RZESZOW UNIVERSITY OF TECHNOLOGY

THE FACULTY OF MECHANICAL ENGINEERING AND AERONAUTICS
RZESZOW UNIVERSITY OF TECHNOLOGY

GAS TURBINE ENGINES

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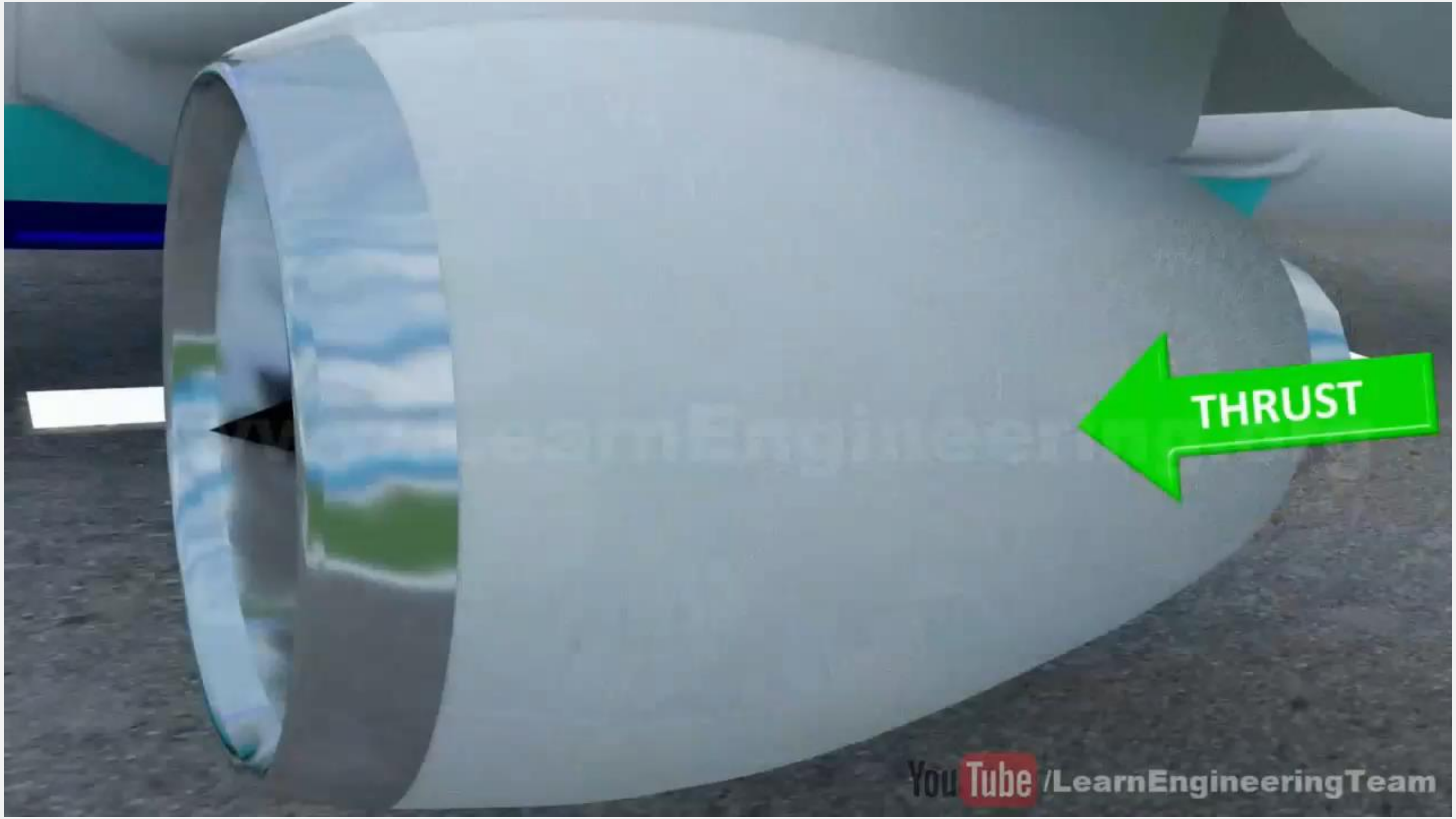
https://robert-jakubowski.v.prz.edu.pl/en/

WHY AIRCRAFT FLY?

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

WHAT IS AN ENGINE ROLE IN THE AIRCRAFT?



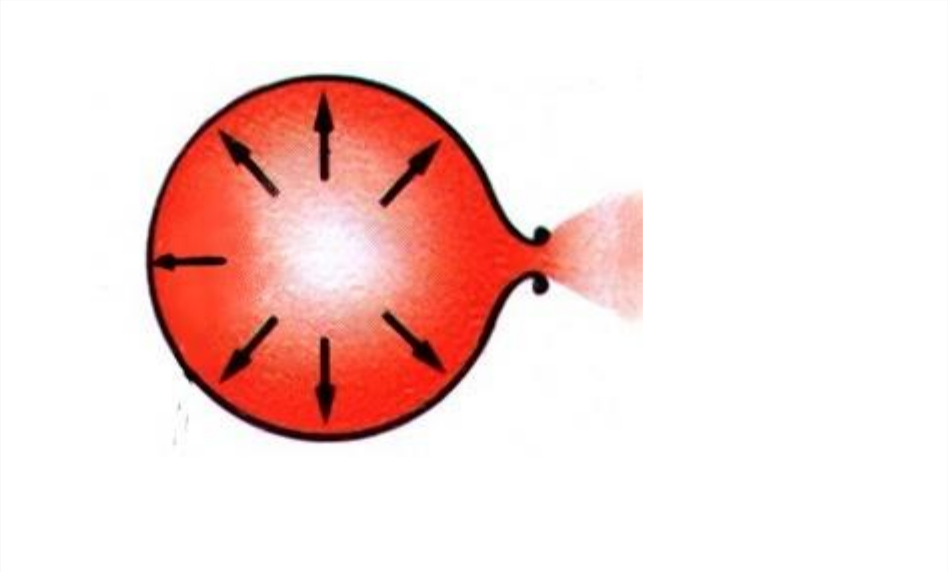
AIRCRAFTS AND THEIR ENGINES

Boeing 787-max 8
Maximum take-off weith (MTOW) 82 190 kg,
Propulsion: 2 engines CFM LEAP 1B, Take-off thrust (TO) 130 kN (13 t)
TO/MTOW=0,317

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

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

WHAT IS IT THRUST?



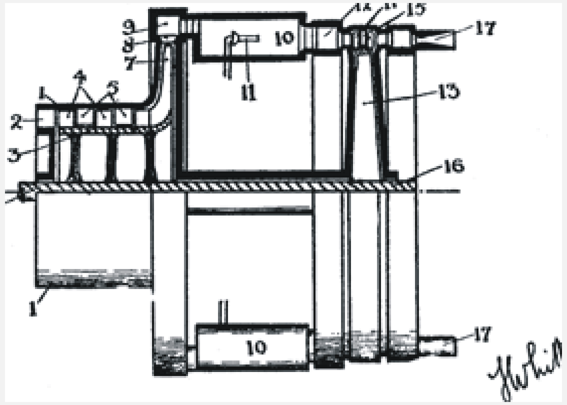
A gas stream flowing out at a speed that deppends on the pressure difference causes an effect according to **Newton's Second and Third Laws of Dynamics**

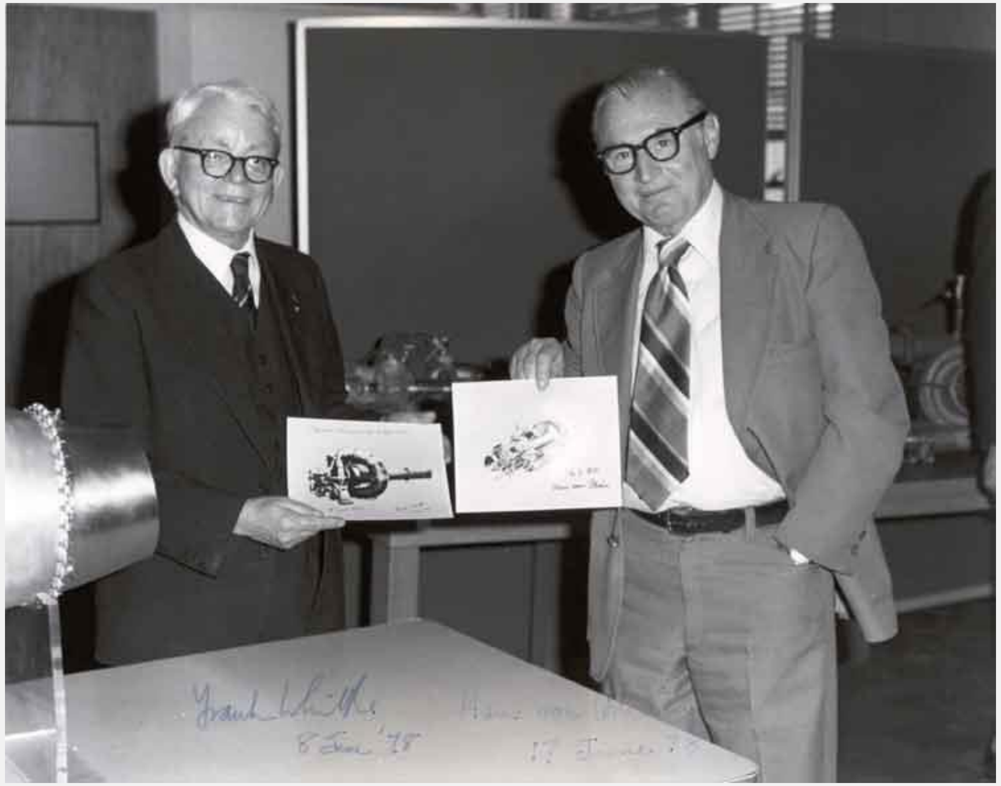
Thrust = gas mass flow x gas speed

THE FORCE GENERATED BY THE EXHAUST GASES OF THE AEROENGINES

BEGINNING OF TURBOJET PROPULSION – 30'S OF XX CENTAURY

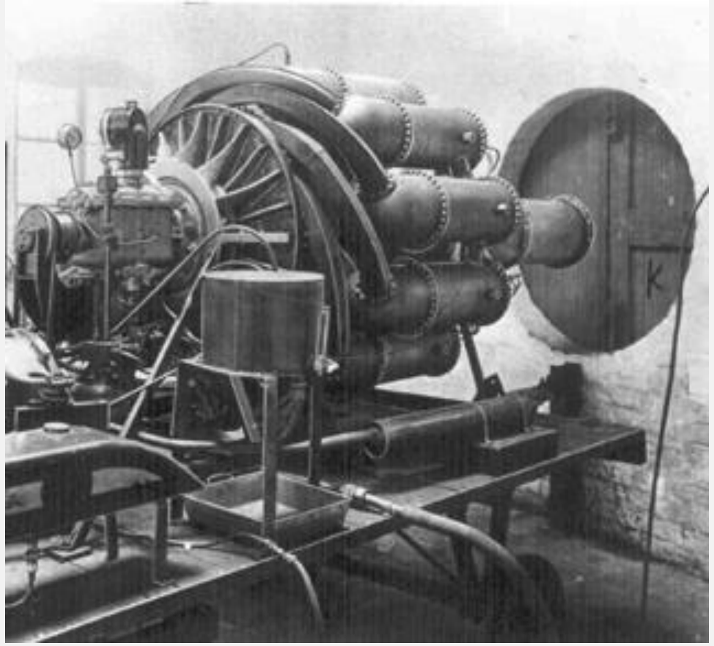
1. Axial compressor casing
2. Intake
3. Compressor body
4. Compressor blades
5. Stator blades
7. Centrifugal compressor
8. Compressor outlet
9. Elbow
10. Combustion chambers
11. Fuel injector
13. Turbine disk
14. Turbine blades
15. Stator blades
16. Shaft
17. Divergent nozzle ring.



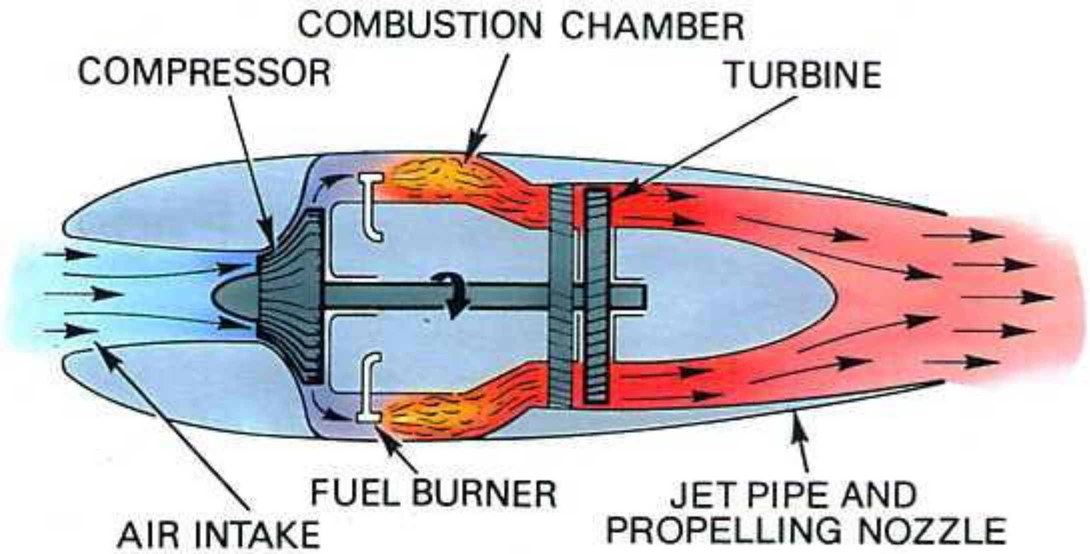


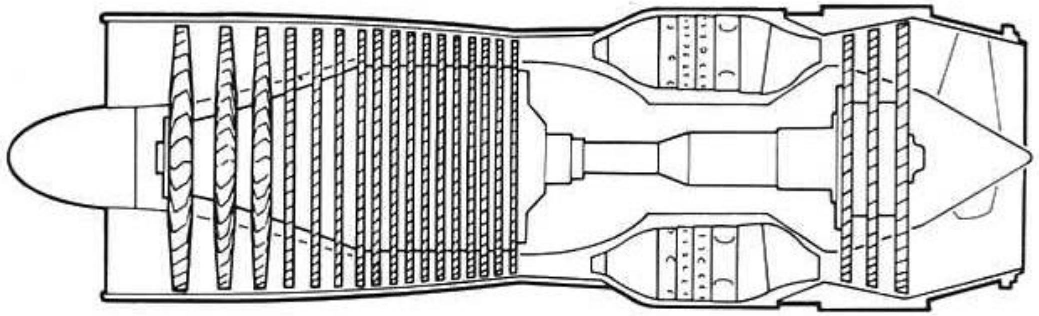
Sir Frank WHITTLE
1907 - 1996

Dr Hans Joachim
PABST von OHAIN
1911 - 1998



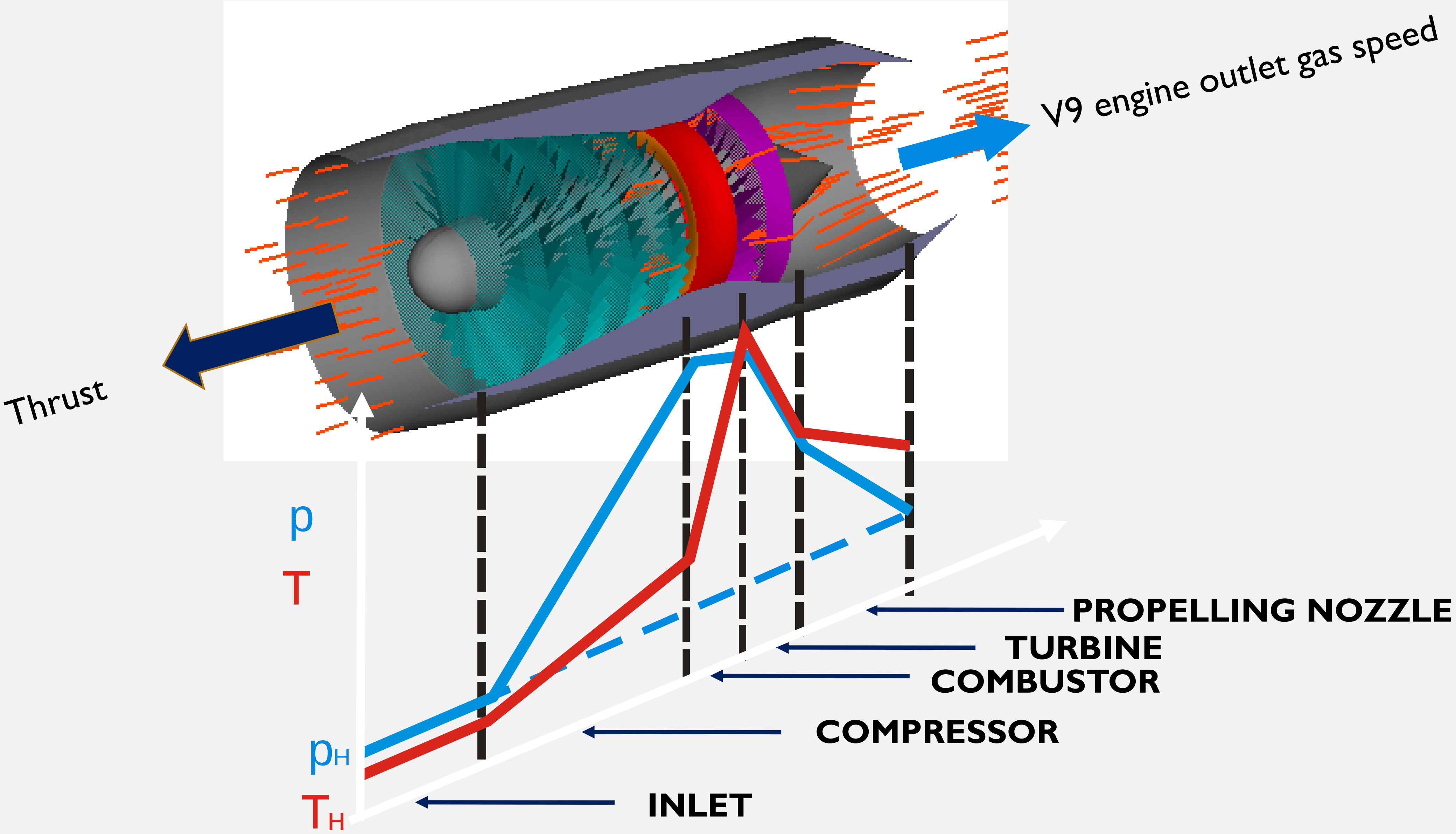
SINGLE SPOOL TURBOJET ENGINE



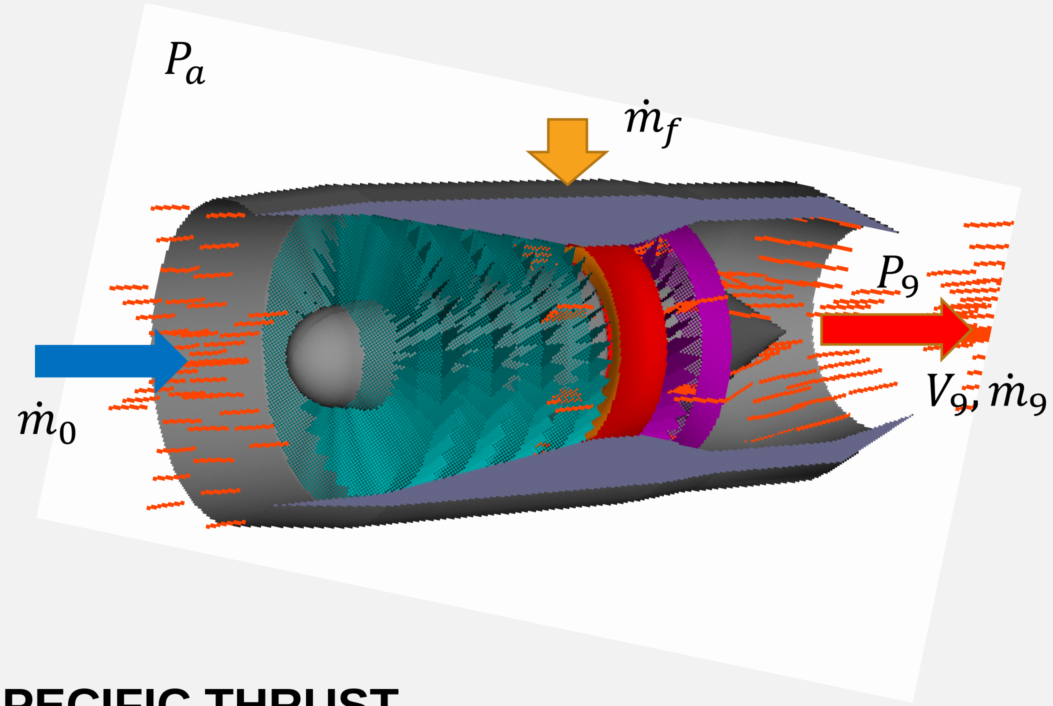


SINGLE-SPOOL AXIAL FLOW TURBO-JET

HOW TURBOJET ENGINE WORKS



ENGINE THRUST AND SPECIFIC PARAMETERS



Flight speed is 0

THTUST / GROS THRUST

$$T = \dot{m}_9 V_9 + A_9(P_9 - P_a)$$

effective exhaust velocity

$$V_{eff} = V_9 + A_9(P_9 - P_a)/\dot{m}_9$$

$$T = \dot{m}_9 V_{eff}$$

Exit pressure = ambient pressure

$$T = \dot{m}_9 V_9$$

Flight speed > 0

THTUST / NET THRUST

$$T = \dot{m}_9 V_9 + A_9(P_9 - P_a) - \dot{m}_0 V_0 = \dot{m}_9 V_{eff} - \dot{m}_0 V_0$$

Net thrust = Gross thrust –Momentum drag

SPECIFIC THRUST

$$ST = T/\dot{m}_0$$

SPECIFIC FUEL CONSUMPTION

$$\mathrm{SFC} = \dot{m}_f/T$$

Details in: **Ahmed F. El-Sayed, Aircraft Propulsion and Gas Turbine Engines, (chapter 2.2)**

ENGINE EFFICIENCIES

Thermal efficency

$$\eta_{TH} = \frac{\text{Power imparted to engine airflow}}{\text{Rate of energy supplied in the fuel}}$$

$$\eta_{TH} = \frac{0{,}5 * (\dot{m}_9 {V_{9e}}^2 - \dot{m}_0 {V_0}^2)}{\dot{m}_f FHV}$$

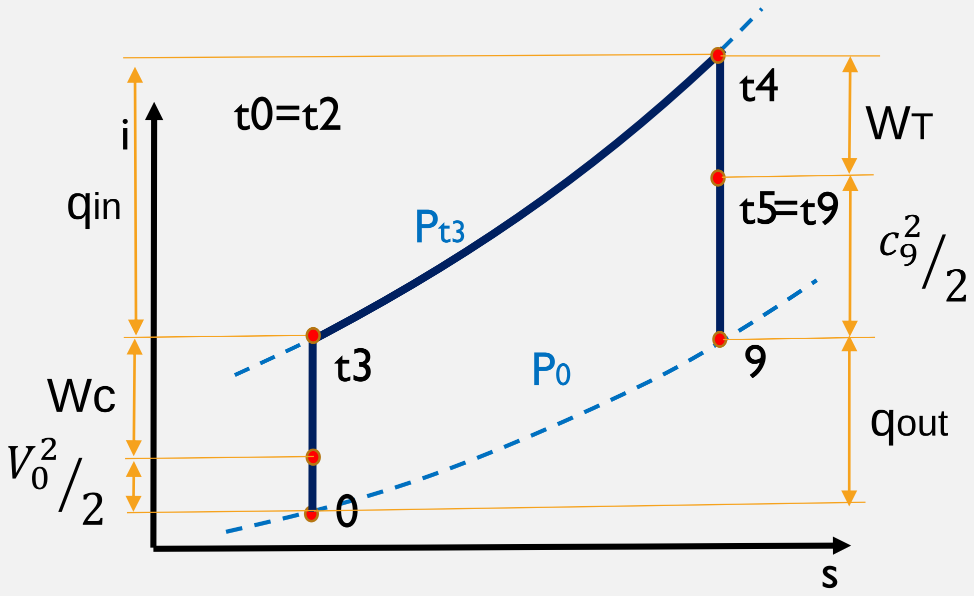
Propulsive efficency

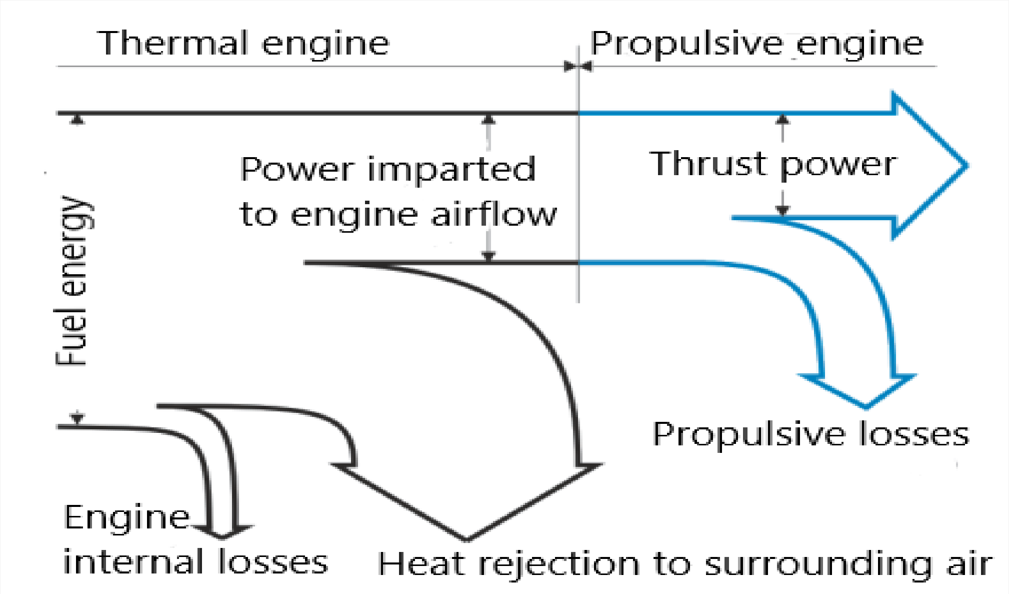
$$\eta_P = \frac{\text{Thrust power}}{\text{Power imparted to engine airflow}}$$

$$\eta_P = \frac{V_0 * T}{0{,}5 * (\dot{m}_9 {V_{9e}}^2 - \dot{m}_0 {V_0}^2)}$$

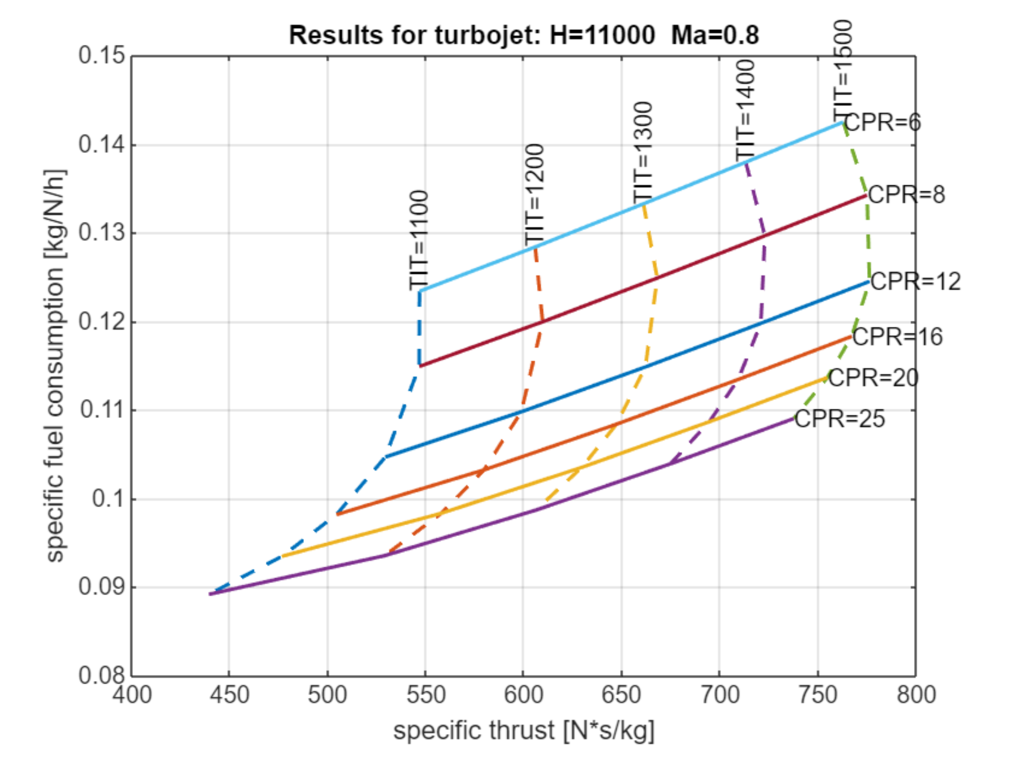
Overall efficency

$$\eta_O = \eta_{TH} * \eta_P = \frac{V_0 * T}{\dot{m}_f FHV}$$





COMPRESSOR PRESSURE RATIO INFLUENCES ON ENGINE PERFORAMANCE

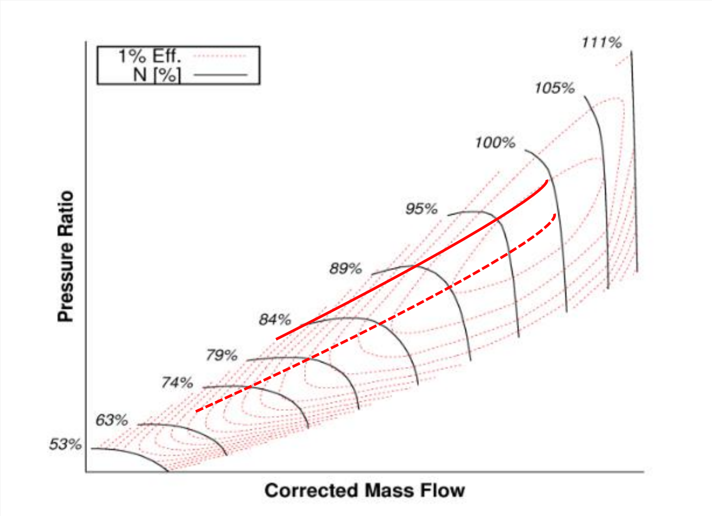


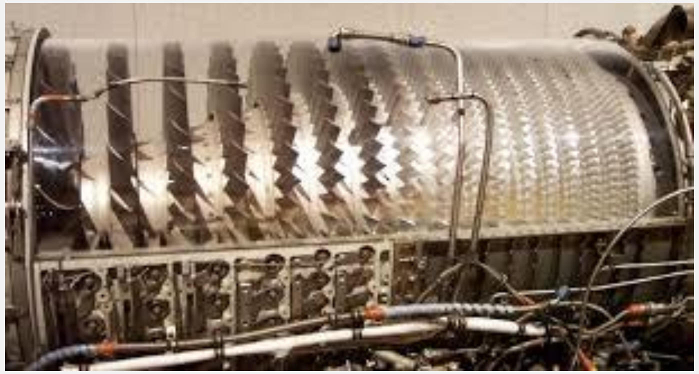
CONCLUSIONS:

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

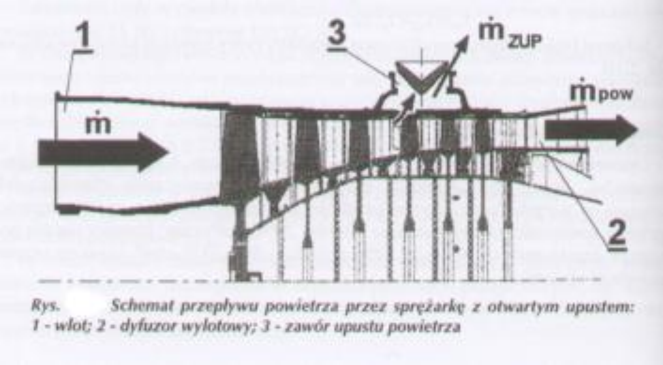
PROBLEMS RELATED TO INCREASING CPR

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

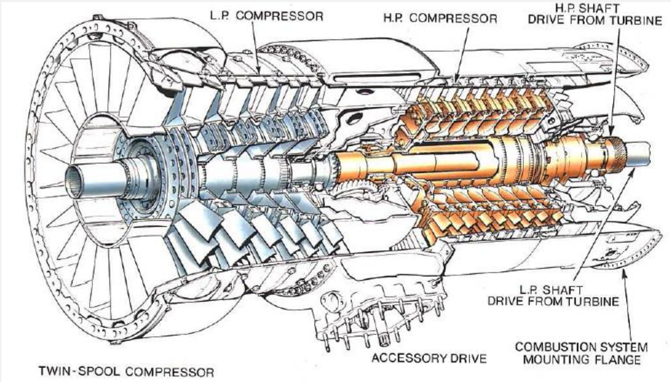




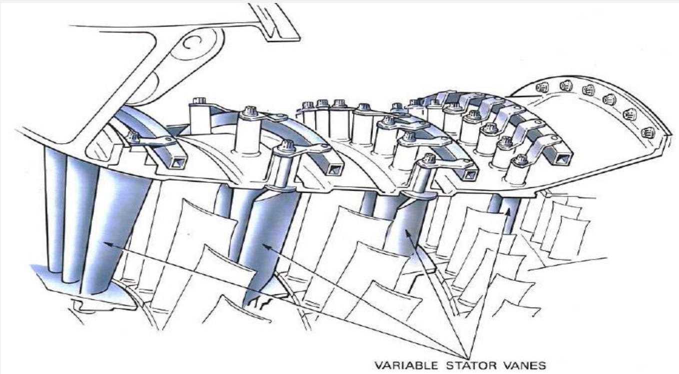
bleed



Split compressor for two rotors

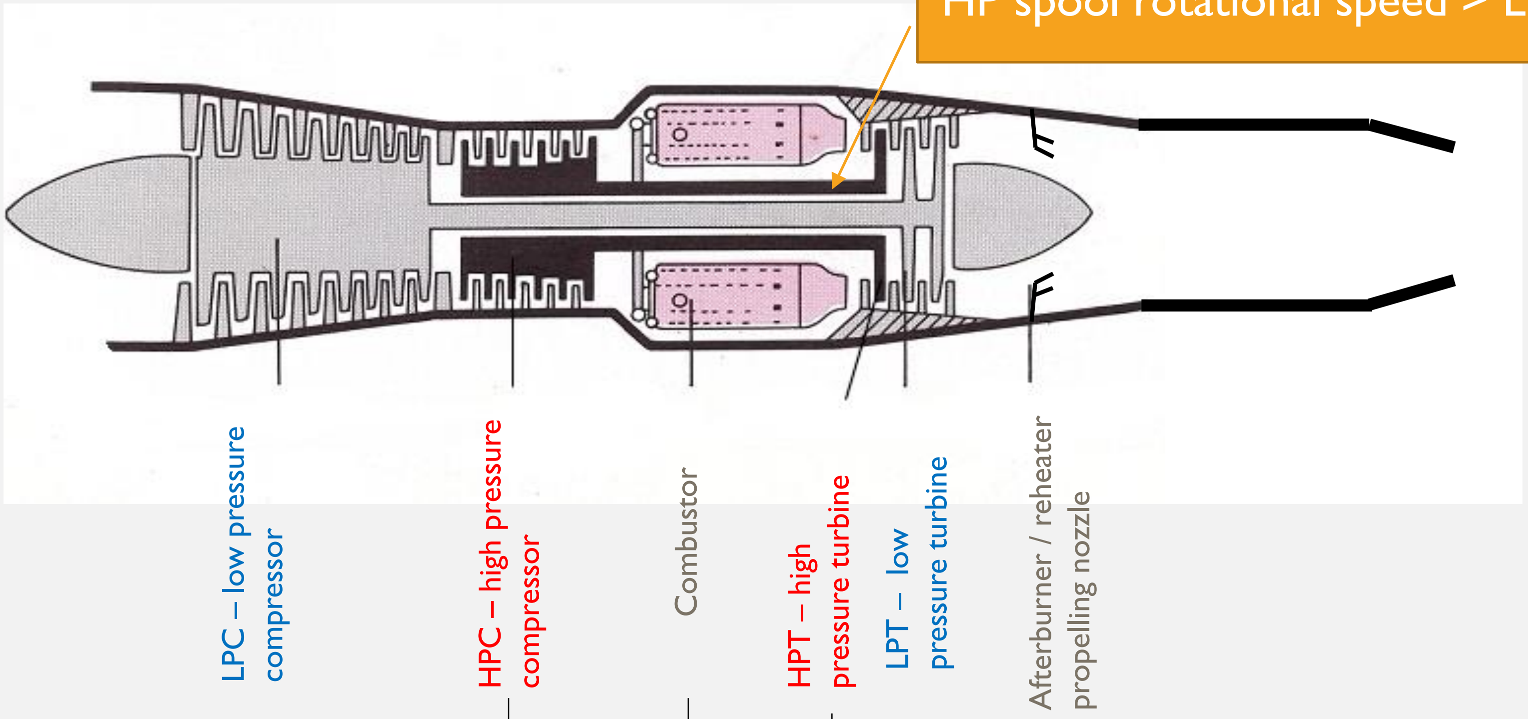


VGV – variable guide vanes



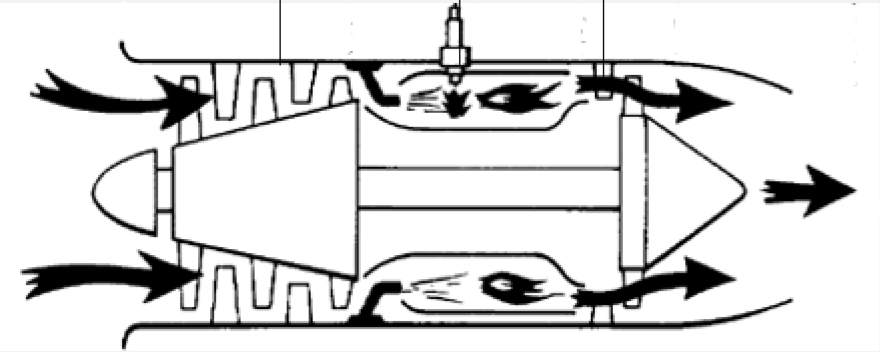
TWO SPOOL TURBOJET ENGINE

HP spool rotational speed > LP spool rotational speed



Two spool turbojet engine with afterburner

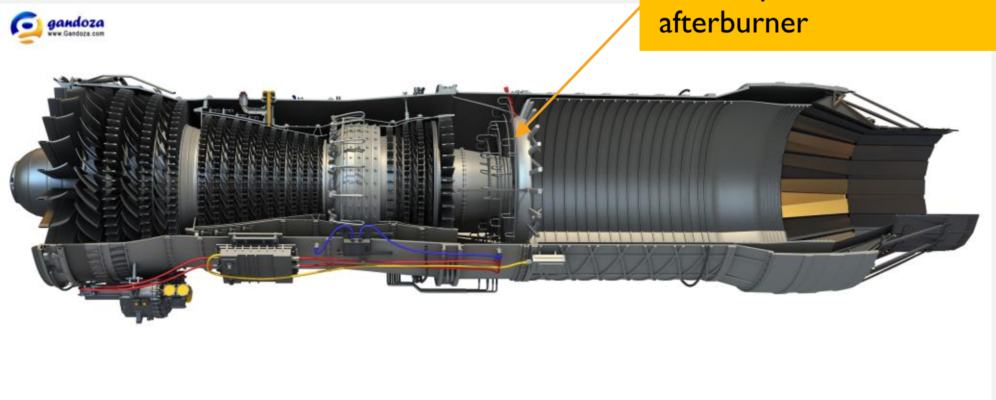
- Higher engine pressure ratio
- Higher engine efficiency
- Higher thrust
- More complex construction



Single spool tutbojet

ENGINE WITH AFTERBURNER

Additional burner and fuel consumption in the afterburner



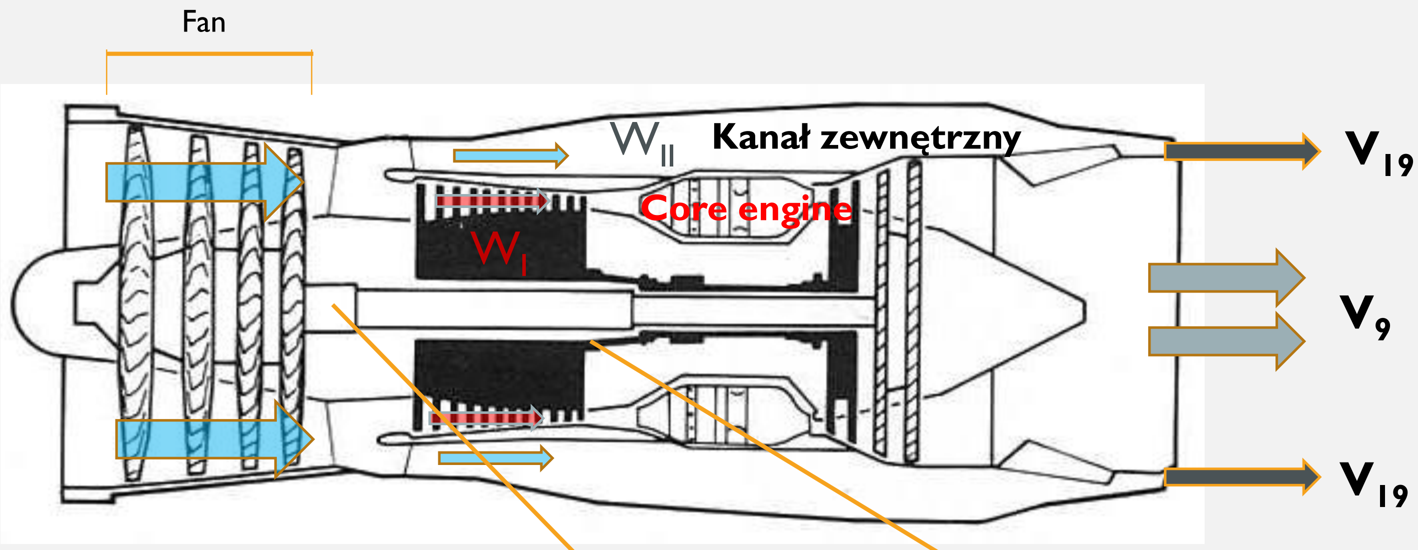
Turning on the afterburner

- 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/(daNh)] (AB OFF)	SFC [kg/(daNh)] (AB ON)
J85-GE-13	12,16	18,14	1,05	2,264
J76-GE-19	52,8	79,6	0,857	2,004
GE4/J5P	229,08	305,15	1,060	1,897
J58-P-4	110,8	151,0	0,816	1,937
Olympus 201R	75,5	106,9	0,816	1,835
Olympus 593	135	170	0,714	1,208

TWO SPOOL BYPASS ENGINE

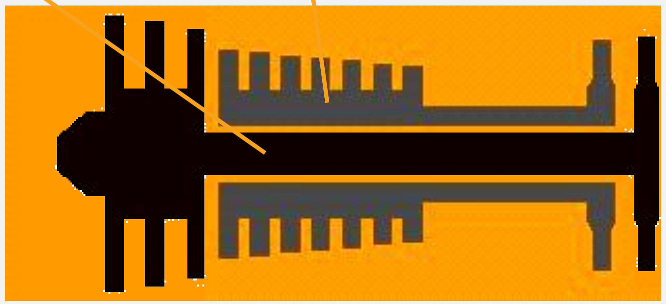


Bypass ratio

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

Fan spool

HP spool



Higher efficiency and lower specific fuel consumption than the turbojet engine

NHP > NLP

BYPASS ENGINES

Midle and high BPR engines

JT15D-5D (Business Jet Aircrfts)

Thrust= 13,54 kN TSFC=0.55 kg/daN/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

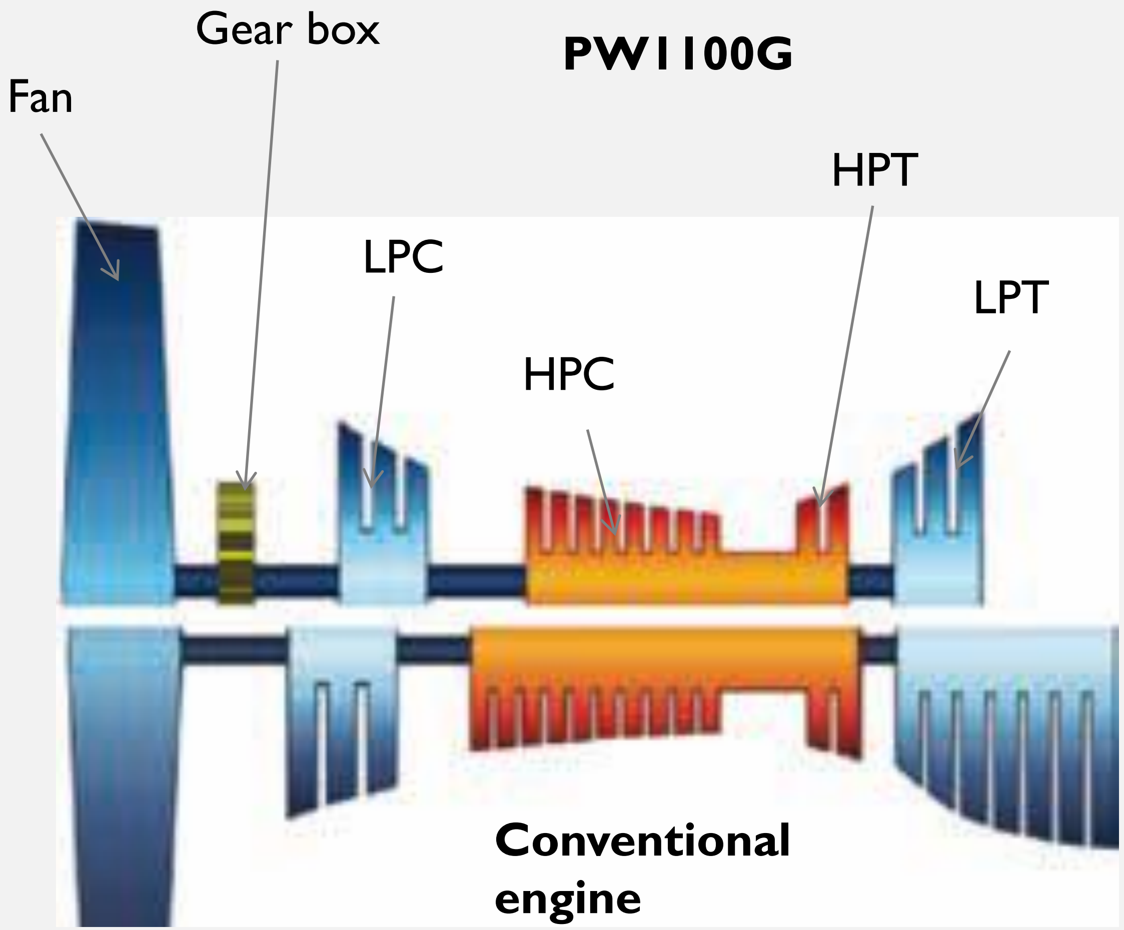
Thrust 143 kN SFC=0.518 kg/daN/h (at cruise)

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

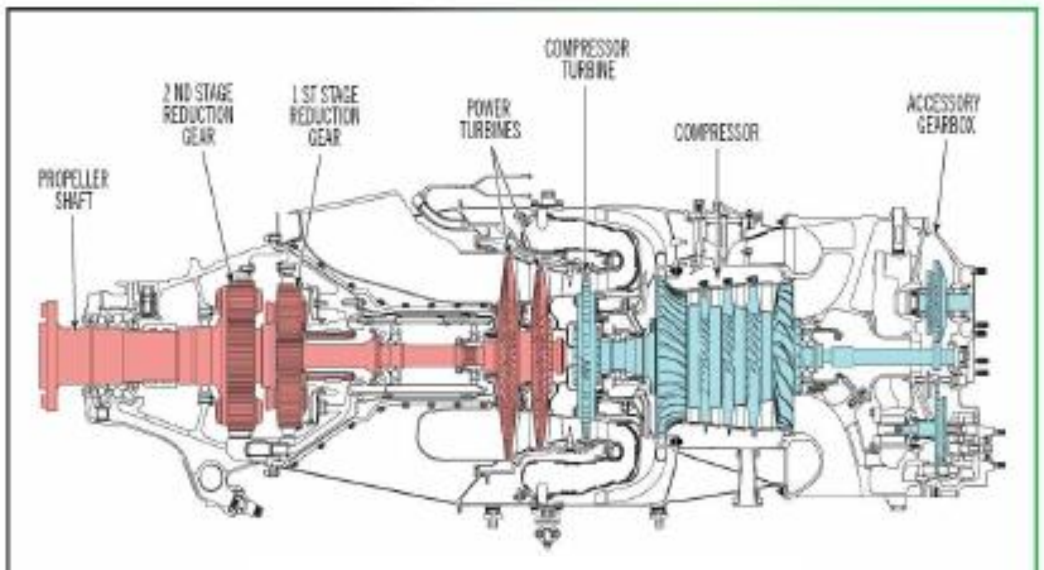
THE BIGEST TURBOFAN ENGINE

GE9x (successor of GE90)

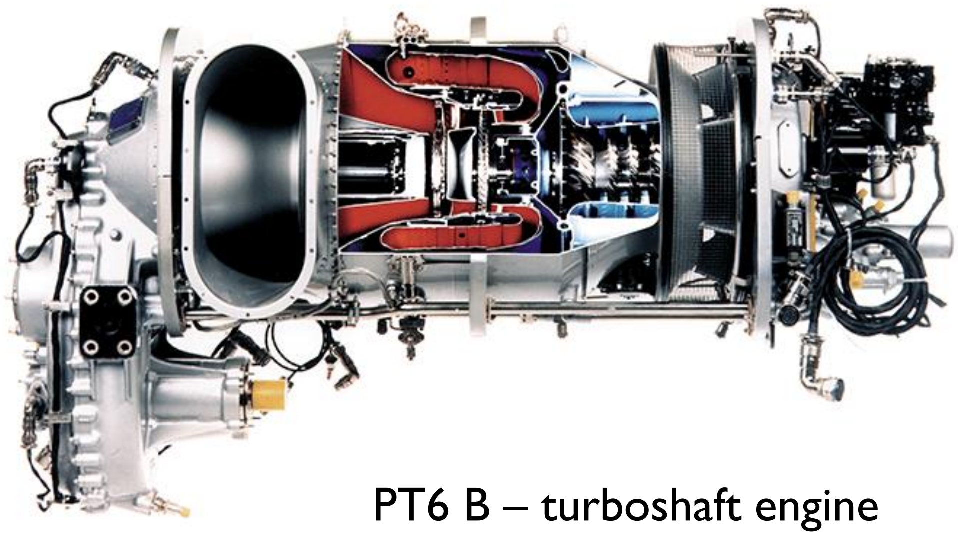
- Fan diameter 340 cm (overall diameter 410 cm)
- Length 569 cm
- Weight 9,6 ton
- Thrust 490 kN

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

TURBOPROP AND TURBOSHAFT ENGINE



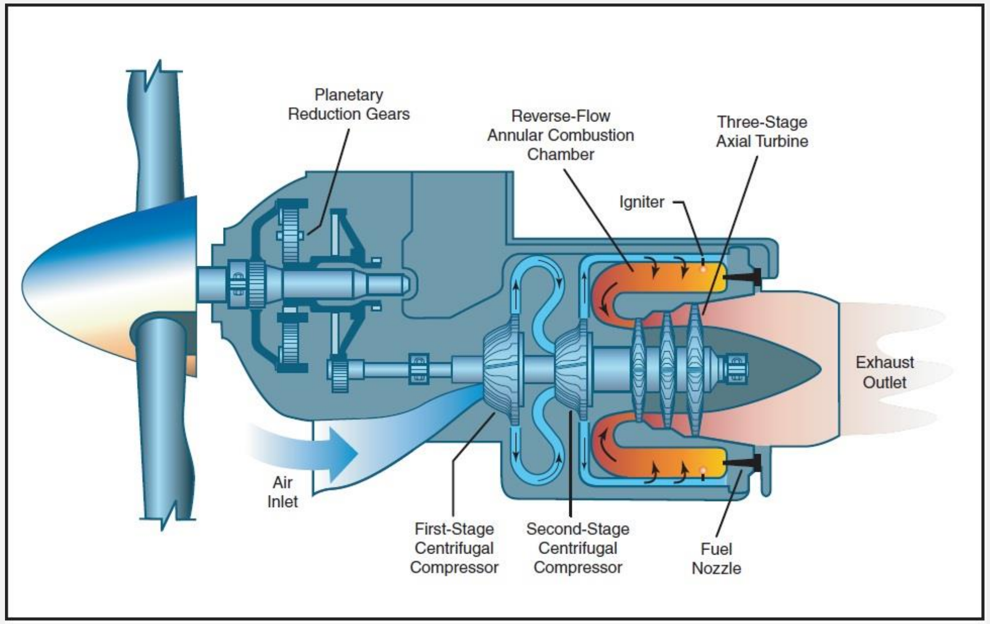
PT6 A – turboprop engine

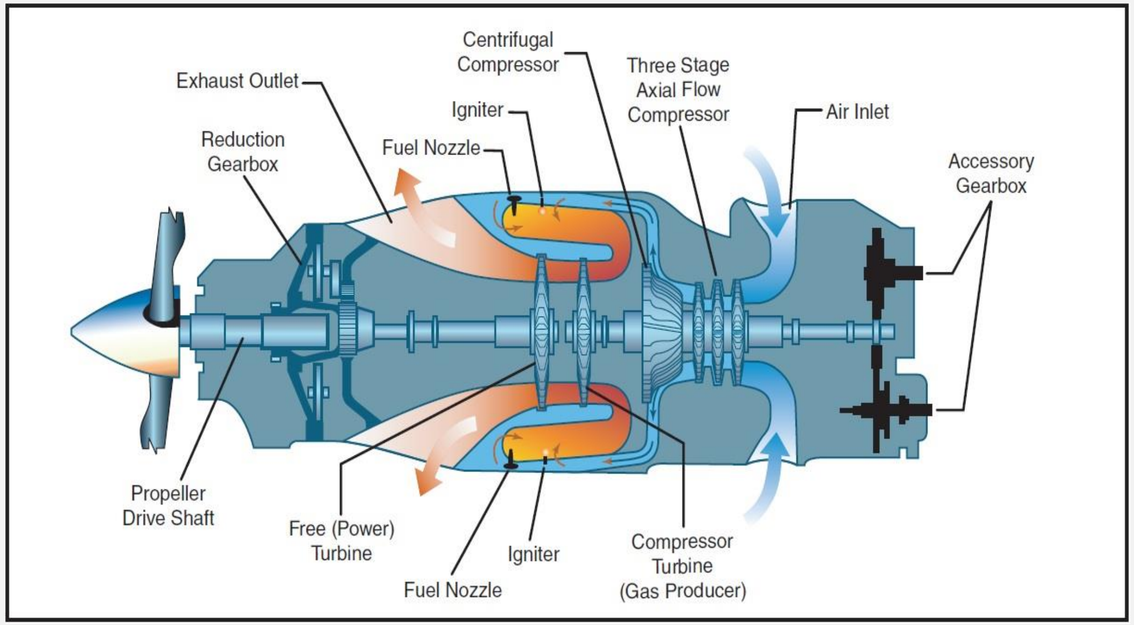


PT6 B – turboshaft engine

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

TURBOPROP PROPULSION SYSTEMS





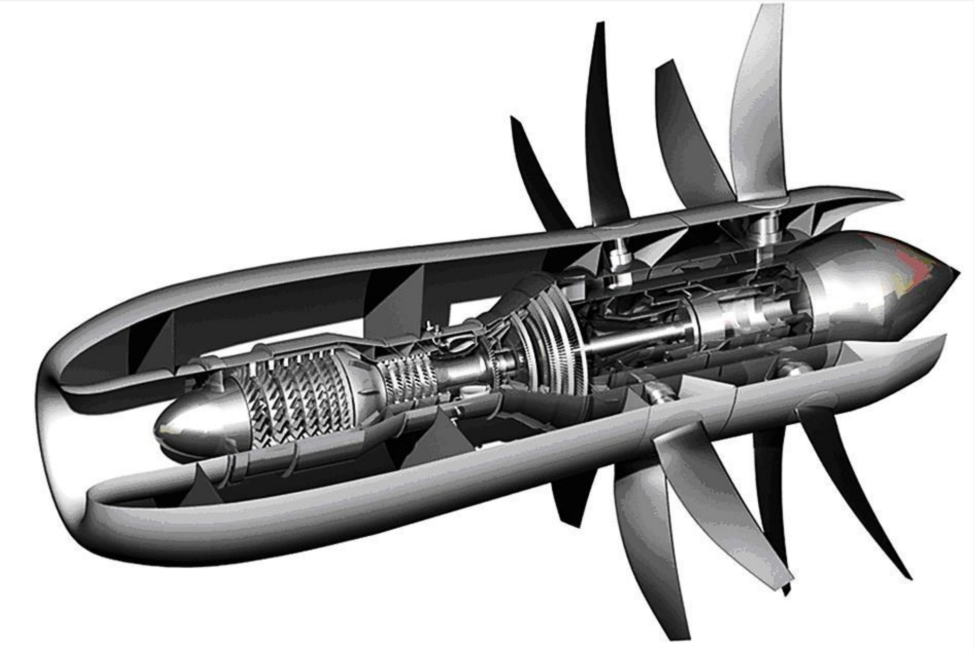
Single spool turboprop

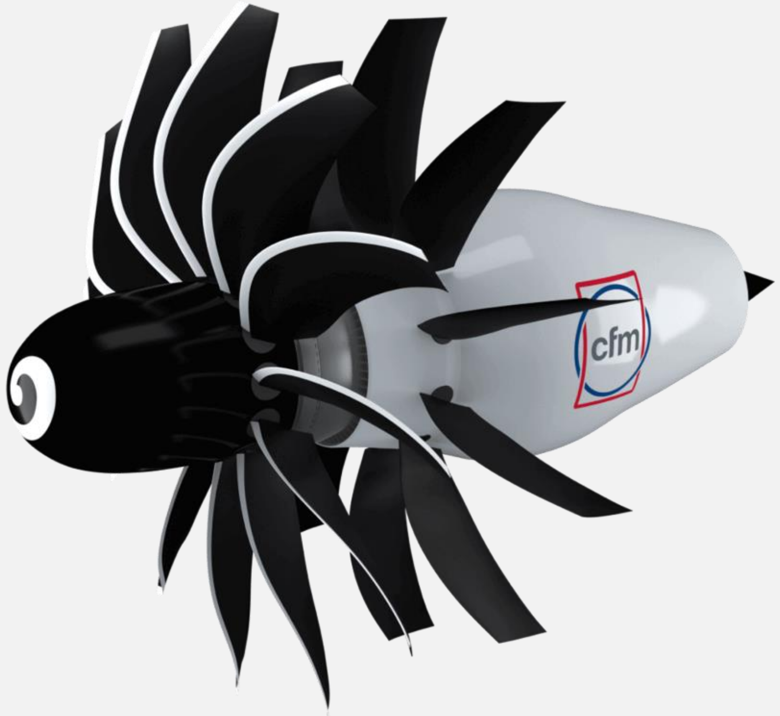
- Simple construction – only one spool.
- The propeller is driven via a reduction gearbox by the same shaft that powers the compressor.

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.

UNDACTED FAN ENGINE





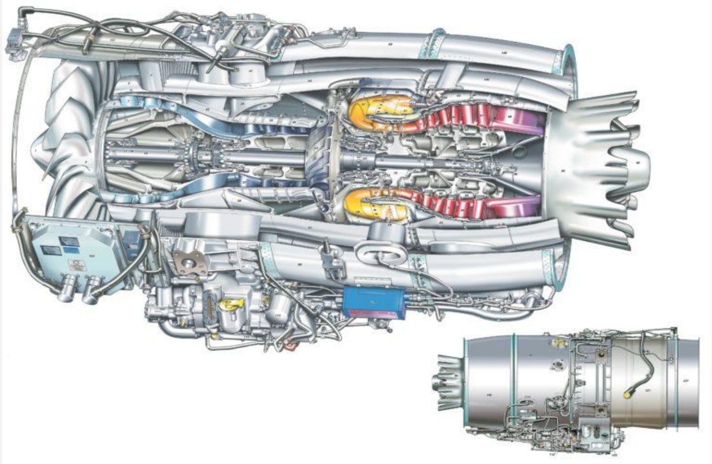
GE36 Open Fan Engine with two sets of exposed, counter-rotating fan blades

- reduced fuel consumption
- Heavy and loud

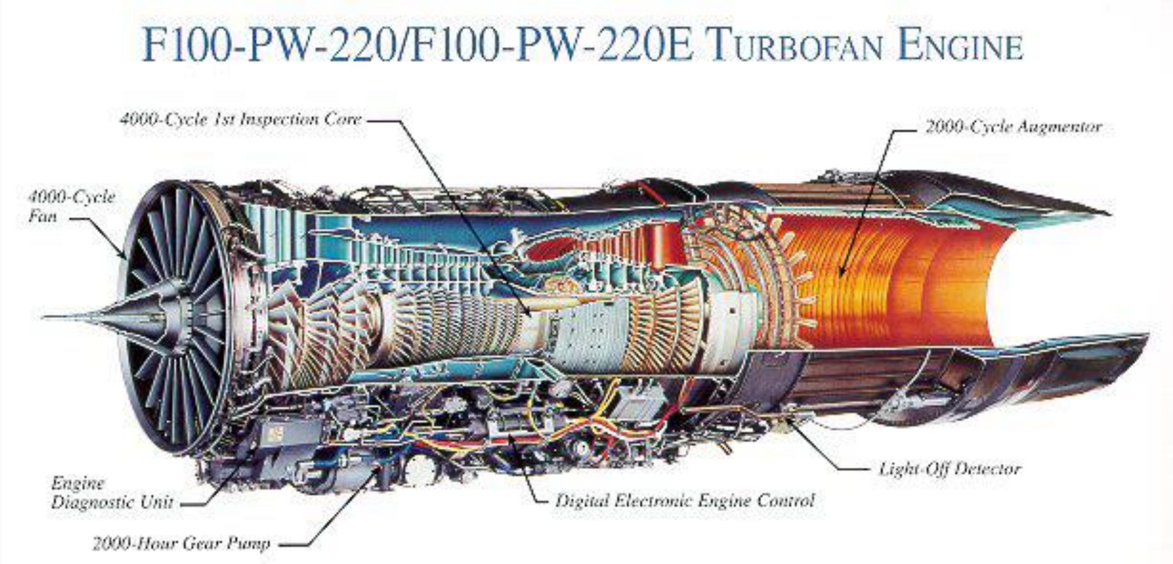
Revolutionary Innovation for Sustainable Engines (RISE)

- 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

BY-PASS ENGINE WITH MIXER STREAMS

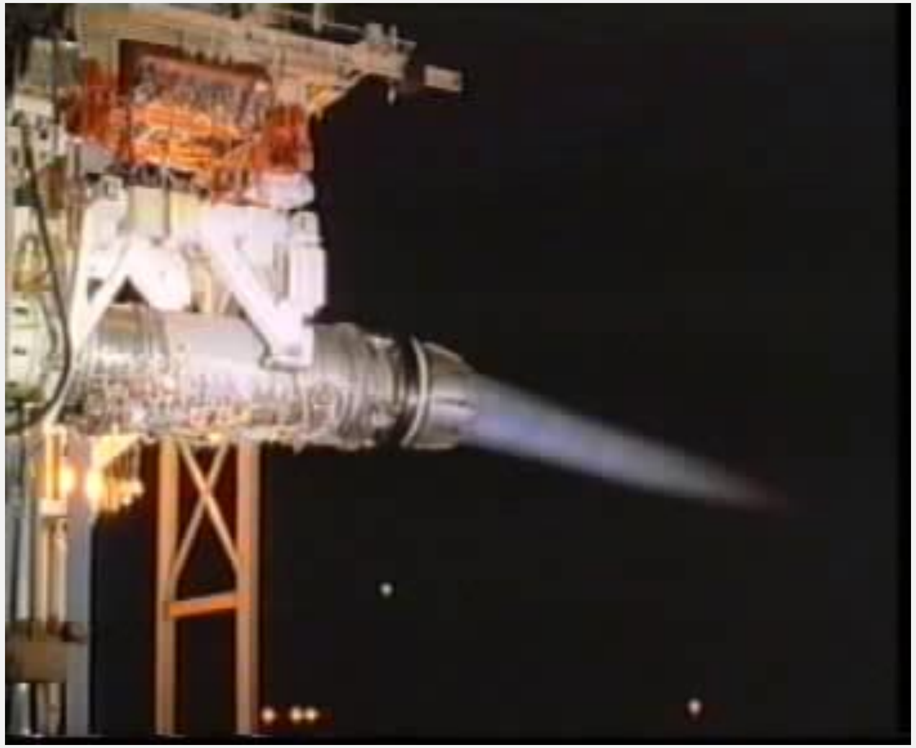


PW-500
Thrust: 18 kN
SFC: 0,4 kg/daN/h
OPR: 13
BPR = 4
Length x diameter 1,74 m x 0,69 m
Application: Cesna Citation - BusinessJet



F100 PW-220
Thrust: 65 kN, **Augmented thrust:** 105,7 kN
SFC 0,77 kg/daN/h **SFC (AB_On):** 1,978 kg/daN/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

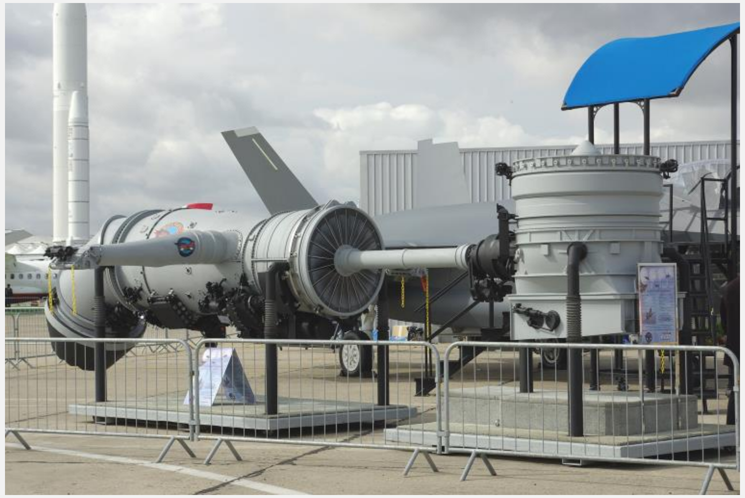
HIGH-MANEUVERING AIRCRAFT (THRUST VEKTORING)



- 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

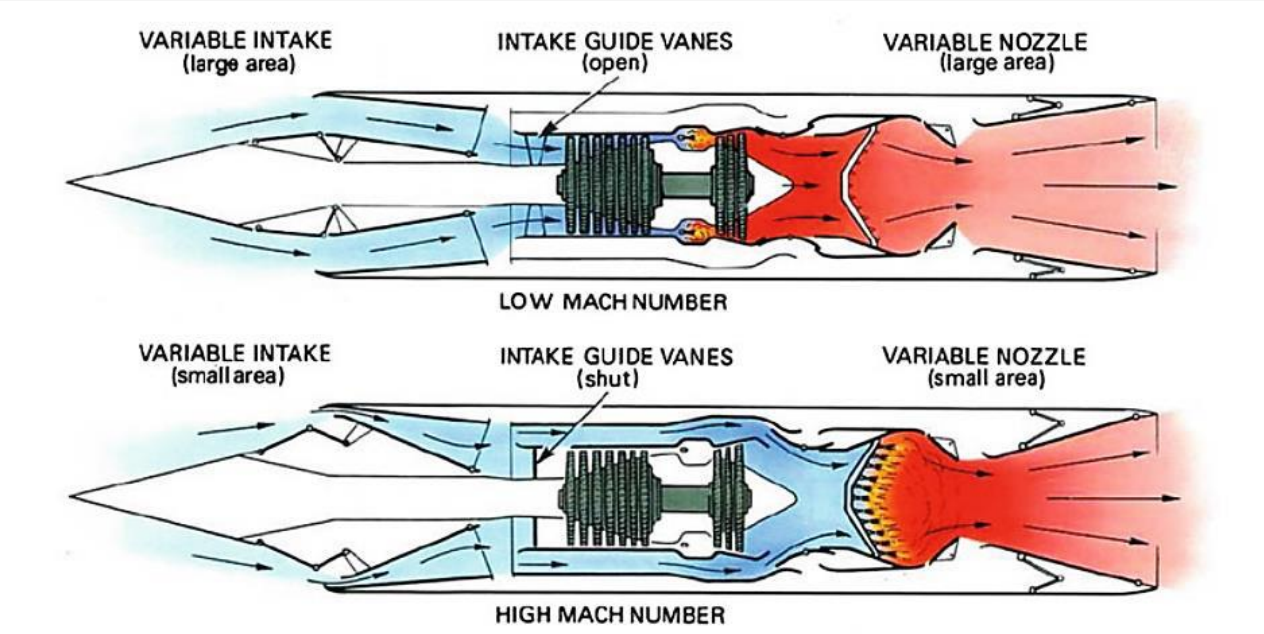


The Rolls-Royce LiftSystem comprises four major components:

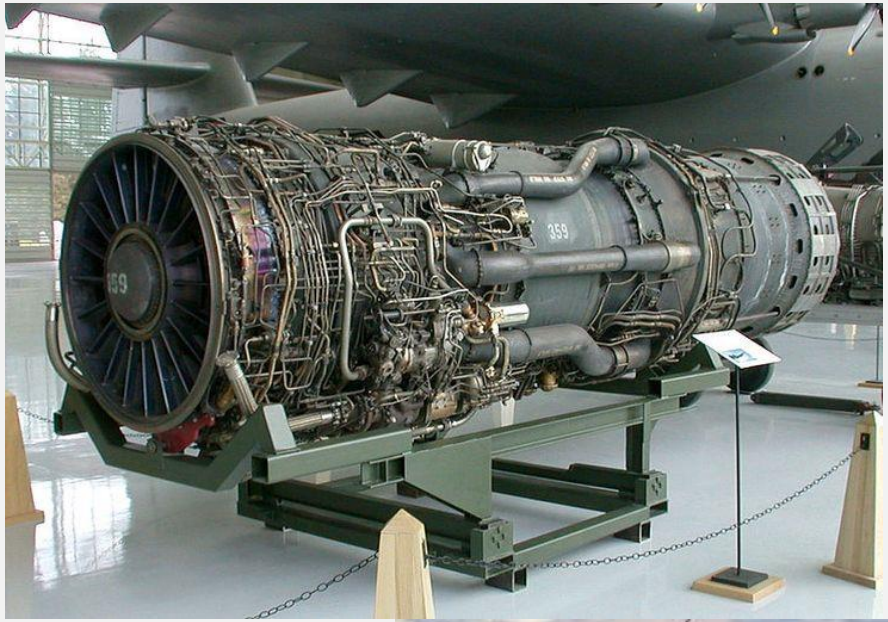
- LiftFan (thrust 80 kN)
- Engine to fan driveshaft
- Three-bearing swivel module (3BSM) (thrust 89 kN)
- Roll posts (two) (thrust 17 kN)

(total thrust (186 kN)

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

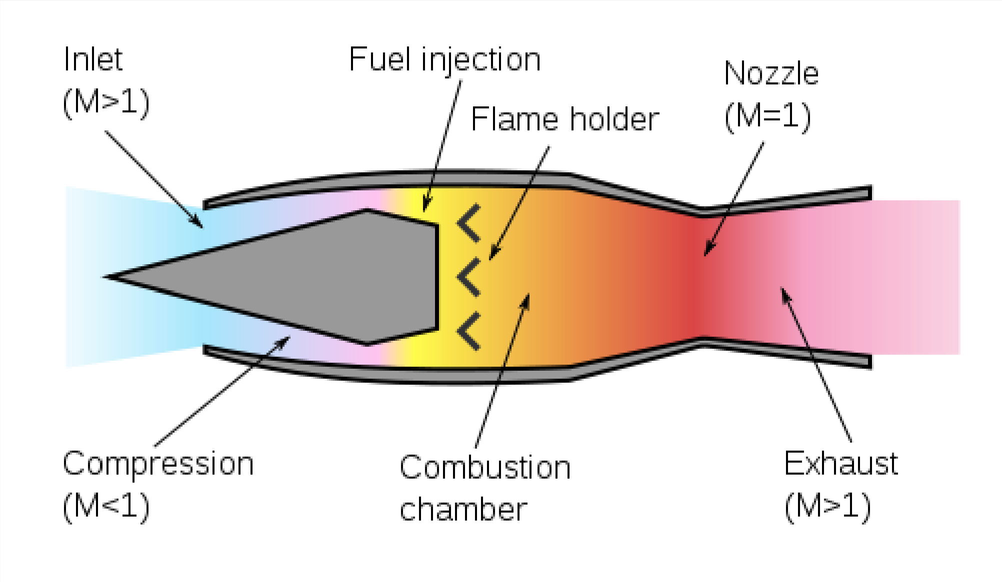


A turbo/ram jet engine.

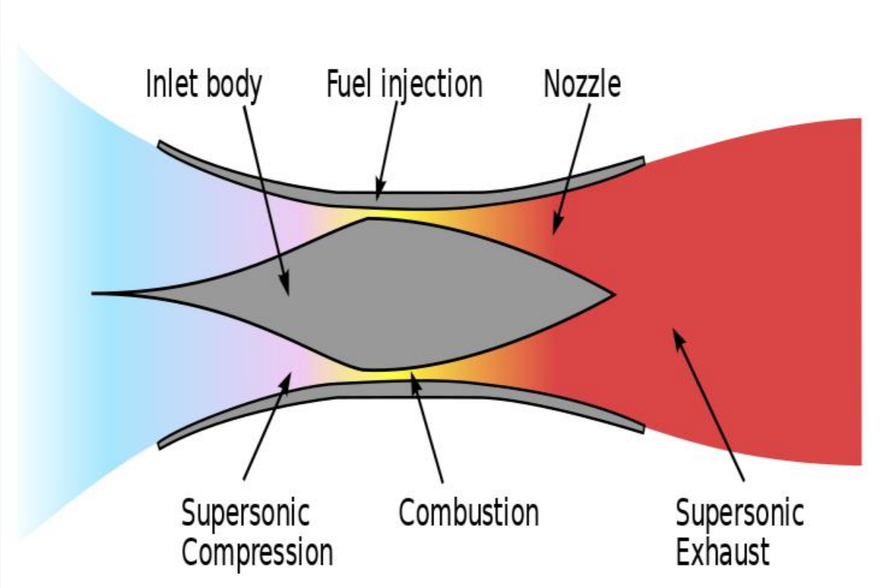


[(520) The Mighty J58 - The SR-71's Secret Powerhouse - YouTube: https://www.youtube.com/watch?v=F3ao5SCedIk](https://www.youtube.com/watch?v=F3ao5SCedIk)

RAMJET AND SCRAMJET



Ramjet - gas flow in combustor is subsonic



Scramjet – gas flow in combustor is supersonic

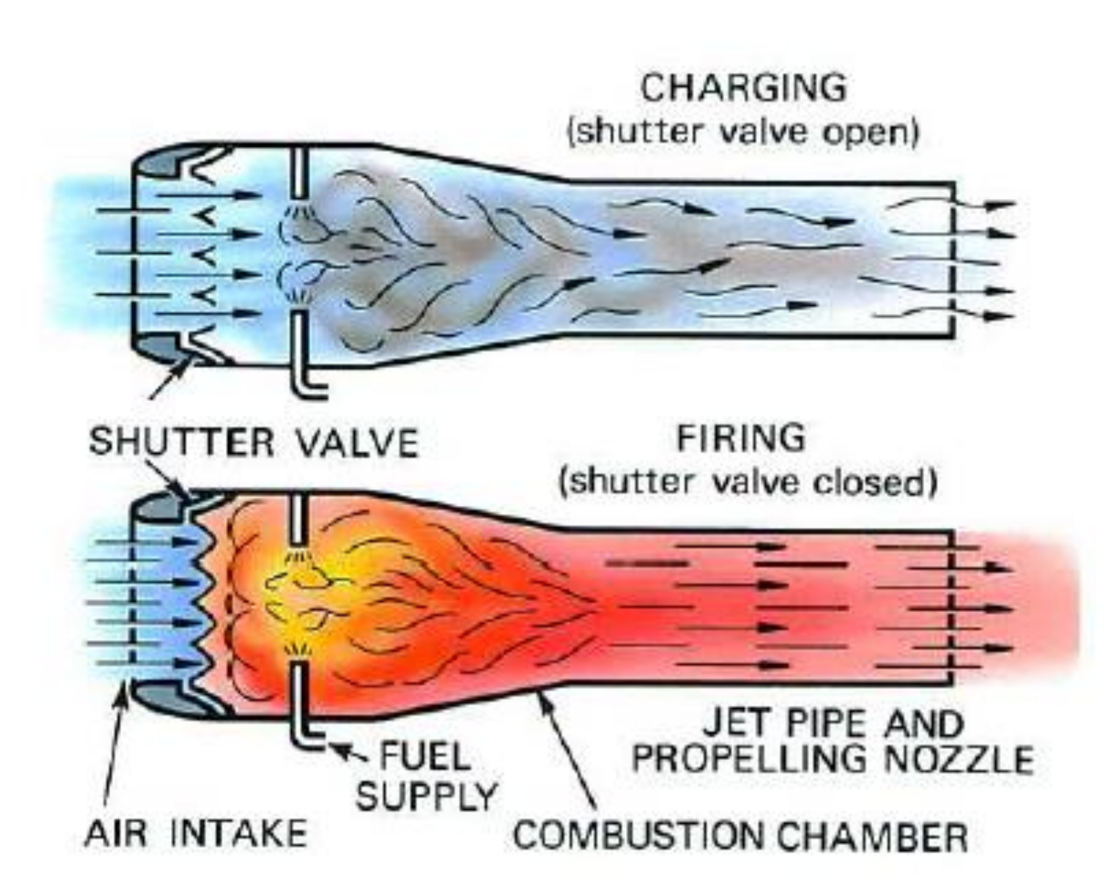
HYPOSED III 7,6 Ma
X-43A achieved speed 9,6 Ma

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

AIRCRAFTS WITH TURBOPROP PROPULSION SYSTEM AND HELICOPTERS

Flying ship	Engine	Engine shaft power [kW]	MTOW [kg]	Power/MTOW [kW/kg]
Eurocopter EC135	Arius 2B2	2x439	2900	0,3
SW-4	RR 250 C20R/2	336	1800	0,18
UH-60 Black Hawk	GE T700-GE-700	2x1165	3600	0,65
Harbin Z-19	WZ-8C	2x700	4250	0,33
Ka-27	Isotov TV3-117V	2x1660	12000	0,27
M28B Bryza	P&W PT6A-65B	2x820	7500	0,21
Bombardier Q400	PW 150 A	2*3750	29260	0,26
ATR 72-200	PW 124B	2*1880	22000	0,17

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.

ENGINES PERFORMANCE PARAMETERS COMPARISON

	Ciąg jednostkowy [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/s]

LITERATURE

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THANKS FOR YOUR ATENTION

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