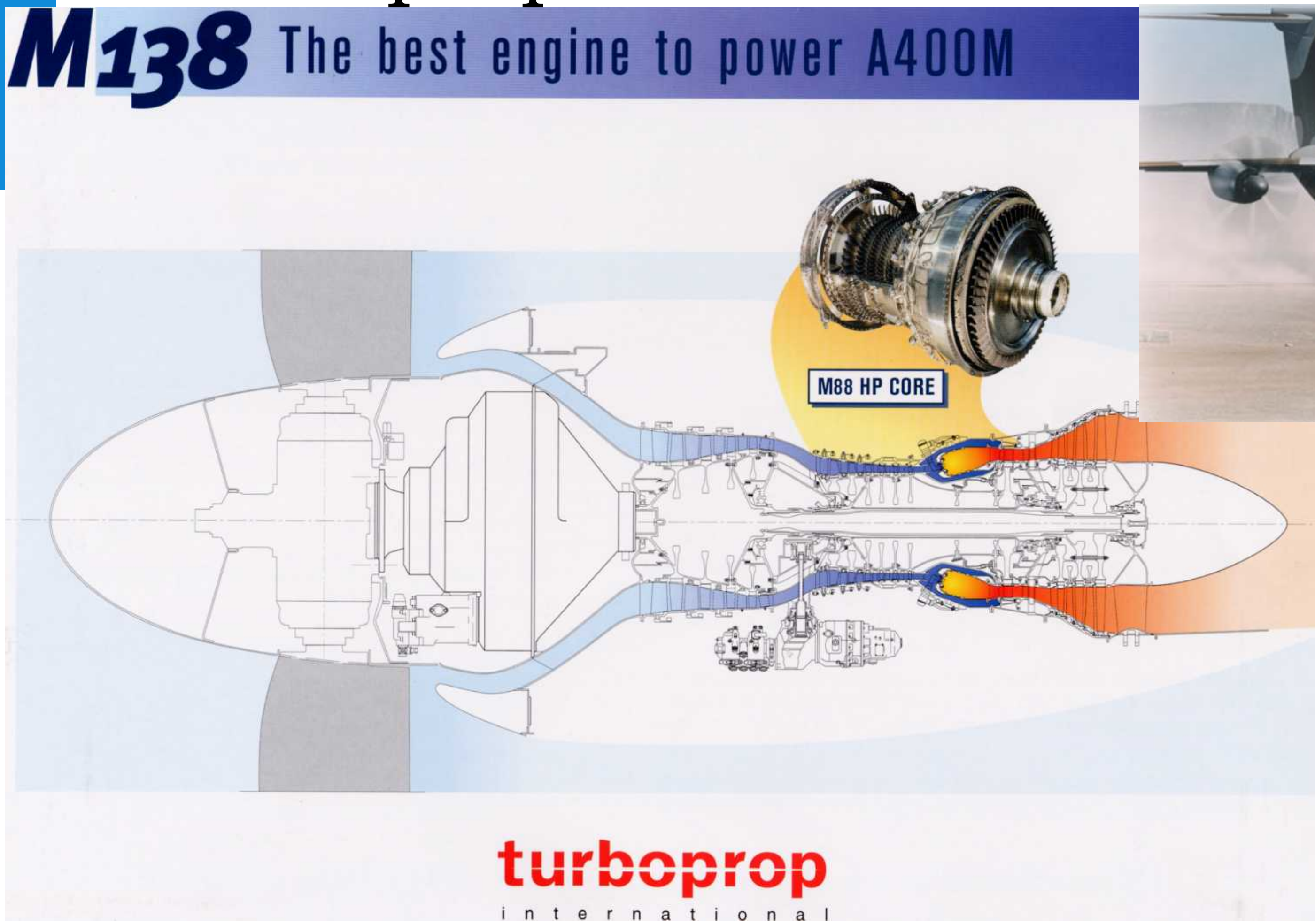
INTAKE COMPRESSION WORK EXHAUST



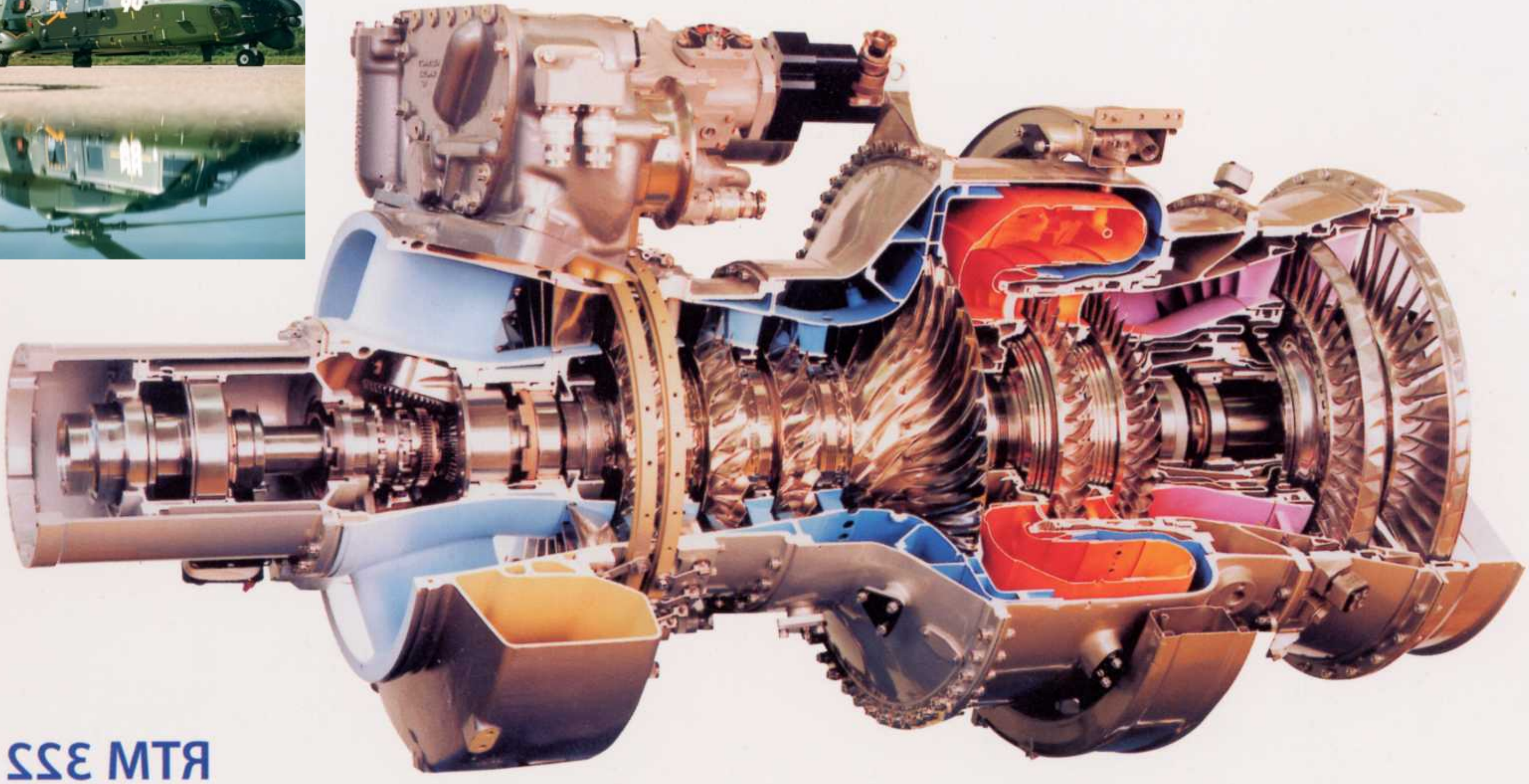
TurboProp/TurboShaft



Turboprop

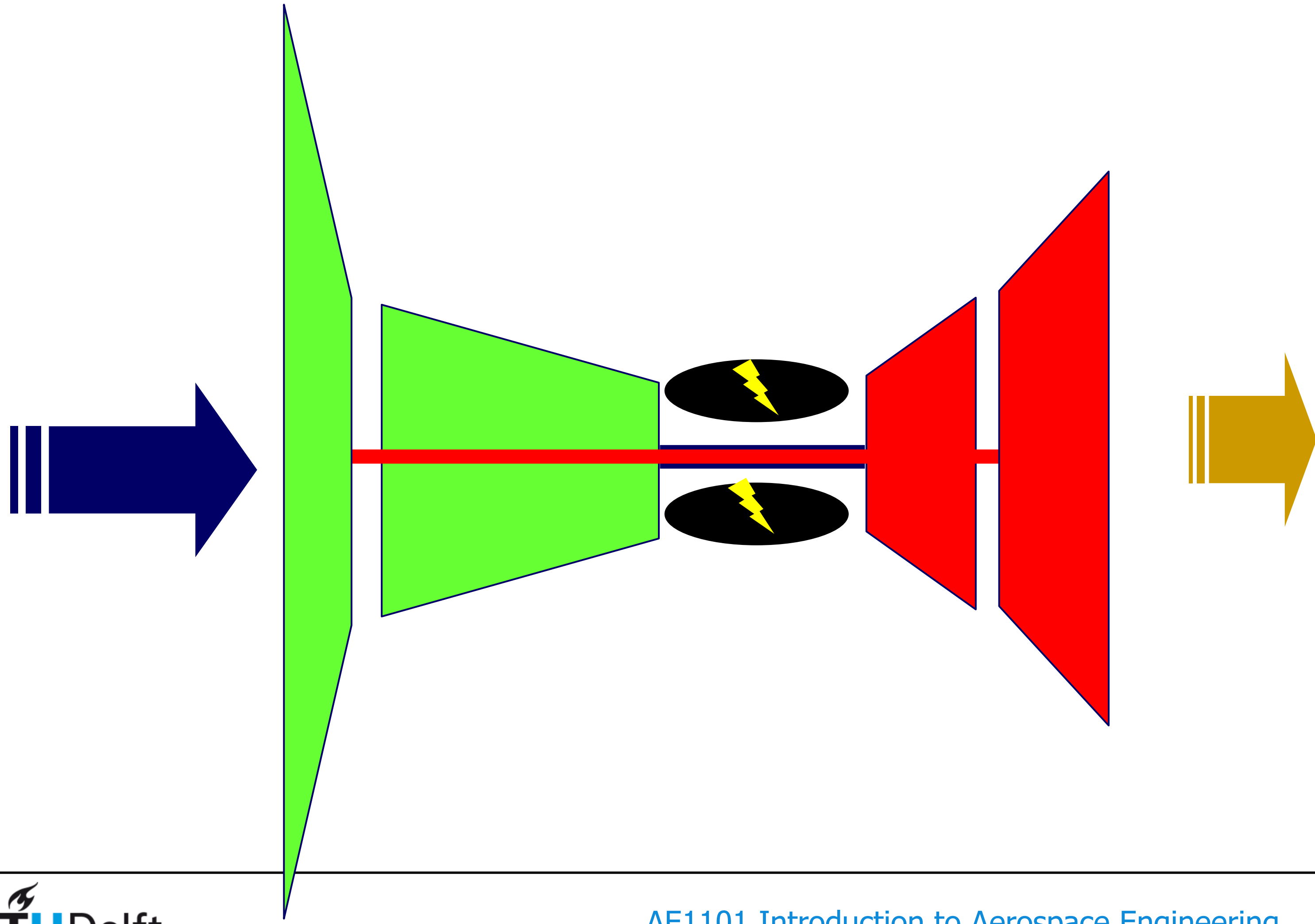

M138 The best engine to power A400M
M88 HP CORE
turboprop
international

Turboshaft

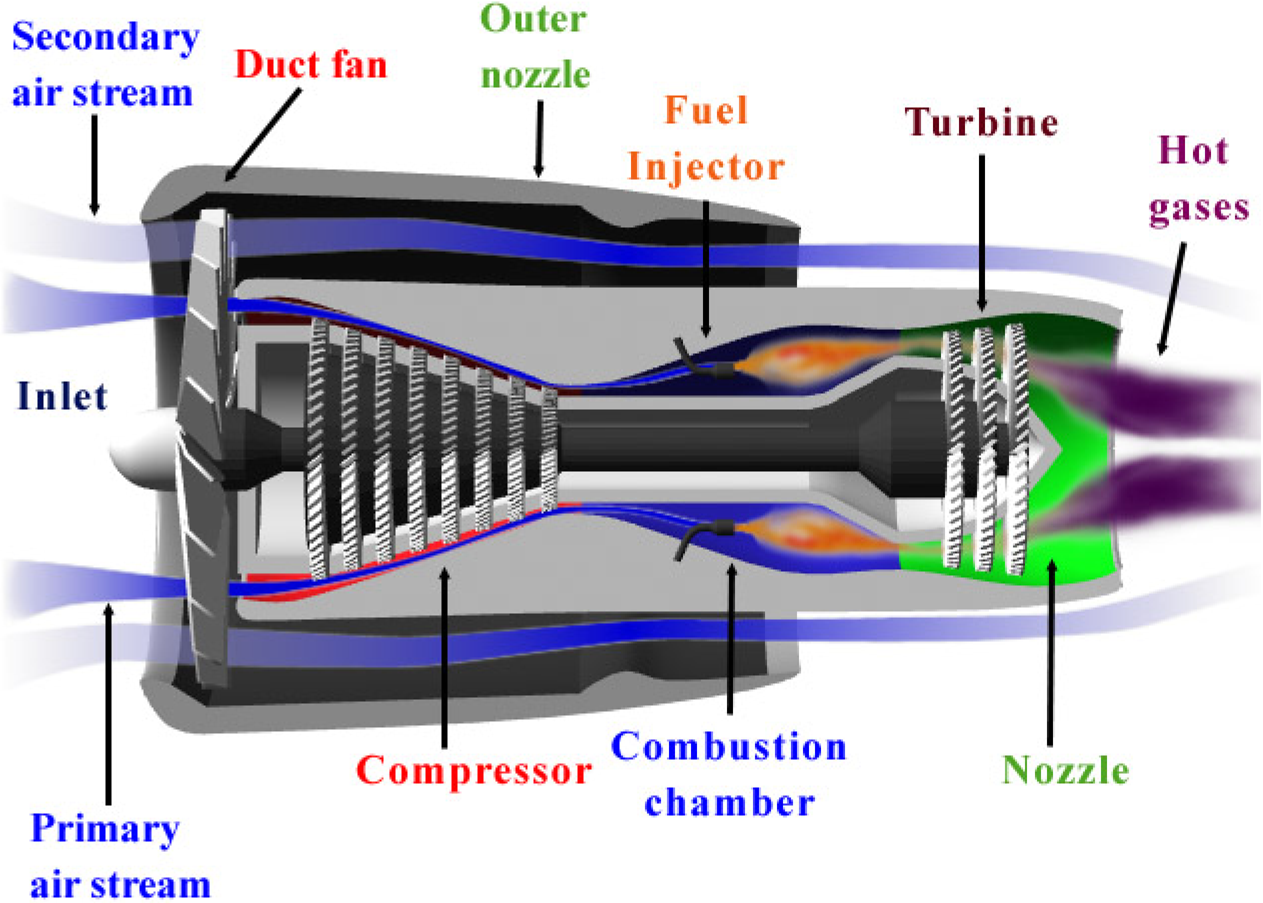


Trading Exhaust Power for Shaft Power

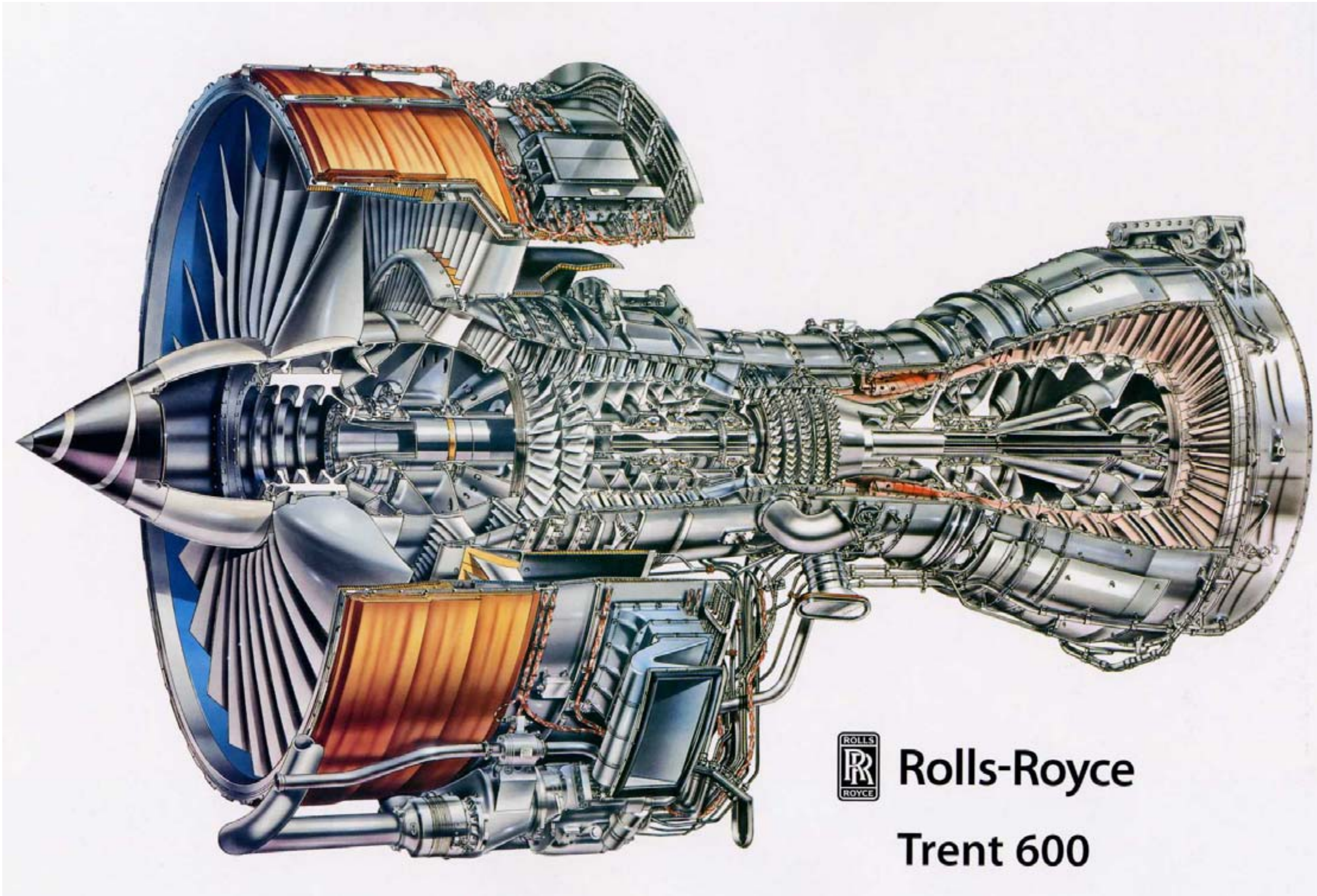
INTAKE COMPRESSION WORK EXHAUST



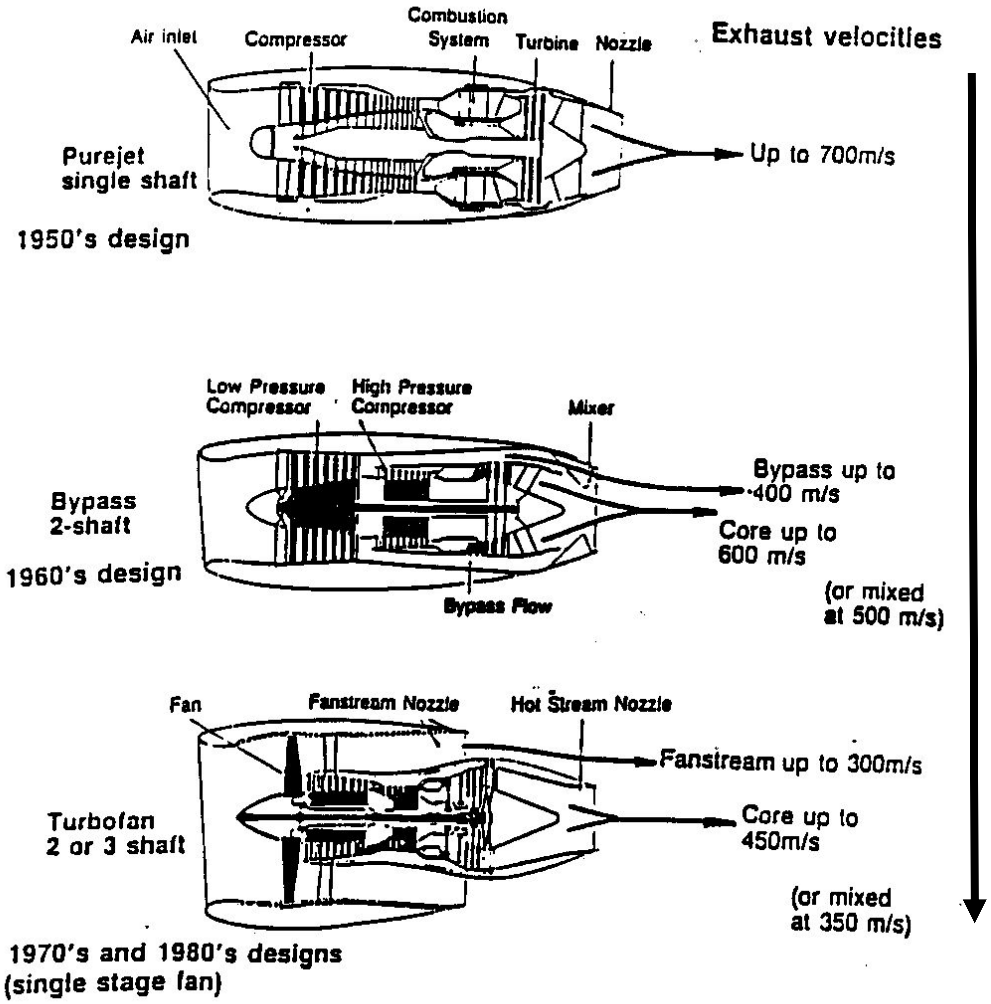
TurboFan


Secondary
air stream
Duct fan
Outer
nozzle
Fuel
Injector
Turbine
Hot
gases
Inlet
Compressor
Combustion
chamber
Nozzle
Primary
air stream

This is quite a large duct fan (high bypass flow) Why?



Engine development 1950-1980



Higher Bypass-ratio

$$\frac{\text{Bypass airflow (Cold)}}{\text{Core airflow (Hot)}}$$

$$B = \frac{\dot{m}_c}{\dot{m}_h}$$

↓

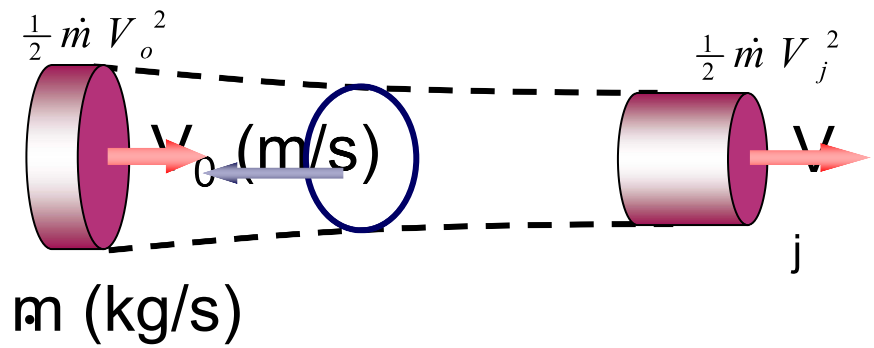
More air, less velocity

↓

Higher propulsive efficiency

Can you explain why?

Jet efficiency



What is efficiency of jet?

$$P_j = \tfrac{1}{2}\dot{m}\left(V_j^2 - V_0^2\right) \qquad T = \dot{m}(V_j - V_0) \qquad P_a = T\,V_0$$

Jet efficiency

$$\eta_j = \frac{P_a}{P_j} = \frac{TV_0}{\tfrac{1}{2}\dot{m}\left(V_j^2 - V_0^2\right)} = \frac{\dot{m}\left(V_j - V_0\right)V_0}{\tfrac{1}{2}\dot{m}\left(V_j + V_0\right)\left(V_j - V_0\right)}$$

$$\eta_j = \frac{2}{1 + V_j / V_0}$$

What is effect on engines of previous slide?

Example of this effect

$$\eta_j = \frac{2}{1 + V_j / V_0}$$

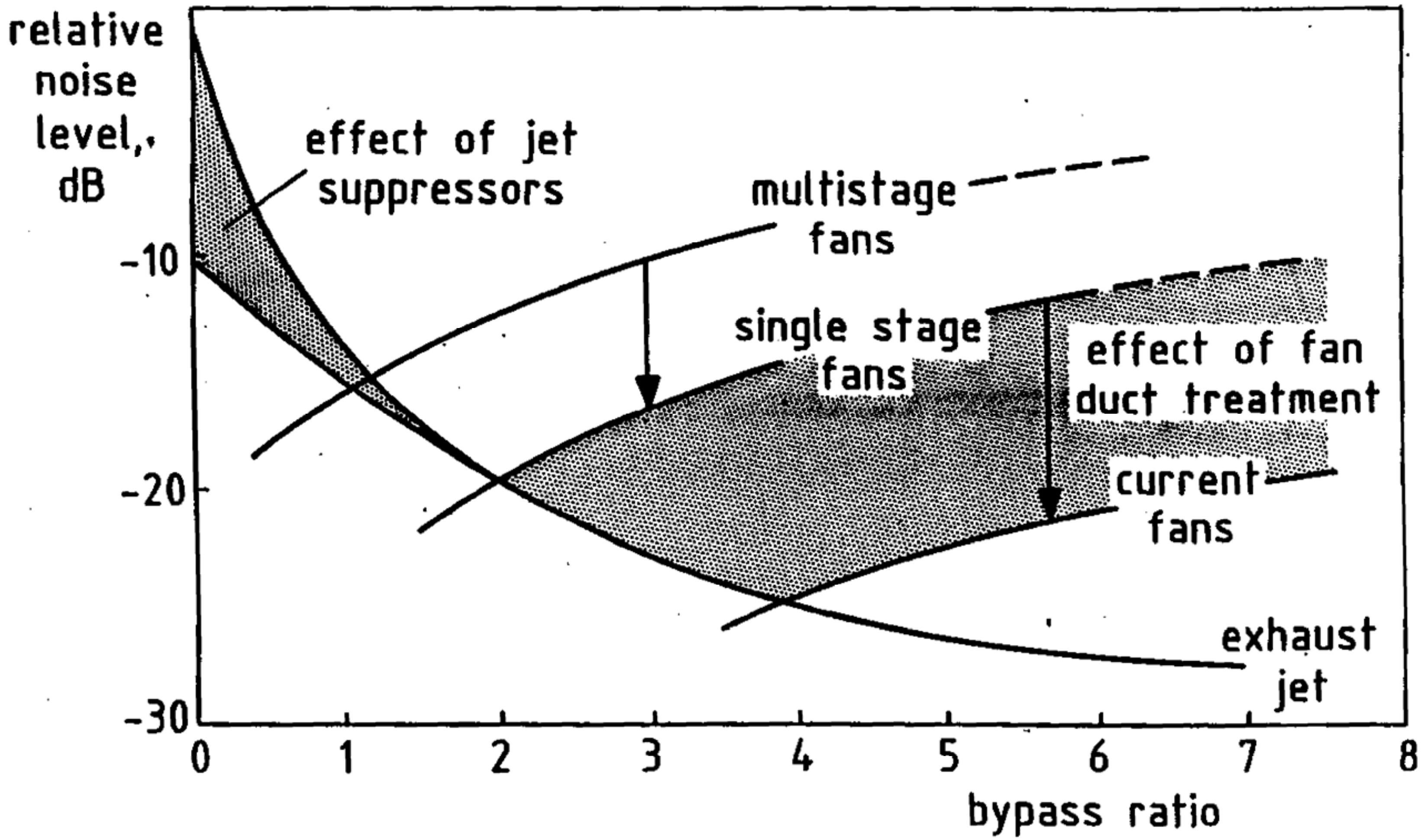
Effect of bypass ratio:

V0	250	kts	128.61	m/s
	Vjet		**Jet efficiency**	
No bypass	700	m/s	?	
Bypass 2-shaft	500	m/s	?	
Turbofan 2/3 shaft	350	m/s	?	

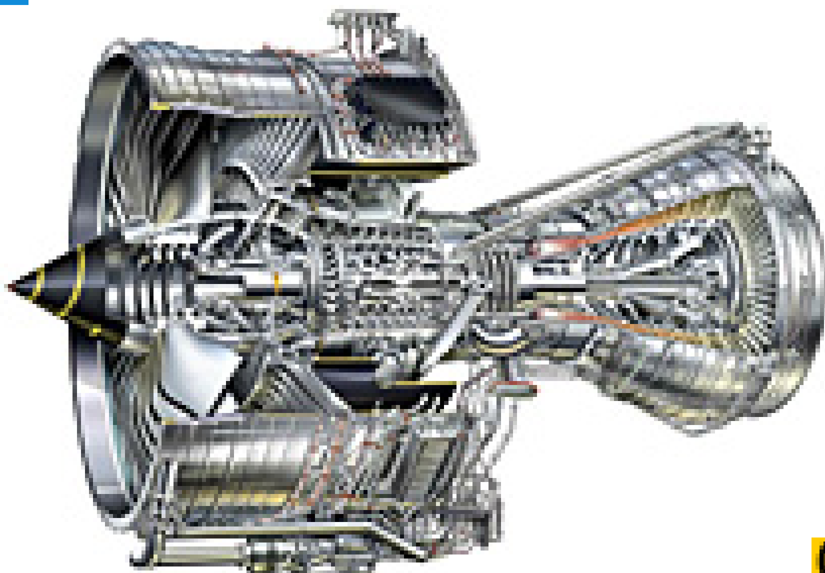
	Vjet		**n jet**
No bypass	700	m/s	0.310423
Bypass 2-shaft	500	m/s	0.409189
Turbofan 2/3 shaft	350	m/s	0.537431

In words: by lowering exhaust speed, the efficiency goes from 31% to 54% (amount of energy used for propulsion)

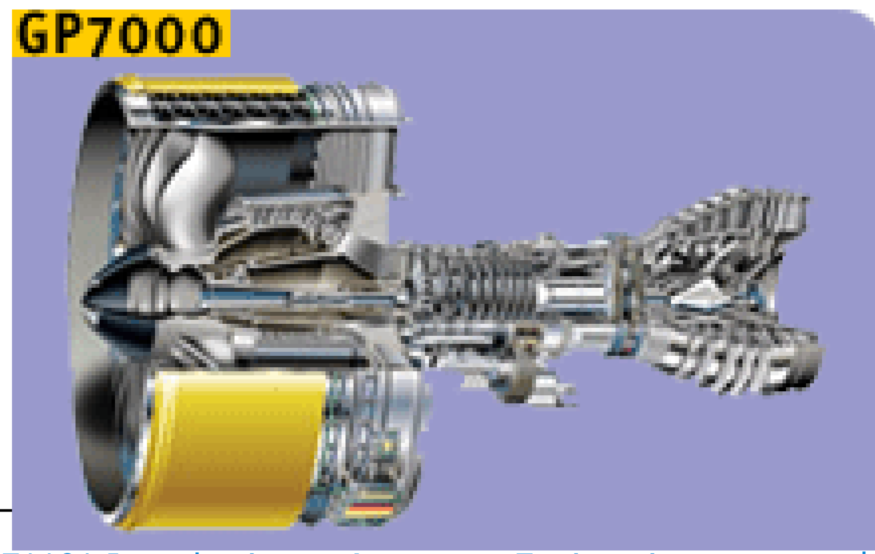
And also less noise due to lower V_j



Engine Development



Very big



Engine Applications

- Single engine training aircraft:
  - Piston engine
- Low subsonic passenger aircraft:
  - Turboprop
- Concorde (Supersonic):
  - Pure (straight) jet
- Helicopter:
  - Turboshaft or piston

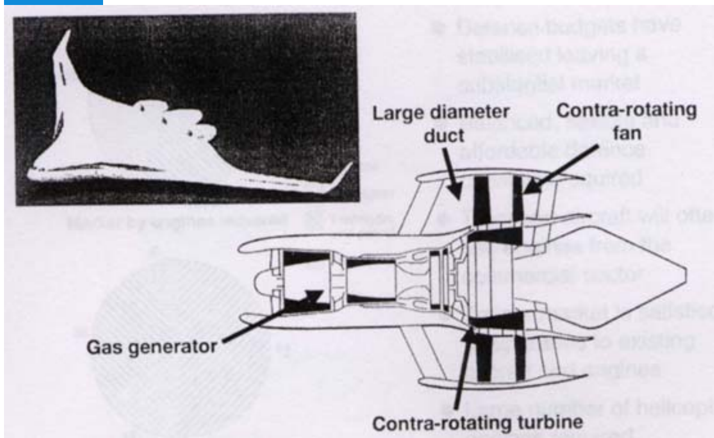
Two or Four Engines? ETOPS

- Extended Twin OPerationS
  - Engines Turning Or Passengers Swimming

- Twin engined airliners restricted to a maximum diversion time (120 to 207 minutes) dependant on strict maintenance and aircraft type.

- Crossing some parts of the atlantic and pacific ocean and both poles is (currently) restricted to four engined airliners.

Future air breathing Engines



n

Je

oProp
oShaft

TurboFan

Tu

AftFan

ScramJet

By-Pass Engine

Turbo Engine With Propfan

Turbo-RamJet

RamRocket

Engines

- Pratt & Whitney – PW127B
  - Turboprop
  - Aircraft: Fokker 50
  - Power: 2750 SHP (x2)
    2050 kW (x2)

Engines

- Rolls Royce - Tay 650
  - Low bypass Turbofan
  - Aircraft: Fokker 100
  - Thrust: 67 kN (x2)
  - Fan Diameter: 1.14 m
  - Length: 2.4 m
  - Bypass Ratio: 3.07

Engines

- General Electric – GE90-115B
  - High bypass turbofan
  - Aircraft: Boeing 777
  - Thrust: 512 kN (x2)
  - Fan Diameter: 2.95 m
  - Length: 4.55 m
  - Bypass Ratio: 9

Largest and highest thrust engine in the world!

Engines

- Rolls Royce – Trent 900
  - High bypass turbofan
  - Aircraft: Airbus 380
  - Thrust: 311 kN (x4)
  - Fan Diameter: 2.95 m
  - Length: 4.55 m
  - Bypass Ratio: 8.5

Engines

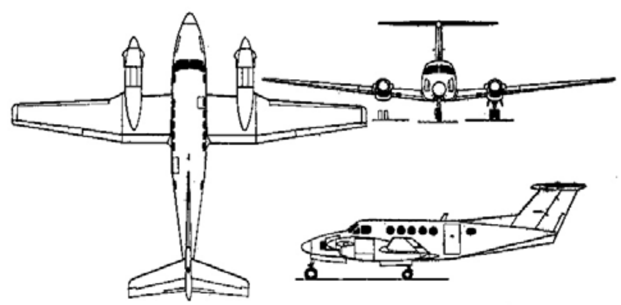
- Rolls Royce / Snecma Olympus 593
  - Pure Turbojet
  - Aircraft: Concorde
  - Thrust: 170 kN* (x4)

*Using afterburner (take-off and transonic)

Links

- www.howstuffworks.com
- www.rollsroyce.com
- www.ge.com

Beechcraft Super King Air 200



Pratt & Whitney PT6A-41

- Per engine: 850 Shaft horse power, P_{br}=634 kW
- Maximum speed at sea level: