RZESZOW UNIVERSITY OF TECHNOLOGY

THE FACULTY OF MECHANICAL ENGINEERING AND AERONAUTICS
RZESZOW UNIVERSITY OF TECHNOLOGY

AERO ENGINES

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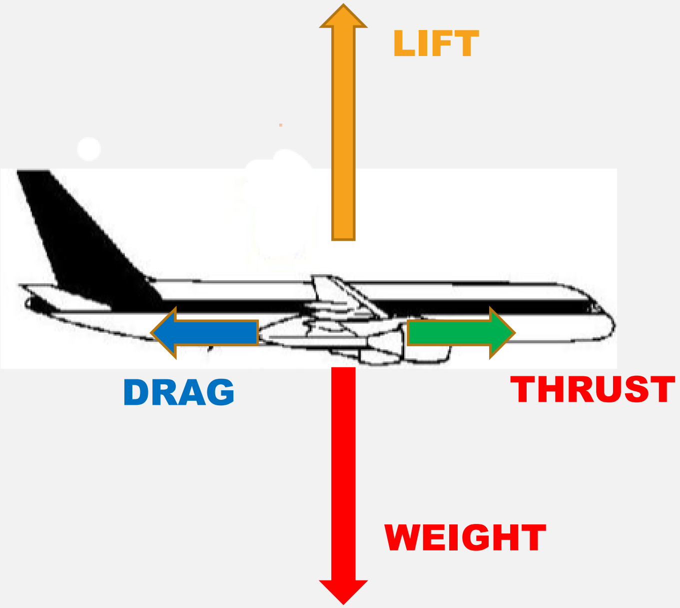
WHY AIRCRAFT FLY?

IS AN ENGINE NEEEDED TO MAKE AN OBJECT HEAVIER THAN AIR FLY ?

FORCES ACTING ON AN AIRCRAFT IN STEADY FLIGHT



Forces

- Thrust – generated by the engine
- Lift – generated by the wing
- Drag – caused by aircraft aerodynamic resistance
- Weight – caused by aircraft gravity

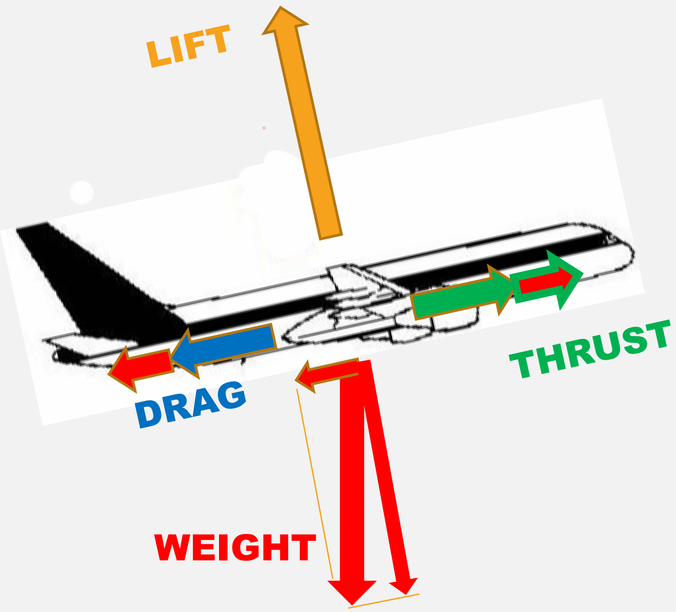
In steady flight:

LIFT=WEIGGHT

THRUST=DRAG

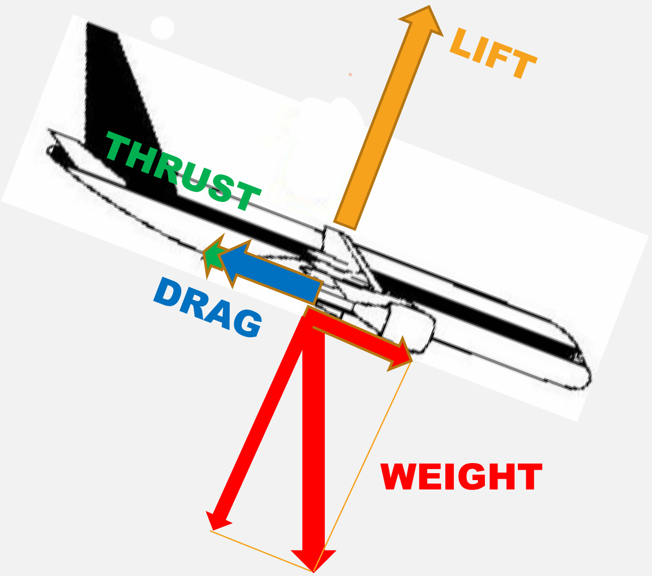
FORCES ACTING ON AN AIRCRAFT

ASCENT



The thrust force must additionally compensate for the component of the aircraft weight.

DESCENT



The weight force counteracts the drag force, which in the case of heavy aircraft requires negative engine thrust.

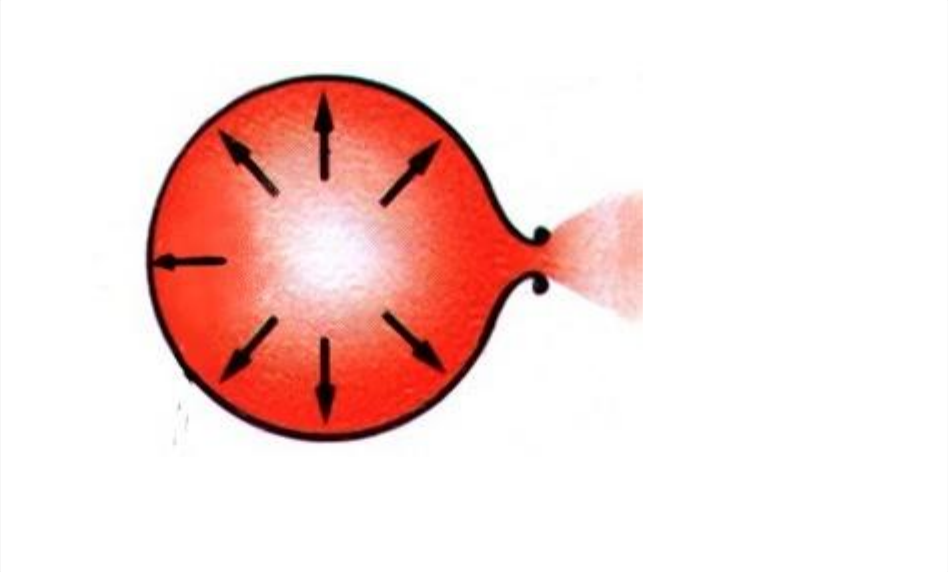
AIRCRAFTS AND THEIR ENGINES

Boeing 737-max 8
Maximum take-off weith (MTOW) 82 190 kg,
Propulsion: 2 engines CFM LEAP 1B, Take-off thrust (TOT) 130 kN (13 t)
TOT/MTOW=0,317

Airbus A380
Maximum take-off weight (MTOW) 545 000 kg,
propulsion 4 engines Trent 900, Take-off thrust (TOT) 356 kN (35,6 t)
TOT/MTOW=0,264

F16 C Blok 52
Maximum take-off weight (MTOW) 16 875 kg,
Propulsion 1 engine F100-PW-229 Take-off thrust (TOT) 79 kN (7,9 t),
augmentet thrust 130 kN
TOT/MTOW=0,47 TOT_AB/MTO=0,77

WHAT IS IT THRUST?



A gas stream flowing out at a speed that deppends on the pressure difference causes an effect according to **Newton's Second and Third Laws of Dynamics**

Thrust = gas mass flow x gas speed

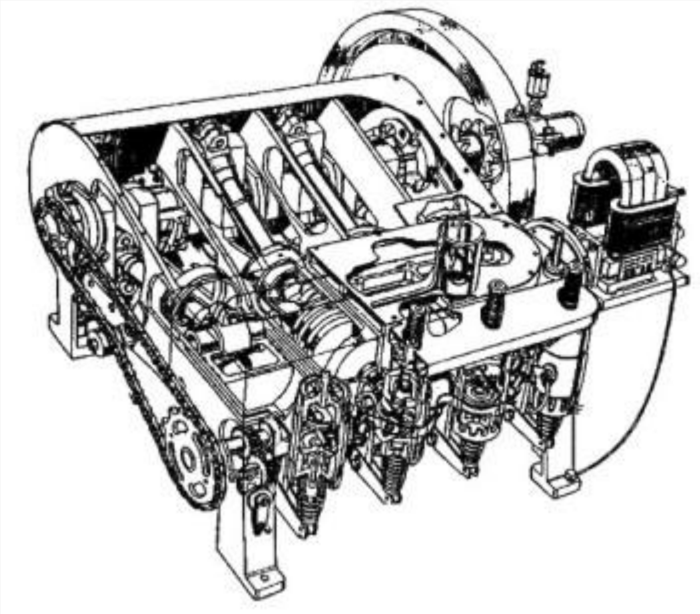
THE FORCE GENERATED BY THE EXHAUST GASES OF THE AEROENGINES

AEROENGINE THRUST

- A force directed opposite to the direction of the acceleration of the flow by the propulsion system.
- In the case of jet engines, this force is generated directly by the engine (a **direct-acting engine**).
- In the case of propulsion systems such as a piston engine with a propeller, the force is produced by the propeller, while the engine generates power that is converted into thrust by the propeller (an **indirect-acting engine**).

FIRST AERO PROPULSION SYSTEM

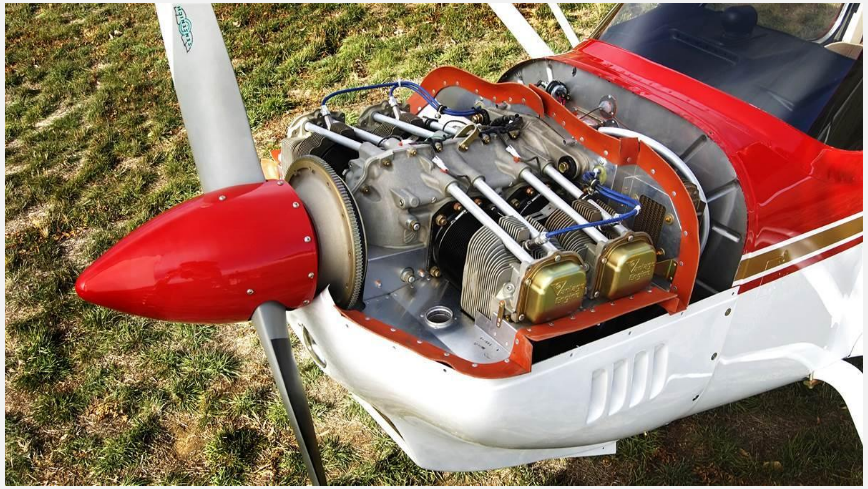
- **PISTON ENGINE – First engine was designed by Wright's Brothers and Charlie Tailor. Engine power -12 HP**
- **First powered flight was done by Wrights in 17 December 1903 in Kitti Hawk, Floryda**



AERO PISTON ENGINES

Star engines

Inline engines

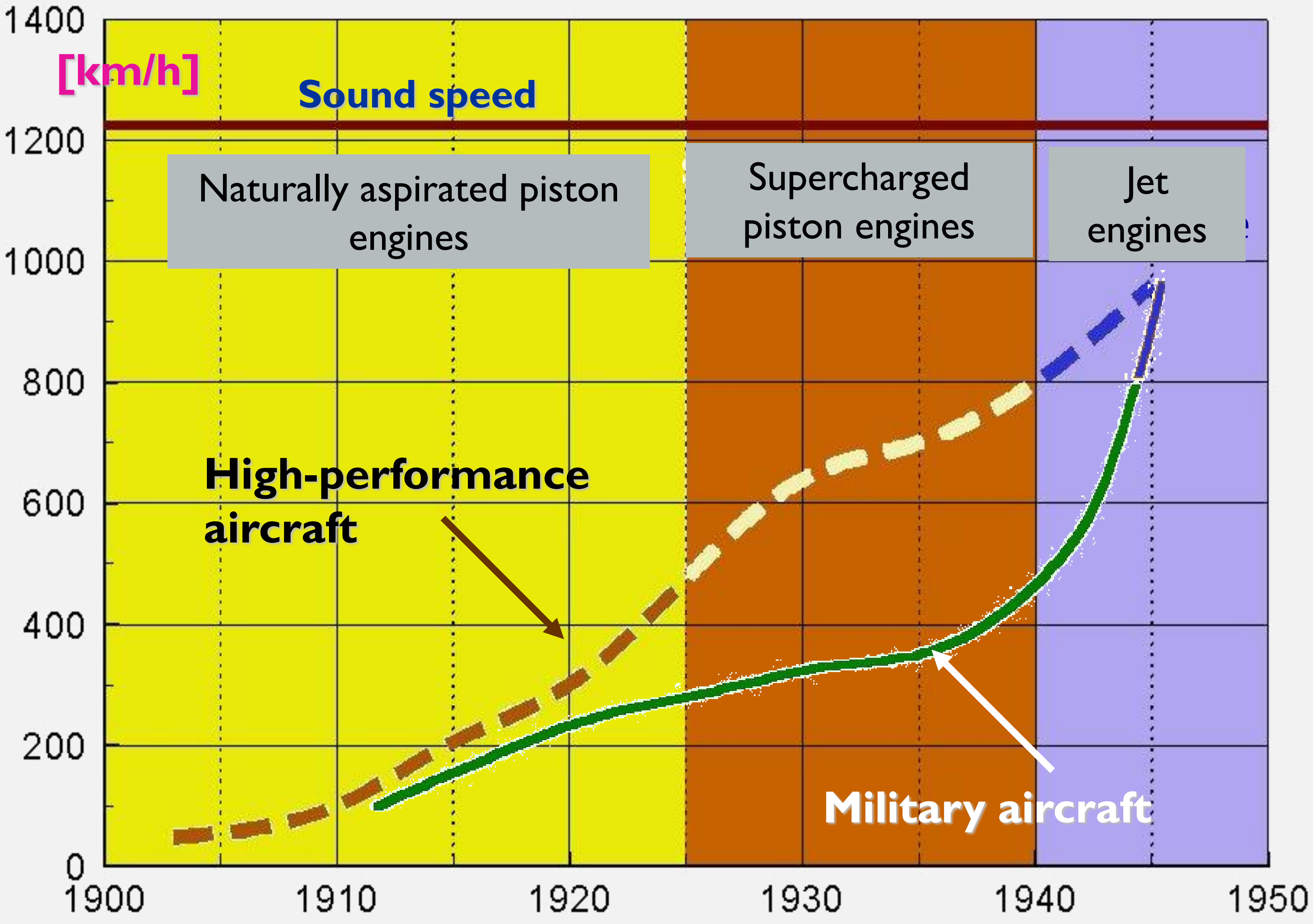


Engines with various cylinder arrangements and fuel supply systems, featuring either spark ignition or compression ignition.

INTENSIVE DEVELOPMENT OF PISTON ENGINES FOR AVIATION

The 1930s–1940s:

- Development of piston engines with progressively improved performance — supercharged and turbocharged engines.
- Engines of increasing power output (the largest, the Pratt & Whitney R-4360 engine, featured two-stage turbocharging and an output of 4300 hp).
- Their application became limited by flight speed due to decreasing propeller efficiency at speeds above Mach 0.6.



CURRENT APPLICATIONS OF PISTON PROPULSION SYSTEMS

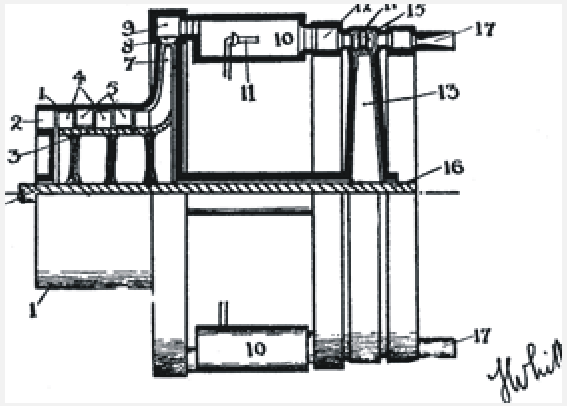
- **APPLICATIONS**
- Small aircraft – general aviation and ultralight types, with maximum flight speeds up to **300 km/h**
- Sport aircraft
- Model aviation and military drones
- **ENGINES USED:**
- Four-stroke piston engines, predominantly in boxer configuration
- Rotary piston engines (Wankel type)
- Engines with both compression ignition and spark ignition
- **ADVANTAGES**
- Low fuel consumption
- Simple design
- Ease of maintenance and overhaul
- Low purchase and operating costs

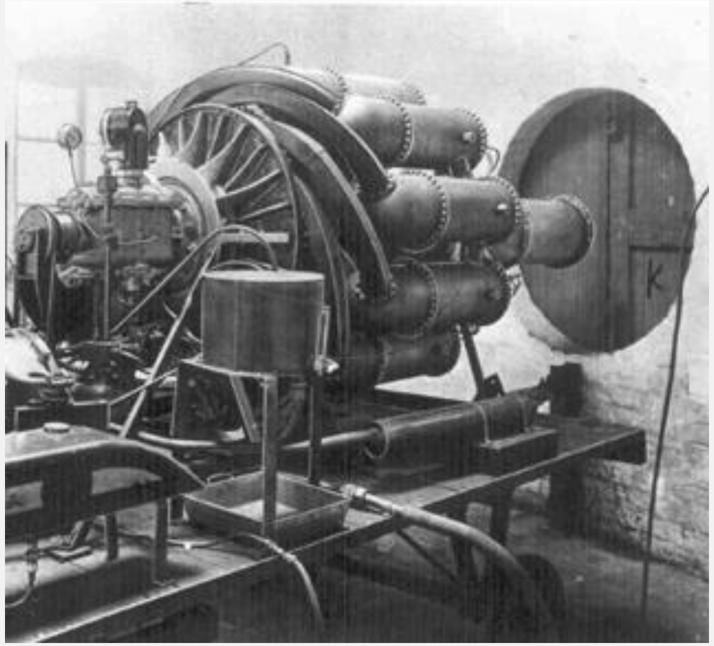
BEGINNING OF TURBOJET PROPULSION – 30'S OF XX CENTAURY

Sir Frank WHITTLE
1907 - 1996

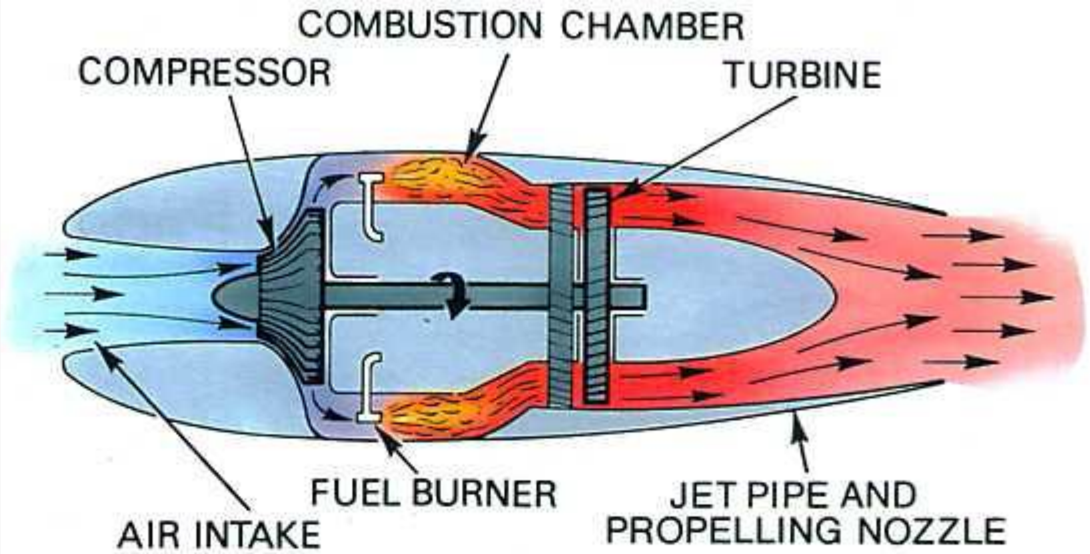
Dr Hans Joachim PABST von OHAIN
1911 - 1998

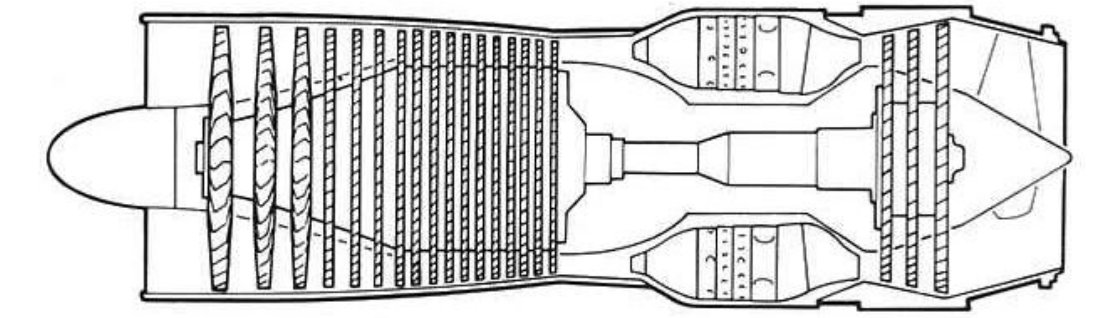
1. Axial compressor casing
2. Intake
3. Compressor body
4. Compressor blades
5. Stator blades
7. Centrifugal compressor
8. Compressor outlet
9. Elbow
10. Combustion chambers
11. Fuel injector
13. Turbine disk
14. Turbine blades
15. Stator blades
16. Shaft
17. Divergent nozzle ring.





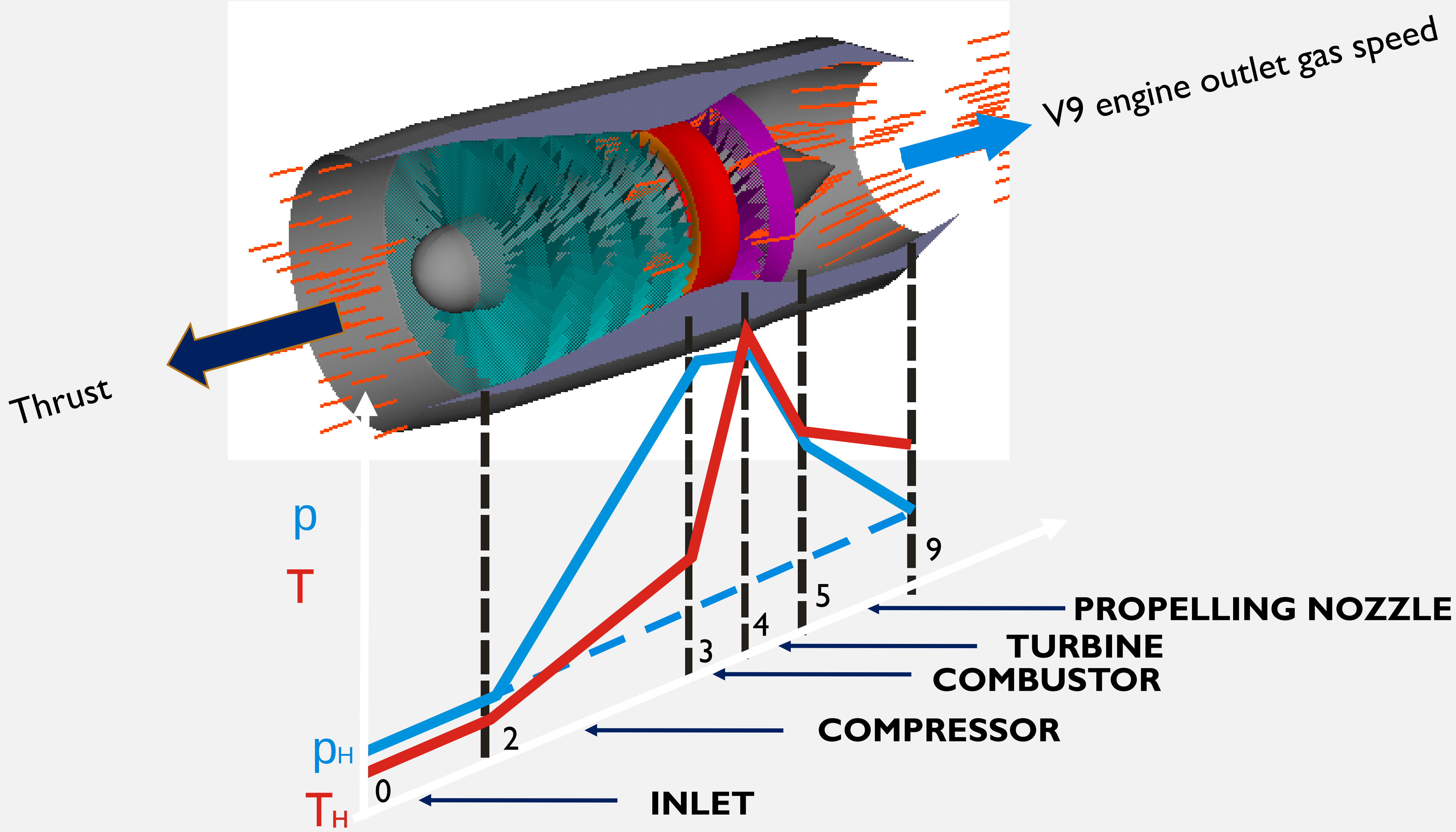
SINGLE SPOOL TURBOJET ENGINE





SINGLE-SPOOL AXIAL FLOW TURBO-JET

HOW TURBOJET ENGINE WORKS



ENGINE PERFORMANCE PARAMETHERS

- Thrust

$$T = m_9 V_9 - m_0 V_0$$

- Specific Thrust

$$ST = \frac{T}{m_0} = (1 + f_B)V_9 - V_0$$

- Specific Fuel Consumption

$$SFC = \frac{m_f}{T} = \frac{f_B}{(1 + f_B)V_9 - V_0}$$

- Thermal efficiency

$$\eta_{th} = \frac{m_9 {V_9}^2 - m_0 {V_0}^2}{2\, m_f\, FHV} = \frac{(1 + f_B){V_9}^2 - {V_0}^2}{2\, f_B FHV}$$

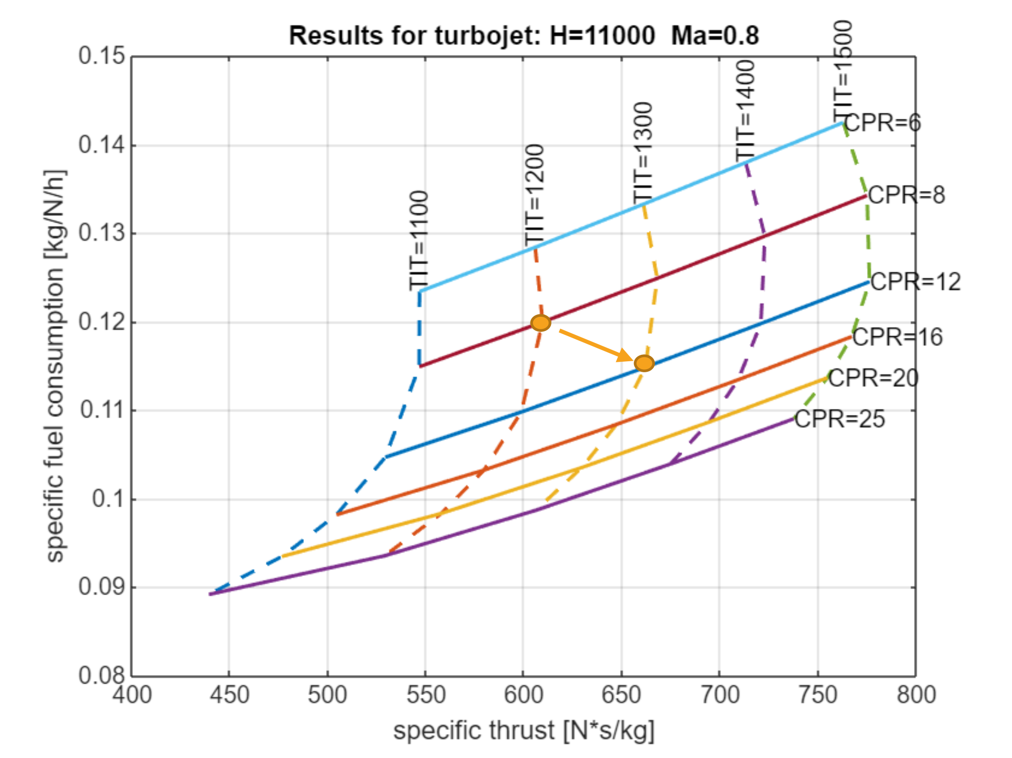
- Propulsive efficiency

$$\eta_p = \frac{2\, T\, V_0}{m_9 {V_9}^2 - m_0 {V_0}^2} = \frac{2\, ST\, V_0}{(1 + f_B){V_9}^2 - {V_0}^2}$$

- Overall efficiency

$$\eta_o = \frac{T\, V_0}{m_f\, FHV} = \frac{ST\, V_0}{f_B\, FHV} = \eta_{th}\eta_p$$

COMPRESSOR PRESSURE RATIO INFLUENCES ON ENGINE PERFORAMANCE

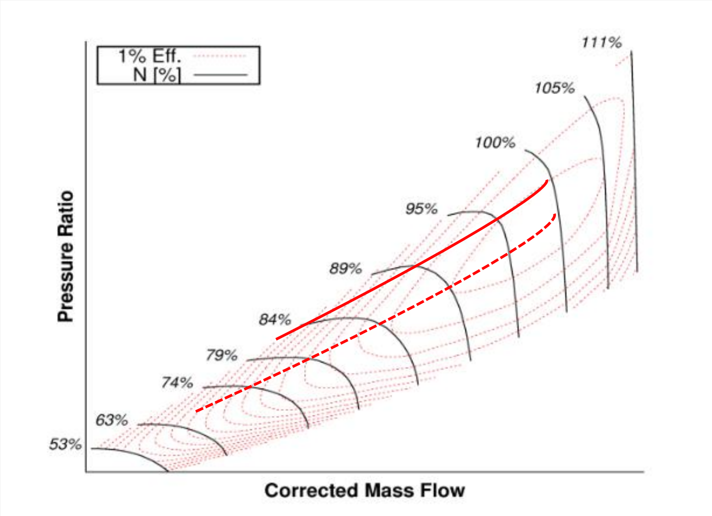


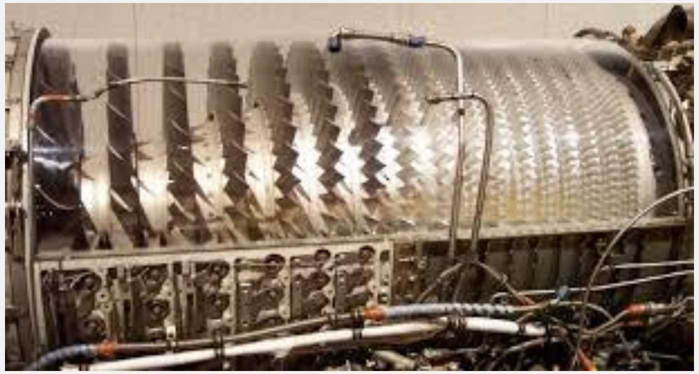
CONCLUSIONS:

- CPR increase improves SFC
- TIT rise improves ST but when CPR is constant than it cause SFC worsen
- Engine performance improvement requires ingreasing both TIT and CPR

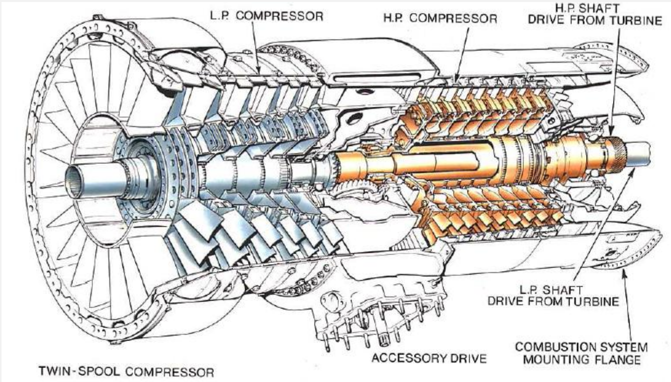
PROBLEMS RELATED TO INCREASING CPR

- Increasing the number of compressor stages and its dimensions, which increases its mass and moment of inertia
- Compressor stability problems beyond the design point

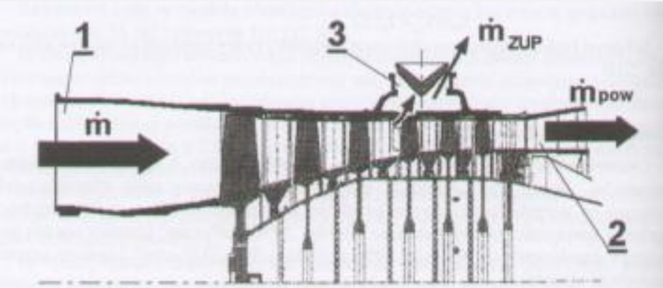




Split compressor for two rotors

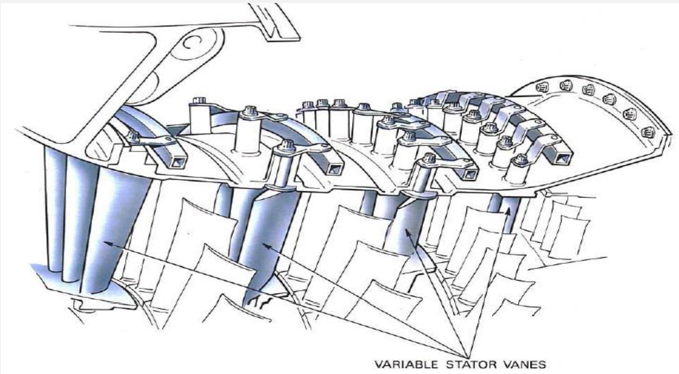


bleed

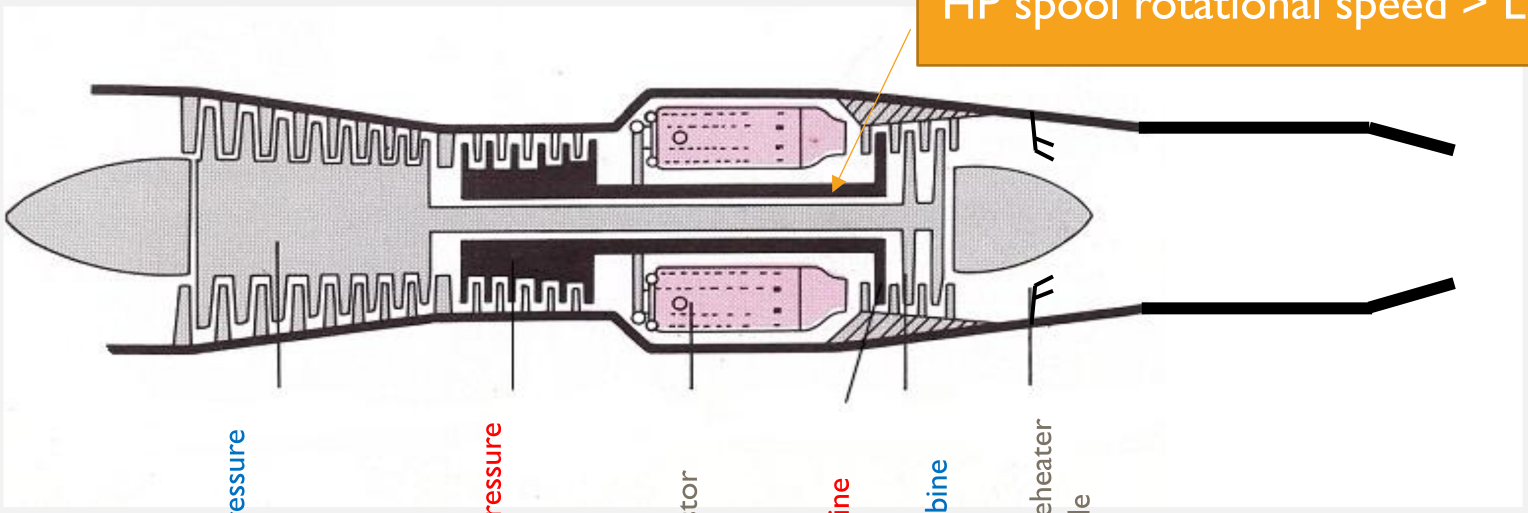


Rys. Schemat przepływu powietrza przez sprężarkę z otwartym upustem:
1 - wlot; 2 - dyfuzor wylotowy; 3 - zawór upustu powietrza

VGV – variable guide vanes

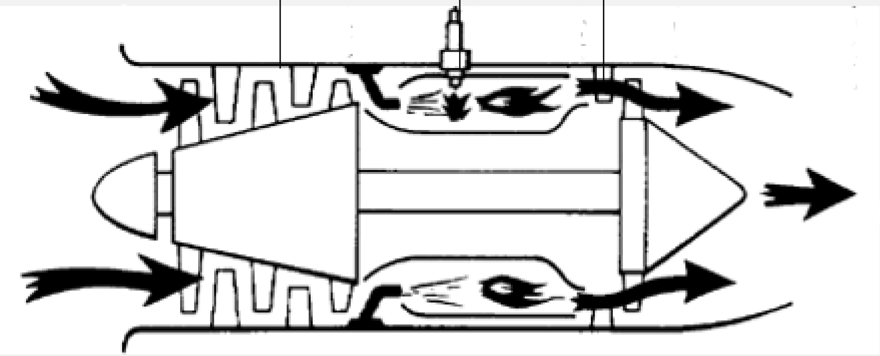


TWO SPOOL TURBOJET ENGINE



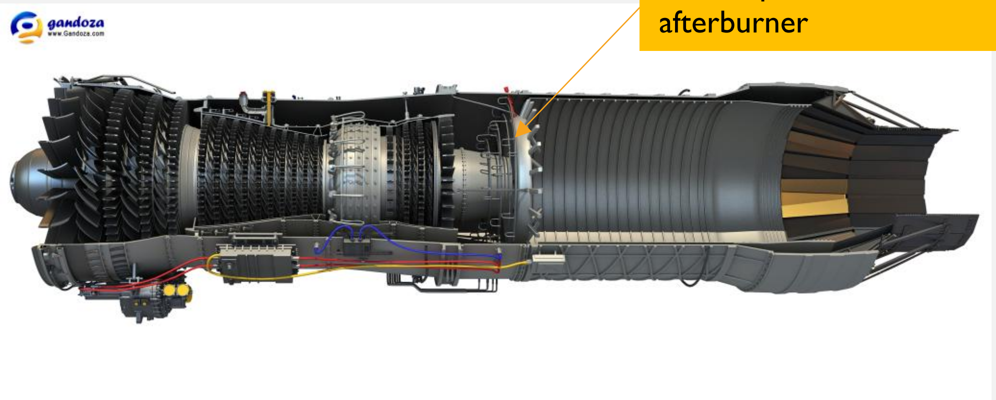
Two spool turbojet engine with afterburner

- Higher engine pressure ratio
- Higher engine efficiency
- Higher thrust
- More complex construction



Single spool tutbojet

ENGINE WITH AFTERBURNER



Additional burner and fuel consumption in the afterburner

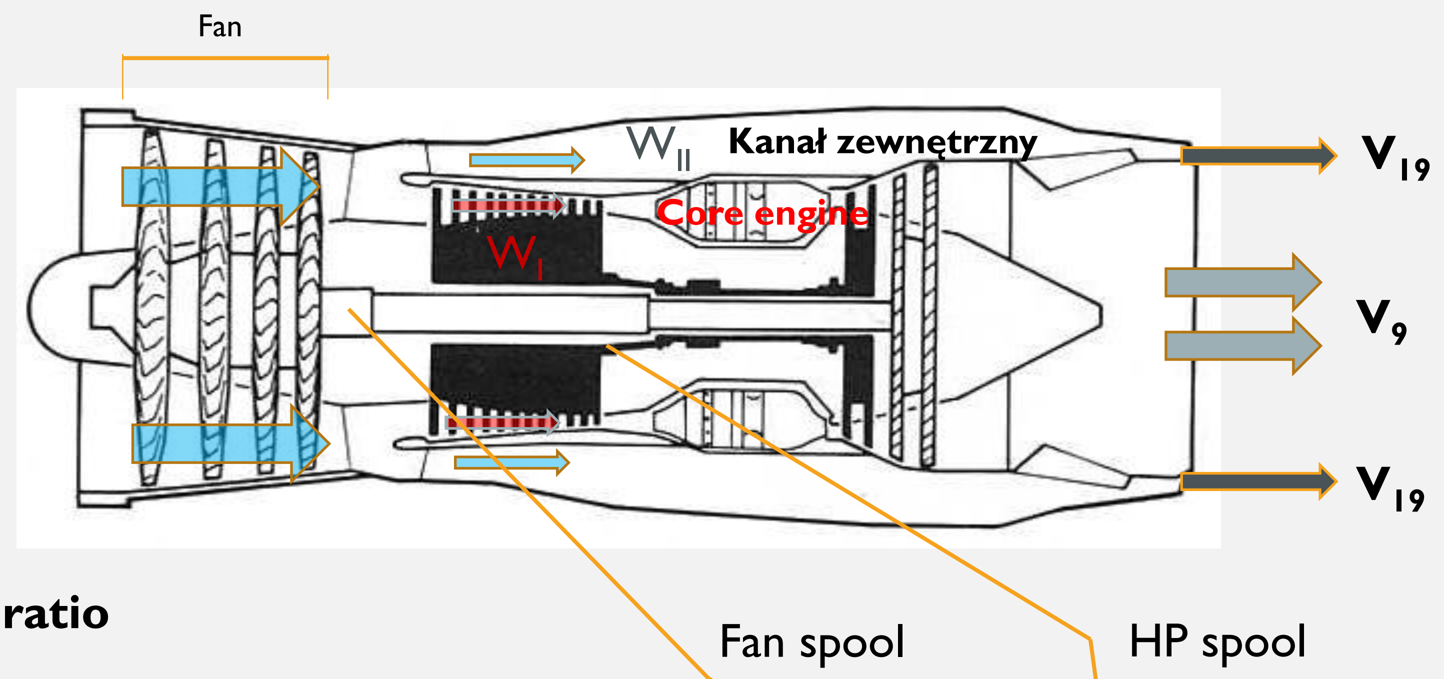
Turning on the afterburner

- Increases engine thrust
- Significantly increases fuel consumption (up to three times)
- Increases noise

TURBOJET ENGINE COMPARISON FOR AFTERBURNER OFF/ON

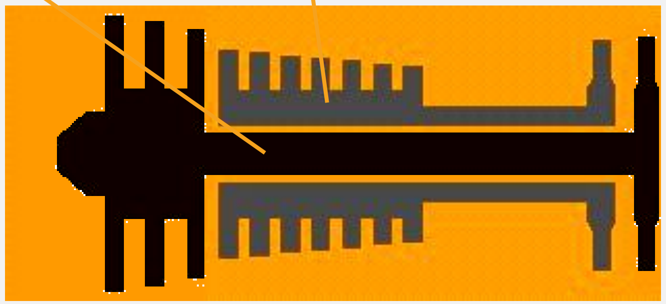
Engine	Thrust [kN] (AB OFF)	Thrust [kN] (AB ON)	SFC [kg/(Nh)] (AB OFF)	SFC [kg/(Nh)] (AB ON)
J85-GE-13	12,16	18,14	0,105	0,2264
J76-GE-19	52,8	79,6	0,0857	0,2004
GE4/J5P	229,08	305,15	0,1060	0,1897
J58-P-4	110,8	151,0	0,0816	0,1937
Olympus 201R	75,5	106,9	0,0816	0,1835
Olympus 593	135	170	0,0714	0,1208

TWO SPOOL BYPASS ENGINE



Bypass ratio

$$BPR = {}^{W_{II}}/_{W_I}$$



NHP > NLP

Higher efficiency and lower specific fuel consumption than the turbojet engine

BYPASS ENGINES

Midle and high BPR engines

JT15D-5D (Business Jet Aircrfts)

Thrust= 13,54 kN TSFC=0.055 kg/N/h

BPR=3,3

Weight = 292,6 kg length / diameter=1531/520mm

N1=15,900 RPM, N2= 32,760 RPM

Application: Cesna CitationV, Hawker 400

LEAP 1A (passenger aircrafts)

Compressors: OPR=40:

F – 1 stage, LPC – 3 stages, HPC - 10 stages Turbines HPT – 2 stages, LPT – 7 stages

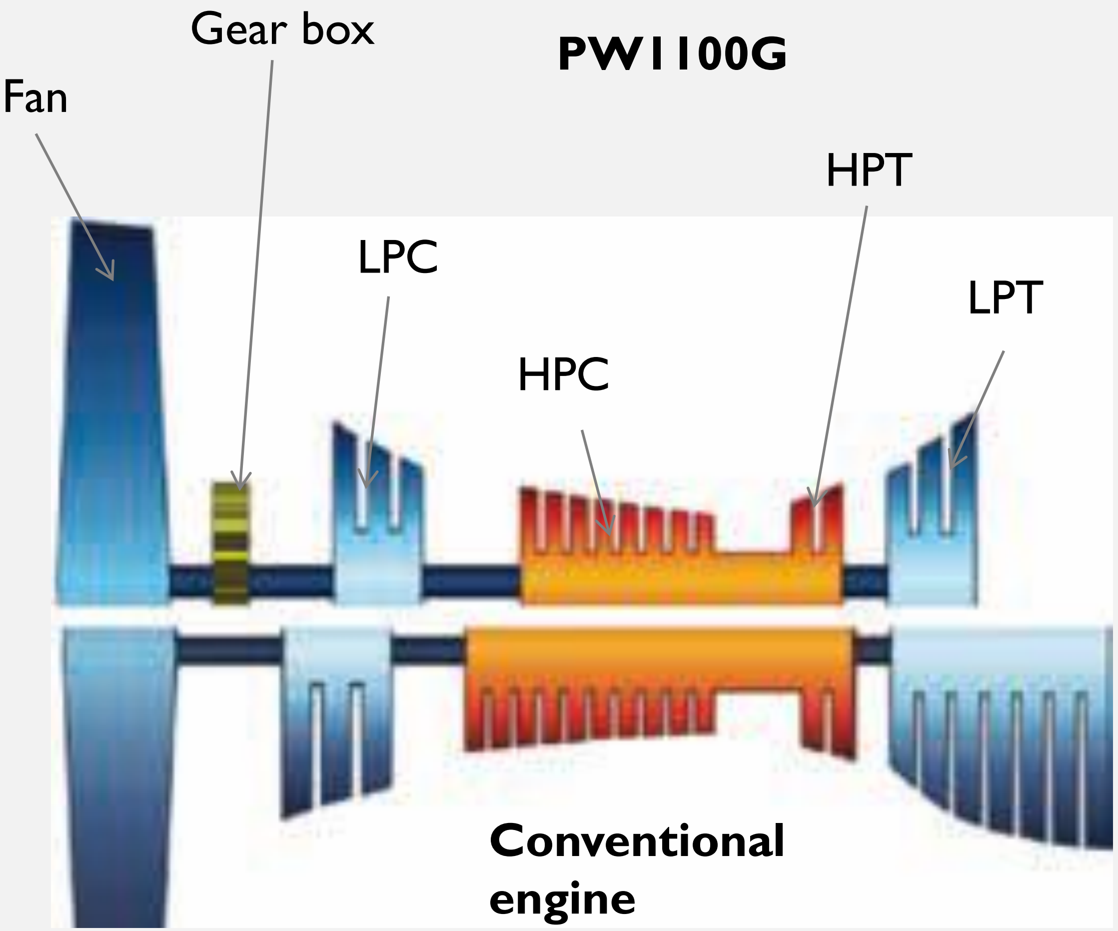
Thrust 143 kN SFC=0.052 kg/N/h (at cruise)

BPR 11

length 3,328 m/ diameter 1,93 m N1=3894 RPM, N2=19391 RPM

Application: A-320neo

GTF (GEARED TURBOFAN)



	TF CFM56	GTF PW1100
N HPC [RPM]	15180	22300
N LPC [RPM]	5200	10050
N F [RPM]	5200	3280

GTF :

- more efficient LPT operation, which reduces the number of LPT stages
- Higher LPC PR
- Reduced fan speed reduces noise level

THE BIGEST TURBOFAN ENGINE

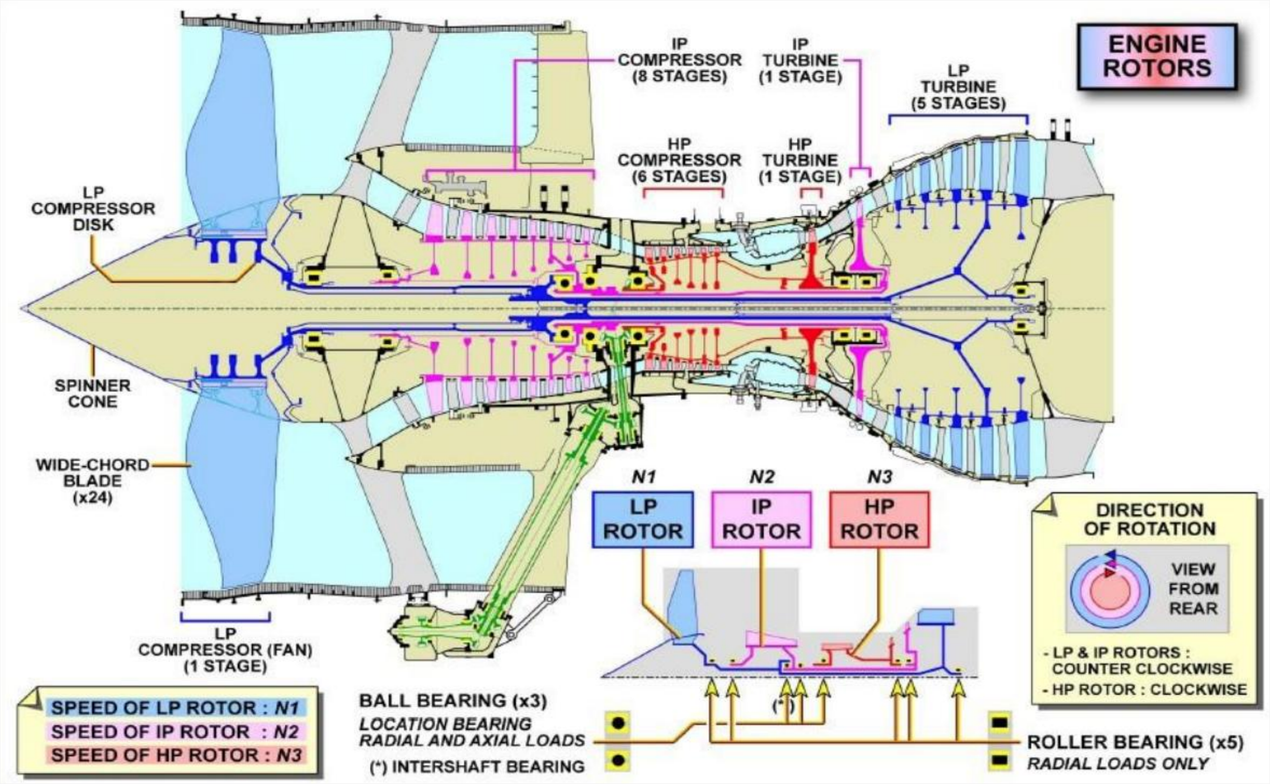
GE9x (successor of GE90)

- Fan diameter 340 cm (overall diameter 410 cm)
- Length 569 cm
- Weight 9,6 ton
- Thrust 490 kN

Compressors	1 fan , 3-stage LP, 11-stage HP
Turbines	2-stage HP, 6-stage LP

THREE SPOOL TURBOFAN ENGINE

Rolls-Royce Trent 7000



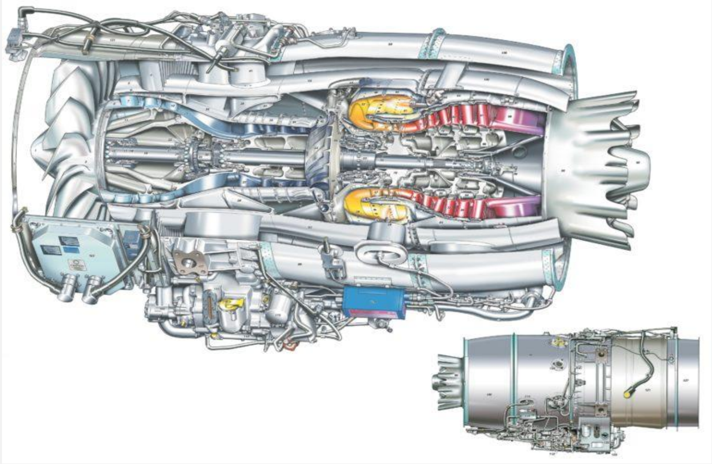
- **MTO:** 324,0 kN / 72 834 lbf
- **MCT:** 289,2 kN / 65 005 lbf
- **Pressure ratio :** 50:1
- **BPR :** 10:1
- **TIT:** > 1835 K (1562 °C; 2843 °F
- **SFC** (curse) = 14,4 g/kN/s =0,0518 kg/N/h
- **Stosunek ciągu do masy :** 5,13
- **Rotation:** (100%):
- HP 13 391 RPM, IP 8937 RPM, LP 2683 RPM

Application: **A330 neo**

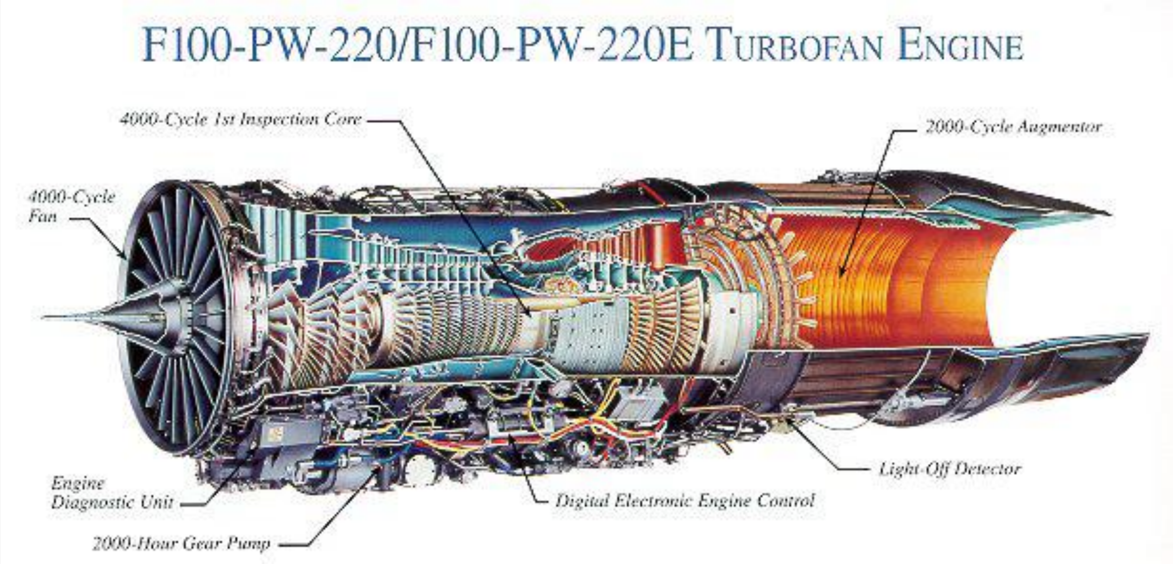
Coppressors:
F – single stage
IP – 8 stages
HP – 6 stages

Turbines:
LP – 6 stages
IP – single stage
HP – single stage

BY-PASS ENGINE WITH MIXER STREAMS

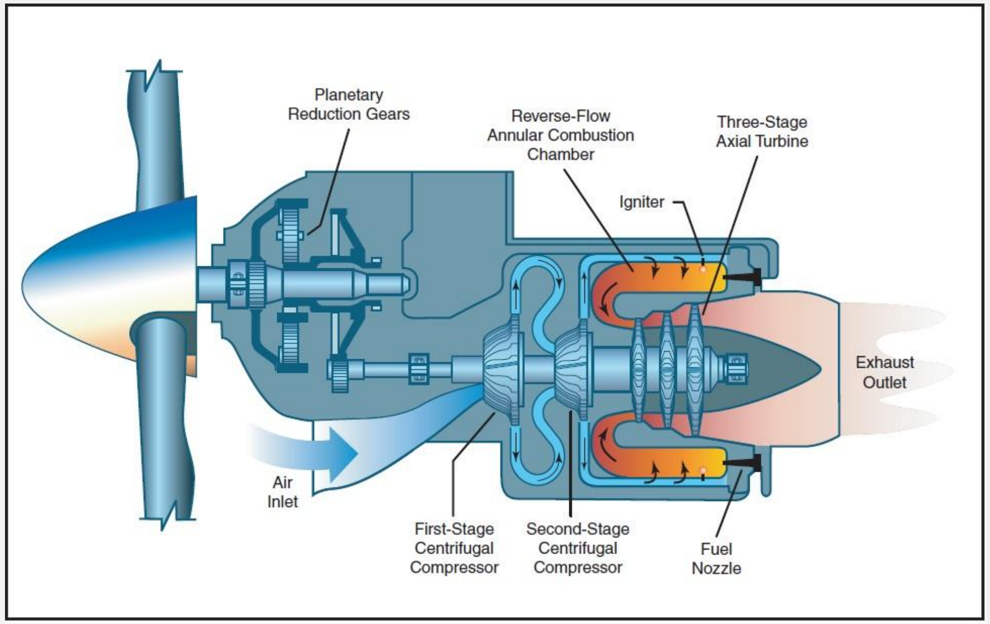


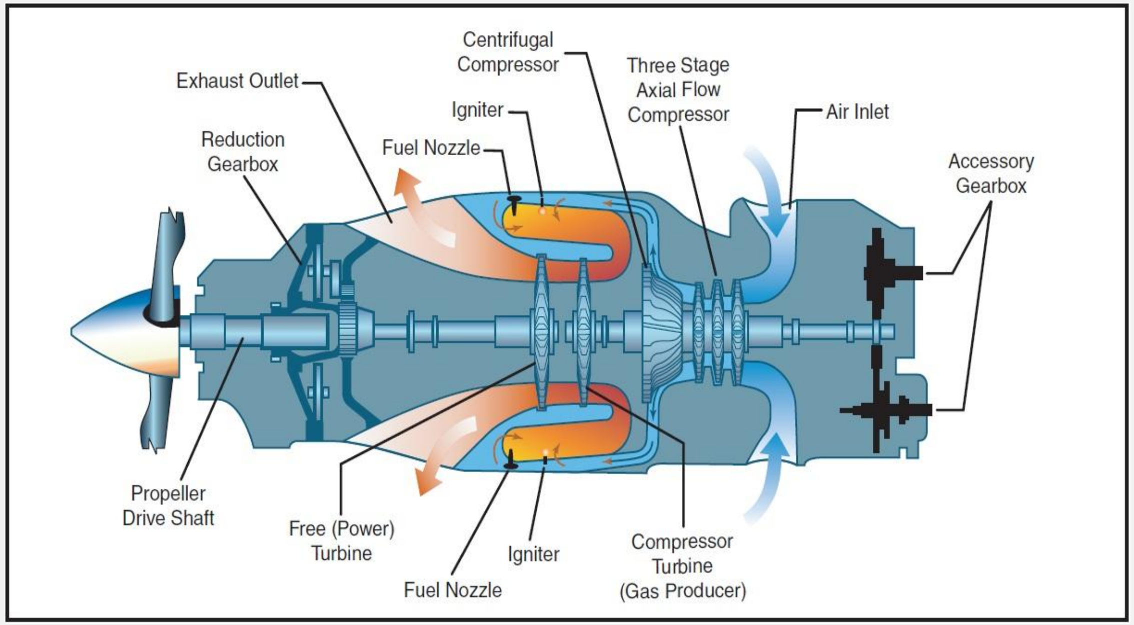
PW-500
Thrust: 18 kN
SFC: 0,04 kg/N/h
OPR: 13
BPR = 4
Length x diameter   1,74 m x 0,69 m
Application: Cesna Citation - BusinessJet



F100 PW-220
Thrust: 65 kN, **Augmented thrust:** 105,7 kN
SFC 0,077 kg/N/h **SFC (AB_On):** 0,198 kg/N/h
OPR: 32
BPR = 0,63
Length x diameter 4,85 m x 1,18 m, Weight: 1 696 kg
Application: F-15 i F16

TURBOPROP PROPULSION SYSTEMS





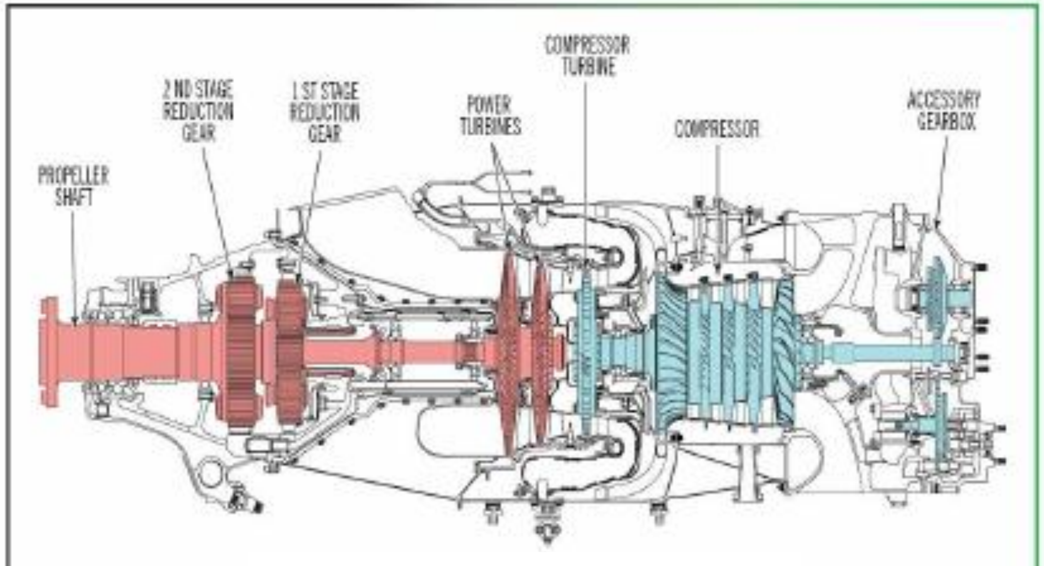
Single spool turboprop

- Simple construction – only one spool.
- The propeller is driven via a reduction gearbox by the same shaft that powers the compressor.

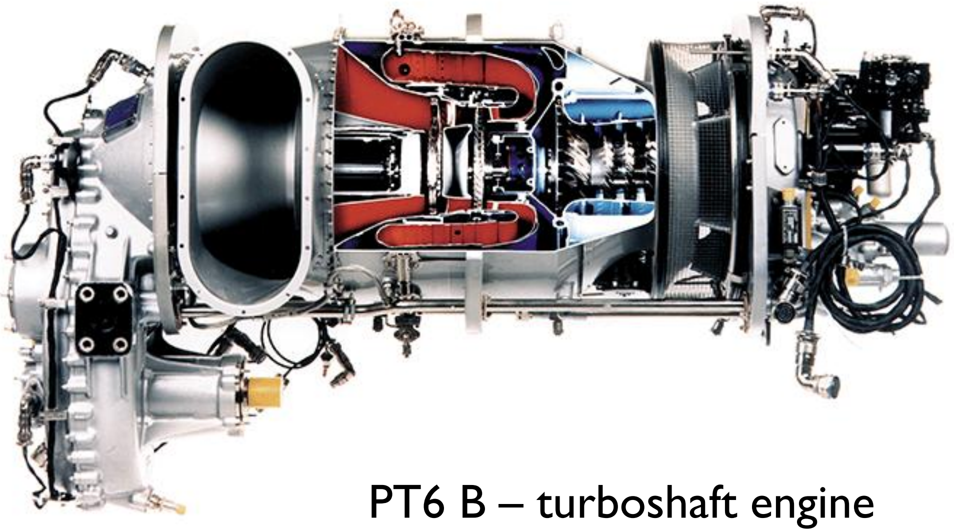
Free power turbine turboprop

- Offers better flexibility and performance during rapid power changes, such as during takeoff and landing,
- The propeller is driven by the free turbine through a separate shaft, allowing optimized, slower propeller speeds regardless of the gas generator speed.

TURBOPROP AND TURBOSHAFT ENGINE



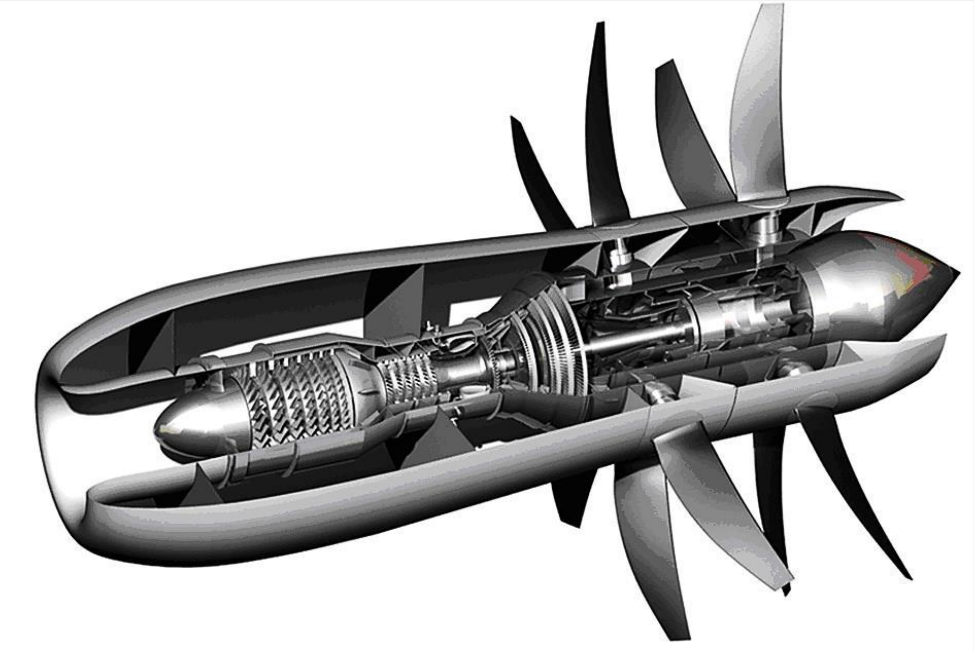
PT6 A – turboprop engine



PT6 B – turboshaft engine

PT 6 engine family of the shaft power from 500 shp to 19500 shp

UNDACTED FAN ENGINE



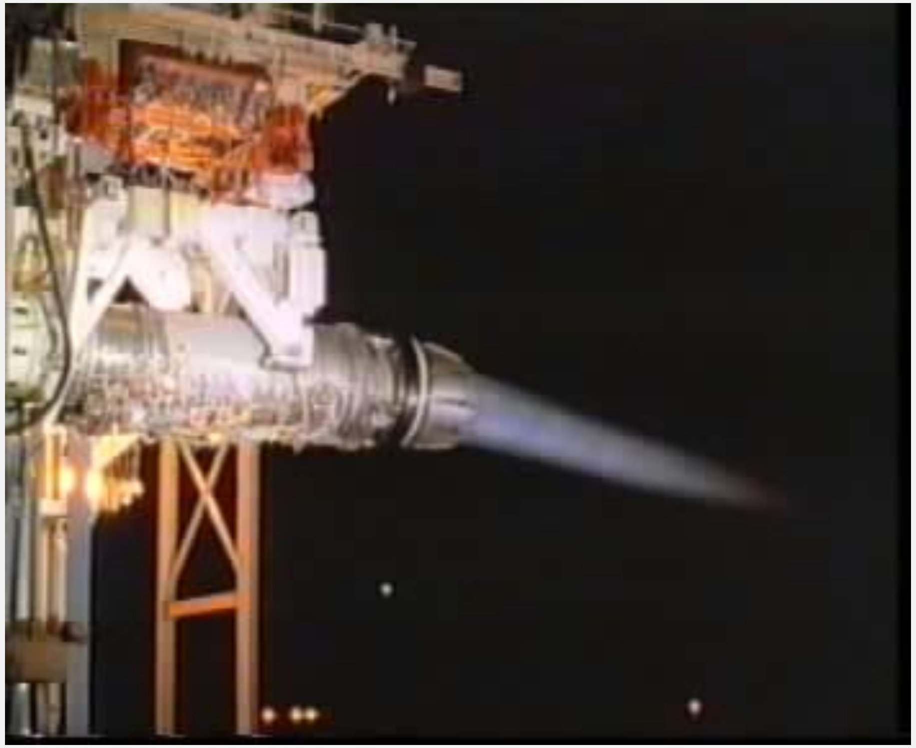
GE36 Open Fan Engine with two sets of exposed, counter-rotating fan blades

- reduced fuel consumption
- Heavy and loud

Revolutionary Innovation for Sustainable Engines (RISE)

- 20% more fuel-efficient, with 20% lower carbon emissions
- New materials to reduce mass (i.e. carbon-fiber comosite fan blades)
- Compatibility with next-generation fuels, including unblended sustainable aviation fuel (SAF) and hydrogen

HIGH-MANEUVERING AIRCRAFT (THRUST VEKTORING)



- Thrust vectoring allows for tight, low-speed maneuvers for a tactical advantage in combat missions.
- The F-22A Raptor Su-35 are fighters jet with advanced thrust vectoring capabilities.

SHORT TAKE-OFF VERTICAL LANDING AIRCRAFTS (STOVL)

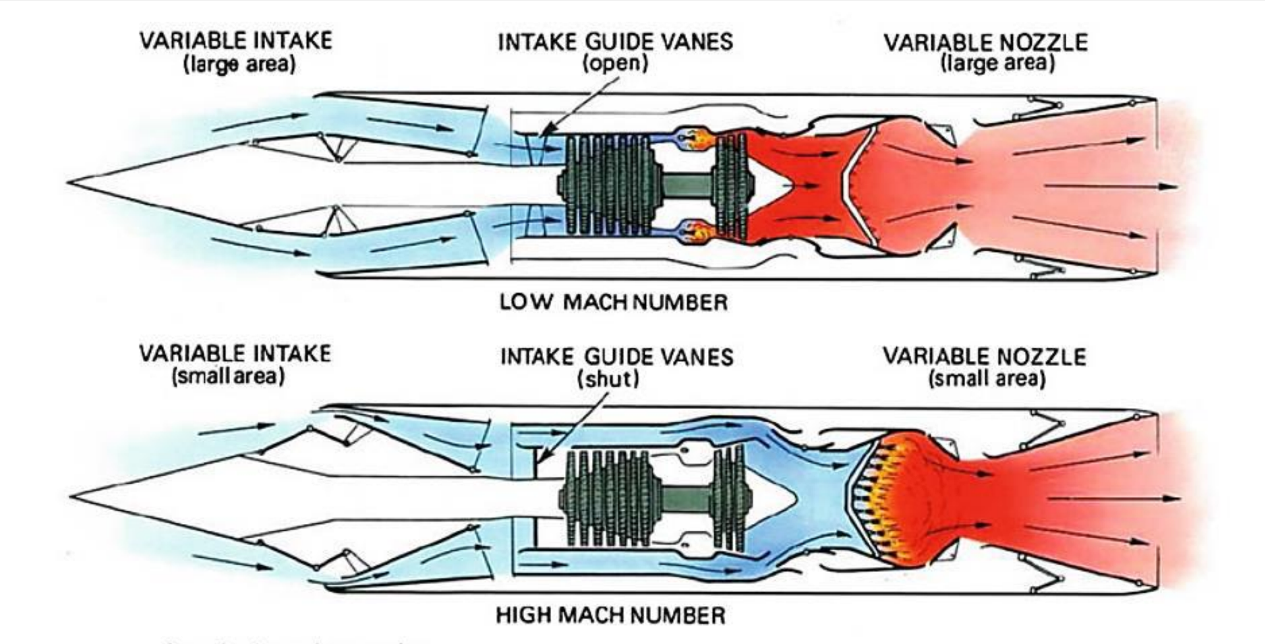
Lockheed Martin F-35B Lightning II

The Rolls-Royce LiftSystem comprises four major components:

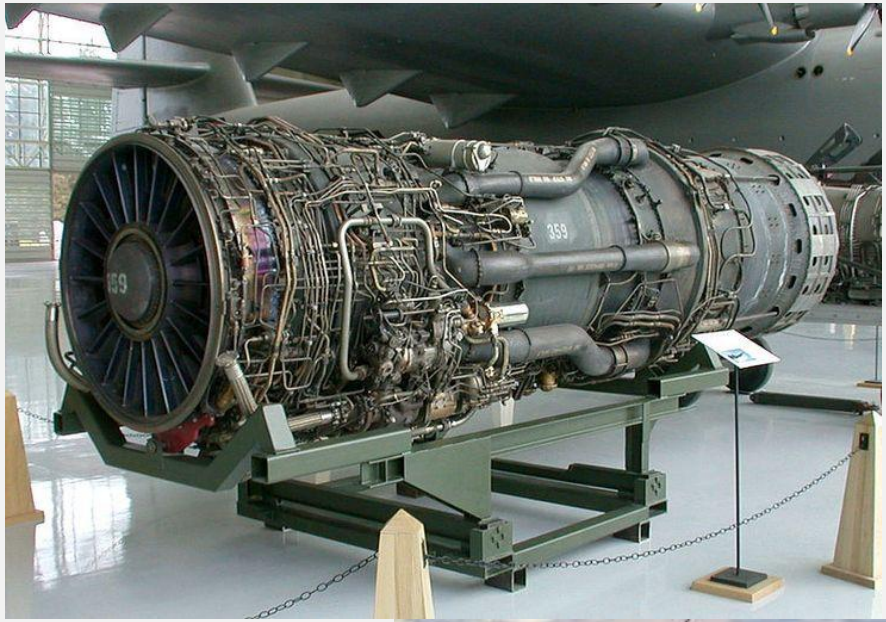
- LiftFan (thrust 80 kN)
- Engine to fan driveshaft
- Three-bearing swivel module (3BSM) (thrust 89 kN)
- Roll posts (two) (thrust 17 kN)

(total thrust (186 kN)

VCE (VARIABLE CYCLE ENGINE) J-85 FOR SR 71 BLACK BIRD OPERATION RANGE MA=0-3.2

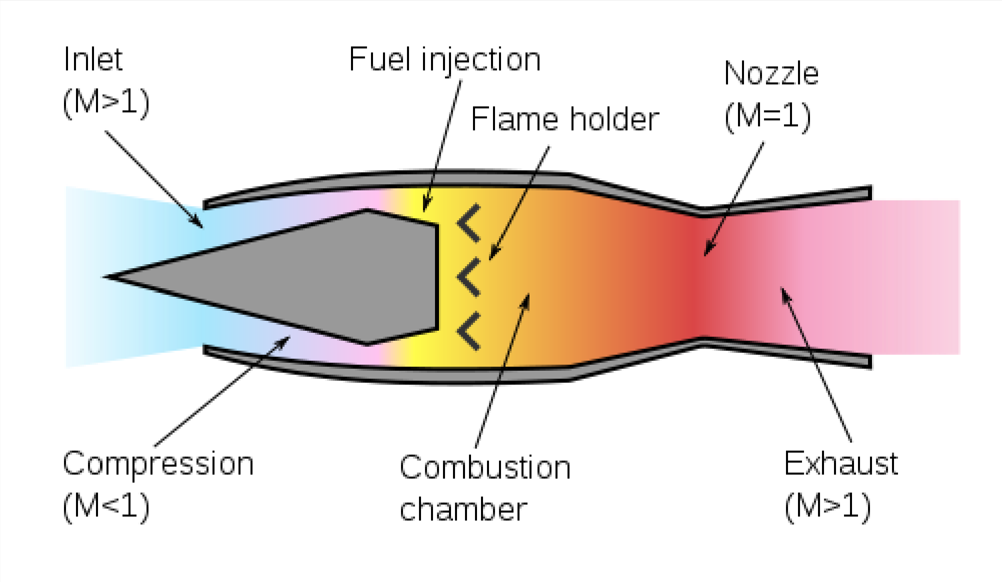


A turbo/ram jet engine.

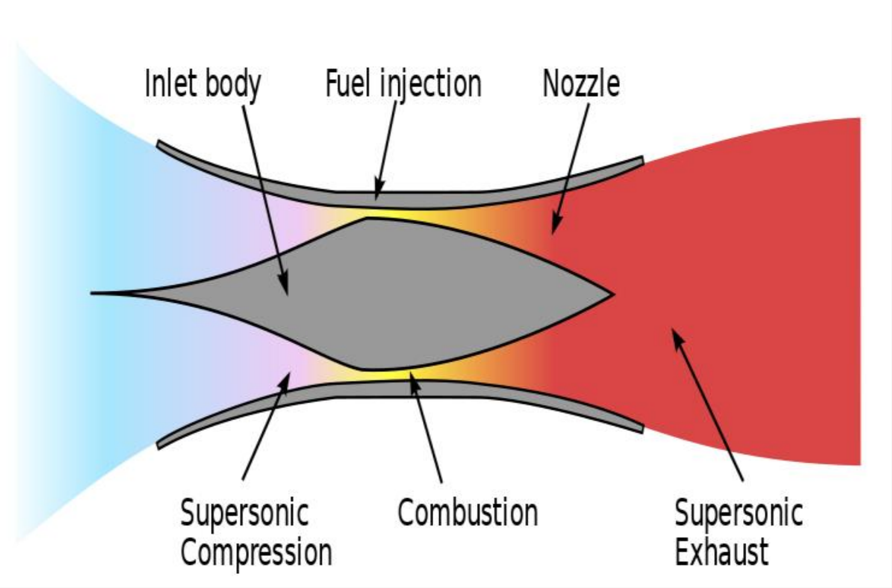


[(520) The Mighty J58 - The SR-71's Secret Powerhouse - YouTube: https://www.youtube.com/watch?v=F3ao5SCedIk](https://www.youtube.com/watch?v=F3ao5SCedIk)

RAMJET AND SCRAMJET



Ramjet - gas flow in combustor is subsonic

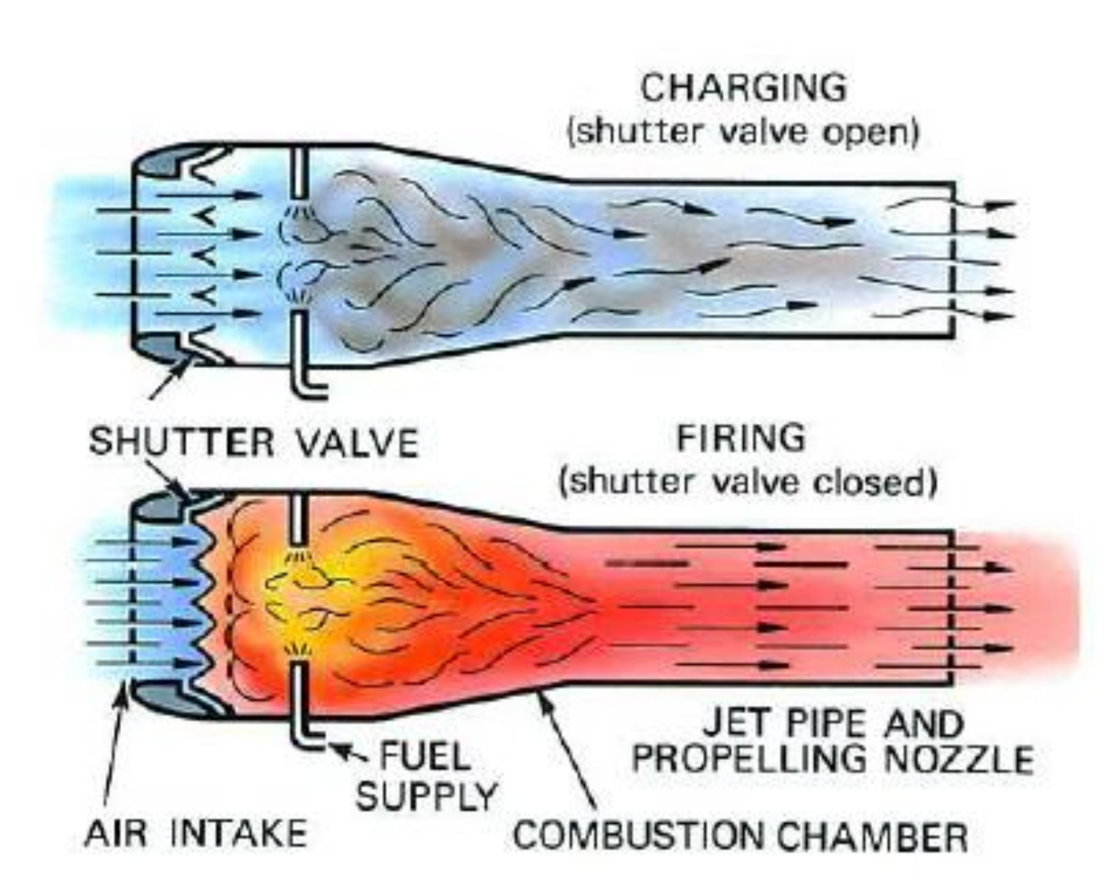


Scramjet – gas flow in combustor is supersonic

HYPOSED III 7,6 Ma
X-43A achieved speed 9,6 Ma

https://www.youtube.com/supported_browsers?next_url=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3DxpOa3B03gYg

PULSE JET ENGINE

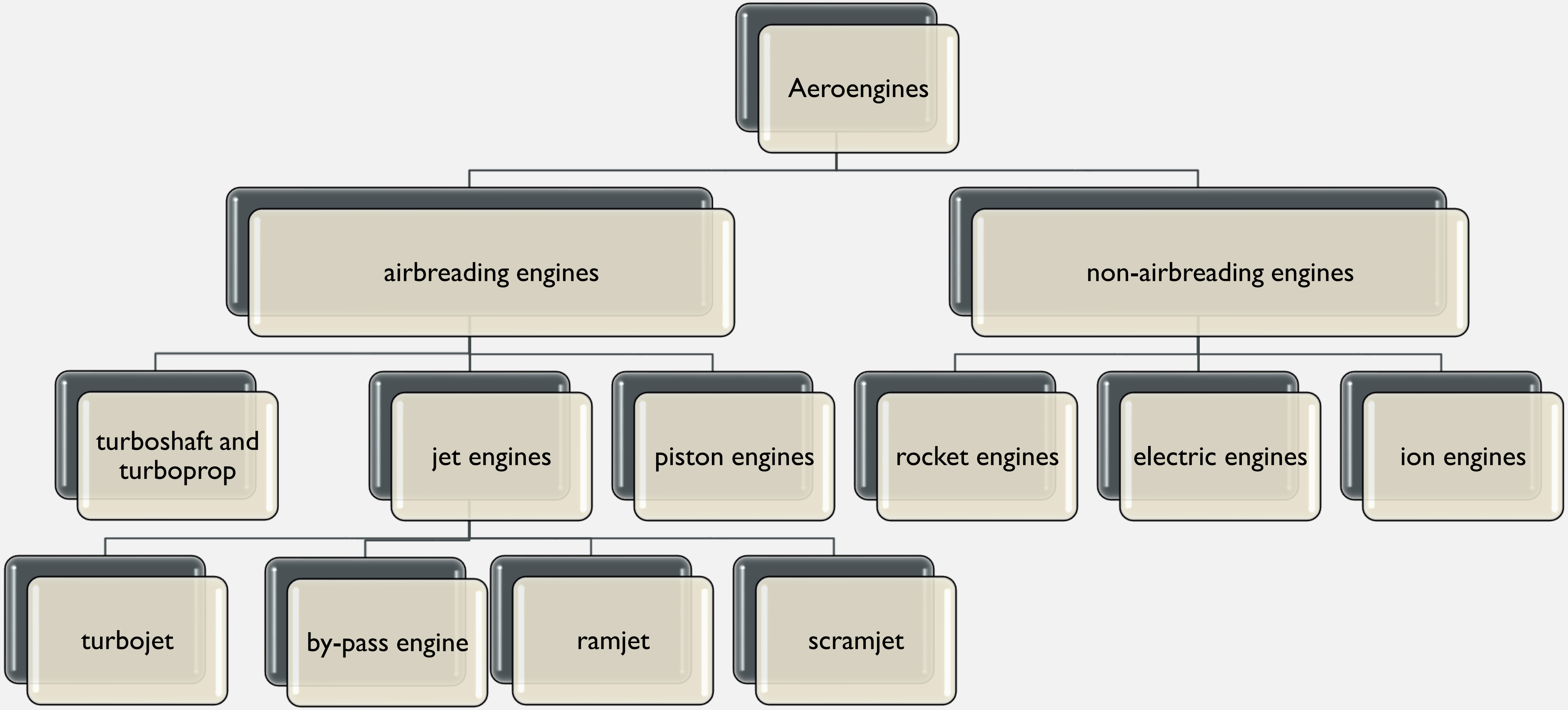


The most widely known pulsejet was the German V-1 missile, or buzz bomb, used near the end of World War II, which fired at a rate of about 40 cycles/s.

The pulsing effect can also be achieved in a **valveless engine**, or wave engine, in which the cycling depends on pressure waves traveling back and forth through a properly scaled engine.

A pulsejet engine delivers thrust at zero speed and can be started from rest, but the maximum possible flight speeds are below 960 km/h (600 mph). Poor efficiency, severe vibration, and high noise limited its use to low-cost, pilotless vehicles.

AEROENGINE CLASYFICATION



ENGINES PERFORMANCE PARAMETERS COMPARISON

	ST [N*s/kg]	SFC [kg/N/h]
Turbojet engine	500-700	0.08-0.11
Turbojet engine AB on	800-1100	0.17-0.22
Turbofan mixed stream engine	500-750	0.06-0.08
Turbofan mixed stream engine AB on	750-1100	0.19-0.25
High bypass ratio turbofan engine	250-600	0.025-0.05
Turboprop/turboshaft engine	160-300 [kW*s/kg] 2400-4500 [N*s/kg]	0.22-0.35 [kg/kW/h] 0.015-0.025[kg/N/h]

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