Institute for
Thermal Turbomaschinery
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Graz University of Technology
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Gas Turbine Technology

Lecture at the
Department of Aerospace Engineering
Middle East Technical University
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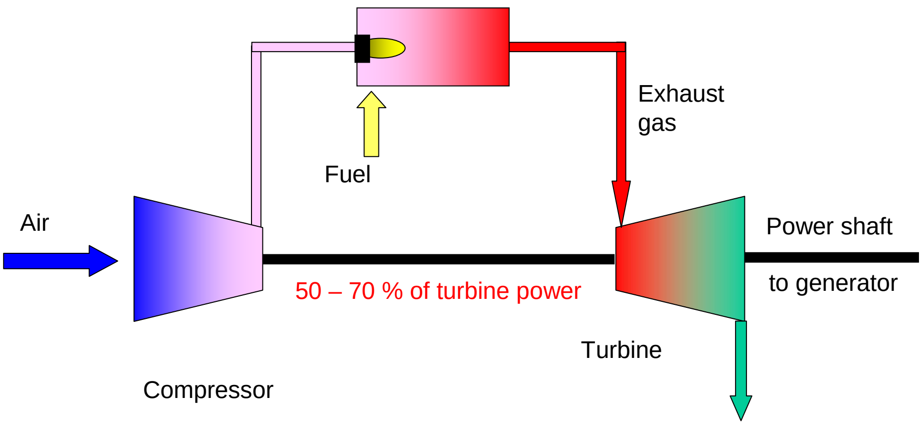
>>MIDDLE EAST TECHNICAL UNIVERSITY

Content

- Gas turbine design
- History
- Thermodynamics of gas turbine cycle
- Peak temperature and blade cooling
- Cycle options
- Influence of environmental conditions
- Heavy duty vs. aeroderivative
- Combustion
- Gas turbine prices
- Selected gas turbine models

Basic Principle



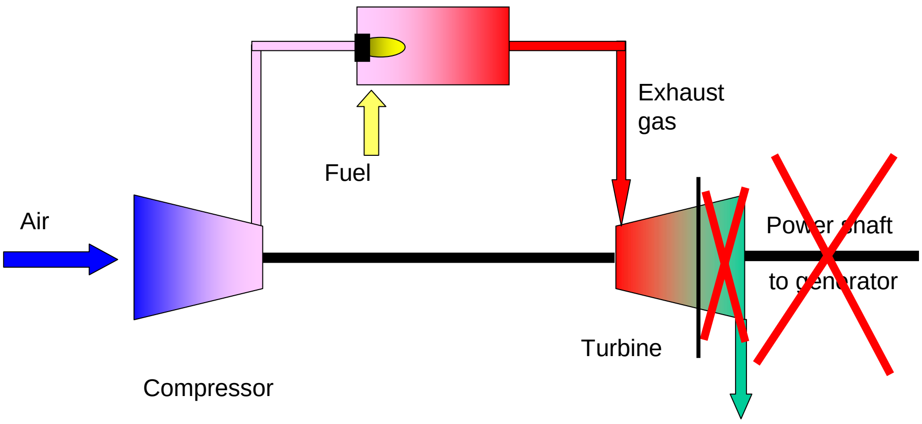
Pressure ratio: usually about 15, but up to 40 and more

Turbine inlet temperature (TIT): 900° - 1700°C

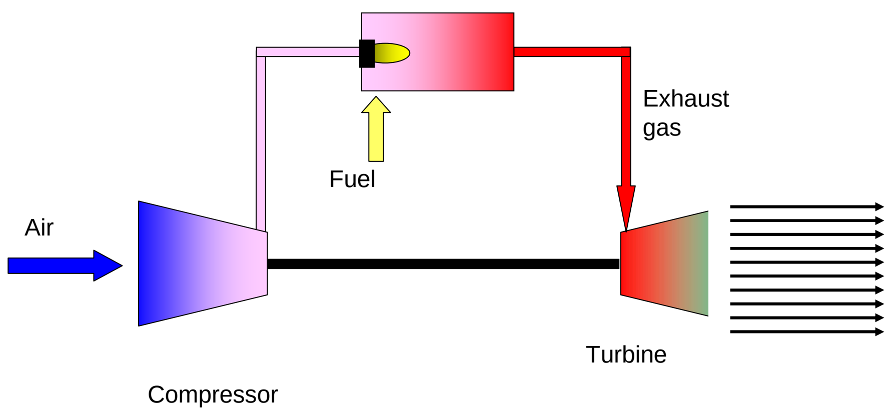
Turbine exit temperature (TET): 400° - 600°C

Power: 100 kW – 300 MW

Jet engine

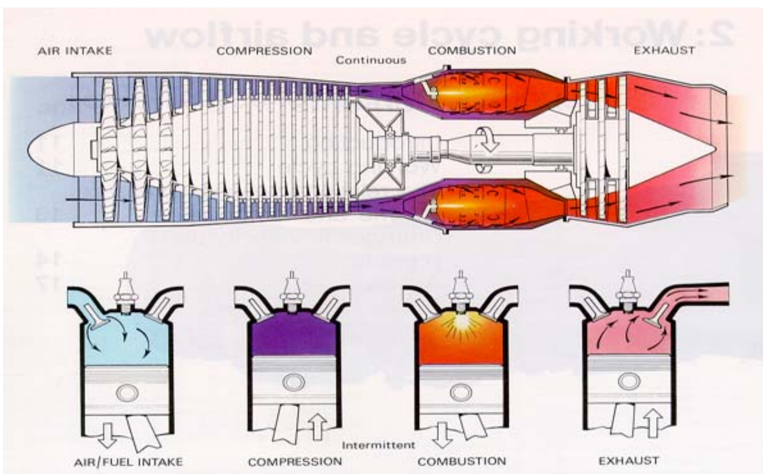


Jet engine

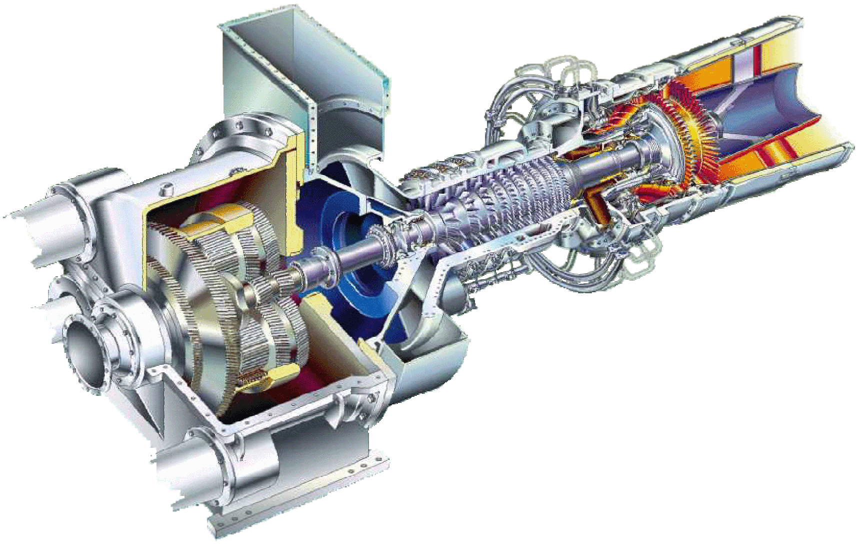


Useful power is the kinetic energy of high-speed jet

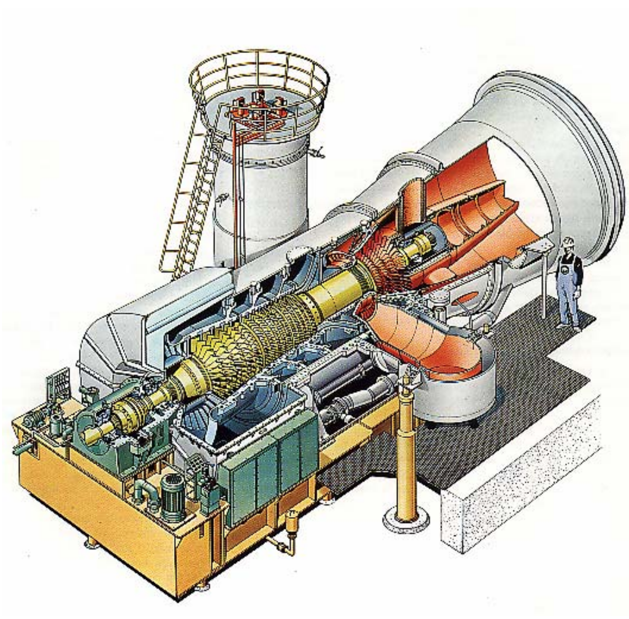
Comparison gas turbine – piston engine



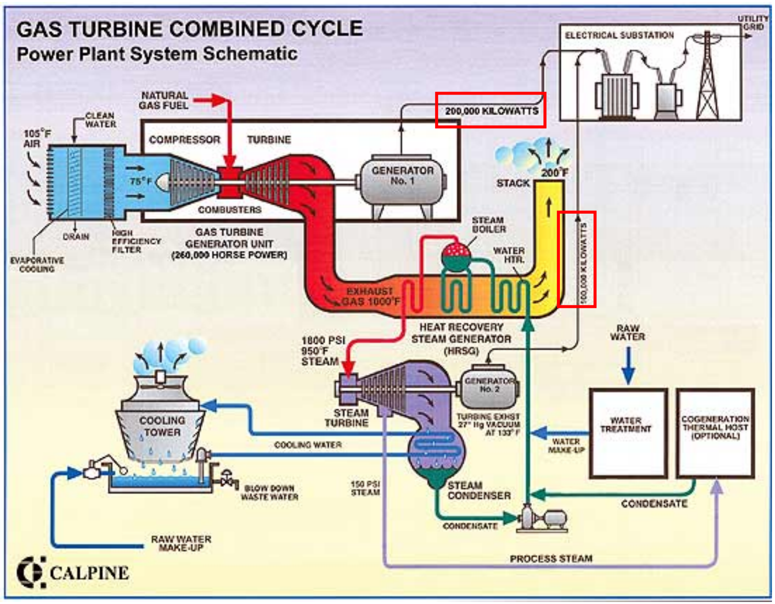
Stationary Gas Turbine



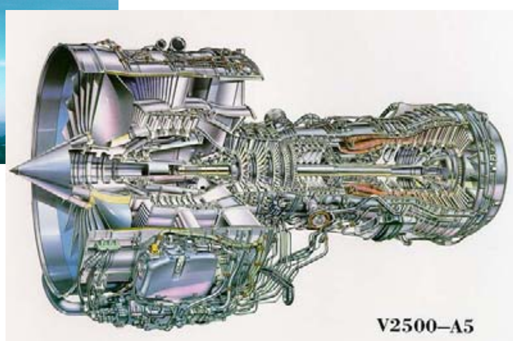
Stationary Gas Turbine



Combined Cycle Power Plant



Aero Engine



Influence of flight velocity

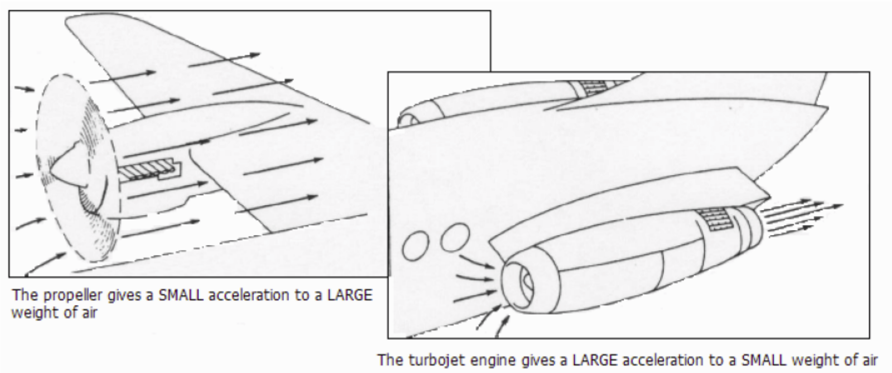
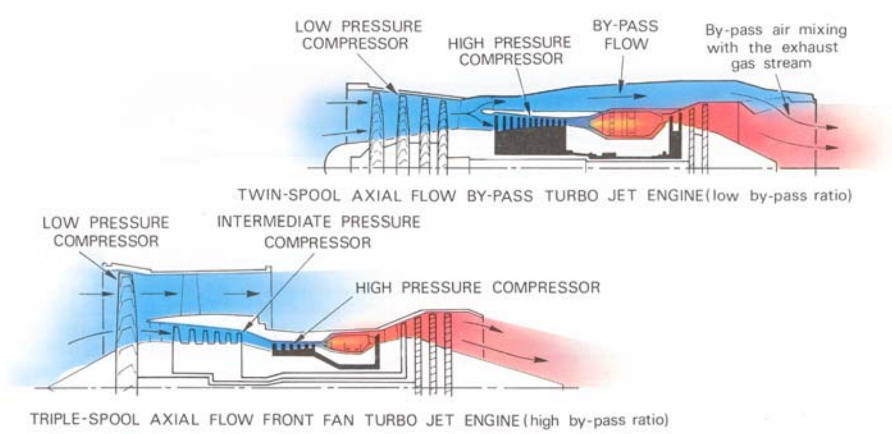
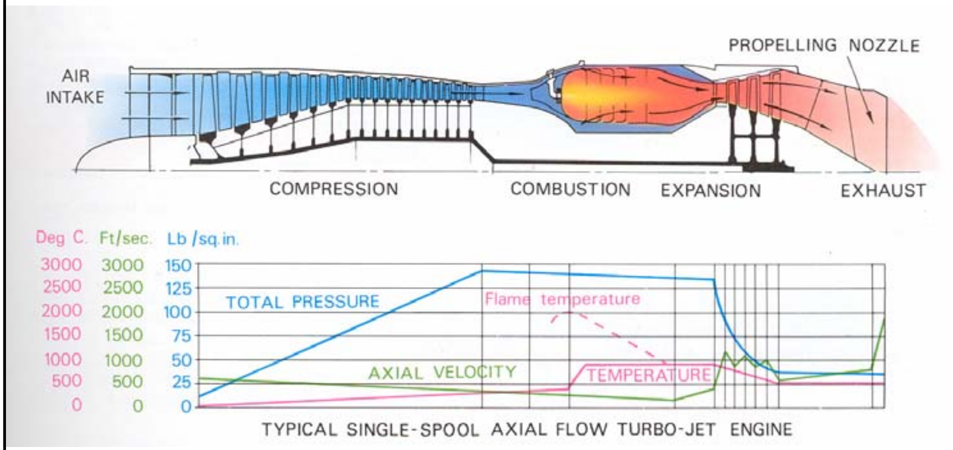


Fig. 9. Propulsive efficiency is high for a propeller and low for a jet. (Source: Rolls-Royce, UK)

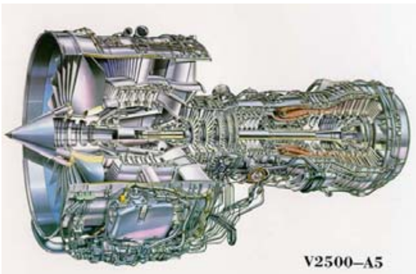
Twin-spool and Triple-spool design



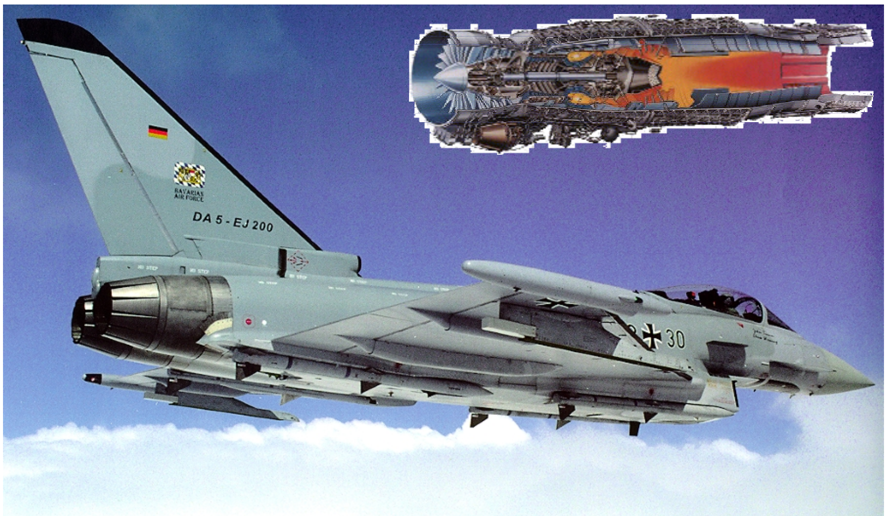
Conditions in an aero engine



Aero Engine (High Bypass Ratio)



Aero Engine (Low Bypass Ratio)



Gas turbine history

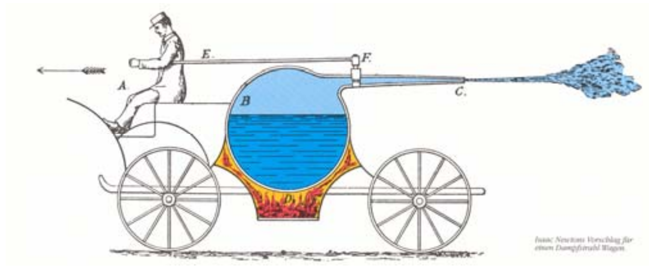
- 18th century: First patents of John Barber, Dumpell and Bresson
- 1902: Moss (USA) built a gas turbine with „negative“ output
- 1904: Stolze (Germany) hot air turbine, not successful
- In 1930s: heat resistant steels, aerodynamic knowledge -> modern design
- In Switzerland Escher-Wyss, BBC and Sulzer built gas turbines up to 20 MW power with TIT of 650°C
- Strong impetus from the development of jet engines during and after WWII
- Since 1950: jet engine became dominant propulsion system
- Since 1960: strong development of stationary gas turbines, at the beginning mostly modified jet engines

The world‘s first industrial gas turbine set – Neuchatel, Switzerland (1939-2002)

Source: Alstom

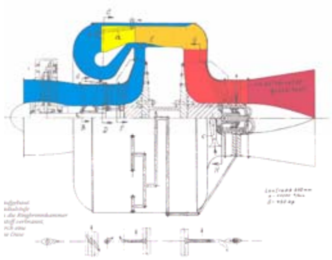
Jet engine history

- Principle of jet propulsion goes back to ancient Greeks
- 1666: Isaac Newton in „Principia“: coach driven by a steam jet
- 1921: Guillaume (France) patented the main principles of a jet engine
- Development of turbo chargers for airplane piston engines were pre-condition for jet engines

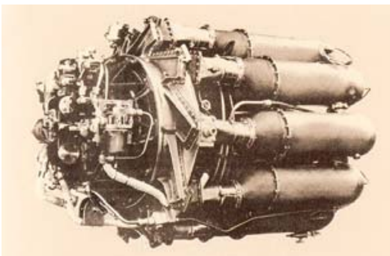


Jet engine history

- German **Hans Pabst von Ohain** developed the first jet engine (first tests in March 1937)
- 1939: the first flying jet engine **He S 3 B**
- 1939: First airplane Heinkel He 178 with jet engine achieved 700 km/h
- Parallel to Ohain the British **Frank Whittle** developed a jet engine (first tests in April 1937)
- 1941: First flight of the British jet plane Gloster E-28/39 with a Whittle engine
- 1941: General Electric (USA) built the engine GE-IA on the basis of the Whittle engine



HE S 3 B



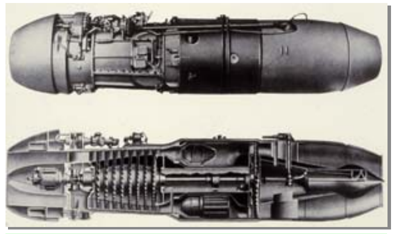
Whittle engine W2

Series production of jet engines

During WWII 6000 jet engine Jumo 004B were built in Germany

Life time of several hours due to material problems

Einsatz in Messerschmitt Me 262A-1a

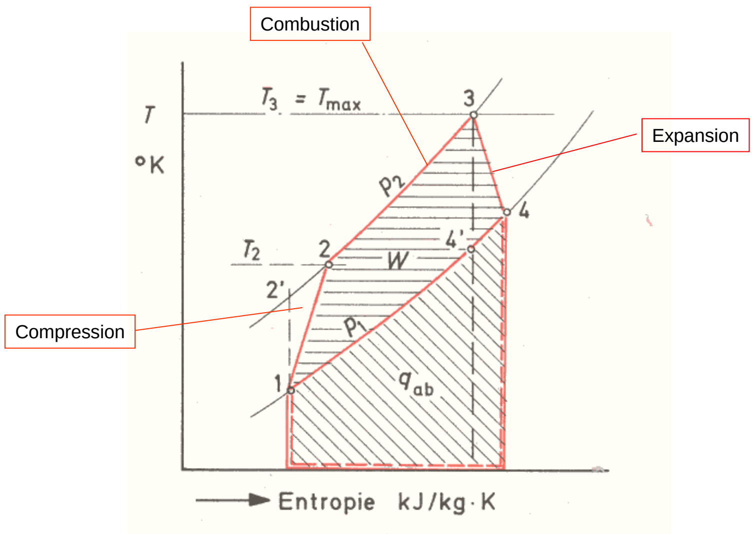


Entwicklung ab 1939, Großserie von 1944-45 mit über 6000 Triebwerken

EJ 200 für EF 2000

Leistungsdaten im Vergleich:	Jumo 004B	EJ200
Standschub (KN):	8.8	90. mit NB
Durchsatz (kg/sec):	20	75
Schub/Durchsatz (KN/kg/sec):	0.42	0.77
Schub/Gewicht:	1.21	9.
Nebenstromverhältnis:	0.	0.4
Druckverhältnis in 8 Stufen:	3.2	25.
Turbineneintrittstemperatur (K):	1050.	1800.

T-s diagram of gas turbine process

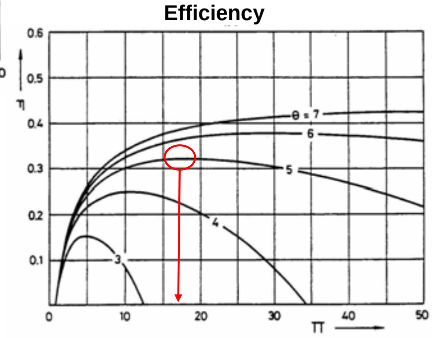


Enthalpy difference is higher between 3 and 4 than between 1 and 2 !

Characteristics of gas turbine process

Dimensionless Power

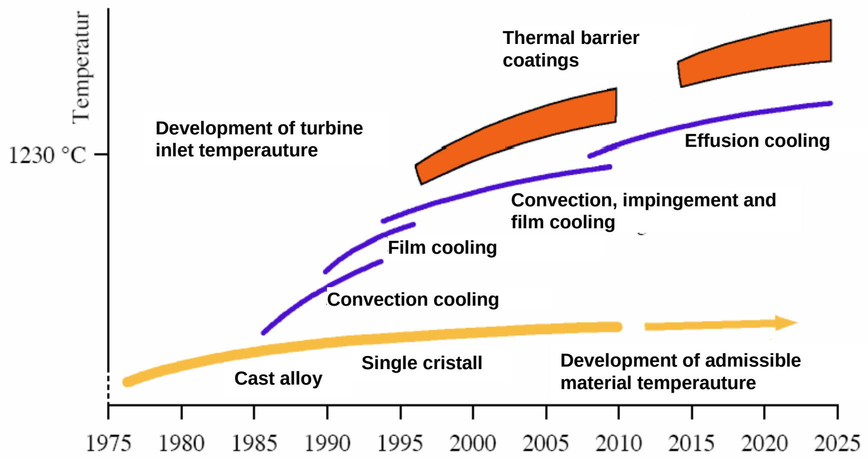
Efficiency



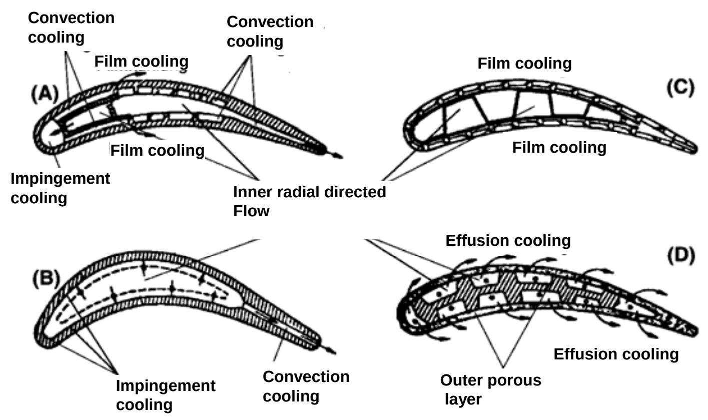
Π ... pressure ratio

Θ ... ratio of peak temperature to inlet temperature

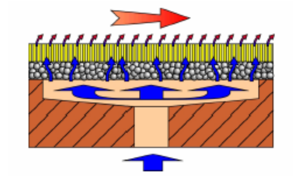
Development of peak temperature



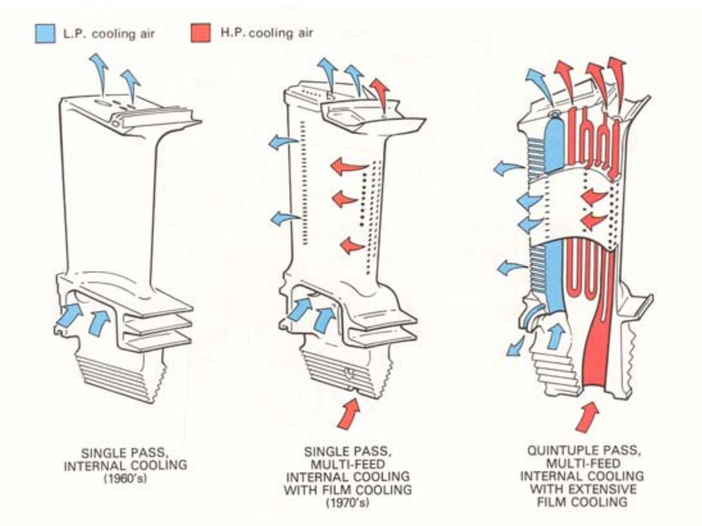
Turbine blade cooling



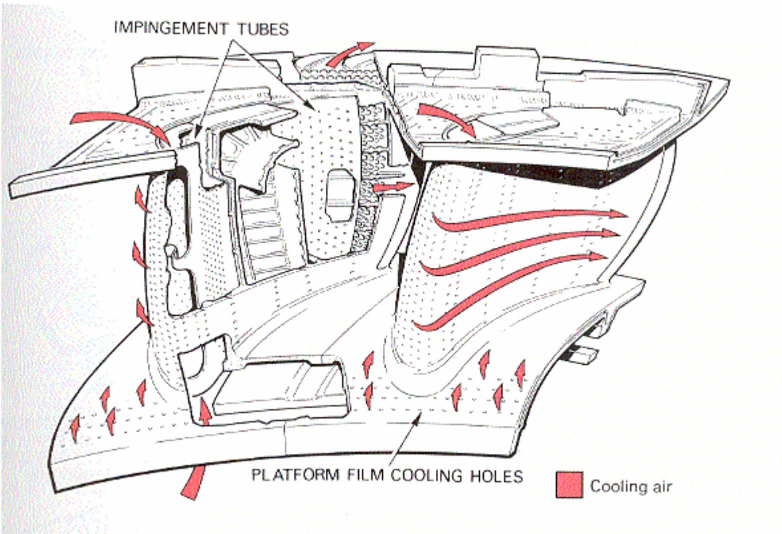
Detail of effusion cooling



Turbine blade cooling



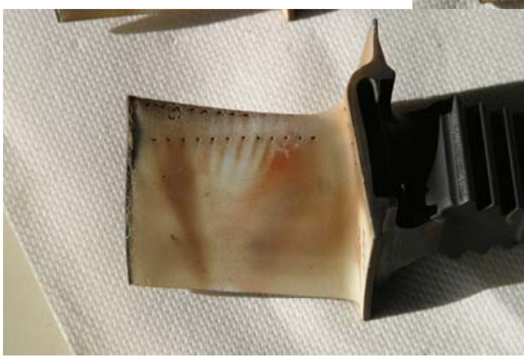
Turbine blade cooling



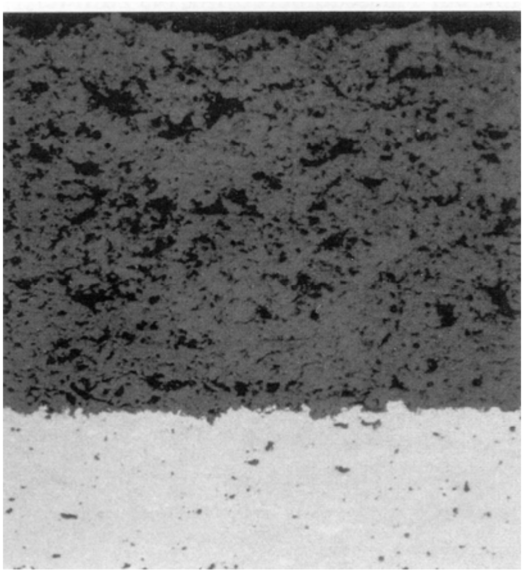
Cooled turbine blade

Overheated Turbine Blades

Overheated Turbine Blades



Thermal barrier coatings



APS ceramic thermal barrier coating (ZrO_2) with an intermediate adhaerance layer

Surface temperature can be reduced by 300K

Source: Werner Stamm, Siemens PG, Turbinenschaufeln mit Keramikbeschichtung, Technik in Bayern, Sept, Okt.2006, S. 12-13

Optimisation by controlled solidification

Quelle: Cerjak

Optimisation by controlled solidification

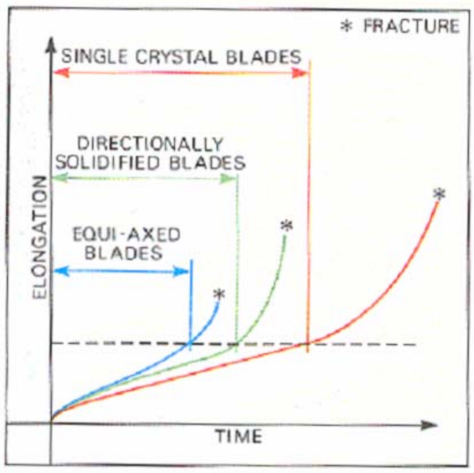
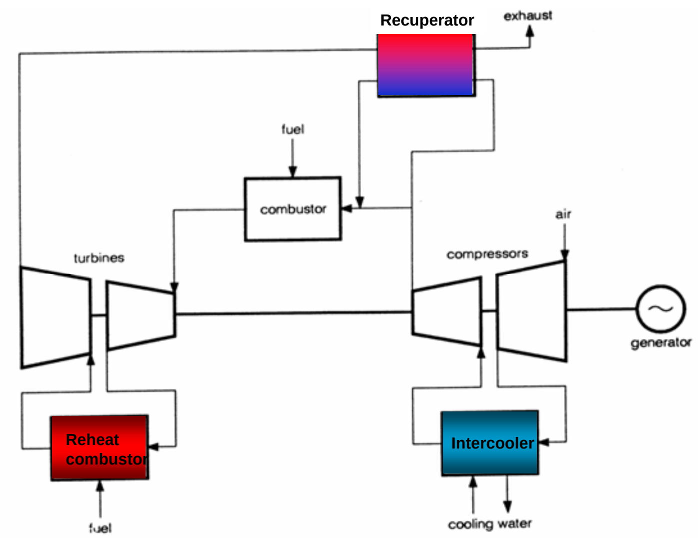


Fig. 5-13 Comparison of turbine blade life properties.

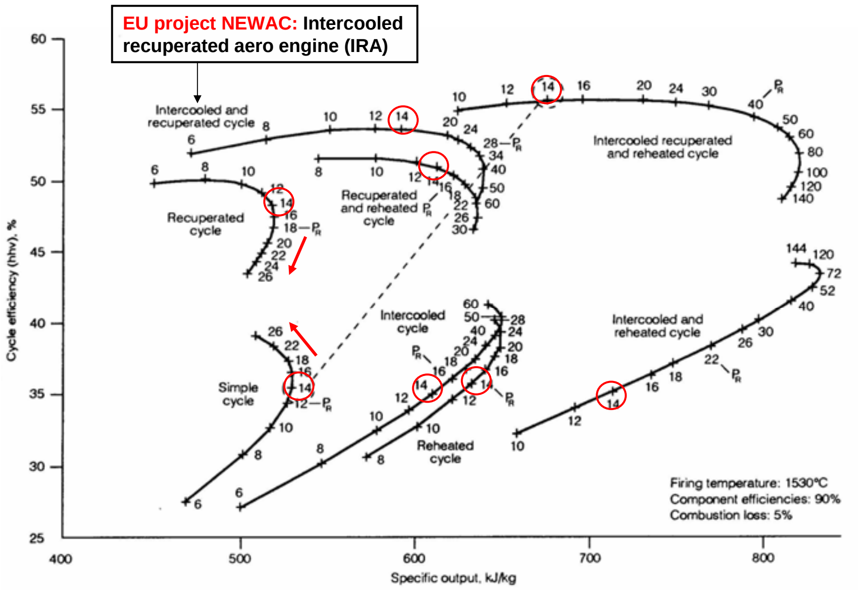
Gas turbine cycle options



Carnot Cycle: The higher the temperature of heat input and the lower the temperature of heat extraction the better the cycle efficiency!

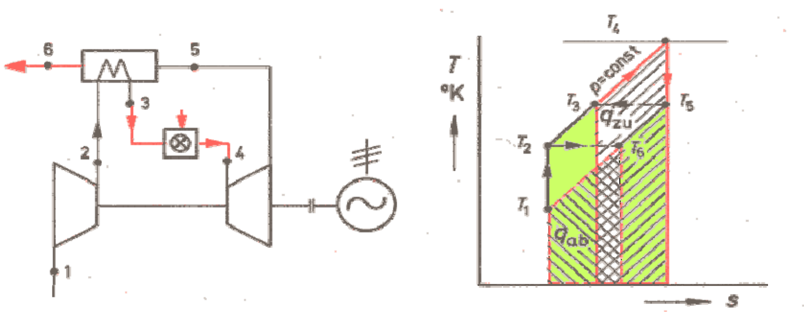
Source: IEA Coal Research, 1995

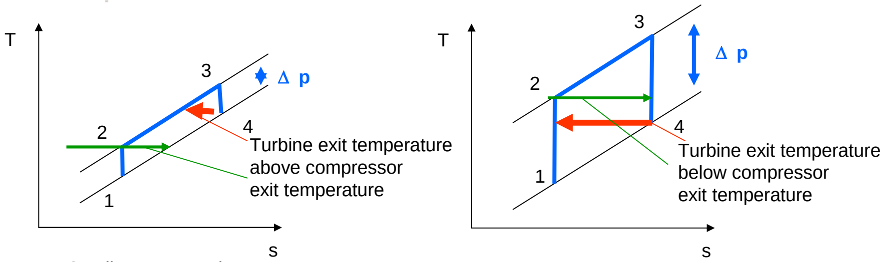
Comparison of gas turbine cycles



Source: IEA Coal Research, 1995

Recuperated gas turbine cycle



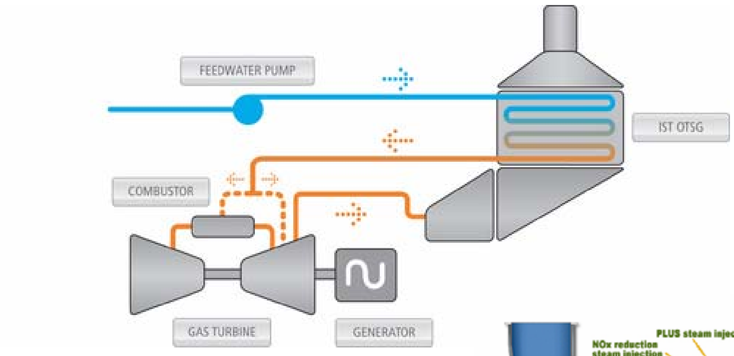


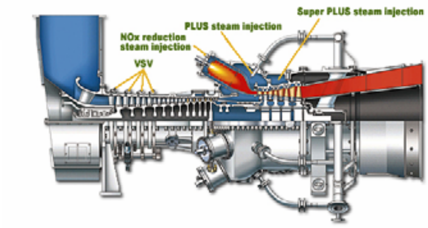
Small pressure ratio:
Regeneration possible

Large pressure ratio:
Regeneration not possible

Steam Injected Gas Turbine (STIG)

STIG cycle takes waste heat from the gas turbine, converts water into steam and then injects this steam into the gas turbine (water treatment)



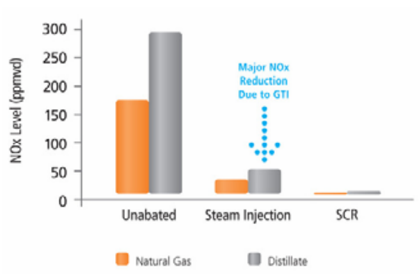


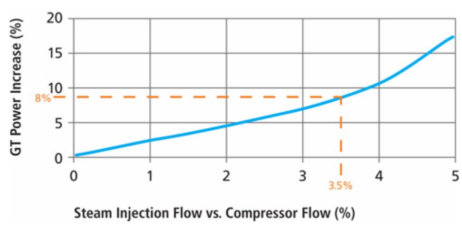
Source: www.otsg.com

Steam-Injected Kawasaki M7A-01ST Gas Turbine

Steam Injected Gas Turbine (STIG)

- **Steam/air flow ratio up to 0.2**
- **Power can be nearly doubled**
- **Efficiency increase by 15% - points**
- **NOx emissions are reduced by up to 80%**
- **Less investment costs than CC plant**
- **Suitable for small power output (- 100 MW)**
- **High efforts for water treatment**
- **5 – 10 % steam flow allowed for many models without adaptations**

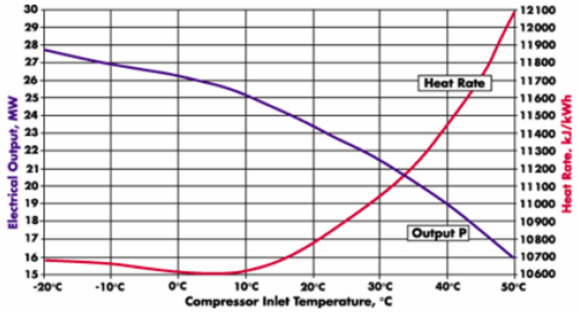




Source: www.otsg.com

Environmental Influence

- **Air temperature and altitude have a strong influence on the power produced and on efficiency (influence on density)**
- **Small effect also of humidity**

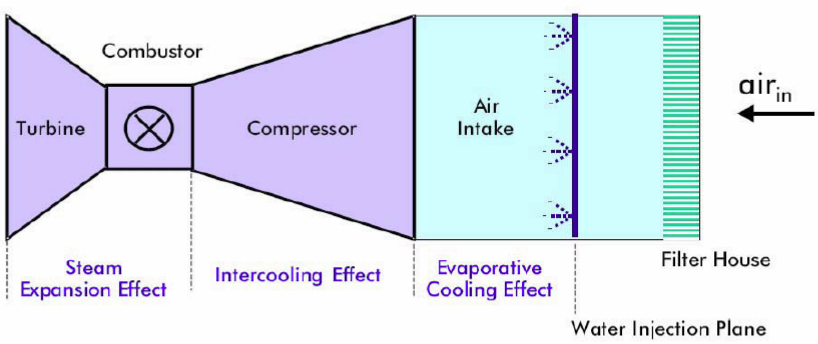


a) Generator output and heat rate versus compressor inlet air temperature

Performance Data: SGT-600 Industrial Gas Turbine - 25 MW (Source: Siemens Westinghouse)

Air inlet cooling

- **Temperature decrease leads to a higher air mass flow swallowed. Relative humidity of the air increased to nearly saturation.**
- **Water evaporation inside compressor reduces compression work.**
- **Turbine power output is increased proportionally to the increased mass flow**



Source: Soares, Gas Turbine Handbook, 2005

50/60 Hz market

- Large gas turbines have to run at frequency of electrical grid (no gears available)
- Europe, Africa, Asia: 50 Hz → 3000 rpm
  America, Japan: 60 Hz → 3600 rpm
- In order to maintain the design of the flow channel and the velocities, the dimensions of 60 Hz variants are decreased by 5/6
- So mass flow and power are about 44 % larger in 50 Hz market

Table 4 Typical gas turbine scale factors

Machine	Frequency, Hz	Speed, rpm	Scale factors, linear	Scale factors, area	Power, MW
GE Frame 7F	60	3600			159
GE Frame 9F	50	3000	1.2	1.44	226.5*
Siemens V64	90	5400			61.7†
Siemens V84	60	3600	1.5	2.25	139.5*
Siemens V94	50	3000	1.2	1.44	200.9

* scale factors are not exact where other cycle parameters also change
† excludes generator drive gearbox

Source: IEA Coal Research, 1995

Heavy Duty vs. Aeroderivative

Gas turbines are divided into industrial gas turbines („Heavy Duty“ or „Heavy Frame“) and in aeroderivatives

Aeroderivatives are re-designed jet engines and use jet engine technology with high specific power, good efficiency and high reliability (e.g. RR Olympus, GE CF6 -> LM2500)

- mounted on light frames
- high performance leads to higher and thus increased maintainance efforts
- large number in operation
- often used in marine applications

Industrial gas turbines are robust, need less maintainance, but have - in general - lower efficiency

- Heavy and robust design

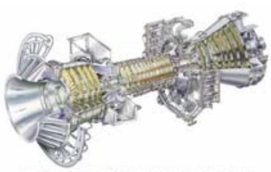


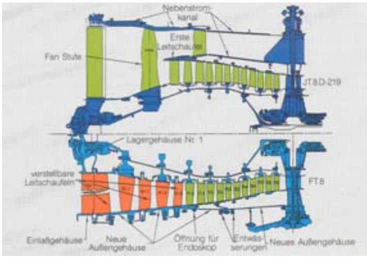
Fig. 13 The GE LM6000 (aeroderivative of the CF6-80C2) (Source: GE Power Systems)

Source: Soares, Gas Turbine Handbook, 2005

Aeroderivative FT8

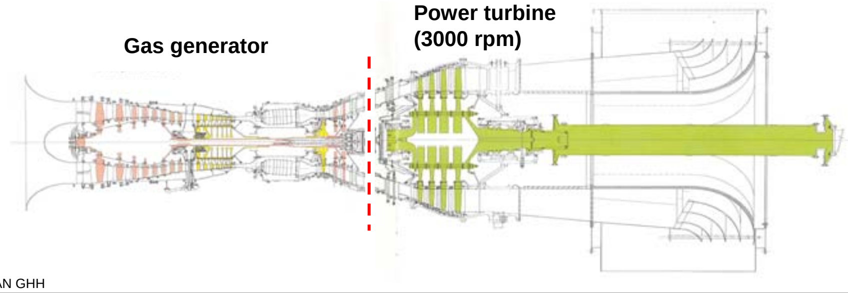
JT8D by Pratt & Whitney (USA): 14 000 engines, 25 MW, high efficiency

Modifications to the gas generator:
- fan removed
- compressor casing
- one turbine stage removed



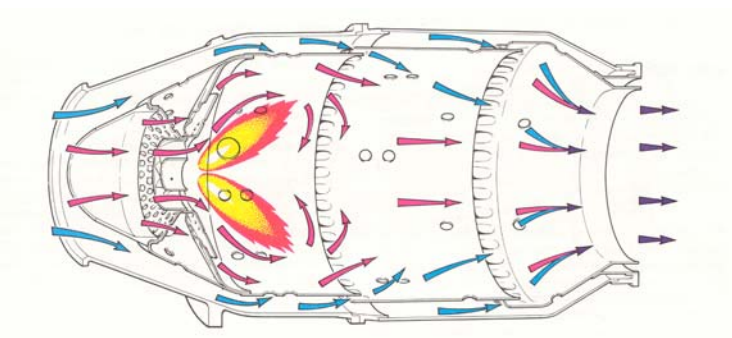
Gas generator

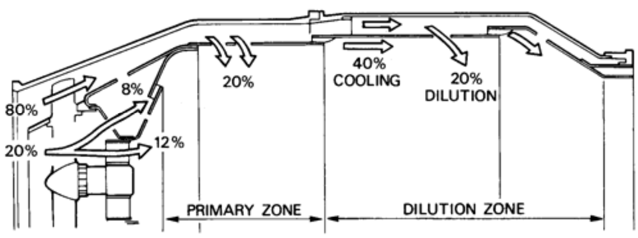
Power turbine (3000 rpm)



Source: MAN GHH

Combustion Chamber Flow Distribution





Combustion Chamber

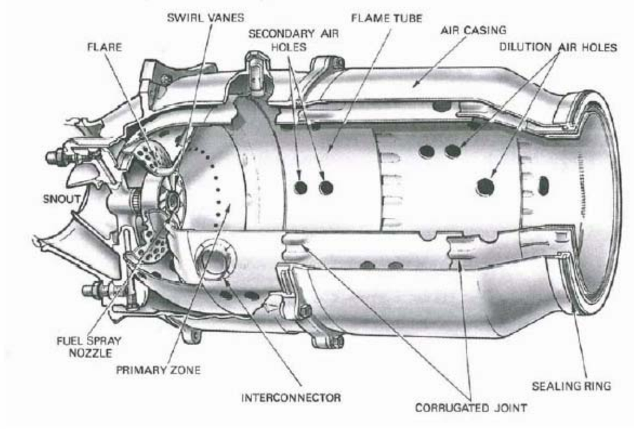


Fig. 25. A combustion chamber. Source: Courtesy of Butterworth Heinemann, from "Process Plant Machinery" 2nd Edition, Bloch, H. and Soares, C., 1998

Flame Tube Combustor (Cans)

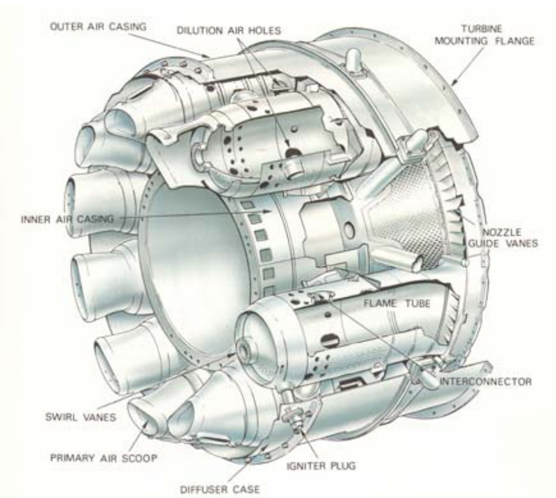


Fig. 28. Multiple Combustion Chambers Source: Courtesy of Butterworth Heinemann, from "Process Plant Machinery" 2nd Edition, Bloch, H. and Soares, C., 1998

Annular Combustor

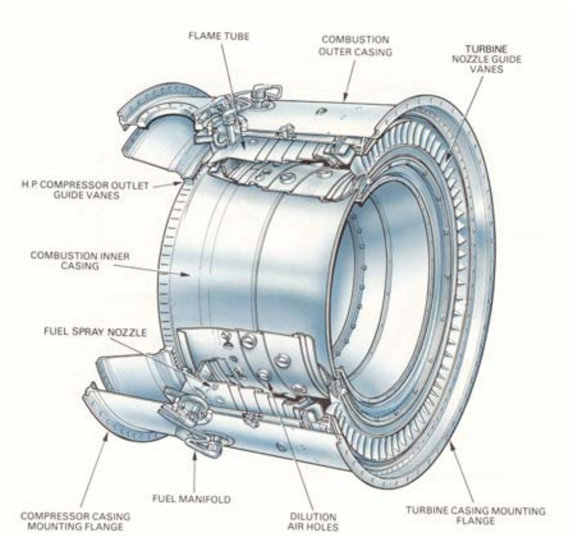
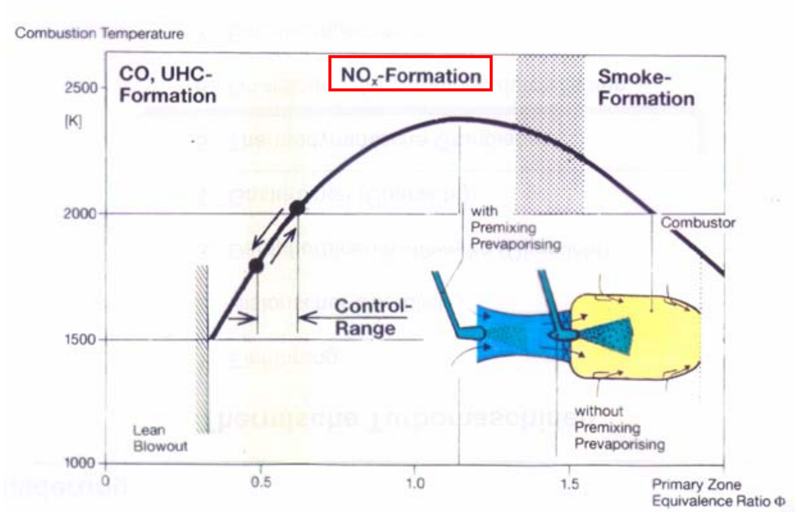
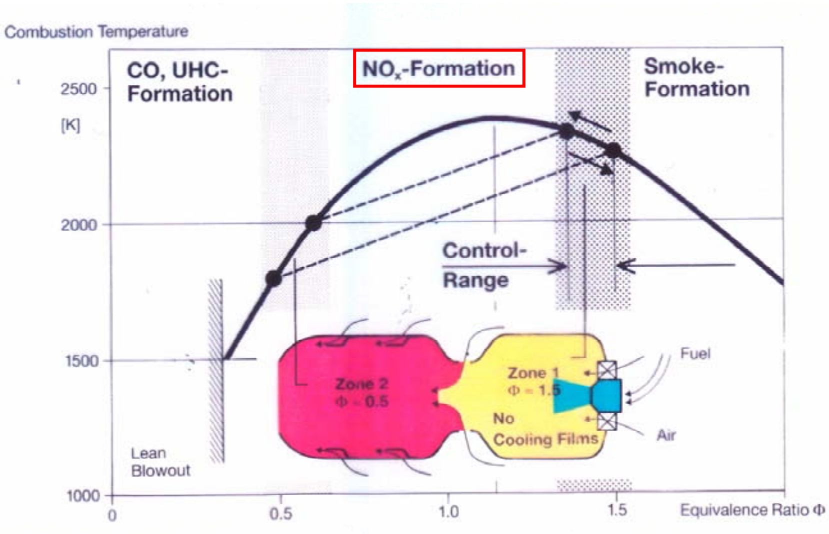


Fig. 29. Annual Combustion Chambers Source: Courtesy of Butterworth Heinemann, from "Process Plant Machinery" 2nd Edition, Bloch, H. and Soares, C., 1998

Lean Combustion



Rich-Lean Combustion

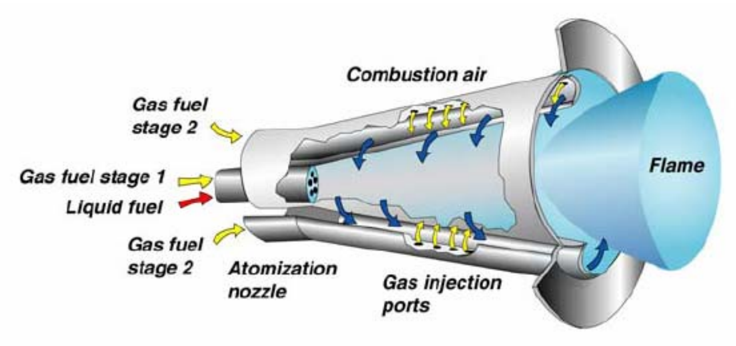


GE DLN Burner

Fig. 31. DLN (dry low NOx) combustor
(Source: GE Power Systems)

Siemens DLE/ Alstom EV Burner

- **Burner consists of a cone split in two halves, slightly offset to form two slots for the combustion air**
- **Main gas supply also enters through these slots via tubes**
- **Primary fuel is injected at the tip of the cone.**
- **Richer fuel mixture stabilizing the flame over a range of load conditions**
- **Burner lowers NOx by reducing the flame temperature (< 25 ppmv)**
- **When burning liquid fuel water injection is required to reduce NOx.**



Source: Siemens Industrial Turbomachinery AB, 2006

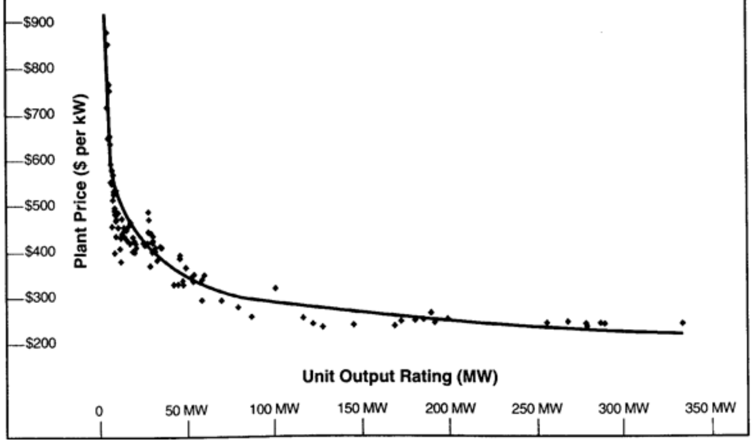
Siemens DLE/ Alstom EV Burner

Fig. 32. The SGT-600 dry, low-emission (DLE) combustion system
Source: Siemens Westinghouse

Source: Soares, Gas Turbine Handbook, 2005

Simple Cycle Plant Prices 2007

Simple Cycle Plant Prices 2007. The decrease in $/kW prices size reflects economy of scale in the manufacturing costs of larger units and ability of advanced designs to produce more kW per pound of air flow.



Source: GTW Handbook 2007

Simple Cycle Plant Prices 2007

Model	Frequency	Base Load Rating	Heat Rate Btu/kWh	LHV Efficiency	Budgetary Price	Price per kW
VPS1	50/60 Hz	514 kW	15,981 Btu	21.4%	$547,000	$1,064
ST6L-813	50/60 Hz	848 kW	13,099 Btu	26.1%	$871,000	$1,027
Makila TI	50/60 Hz	1050 kW	12,580 Btu	27.1%	$1,136,000	$1,082
Saturn 20	50/60 Hz	1200 kW	14,025 Btu	24.3%	$1,056,000	$880
M1A-13D	50/60 Hz	1475 kW	14,229 Btu	24.0%	$1,315,000	$892
KG2-3C	50/60 Hz	1499 kW	22,367 Btu	15.3%	$1,092,000	$728
KG2-3E	50/60 Hz	1895 kW	21,543 Btu	15.8%	$1,241,000	$655
ST18A	50/60 Hz	1961 kW	11,237 Btu	30.4%	$1,677,000	$855
OGT2500	50/60 Hz	2670 kW	12,780 Btu	26.7%	$2,051,000	$768
UGT-2500	50/60 Hz	2850 kW	11,970 Btu	28.5%	$2,146,000	$753
M1T-13D	50/60 Hz	2907 kW	14,439 Btu	23.6%	$1,899,000	$653
VPS3	50/60 Hz	3106 kW	12,675 Btu	26.9%	$1,979,000	$637
Centaur 40	50/60 Hz	3515 kW	12,240 Btu	27.9%	$2,085,000	$593
VPS4	50/60 Hz	3568 kW	11,714 Btu	29.1%	$1,975,000	$554
501-KB5S	50/60 Hz	3897 kW	11,747 Btu	29.1%	$2,147,000	$551
ST40	50/60 Hz	4039 kW	10,310 Btu	33.1%	$2,339,000	$579
OGT4000 SI	50/60 Hz	4050 kW	10,065 Btu	33.9%	$2,203,000	$544
GTES-4	50/60 Hz	4100 kW	14,132 Btu	24.2%	$1,823,000	$445
Centaur 50S	50/60 Hz	4600 kW	11,630 Btu	29.3%	$2,347,000	$510
Mercury 50	50/60 Hz	4600 kW	8865 Btu	38.5%	$2,923,000	$635
501-KB7S	50/60 Hz	5245 kW	10,848 Btu	31.5%	$2,919,000	$557
SGT-100	50/60 Hz	5250 kW	11,203 Btu	30.5%	$2,700,000	$514
CX501-KB7	50/60 Hz	5344 kW	10,640 Btu	32.1%	$2,806,000	$525
M7A-01D	50/60 Hz	5381 kW	11,648 Btu	29.3%	$2,565,000	$477
M7A-01	50/60 Hz	5512 kW	11,530 Btu	29.6%	$2,473,000	$449
GE5	50/60 Hz	5520 kW	11,130 Btu	30.7%	$2,520,000	$457
Taurus 60	50/60 Hz	5670 kW	11,225 Btu	30.4%	$2,575,000	$454
THM1203A	50/60 Hz	5760 kW	15,184 Btu	22.5%	$1,870,000	$325
GTES-6	50/60 Hz	6200 kW	12,782 Btu	26.7%	$2,197,000	$354
Taurus 65	50/60 Hz	6300 kW	10,375 Btu	32.9%	$2,985,000	$474
UGT-6000	50/60 Hz	6360 kW	10,835 Btu	31.5%	$2,956,000	$465
501-KH5	50/60 Hz	6447 kW	8509 Btu	40.1%	$3,456,000	$536
OGT6000	50/60 Hz	6500 kW	11,187 Btu	30.5%	$2,972,000	$457
M7A-02D	50/60 Hz	6721 kW	11,264 Btu	30.3%	$3,173,000	$472
SGT-200	50/60 Hz	6750 kW	10,824 Btu	31.5%	$3,330,000	$493
Taurus 70	50/60 Hz	7520 kW	10,100 Btu	33.8%	$3,619,000	$481

Source: GTW Handbook 2007

Simple Cycle Plant Prices 2007

Model	Frequency	Base Load Rating	Heat Rate Btu/kWh	LHV Efficiency	Budgetary Price	Price per kW
SGT-300	50/60 Hz	7900 kW	10,937 Btu	31.2%	$3,505,000	$444
THM1304-9	50/60 Hz	8640 kW	12,341 Btu	27.7%	$3,489,000	$404
UGT-8000	50/60 Hz	9000 kW	10,150 Btu	33.6%	$3,842,000	$427
THM1304-10	50/60 Hz	9320 kW	12,170 Btu	28.0%	$3,503,000	$376
Mars 90	50/60 Hz	9450 kW	10,710 Btu	31.9%	$4,298,000	$455
UGT-10000	50/60 Hz	10,300 kW	9670 Btu	35.3%	$4,888,000	$475
Mars 100	50/60 Hz	10,690 kW	10,520 Btu	32.4%	$5,093,000	$476
THM1304-11	50/60 Hz	10,760 kW	11,459 Btu	29.8%	$4,277,000	$398
GE 10-1	50/60 Hz	11,250 kW	10,892 Btu	31.3%	$5,040,000	$448
THM1304-12	50/60 Hz	11,520 kW	11,165 Btu	30.6%	$4,978,000	$432
GTES-12	50/60 Hz	12,000 kW	10,242 Btu	33.3%	$5,278,000	$440
THM1304-14	50/60 Hz	12,680 kW	11,000 Btu	31.0%	$5,119,000	$404
SGT-400	50/60 Hz	12,900 kW	9817 Btu	34.8%	$6,412,000	$497
PGT16	50/60 Hz	13,720 kW	9760 Btu	35.0%	$7,094,000	$517
LM1600PE	50 Hz	13,748 kW	9749 Btu	35.0%	$7,111,000	$517
MF-111B	50/60 Hz	14,570 kW	11,020 Btu	31.0%	$6,860,000	$471
TITAN 130	50/60 Hz	15,000 kW	9695 Btu	35.2%	$7,752,000	$517
GTES-16	50/60 Hz	16,000 kW	9787 Btu	34.9%	$6,963,000	$435
UGT-15000	50/60 Hz	16,900 kW	9750 Btu	35.0%	$7,243,000	$429
SGT-500	50/60 Hz	17,000 kW	10,600 Btu	32.2%	$6,740,000	$397
L20A	50/60 Hz	17,640 kW	9948 Btu	34.3%	$7,213,000	$409
LM2000PS	50 Hz	17,674 kW	9779 Btu	34.9%	$7,639,000	$432
LM2000PJ	50 Hz	17,855 kW	9888 Btu	34.5%	$7,499,000	$420
PGT25	50/60 Hz	22,417 kW	9404 Btu	36.3%	$9,765,000	$436
LM2500PE	60 Hz	23,292 kW	9315 Btu	36.6%	$10,871,000	$467
SGT-600	50/60 Hz	24,770 kW	9985 Btu	34.2%	$10,460,000	$422
UGT-15000 STIG	50/60 Hz	25,000 kW	8130 Btu	42.0%	$12,731,000	$509
FT8 PowerPac	50/60 Hz	25,490 kW	8950 Btu	38.1%	$12,299,000	$483
OGT25000	50/60 Hz	25,500 kW	9639 Btu	35.4%	$11,336,000	$445
UGT-25000	50/60 Hz	26,200 kW	9400 Btu	36.3%	$11,870,000	$453
PG5371(PA)	50/60 Hz	26,300 kW	11,990 Btu	28.5%	$ 9,786,000	$372
R-25	50/60 Hz	27,500 kW	10,097 Btu	33.8%	$11,228,000	$408
RB211-6562 DLE	50/60 Hz	27,520 kW	9415 Btu	36.3%	$11,886,000	$432
LM2500 PH STIG	60 Hz	27,630 kW	8391 Btu	40.7%	$13,327,000	$482
FT8-3	50/60 Hz	27,970 kW	8900 Btu	38.3%	$12,081,000	$432
SGT-700	50/60 Hz	29,060 kW	9480 Btu	36.0%	$11,906,000	$410
RB211-6762 DLE	50/60 Hz	29,500 kW	9055 Btu	37.7%	$12,624,000	$428
MF-221	50/60 Hz	30,000 kW	10,670 Btu	32.0%	$11,561,000	$385
RB211-6761 DLE	50/60 Hz	32,120 kW	8680 Btu	39.3%	$14,307,000	$445
LM2500 RD	60 Hz	33,165 kW	8774 Btu	38.9%	$14,314,000	$432
PG6561(B)	50/60 Hz	39,620 kW	10,710 Btu	31.9%	$12,083,000	$305
PG6581(B)	50/60 Hz	42,100 kW	10,642 Btu	32.1%	$12,855,000	$305

Source: GTW Handbook 2007

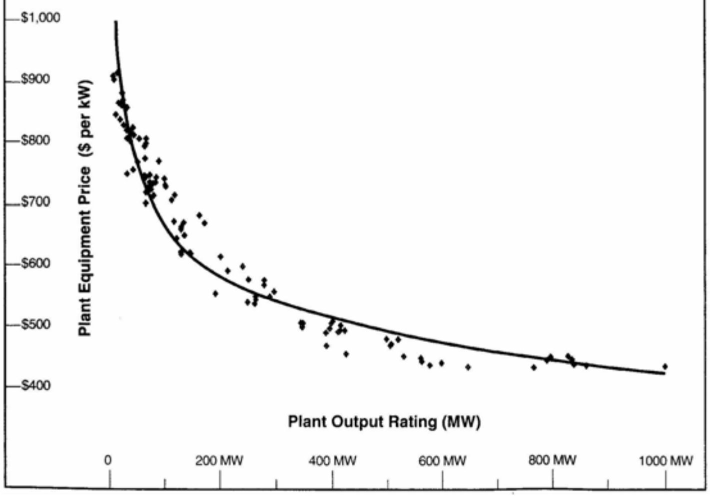
Simple Cycle Plant Prices 2007

Model	Frequency	Base Load Rating	Heat Rate Btu/kWh	LHV Efficiency	Budgetary Price	Price per kW
LM6000PD	60 Hz	43,068 kW	8173 Btu	41.8%	$15,907,000	$369
SGT-800	50/60 Hz	45,000 kW	9215 Btu	37.0%	$15,426,000	$343
PG6591(C)	50/60 Hz	45,400 kW	9315 Btu	36.6%	$15,330,000	$338
LM6000PD Sprint	60 Hz	46,824 kW	8235 Btu	41.4%	$17,548,000	$375
LM6000PC	60 Hz	50,080 kW	8434 Btu	40.5%	$17,863,000	$357
FT8 TwinPac	50/60 Hz	51,350 kW	8890 Btu	38.4%	$17,571,000	$342
Trent 60 DLE	50/60 Hz	51,685 kW	8138 Btu	41.9%	$18,457,000	$357
GT8C2	50 Hz	56,300 kW	10,065 Btu	33.9%	$17,890,000	$318
FT8-3TwinPac	50/60 Hz	56,340 kW	8840 Btu	38.6%	$19,156,000	$340
Trent 60 WLE	50/60 Hz	58,000 kW	8336 Btu	40.9%	$20,551,000	$354
SGT-1000F	50 Hz	67,700 kW	9730 Btu	35.1%	$21,156,000	$313
PG6111(FA)	50/60 Hz	77,060 kW	9620 Btu	35.5%	$22,002,000	$286
PG7121(EA)	60 Hz	85,100 kW	10,430 Btu	32.7%	$19,514,000	$229
LMS100PA	60 Hz	98,816 kW	7569 Btu	45.1%	$32,453,000	$328
GT11N2	50 Hz	113,600 kW	10,247 Btu	33.3%	$25,988,000	$229
GT11N2	60 Hz	115,400 kW	10,065 Btu	33.9%	$27,365,000	$237
SGT6-3000E	60 Hz	120,500 kW	9840 Btu	34.7%	$29,167,000	$242
PG9171(E)	50 Hz	126,100 kW	10,100 Btu	33.8%	$29,172,000	$231
M701DA	50 Hz	144,090 kW	9810 Btu	34.8%	$34,033,000	$236
SGT5-2000E	50 Hz	168,000 kW	9825 Btu	34.7%	$37,800,000	$225
PG7241FA	60 Hz	171,700 kW	9360 Btu	36.5%	$40,176,000	$234
GT13E2	50 Hz	179,900 kW	9247 Btu	36.9%	$42,433,000	$236
PG7251FB	60 Hz	184,400 kW	9215 Btu	37.0%	$44,004,000	$239
GT24	60 Hz	188,782 kW	8956 Btu	38.1%	$46,421,000	$246
SGT5-3000E	50 Hz	191,000 kW	9825 Btu	34.7%	$42,093,000	$220
SGT6-5000F	60 Hz	198,300 kW	8985 Btu	38.0%	$46,982,000	$237
PG9351(FA)	50 Hz	255,600 kW	9250 Btu	36.9%	$57,123,000	$224
SGT6-6000G	60 Hz	267,500 kW	8715 Btu	39.2%	$64,065,000	$240
M701F	50 Hz	278,300 kW	8810 Btu	38.7%	$66,020,000	$237
PG9371(FB)	50 Hz	279,200 kW	9016 Btu	37.9%	$64,044,000	$229
SGT5-4000F	50 Hz	286,600 kW	8638 Btu	39.5%	$70,023,000	$244
GT26	50 Hz	289,139 kW	8716 Btu	39.2%	$69,347,000	$240
M701G	50 Hz	334,000 kW	8630 Btu	39.5%	$80,824,000	$242

Source: GTW Handbook 2007

Combined Cycle Plant Prices 2007

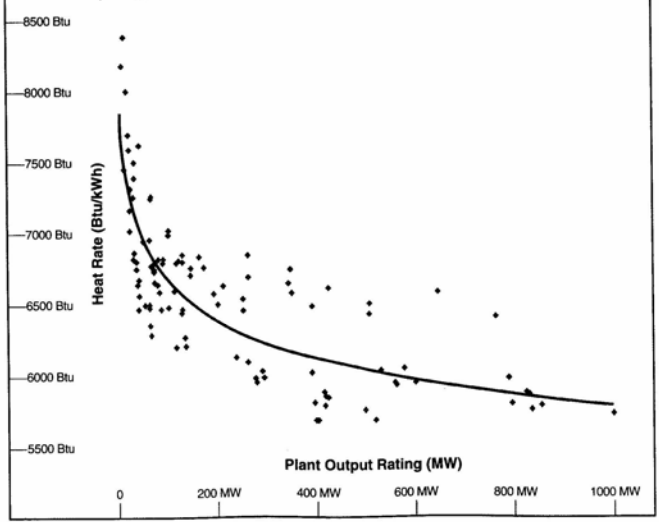
Combined Cycle Plant Prices 2007. Here again, plant prices vary considerably, depending on design integration of the gas turbine, HRSG and steam turbine. In the larger unit sizes, the lower $ per kW prices reflect economy of scale in the equipment design and manufacture.



Source: GTW Handbook 2007

Combined Cycle Heat Rates 2007

Combined Cycle Heat Rates 2007. As shown, heat rates vary all over the place, depending on HRSG and steam turbine design, and on whether or not the gas turbine design is optimized for combined cycle application.



Source: GTW Handbook 2007

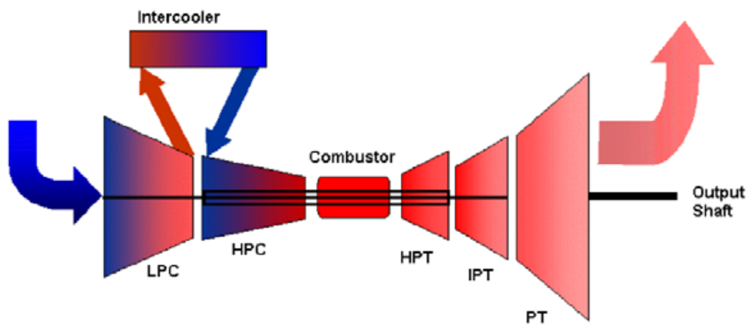
Selected Gas Turbine Models

- GE LMS 100 (46 % efficiency)
- H technology by GE and Mitsubishi
- Alstom GT24/26 (Reheat Gas Turbine)
- Siemens SGT5 – 8000H (340 MW)
- Solar Mercury (Recuperated Gas Turbine)
- Microturbine Turbec T100 (100 kW)

Quelle: European Power News, March 2003

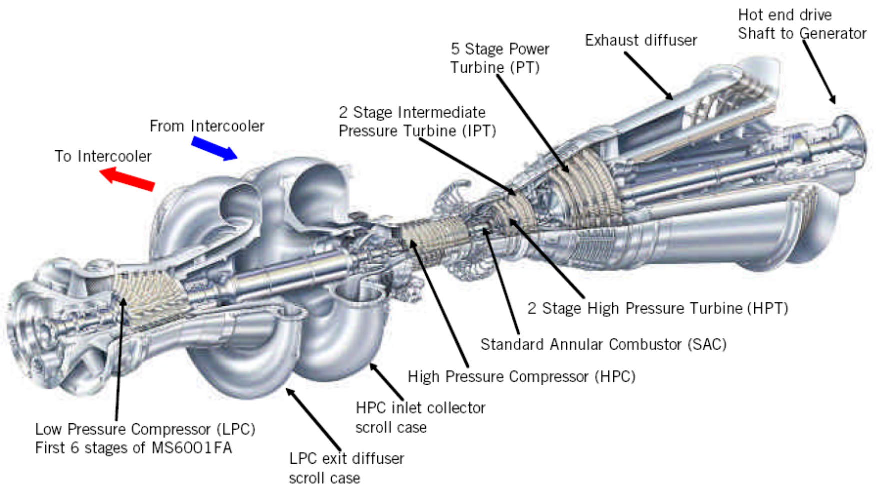
GE LMS 100

- Output 100 MW
- Highest simple cycle efficiency of 46 %
- Cycle pressure ratio 42:1
- Off-engine intercooling reduces compression work and supplies colder cooling air
- Three-spool design
- 1380°C firing temperature class



Source: General Electrics Company

GE LMS 100



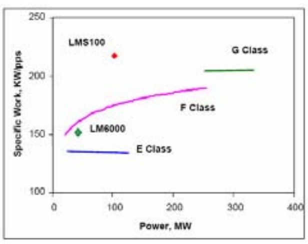
- **LPC uses stationary FA gas turbine technology**
- **CF6 aeroengine technology for supercore (HPC, Combustor, HPT, IPT)**

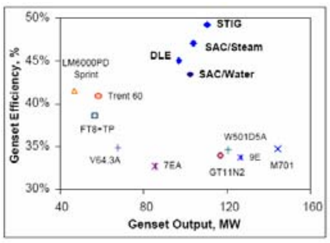
Source: General Electrics Company

GE LMS 100

LMS100 ISO Performance Data

Model	ISO Base Rating (kW)	Heat Rate (Btu/kWh)	Efficiency%	Mass Flow (lb/sec)	Turbine Speed (RPM)	Exhaust Temp (F)	Comments
LMS100PB	97,718	7,592	45.0%	453	3,600	783	DLE, 25 ppm NO_X
LMS100PB	97,878	7,579	45.0%	453	3,000	784	DLE, 25 ppm NO_X
LMS100PA	103,112	7773	43.9%	469	3,600	770	water injected to 25 ppm NO_X
LMS100PA	103,162	7769	43.9%	469	3,000	767	water injected to 25 ppm NO_X



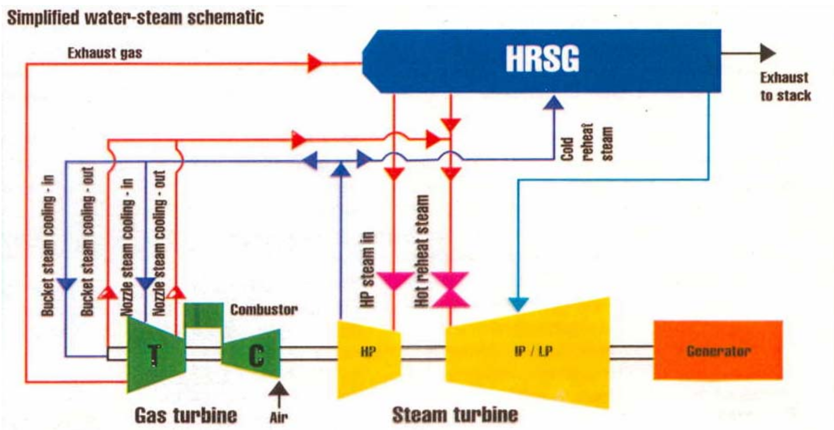


- **Attractive for peaking and mid-range dispatch applications, where cyclic operation is required and efficiency becomes more important**
- **Limited applicability for combined cycle operation due to low exhaust temperature: 120 MW at 53.8 % efficiency**

Source: General Electrics Company

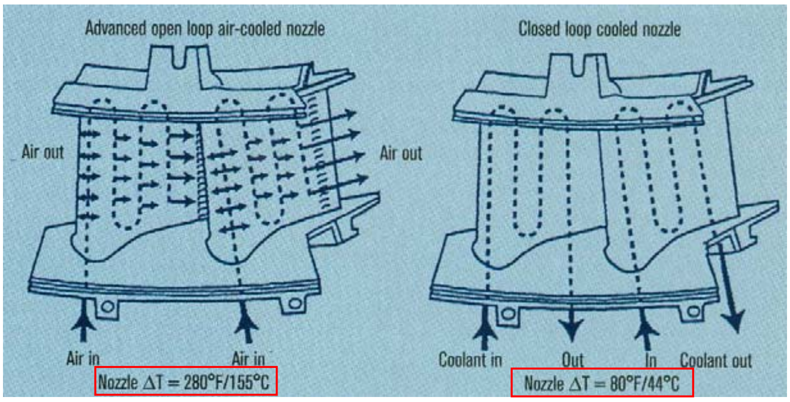
H technology by GE (and Mitsubishi)

Reheat steam from steam cycle is used for cooling the turbine rotor and first and second stage blades



Source: GE Power Systems

H technology by GE (and Mitsubishi)



H technology demands convective cooling of blades

Higher heat capacity of steam compared to air gives better cooling effectiveness

Source: GE Power Systems

H technology by GE (and Mitsubishi)

H System combined cycle plant performance characteristics

	7FA	7G	7H	9H
Firing temperature (°C)	1300	1430	1430	1430
Air flow (kg/s)	442	558	558	685
Compressor pressure ratio	15	23	23	23
Specific work (MW/kg/s)	0.57	0.63	0.72	0.70
Combined cycle net output (MWe)	253	350	400	480
Net thermal efficiency (%)	55	58	60	60
NOx (ppmvd at 15% O_2)	9	25	9	9

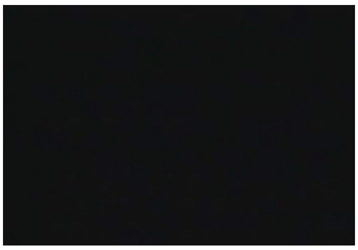
First plant at Baglan Energy Park, UK, in September 2003

March 2005: 8000 hrs of commercial service

Fig. 15. GE-9H gas turbine is prepared for testing (Source: GE Power Systems)

Source: GE Power Systems

GE 9001H in Baglan Bay, UK



Source: GE Power Systems

H technology by GE (and Mitsubishi)

MHI also has a long experience in steam cooling technology, mainly for the combustor liner, but also for turbine blades

As of March 2004, MHI had 150,000 operating hours of steam cooling experience with their G units.

Both their G and H models have steam cooled combustion liners.

The H model also has blades and vanes in the first two rows of its turbine rotor and the blade rings, steam cooled.

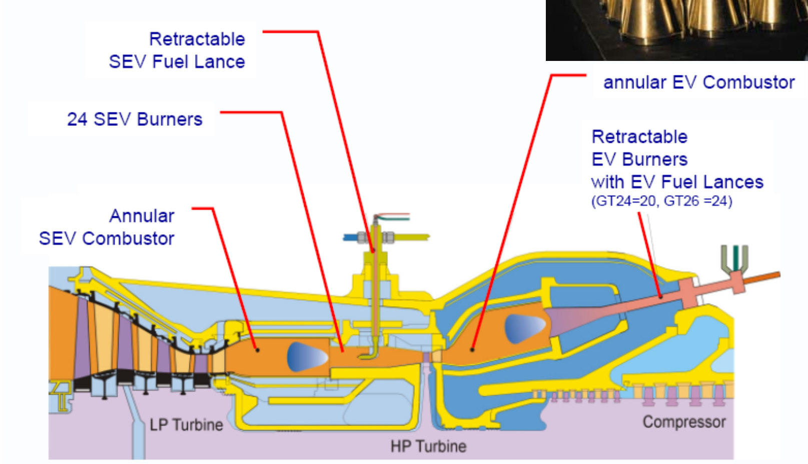
Table 5. Categories of gas turbines for the Mitsubishi Gas Turbine product line [5]

GT type	TIT	Cooling Type		Performance (ISO: LHV)				NOx
	deg C	Turbine	Combustor	Gas turbine		Combined Cycle		ppm
M501DA	1250	Air	Air	114MW	34.9%	167MW	51.4%	9
M501F	1350	Air	Air	153MW	35.3%	229MW	52.8%	25
M501F3	1400	Air	Air	185MW	37.0%	285MW	57.1%	9
M501G	1500	Air	Steam	254MW	38.7%	371MW	58.0%	25
M501G1	1500	Air	Steam	267MW	39.1%	399MW	58.4%	15
M501H	1500	Steam	Steam	-	-	403MW	60.0%	15

Source: Soares, Gas Turbine Handbook, 2005

Alstom GT24/26

Reheat turbine for combined cycle application

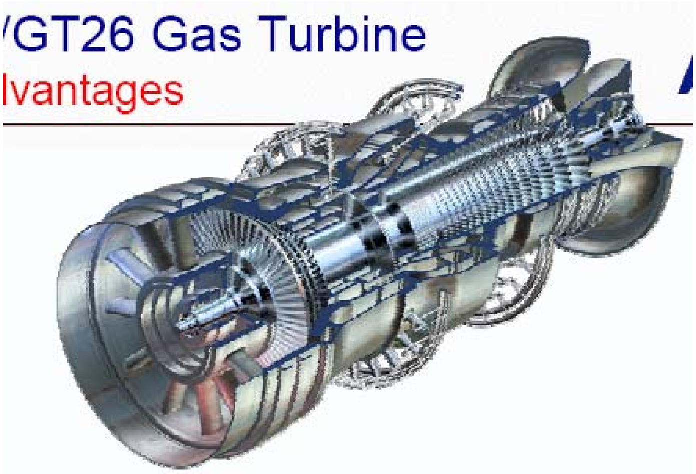


Source: Alstom

Alstom GT24/26

GT 26: 280 MW

Efficiency: 38 %



Source: Alstom

Alstom GT24/26 – Performance data

GT24 (ISO 2314:1989)

Fuel	Natural gas
Frequency	60 Hz
Gross Electrical output	187.7 MW*
Gross Electrical efficiency	36.9 %
Gross Heat rate	9251 Btu/kWh
Turbine speed	3600 rpm
Compressor pressure ratio	32:1
Exhaust gas flow	445 kg/s
Exhaust gas temperature	612 °C
NOx emissions (corr. to 15% O2,dry)	< 25 vppm

GT26 (ISO 2314:1989)

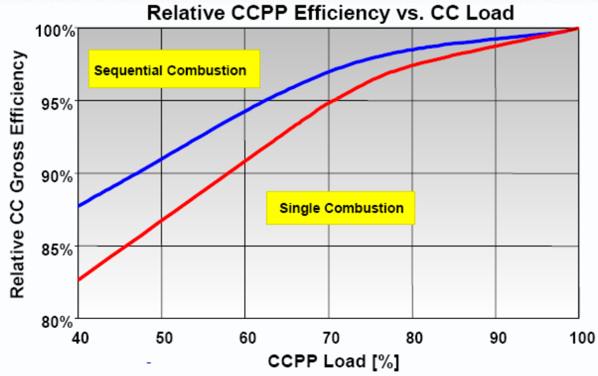
Fuel	Natural gas
Frequency	50 Hz
Gross Electrical output	281 MW*
Gross Electrical efficiency	38.3 %
Gross Heat rate	8910 Btu/kWh
Turbine speed	3000 rpm
Compressor pressure ratio	32:1
Exhaust gas flow	632 kg/s
Exhaust gas temperature	615 °C
NOx emissions (corr. to 15% O2, dry)	< 25 vppm

Source: Alstom

Alstom GT24/26

Combined Cycle Efficiency: 58 %

12 MW (GT26) or 10 MW (GT24) is produced by steam turbine through heat from turbine cooling air coolers



- GT exhaust temperature maintained from 40% to 100% GT load
- High exhaust energy - optimal for high steam parameters under full and part load conditions

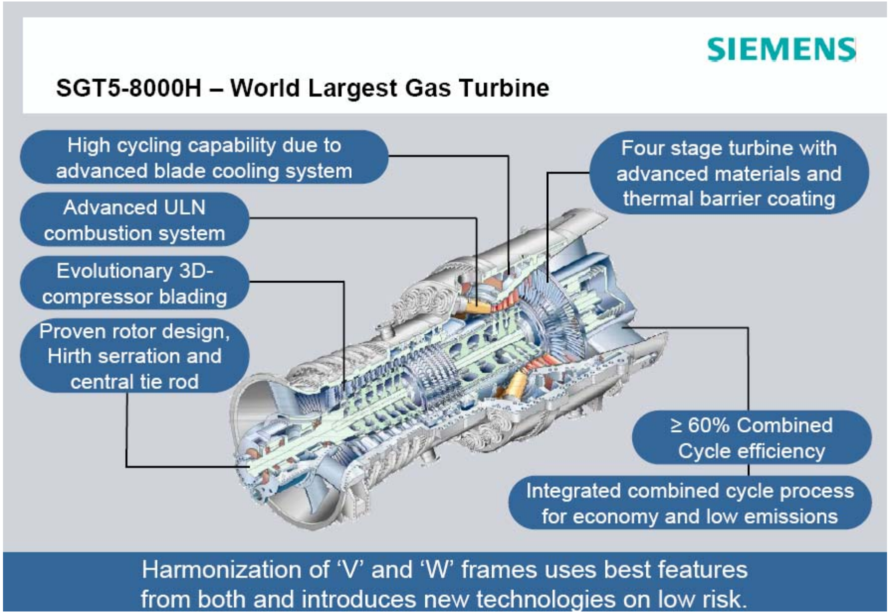
Source: Alstom

Siemens SGT5 – 8000H

- **Largest gas turbine with 340 MW output**
- **Weight: 440 t (Airbus 380: 361 t), Length: 13.2 m, Height: 5 m, Width: 5m**
- **Pressure ratio: 19.2 : 1**
- **Exhaust temperature: 620°C**
- **60 % efficiency in combined cycle operation (530 MW)**

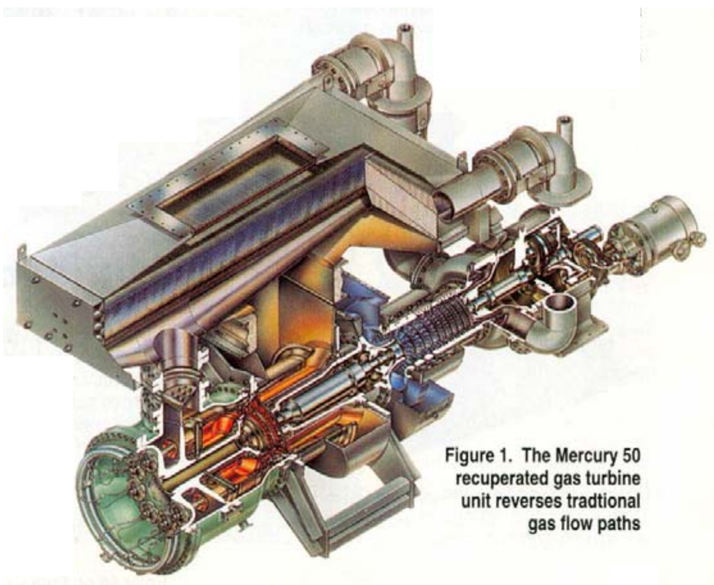
Source: Siemens Power Generation

Siemens SGT5 – 8000H



Source: Siemens Power Generation

Solar Mercury 50



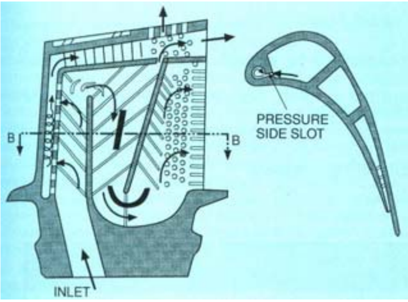
Source: Modern Power Systems

Solar Mercury

Output (continuous):	**4.2 MW**
Compression ratio:	**9.1 : 1**
Compressor stages:	**10**
Turbine inlet temperature:	**1093 °C**
Turbine stages:	**2**
Thermal efficiency:	**40.5 %**

Cooling of first stage blades with a novel cooling scheme:
vortex cooling = use of swirled flow

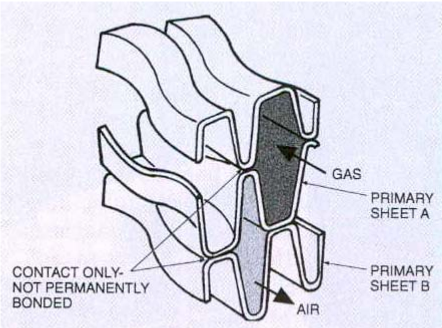
no showerhead cooling needed



Source: Modern Power Systems

Solar Mercury

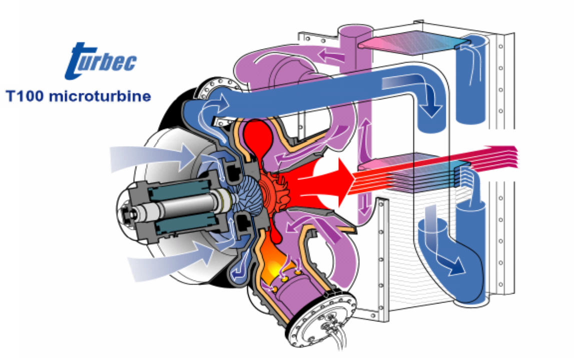
- **Gas turbine recuperators have high transient thermal stresses: risk of low cycle fatigue**
- **Solar design: clamped air cell structure with no internal welds or joints**
- **This design allows free deformation to relieve stresses**
- **Multiple friction interfaces also damp high cycle oscillations**



Source: Modern Power Systems

Microturbines

- Microturbines are small fast-running gas turbines
- Power range: 20 – 500 kW
- Pressure ratio: ~ 4 : 1 High shaft speed > 40 000 rpm
- Recuperator to increase electrical efficiency (25 – 30 %)
- Direct drive high-frequency alternator
- Attractive for distributed power generation and cogeneration application
- Recuperator bypass control for variable heat production for cogeneration



Source: Turbec AB

The End

Thank you for your attention!