MATERIALE DI SUPPORTO FONDAMENTI DI PROPULSIONE AERONAUTICA

Thrust

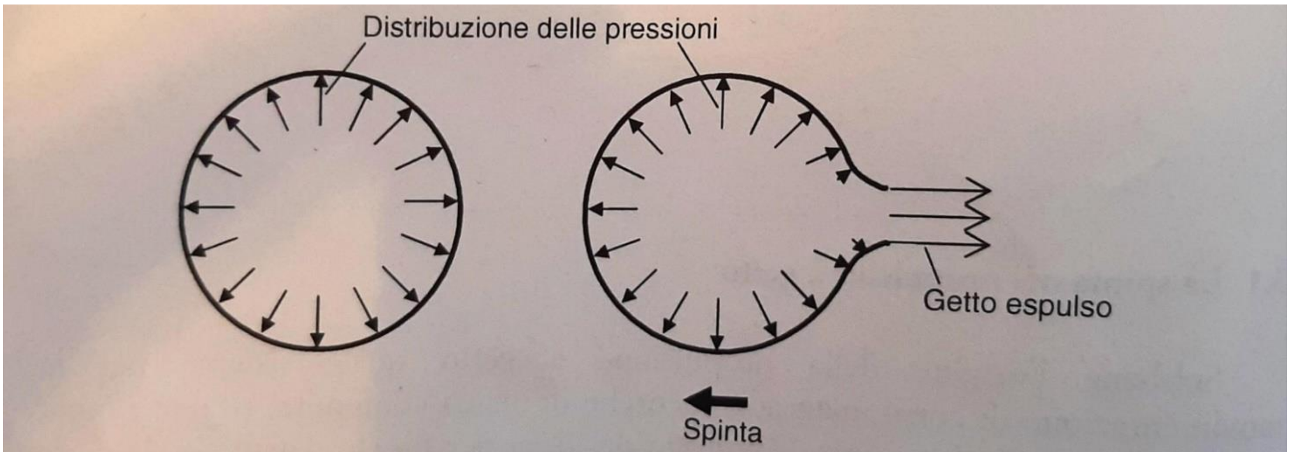


Figura 3.1 – Distribuzione delle pressioni in un recipiente in quiete (a sinistra) e in uno forato (a destra).

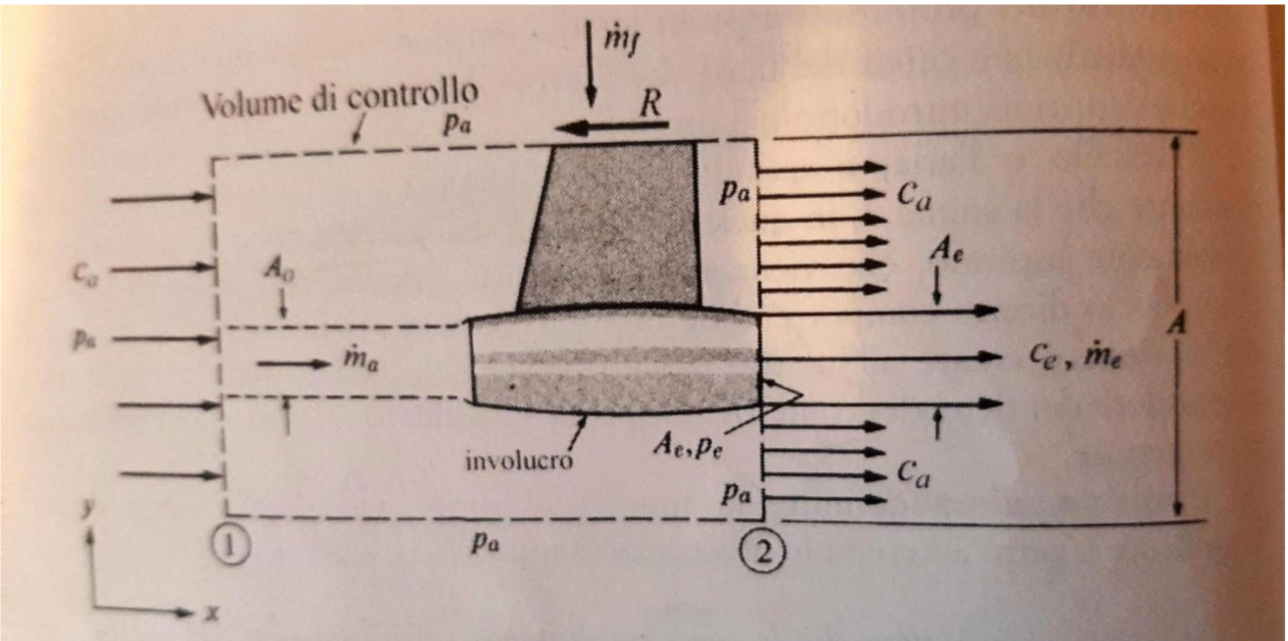
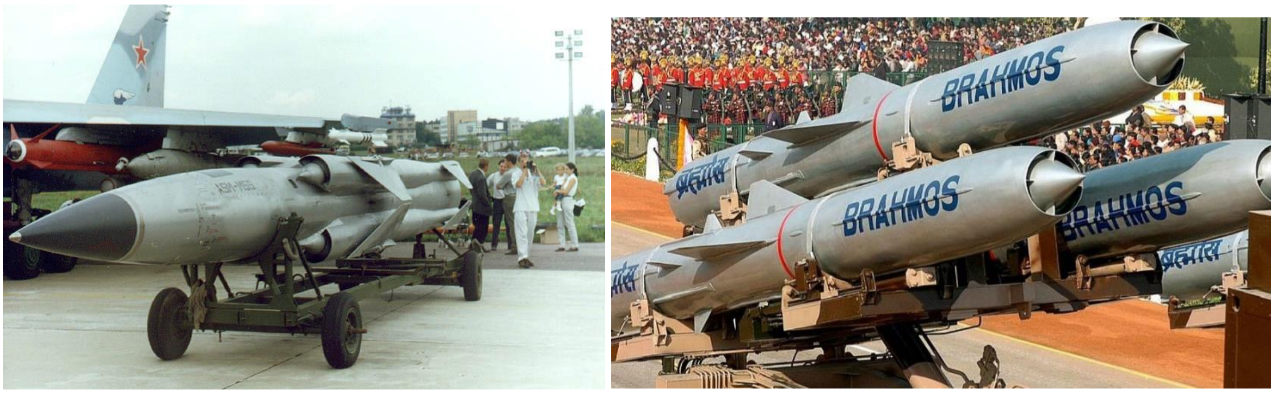


Figura 3.2 – Modello di riferimento per il calcolo della spinta in un propulsore aspirato (adattata da Hill – Peterson).

$$T = (\dot{m}_a + \dot{m}_f)V_e - \dot{m}_a V_0 + (p_e - p_a)A_e$$

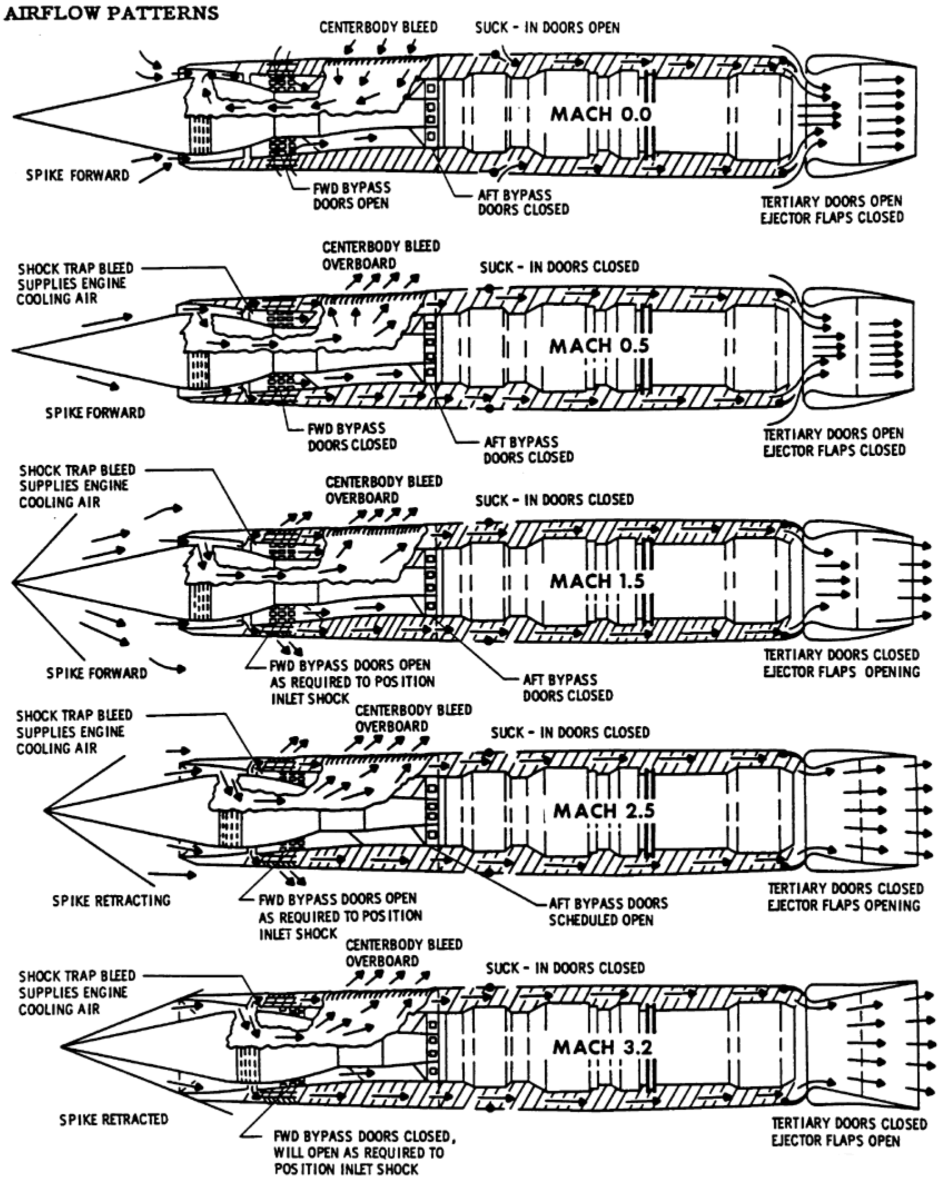
$$T \approx \dot{m}_a (V_e - V_0) + (p_e - p_a)A_e$$

Ramjet



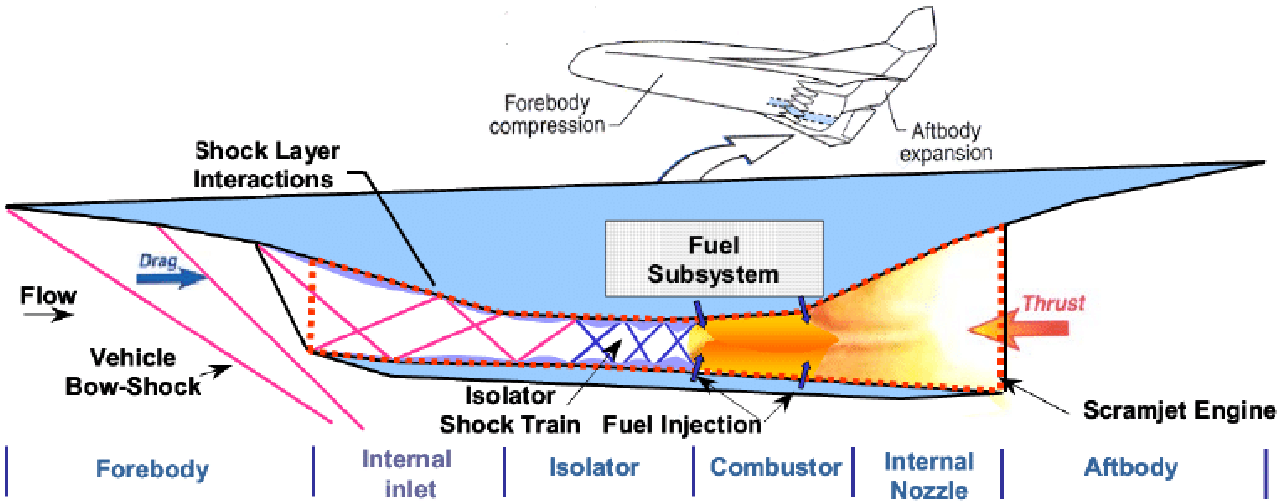
P-270 Moskit (left), BrahMos (right)

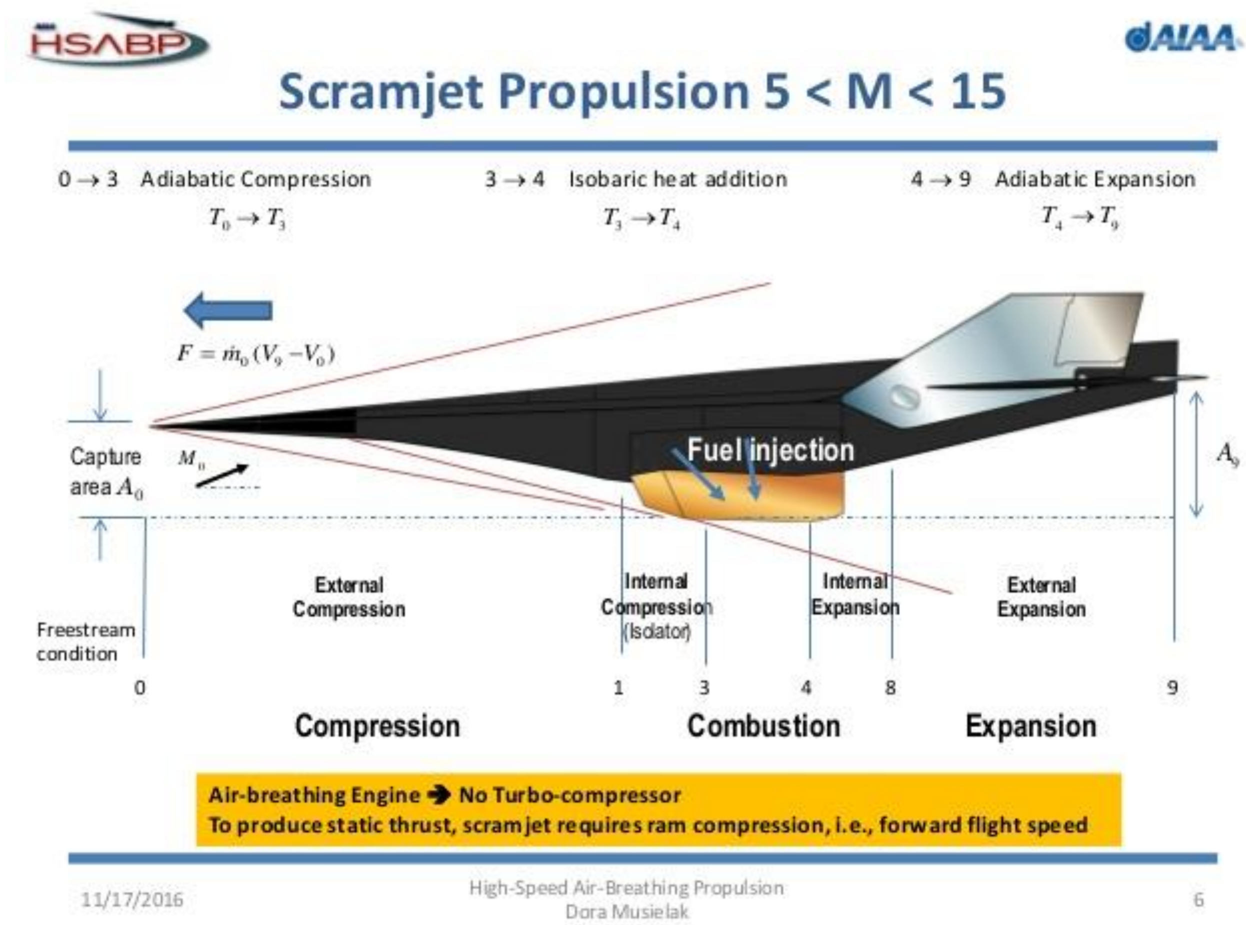
Turboramjet



Pratt & Whitney J-58 turbo(ram)jet

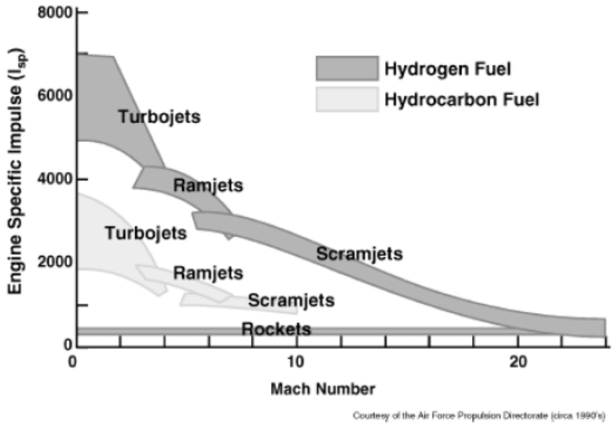
Scramjet

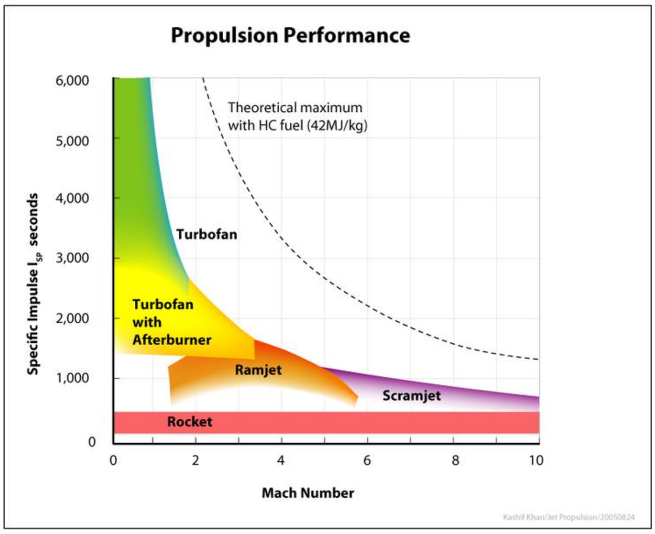

Forebody compression
Aftbody expansion
Shock Layer Interactions
Fuel Subsystem
Drag
Flow
Thrust
Vehicle Bow-Shock
Isolator Shock Train
Fuel Injection
Scramjet Engine
Forebody
Internal inlet
Isolator
Combustor
Internal Nozzle
Aftbody

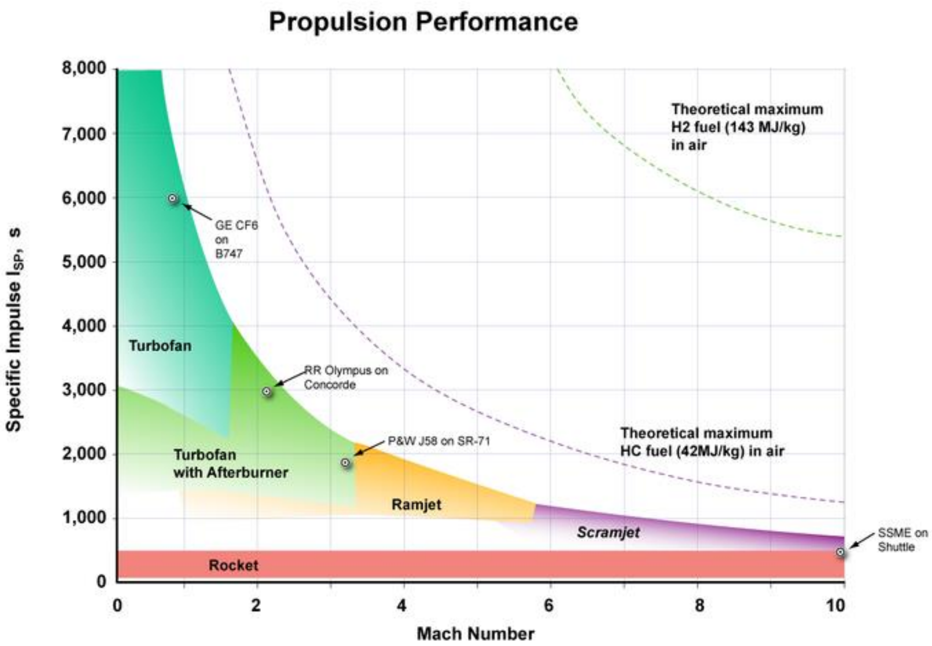

HSABP
AIAA
Scramjet Propulsion 5 < M < 15
0 → 3 Adiabatic Compression
$T_0 \to T_3$
3 → 4 Isobaric heat addition
$T_3 \to T_4$
4 → 9 Adiabatic Expansion
$T_4 \to T_9$
$F = \dot{m}_0 (V_9 - V_0)$
Capture area A_0
M_0
A_9
Fuel injection
Freestream condition
External Compression
Internal Compression (Isolator)
Internal Expansion
External Expansion
0
1
3
4
8
9
Compression
Combustion
Expansion
Air-breathing Engine → No Turbo-compressor
To produce static thrust, scramjet requires ram compression, i.e., forward flight speed
11/17/2016
High-Speed Air-Breathing Propulsion
Dora Musielak
6

Specific impulse

$$Isp = \frac{T}{\dot{m}_p g_0} = \frac{V_e}{g_0} \quad [s] \quad rockets \qquad Isp = \frac{T}{\dot{m}_f g_0} = \frac{\dot{m}_p}{\dot{m}_f}\frac{V_e - V_0}{g_0} \quad [s] \quad air\ breathing$$

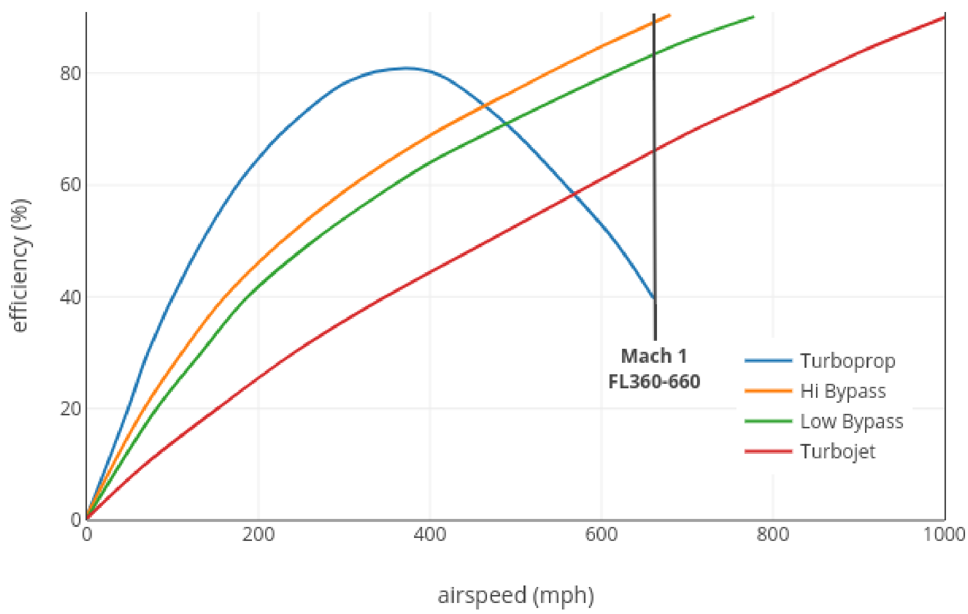




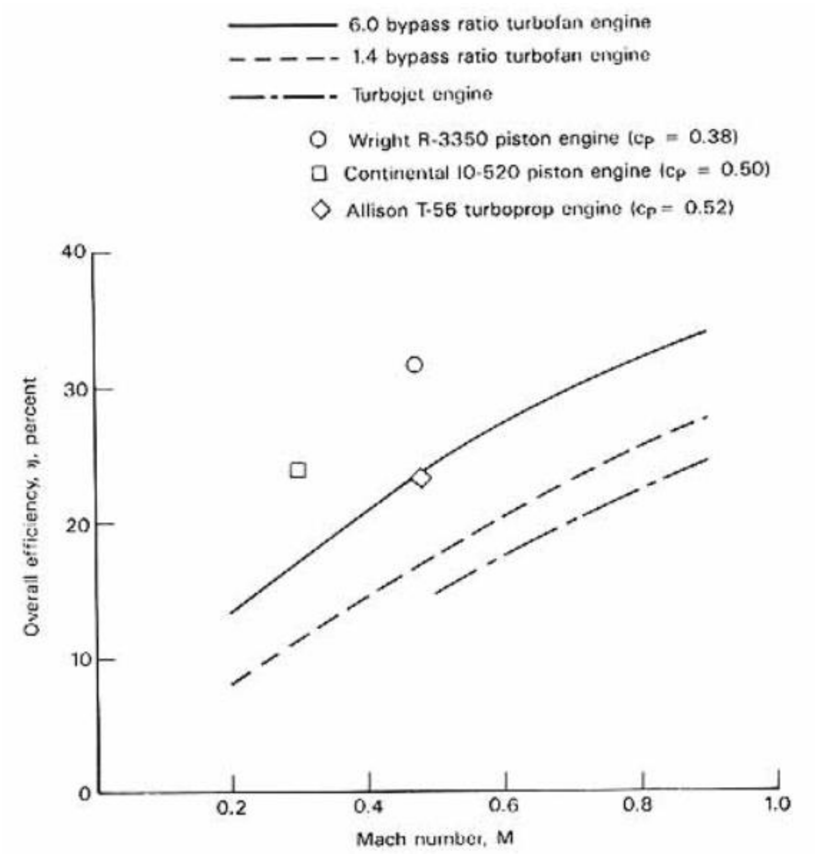


Propulsive efficiency

Propulsive efficiency comparison for various gas turbine engine configurations



Overall efficiency



Overall efficiency with Mach number

Engine bypass ratios

Engine Name	Major applications	Bypass ratio
turbojet	early jet aircraft, Concorde	0.0
SNECMA M88	Rafale	0.30
GE F404	F/A-18, T-50, F-117	0.34
PW F100	F-16, F-15	0.36
Eurojet EJ200	Typhoon	0.4
Klimov RD-33	MiG-29, Il-102	0.49
Saturn AL-31	Su-27, Su-30, J-10	0.59
Kuznetsov NK-144A	Tu-144	0.6
PW JT8D	DC-9, MD-80, 727, 737 Original	0.96
Soloviev D-20P	Tu-124	1.0
Kuznetsov NK-321	Tu-160	1.4
GE Honda HF120	HondaJet	2.9
RR Tay	Gulfstream IV, F70, F100	3.1
GE CF6-50	A300, DC-10-30,Lockheed C-5M Super Galaxy	4.26
PowerJet SaM146	SSJ 100	4.43
RR RB211-22B	TriStar	4.8
PW PW4000-94	A300, A310, Boeing 767, Boeing 747-400	4.85
Progress D-436	Yak-42, Be-200, An-148	4.91
GE CF6-80C2	A300-600, Boeing 747-400, MD-11, A310	4.97-5.31
RR Trent 700	A330	5.0
PW JT9D	Boeing 747, Boeing 767, A310, DC-10	5.0

Engine Name	Major applications	Bypass ratio
CFM56-7B	737	5.1-5.5
CFM56-5B	A318, A319, A320, A321	5.4-6.0
Progress D-18T	An-124, An-225	5.6
PW PW2000	757, C-17	5.9
RR Trent 500	A340-500/600	7.6
GE TF39	Lockheed C-5 Galaxy	8.0
Aviadvigatel PD-14	Irkut MC-21	8.5
RR Trent 900	A380	8.7
GE GE90	777	8.4-9
CFM International LEAP-1B	737 MAX	9.0
RR Trent XWB	A350	9.3
GE GEnx	747-8, 787	9.6
GE9X	777X	10.0
RR Trent 1000	787	10.0
RR Trent 7000	A330neo	10.0
CFM International LEAP-1A, 1C	Airbus A320neo, COMAC C919	11.0
PW PW1500G	Airbus A220	12.0
PW PW1100G	Airbus A320neo	12.5
Kuznetsov NK-93	Ilyushin Il-76LL testbed aircraft	16.6
General Electric GE36	Boeing 727, McDonnell Douglas MD-81 testbed aircraft	35
PW-Allison 578-DX	McDonnell Douglas MD-81 testbed aircraft	56

Engine Name	Major applications	Bypass ratio
PWC PT6 / PWC PW100 turboprops[3]	Super King Air / ATR 72	50-60

Thrust coefficient

$$C_F = \frac{T}{p_c A_t} = \frac{\dot{m}V_e + (p_e - p_a)A_e}{p_c A_t}$$

$$T = p_c A_t C_F = \dot{m} c^* C_F \qquad c^* = c^*(RT^0, k)$$

$$C_F = \sqrt{\frac{2}{k-1}\left(\frac{2}{k+1}\right)\left[1-\left(\frac{p_e}{p_c}\right)^{(k-1)/k}\right]} + \frac{p_e - p_a}{p_c}\frac{A_e}{A_t}$$

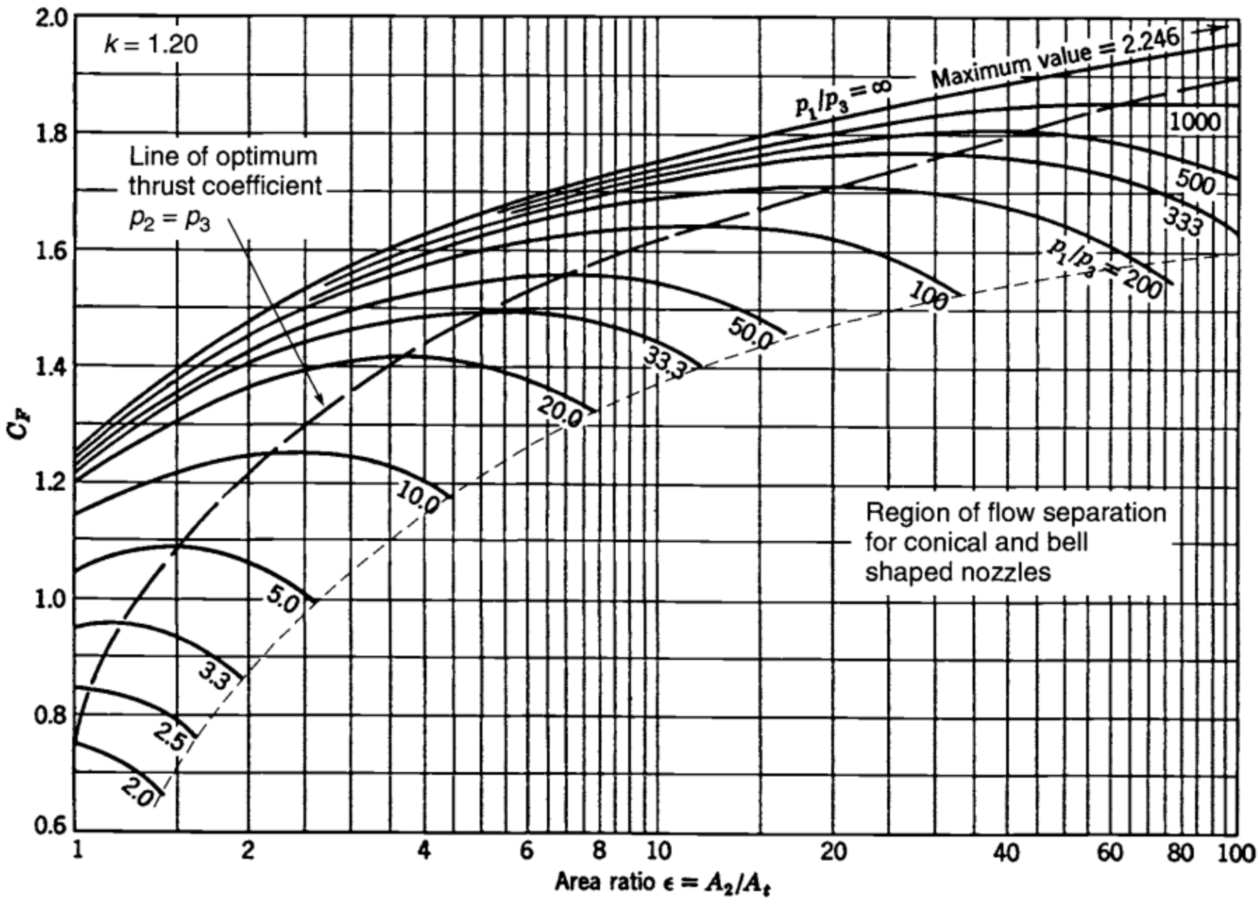
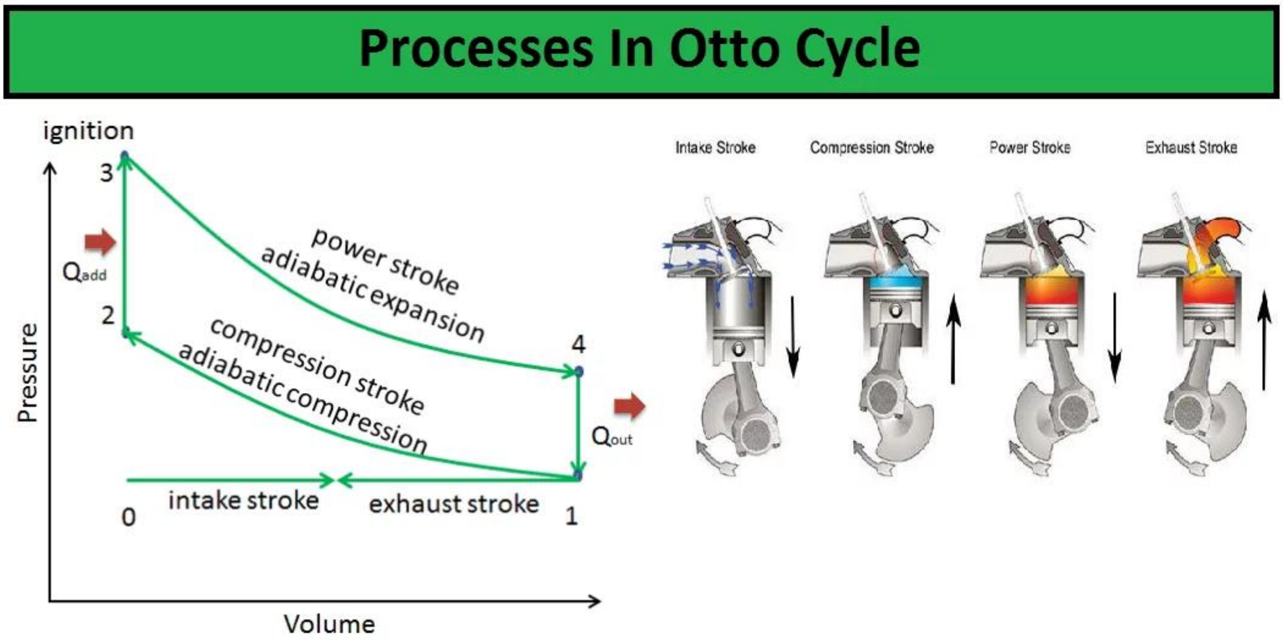
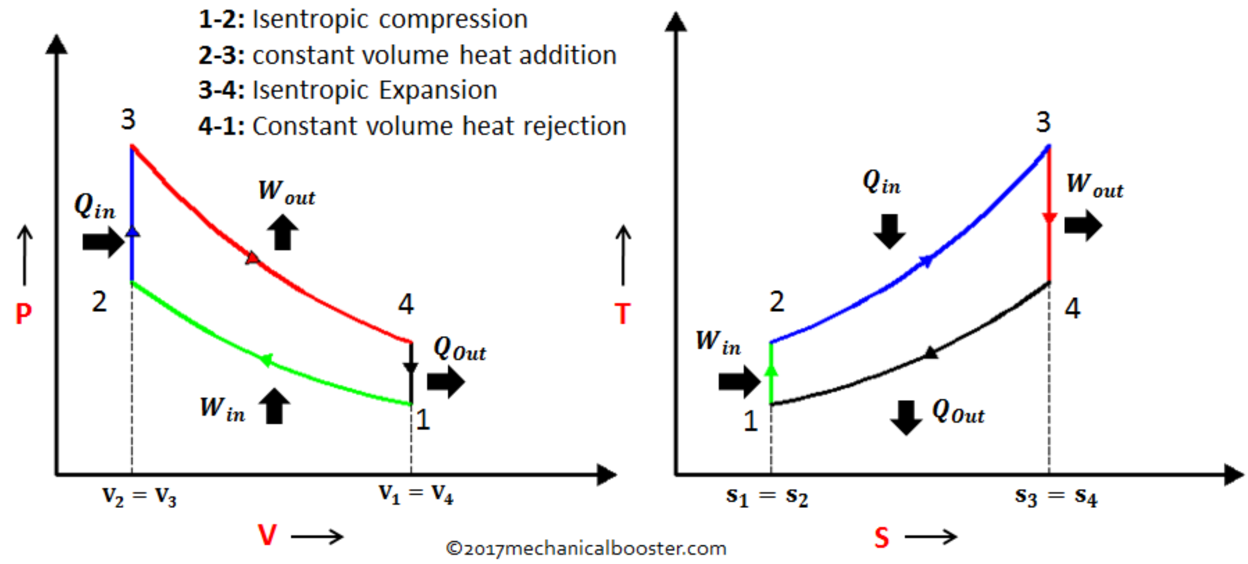


FIGURE 3–7. Thrust coefficient C_F versus nozzle area ratio for $k = 1.20$.

Otto cycle



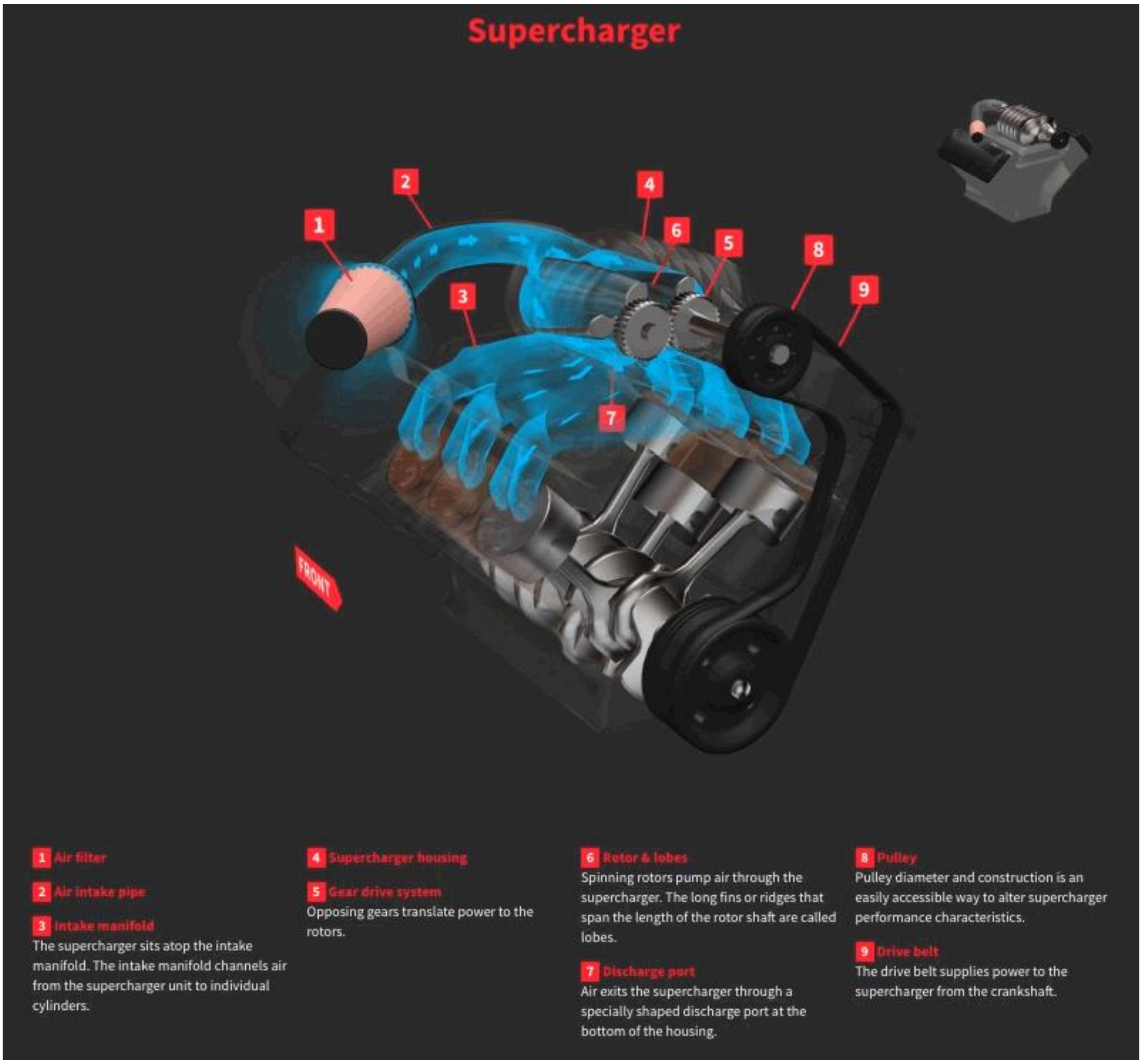


P-V and T-S Diagram of Otto Cycle

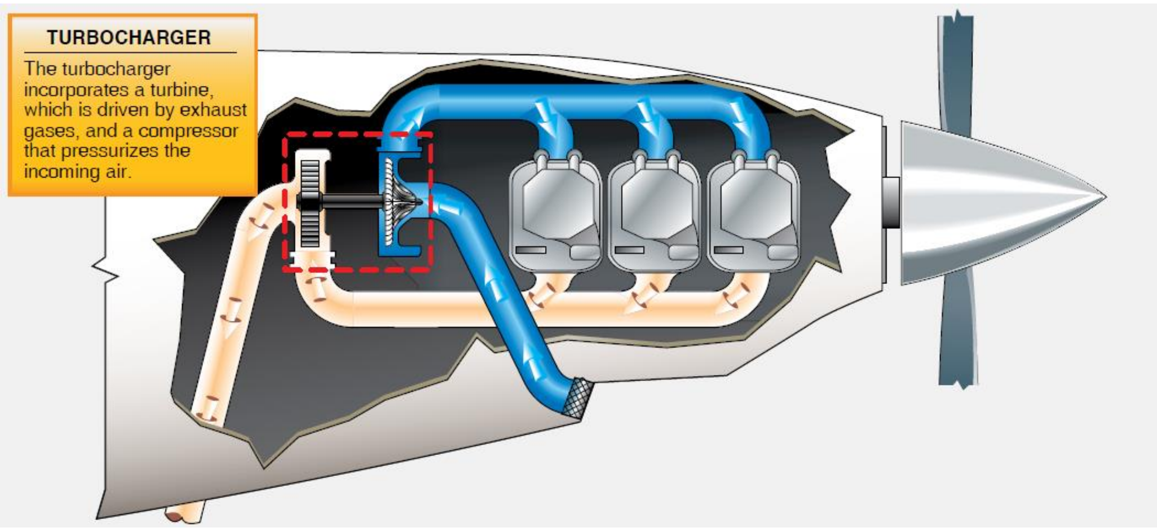
$$\eta = \frac{W_{1-2} + W_{3-4}}{Q_{2-3}} \qquad \eta = 1 - \left(\frac{C_v(T_4 - T_1)}{C_v(T_3 - T_2)}\right) \qquad \eta = 1 - \left(\frac{T_1}{T_2}\right)\left(\frac{T_4/T_1 - 1}{T_3/T_2 - 1}\right)$$

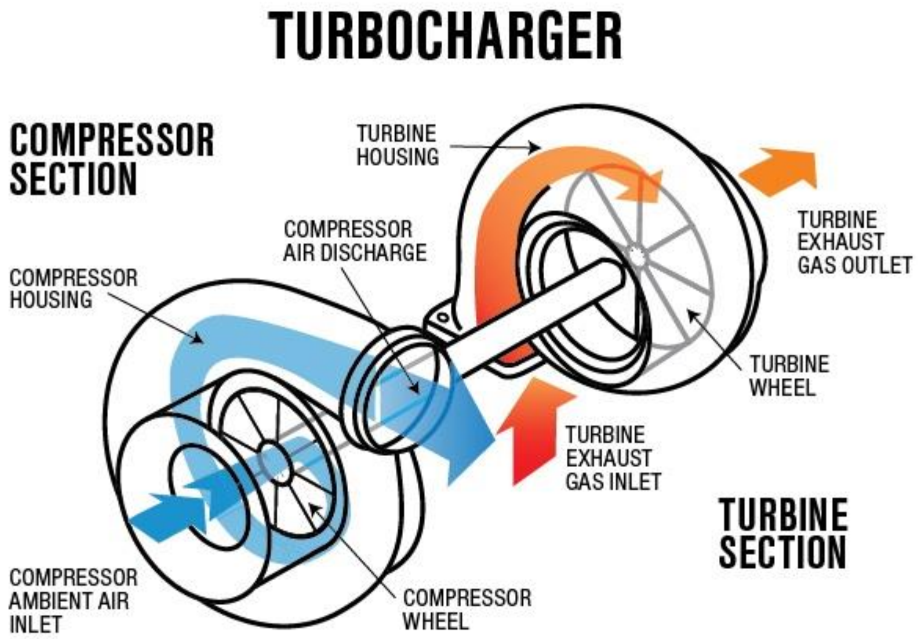
$$\left(\frac{T_2}{T_1}\right) = \left(\frac{V_1}{V_2}\right)^{(\gamma-1)} = r^{(\gamma-1)} \qquad \left(\frac{T_2}{T_1}\right) = \left(\frac{p_2}{p_1}\right)^{(\gamma-1)/\gamma} \qquad \eta = 1 - \left(\frac{T_1}{T_2}\right) \qquad \eta = 1 - \left(\frac{1}{r^{(\gamma-1)}}\right)$$

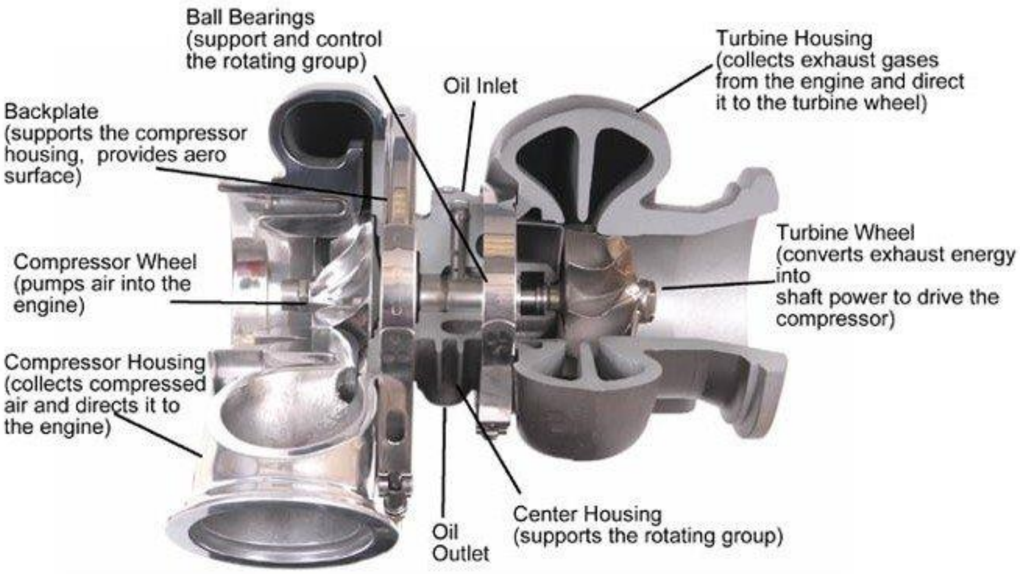
Supercharger

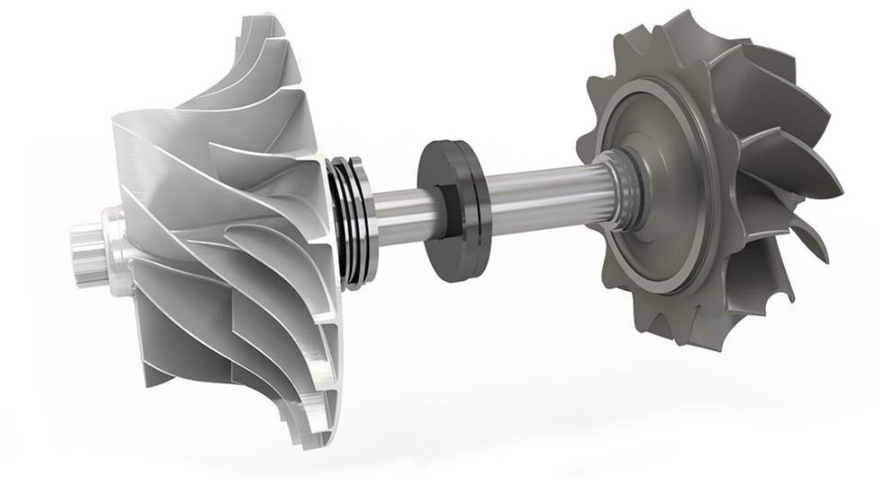


Turbocharger




TURBOCHARGER
COMPRESSOR SECTION
TURBINE HOUSING
COMPRESSOR AIR DISCHARGE
COMPRESSOR HOUSING
TURBINE EXHAUST GAS OUTLET
TURBINE WHEEL
TURBINE EXHAUST GAS INLET
TURBINE SECTION
COMPRESSOR AMBIENT AIR INLET
COMPRESSOR WHEEL

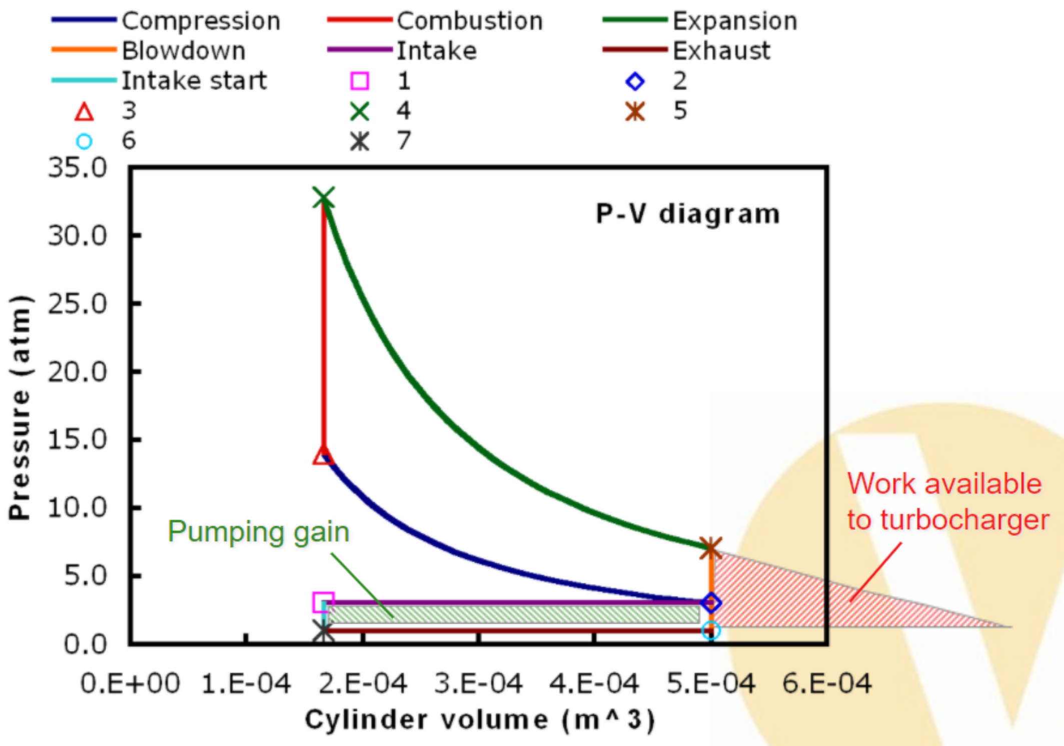

Ball Bearings (support and control the rotating group)
Oil Inlet
Turbine Housing (collects exhaust gases from the engine and direct it to the turbine wheel)
Backplate (supports the compressor housing, provides aero surface)
Compressor Wheel (pumps air into the engine)
Turbine Wheel (converts exhaust energy into shaft power to drive the compressor)
Compressor Housing (collects compressed air and directs it to the engine)
Oil Outlet
Center Housing (supports the rotating group)

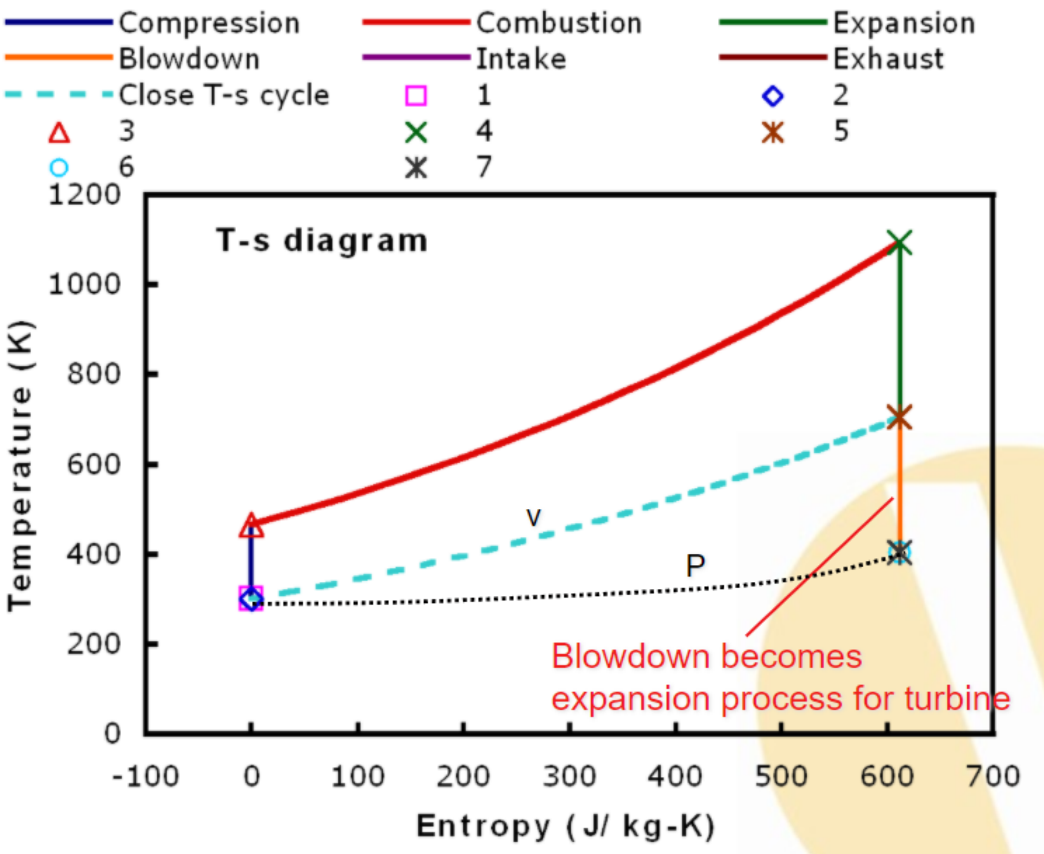


Supercharged Vought F4U Corsair

Turbocharged Republic P-47 Thunderbolt

Supercharging and Turbocharging

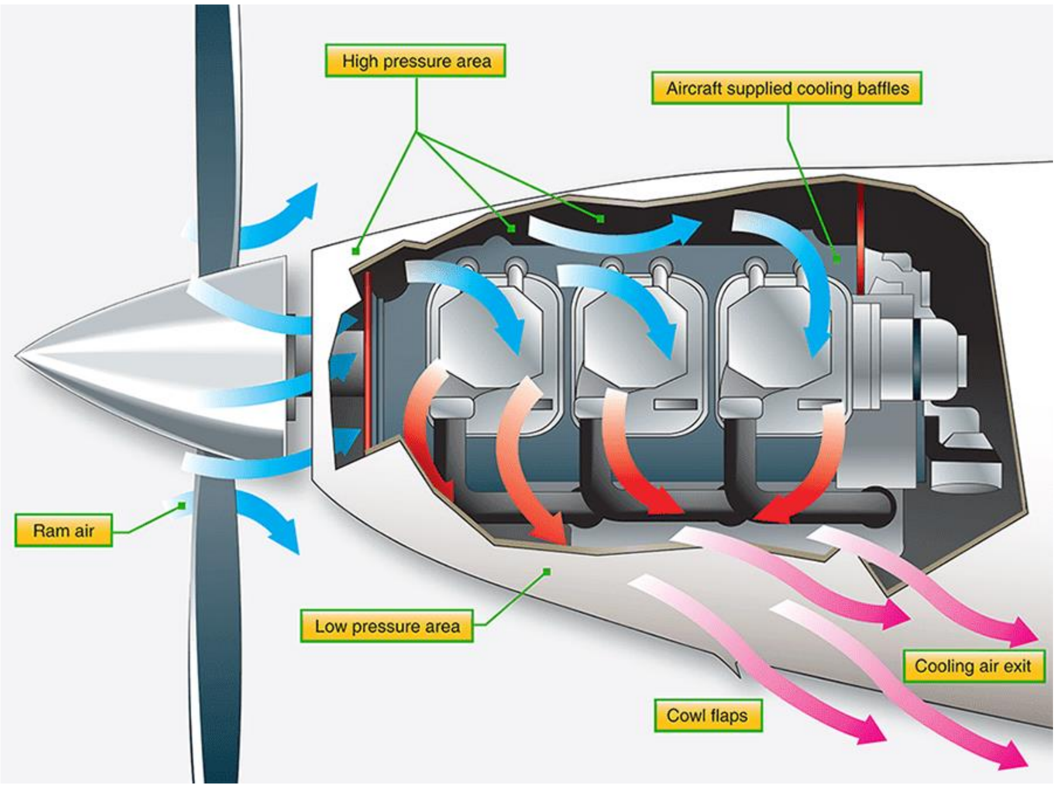




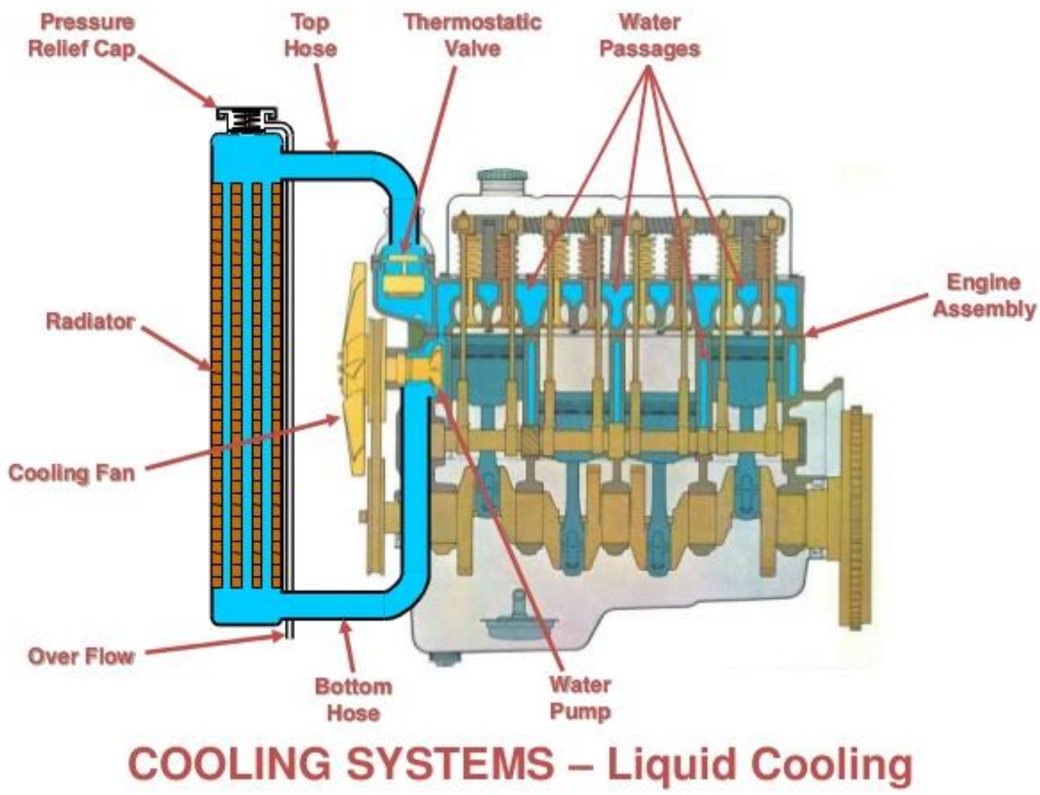
Chemical power boost

Focke-Wulf Ta 152 with GM-1 and MW 50

Cooling



Air cooling



Liquid cooling

Liquid-cooled Packard V-1650 (Rolls-Royce) Merlin on North American P-51 Mustang

Take-off thrust

$$T \approx \dot{m}_a (V_e - V_0) = \dot{m}_a V_e \quad for \quad V_0 = 0$$

$$\eta_T = 0.5 \dot{m}_a V_e^2 / \dot{m}_f h_{PR} \quad for \quad V_0 = 0$$

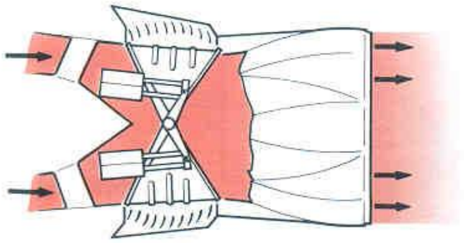
$$T \approx 2 \eta_T \dot{m}_f h_{PR} / V_e \quad for \quad V_0 = 0$$

Allison T-56 turboprop of Lockheed C-130

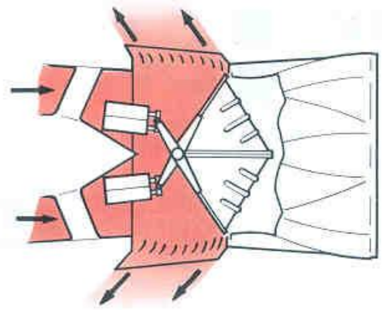
Lockheed C-130 take-off from USS Forrestal aircraft carrier

Reverse

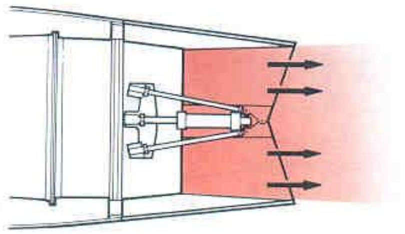
https://en.wikipedia.org/wiki/Thrust_reversal



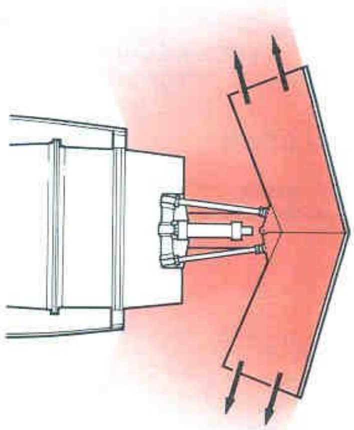
CLAMSHELL DOORS IN FORWARD THRUST POSITION



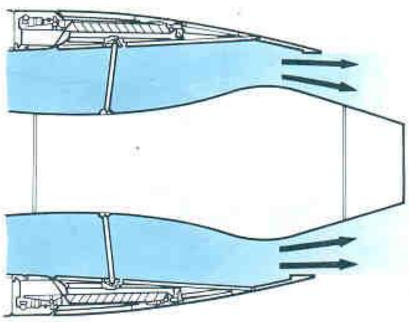
CLAMSHELL DOORS IN REVERSE THRUST POSITION



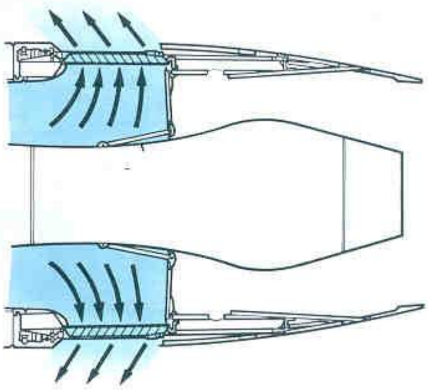
ACTUATOR EXTENDED AND BUCKET DOORS IN FORWARD THRUST POSITION



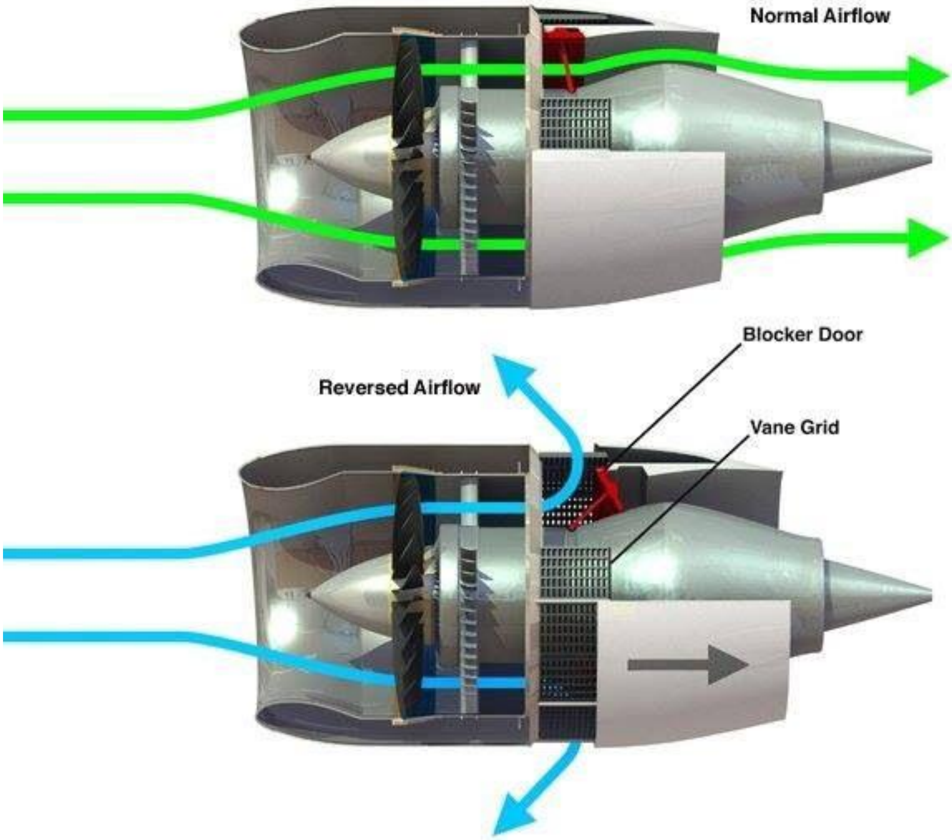
ACTUATOR AND BUCKET DOORS IN REVERSE THRUST POSITION



COLD STREAM REVERSER IN FORWARD THRUST POSITION



COLD STREAM REVERSER IN REVERSE THRUST POSITION



Fokker F70 with reverse in action

Boeing 747-400 with reverse in action

Airbus A340-313 with reverse in action

https://www.youtube.com/watch?v=TUZ_j83R-ug

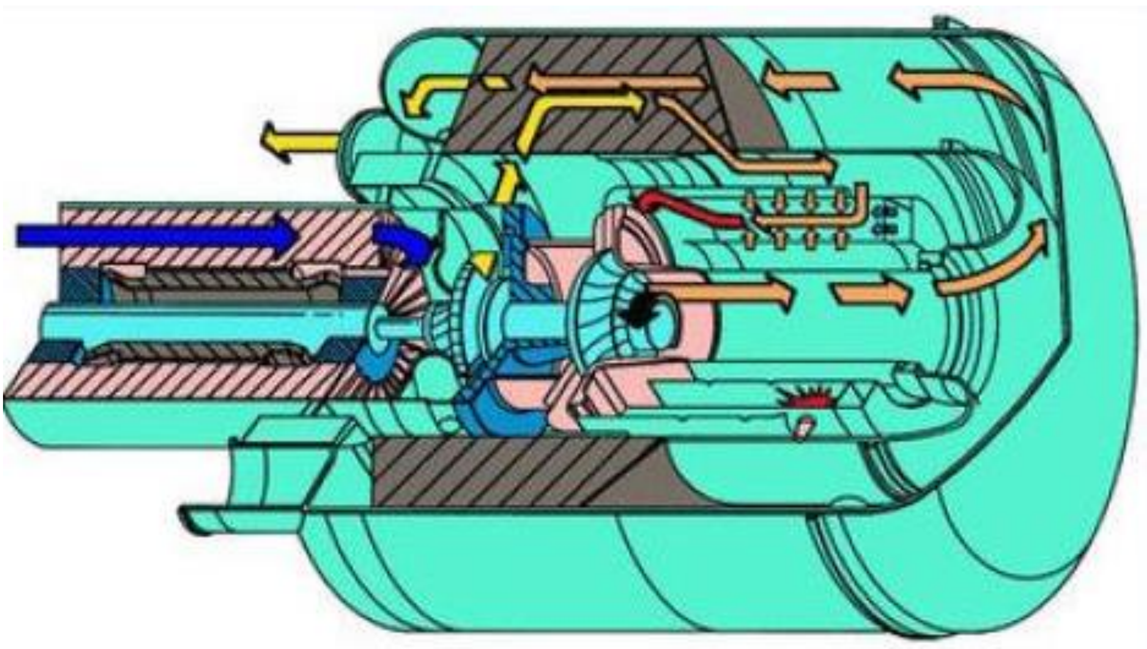
https://www.youtube.com/watch?v=GNRXAHasFvk

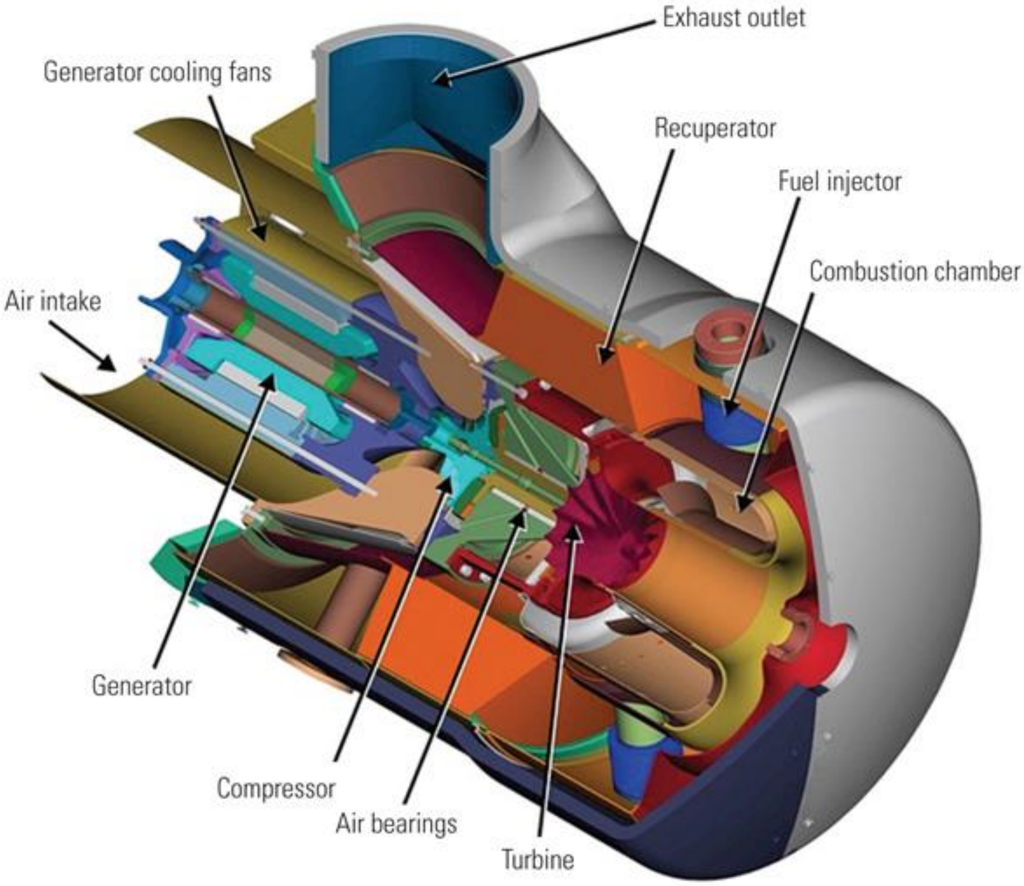
https://www.youtube.com/watch?v=HYwFlM3HMuQ

https://www.youtube.com/watch?v=DodKUmJEnbY

https://www.youtube.com/watch?v=qO56u6-AE3A

Brayton-Joule cycle with Regeneration





Capstone C65 (65 kW) Microturbine