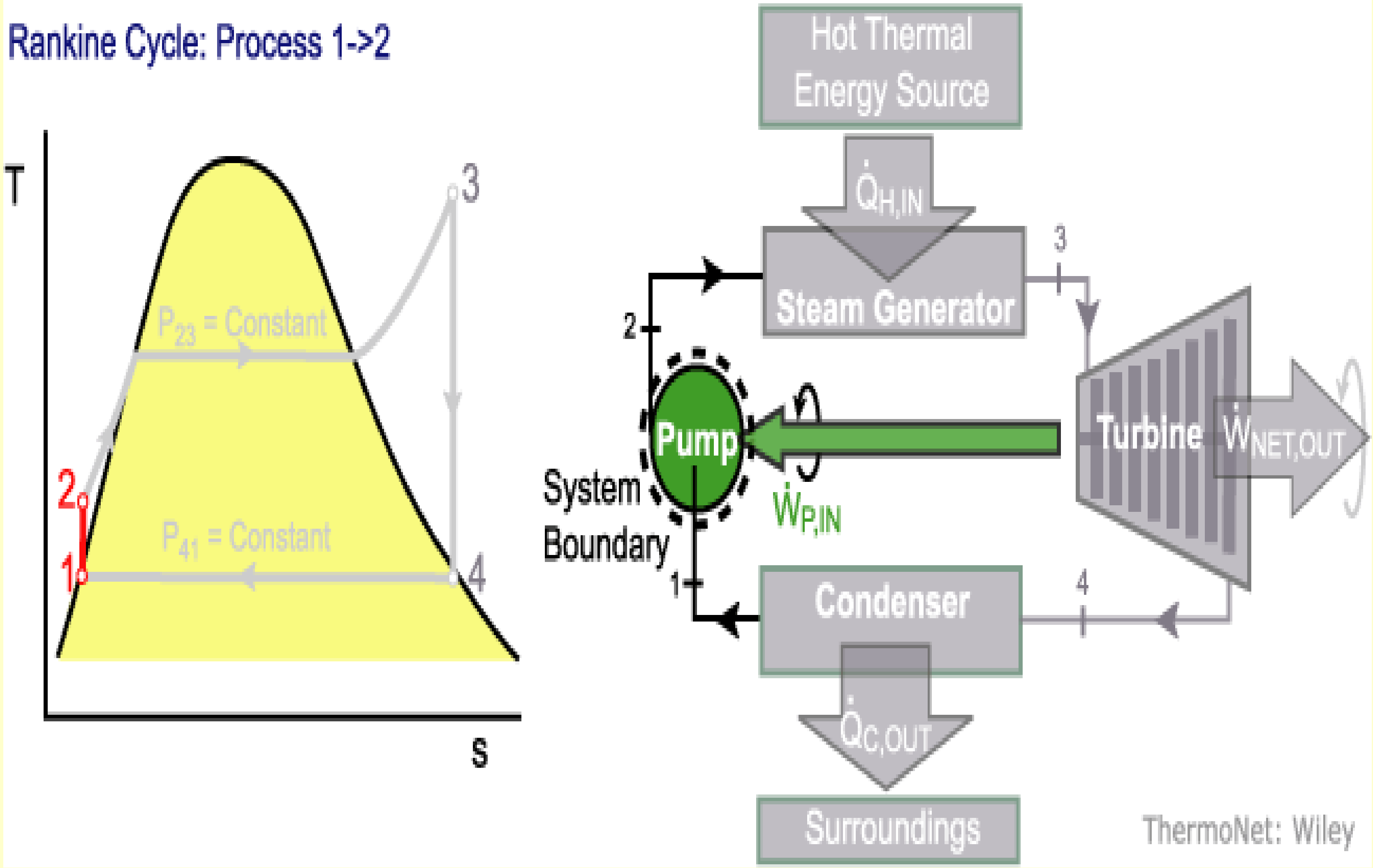
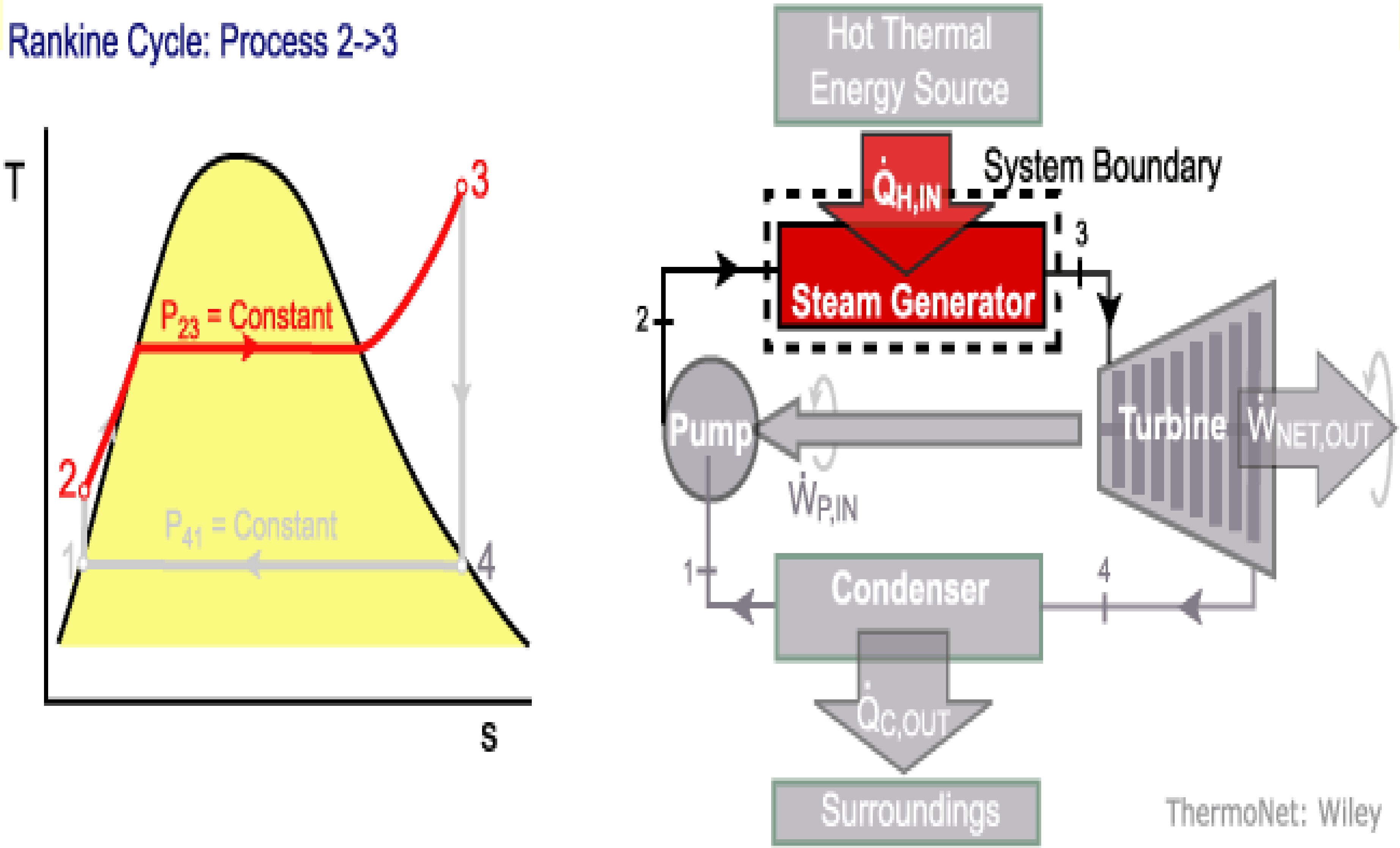
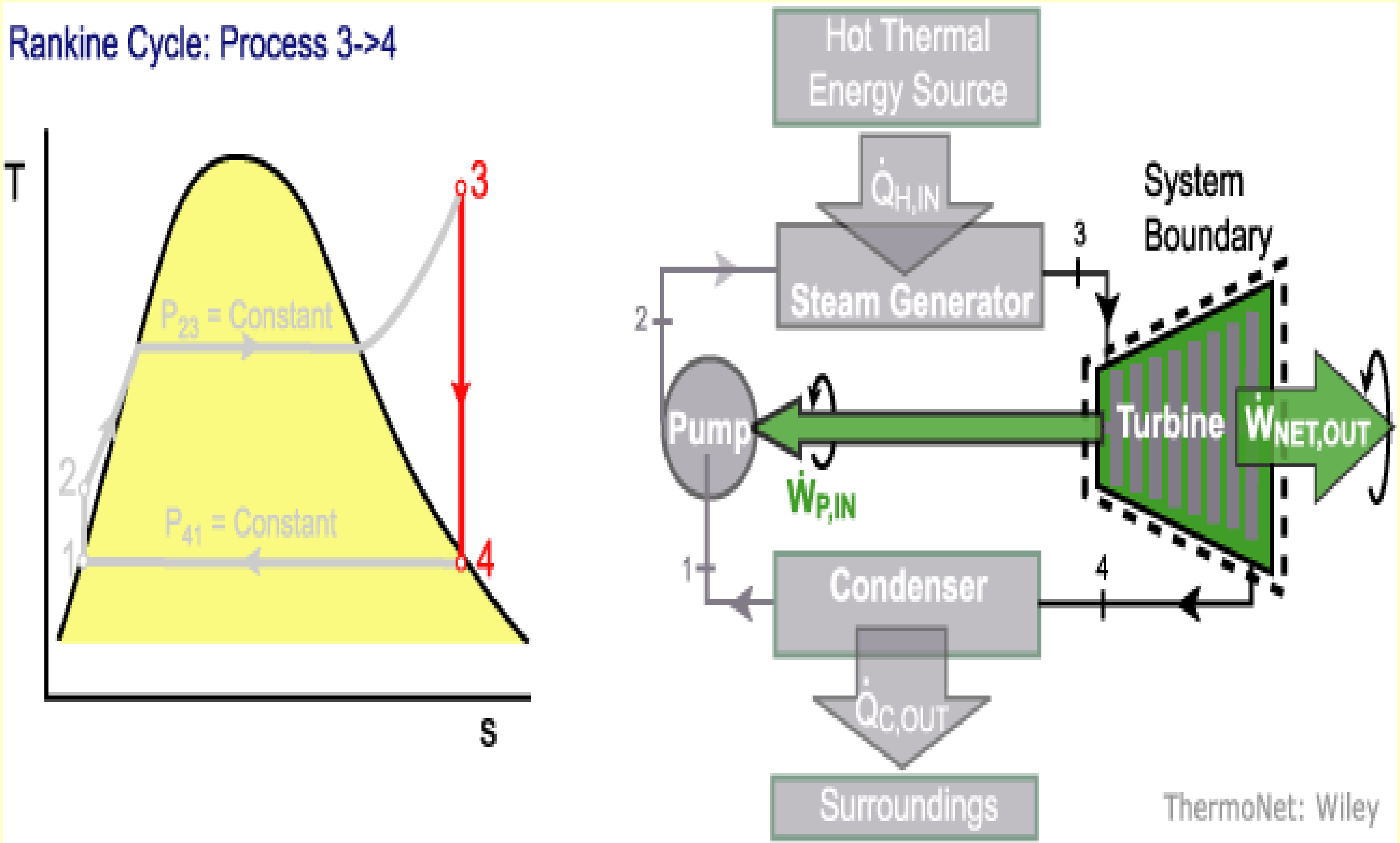
Rankine Cycle



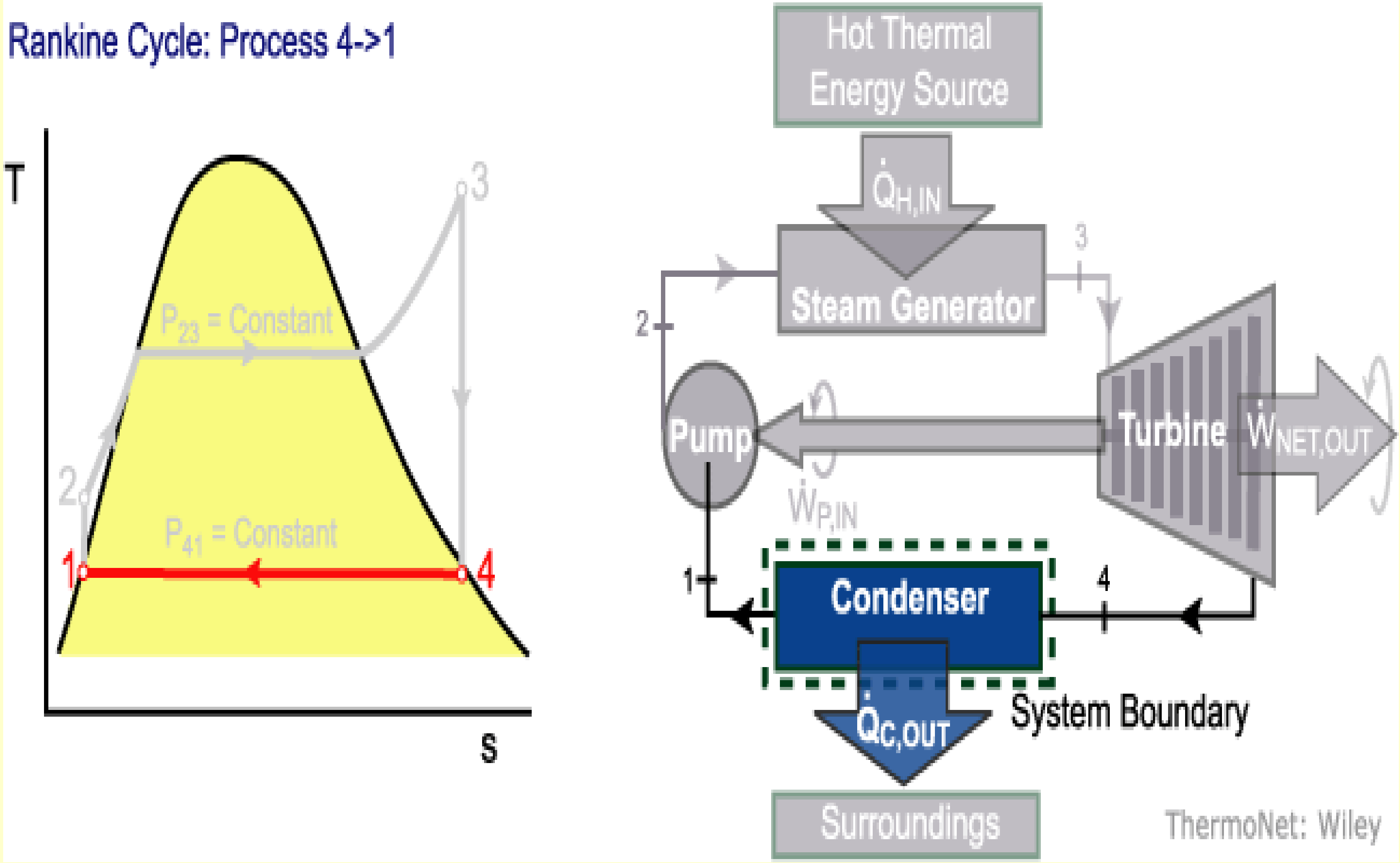
Rankine Cycle



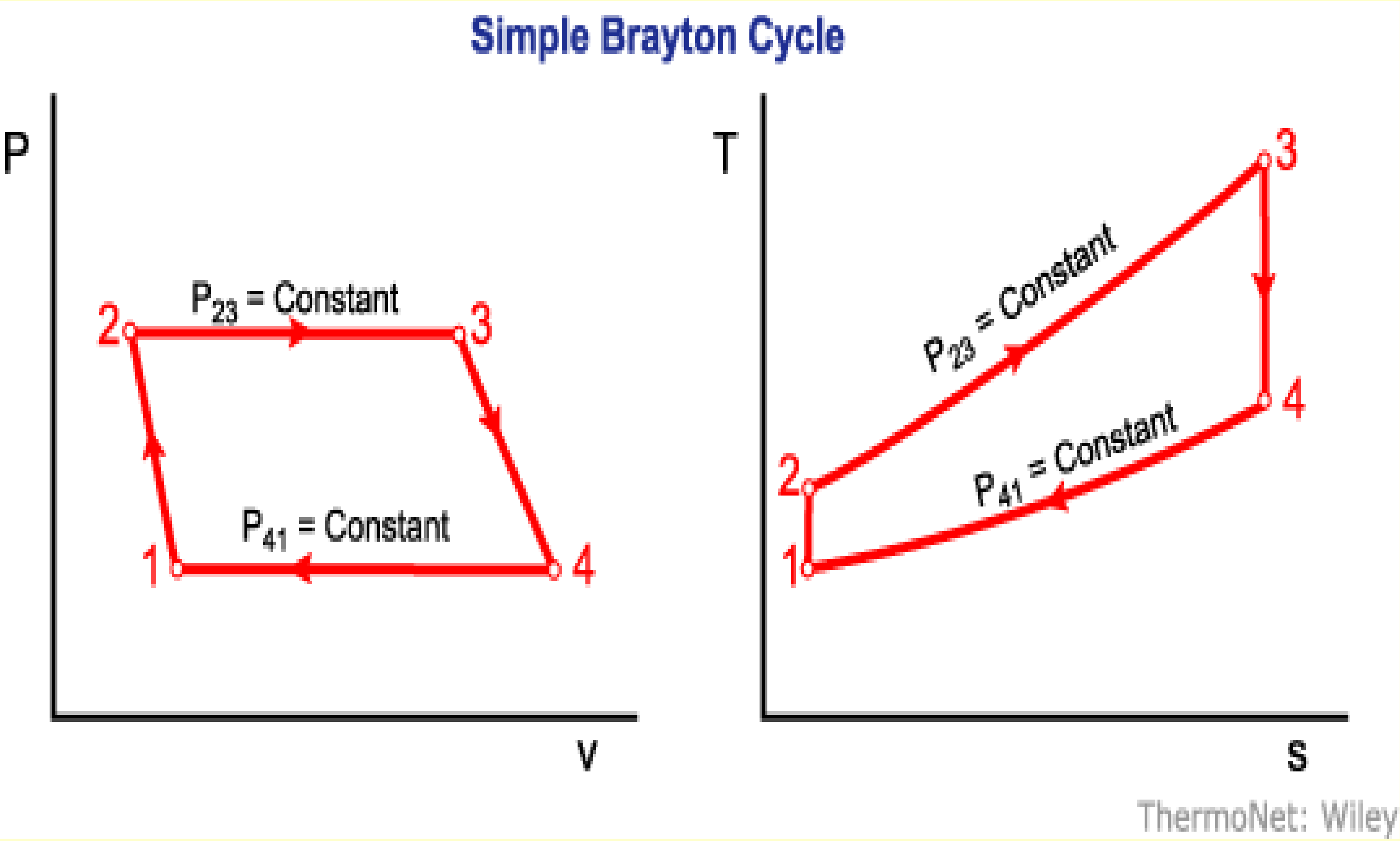
Rankine Cycle



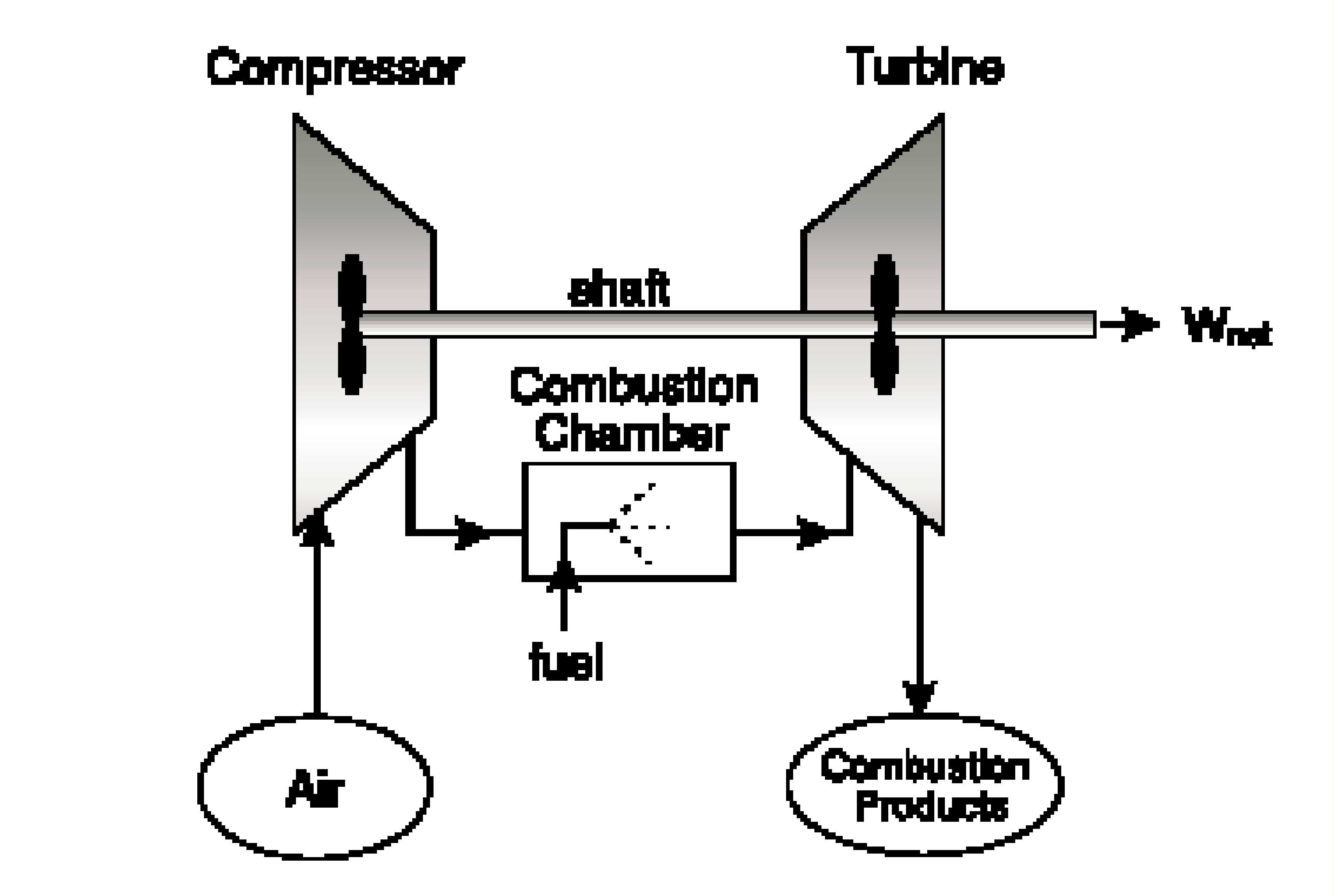
Rankine Cycle



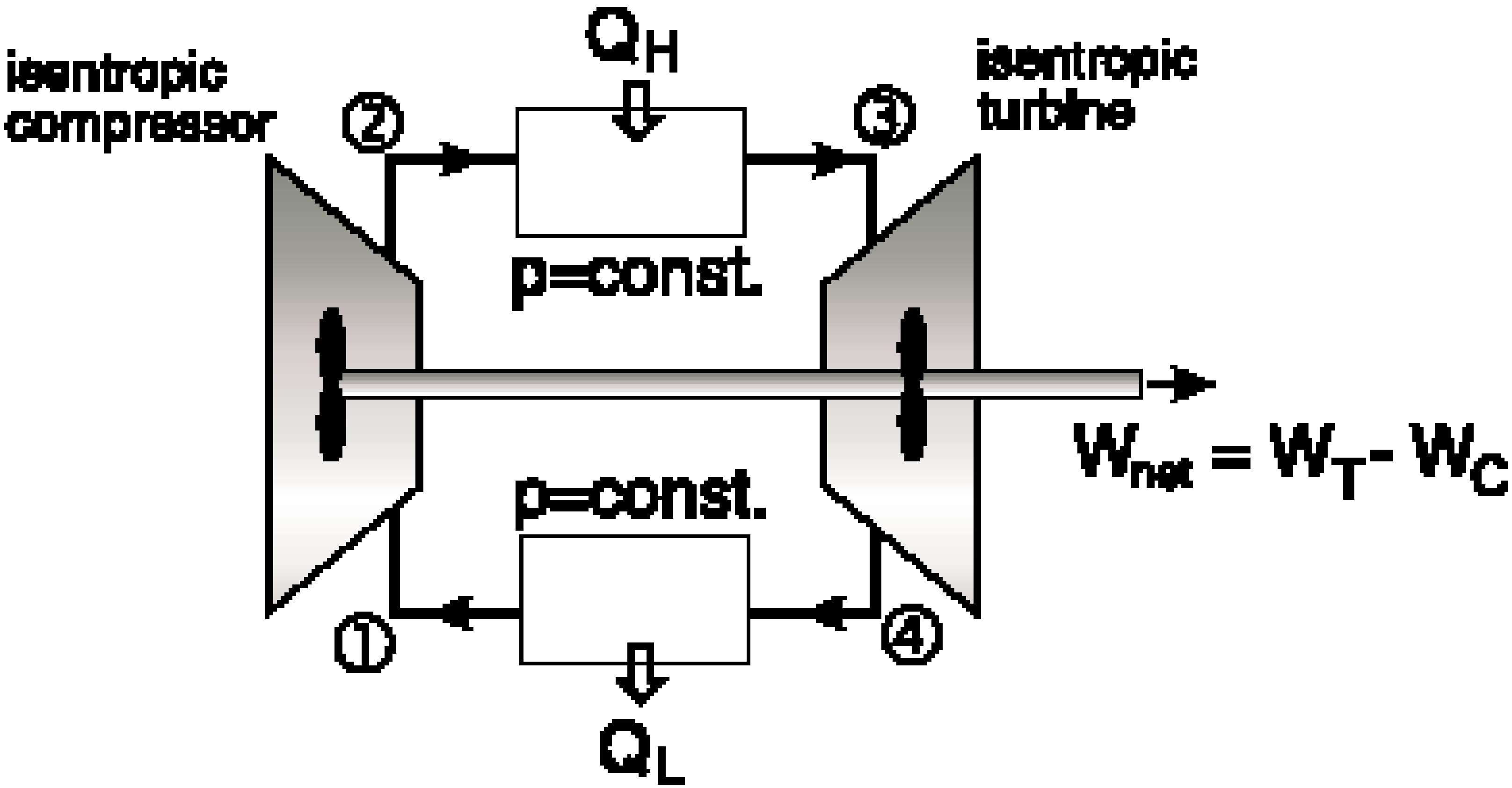
Brayton Cycle



Open Cycle Gas Turbine



Idealized air standard Brayton cycle



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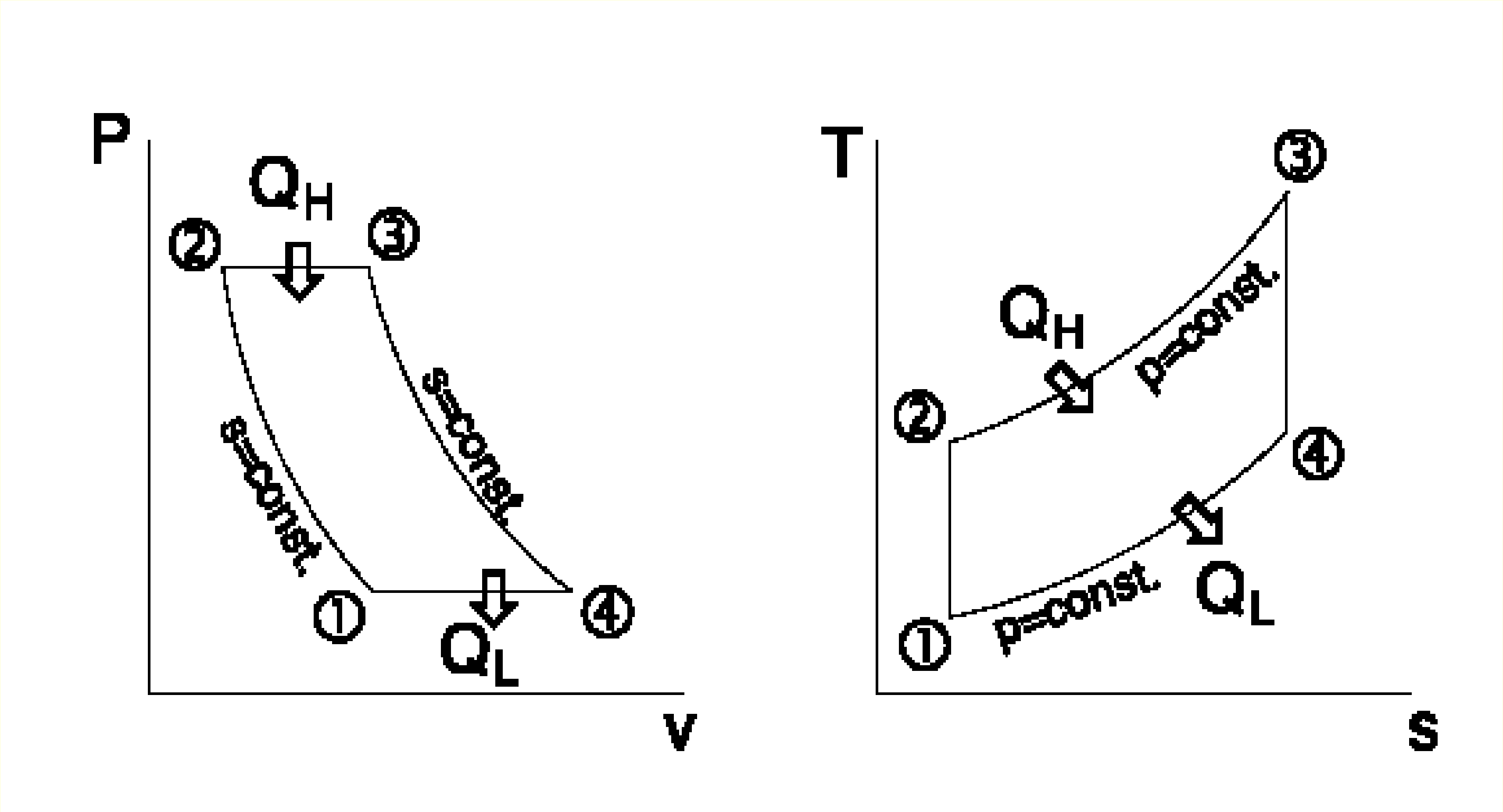
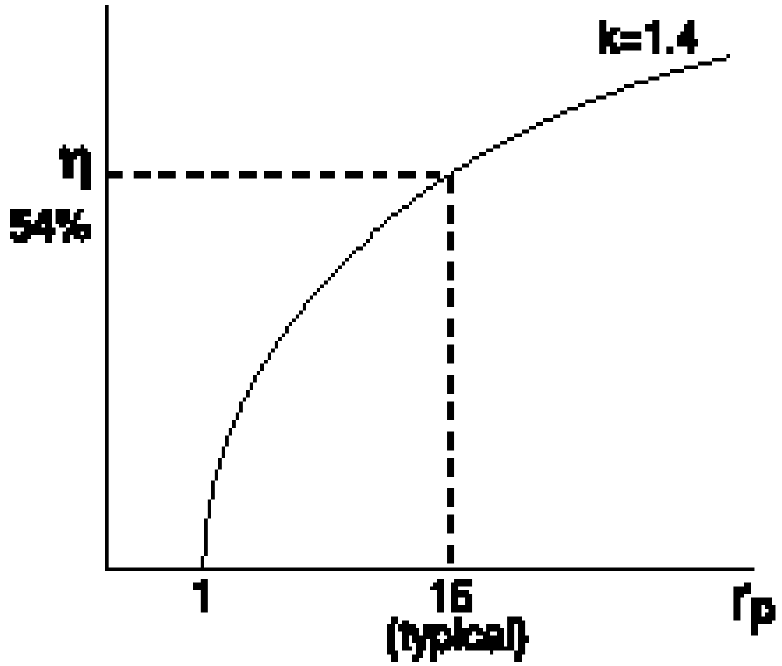


Efficiency,

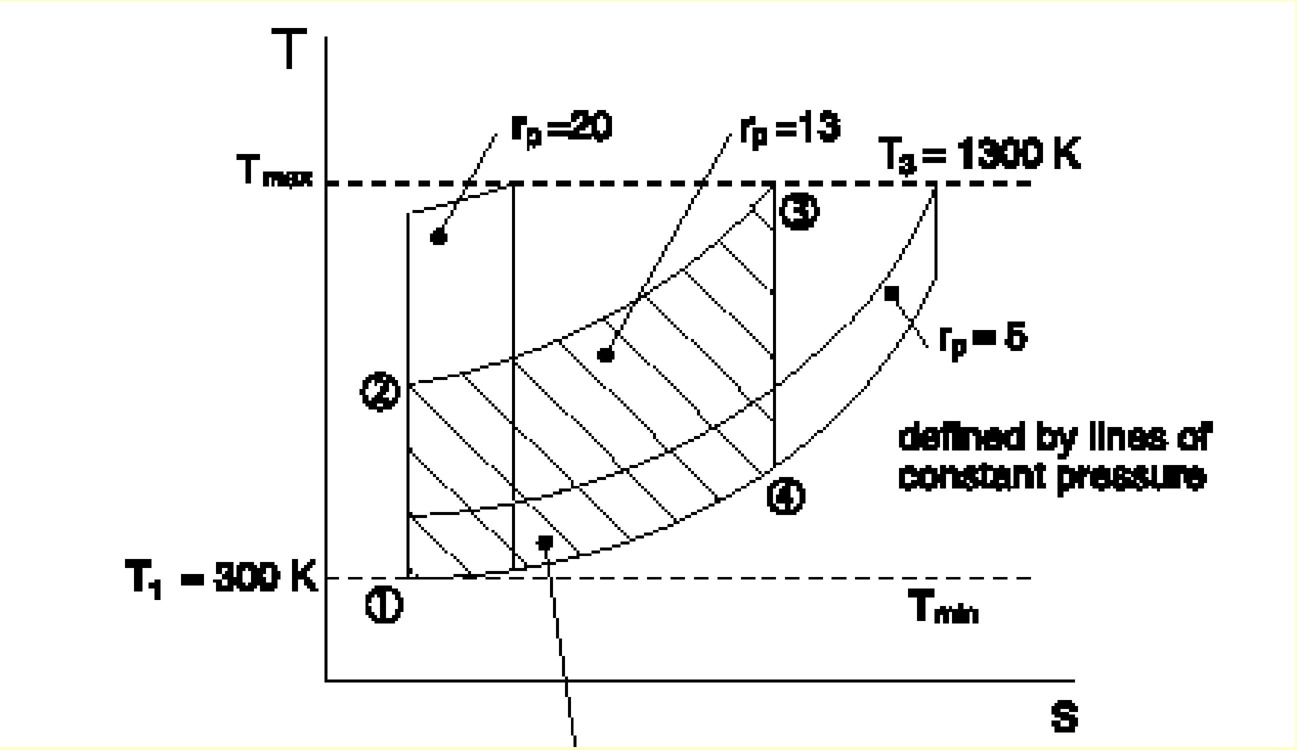
$$\eta = \frac{W_{net}}{Q_H} = 1 - (r_p)^{(1-k)/k}$$

Brayton cycle efficiency

$$\eta = \frac{W_{net}}{Q_H} = 1 - (r_p)^{(1-k)/k}$$

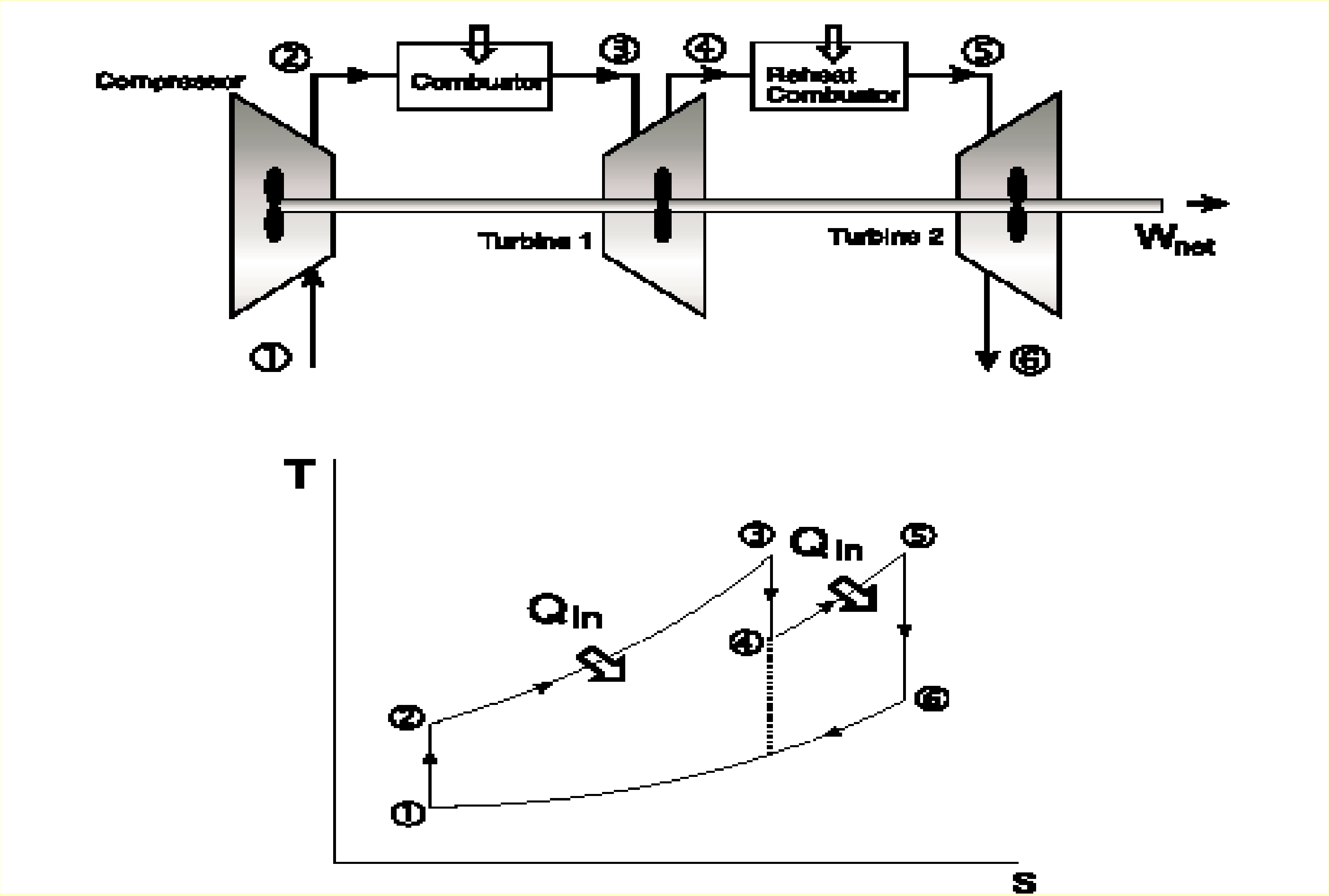


Effect of Maximum Pressure on Cycle output

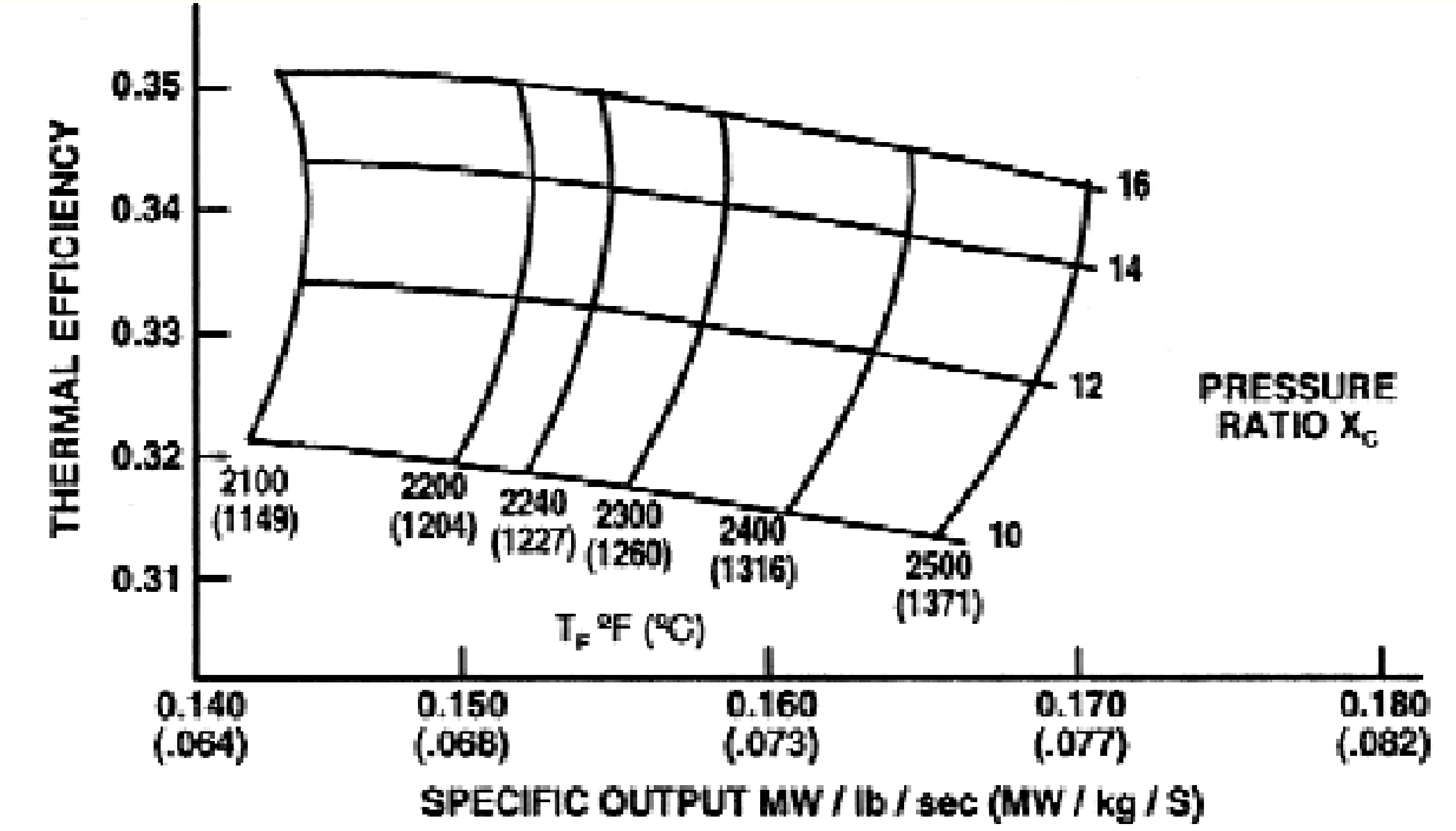


Work Net =

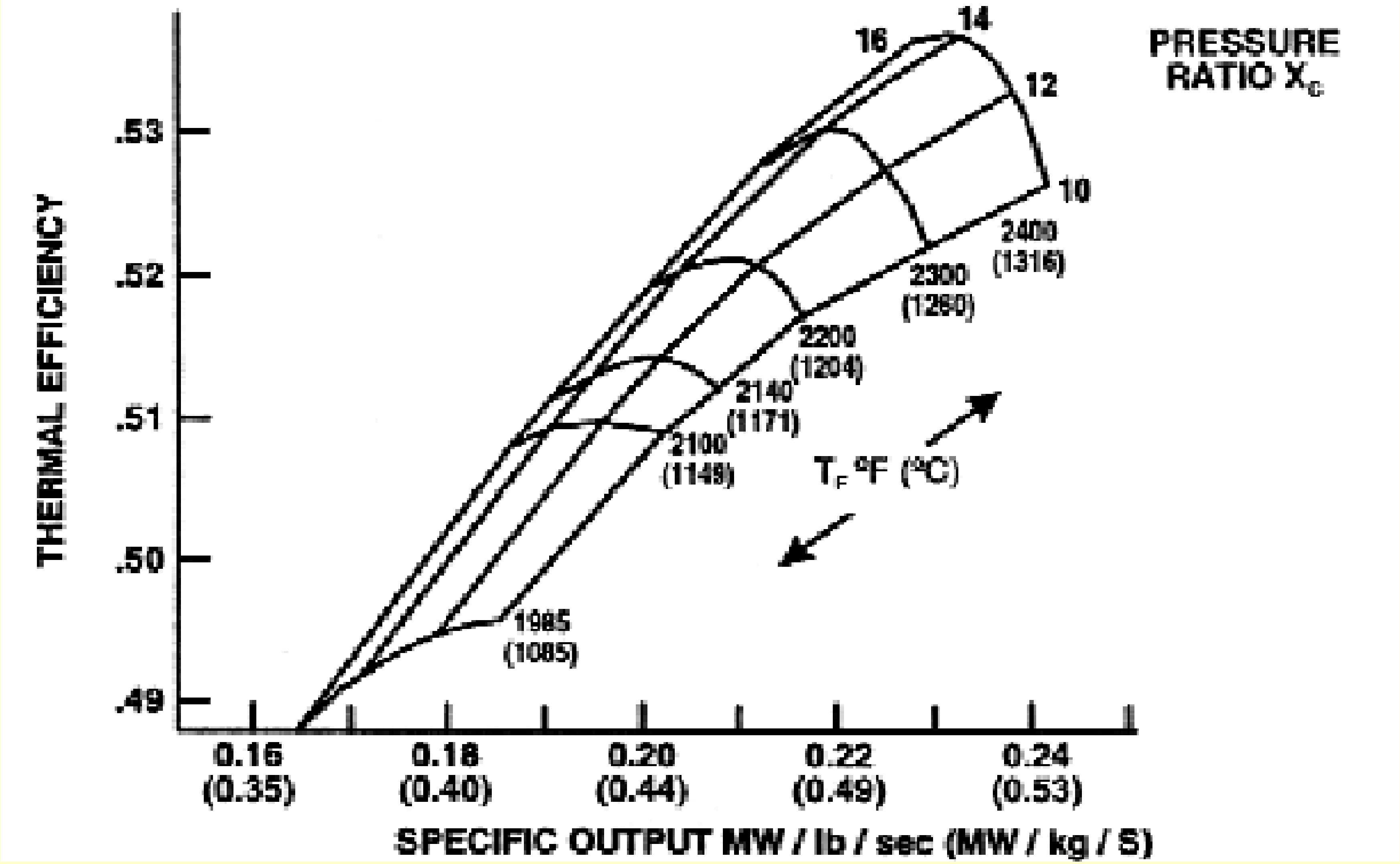
Brayton cycle with reheating



Gas turbine thermodynamics -Simple cycle



Gas turbine thermodynamics -Combined cycle



Gas turbines

- Ranges in size from ½ MW to 300 MW
- 1 MW powers 1000 homes
- Two basic types –Industrial and aero derivatives
- Can fire gas as well as liquid fuels
- Technology well proven
- Peaking resource in simple cycle

Simple cycle plants-Features

- Peaking ,load following and base load capabilities
- Typically 30+ years design life
- Capacity factor –30-85% in peaking mode
- Availability>90%
- Typical efficiency ranges – 35-42 %
- Capital cost :$360-$440 /kw
- Operating cost based on 85 % capacity factor -$34-$44/kw
- Equipment lead time –6-12 months
- Project completion time –12-18 months

Simple Cycle Pros/Cons

- Pros
  - Clean
  - Quick start-(10-12 minutes)
  - Well proven technology
  - Reliable
  - Fast construction
  - Good peaking resource
  - Low o&m cost
  - Can use small site –1-10 acres
  - Lower $/kw compared to CCPP
- Cons
  - Gas/fuel price
  - Lower efficiencies

Gas turbine rating

- ISO rating
- ISO conditions
  - Ambient DBT –59 Deg F(15 Deg C)
  - Relative humidity –60%
  - Ambient barometric pressure – 15 psi (1.03kg/cm2)
- Site rating
- Base rating - Output that can be maintained for 6000 hours or more per year
- Peak rating - Output that can be maintained for 2000 hours or less per year

Brayton Cycle

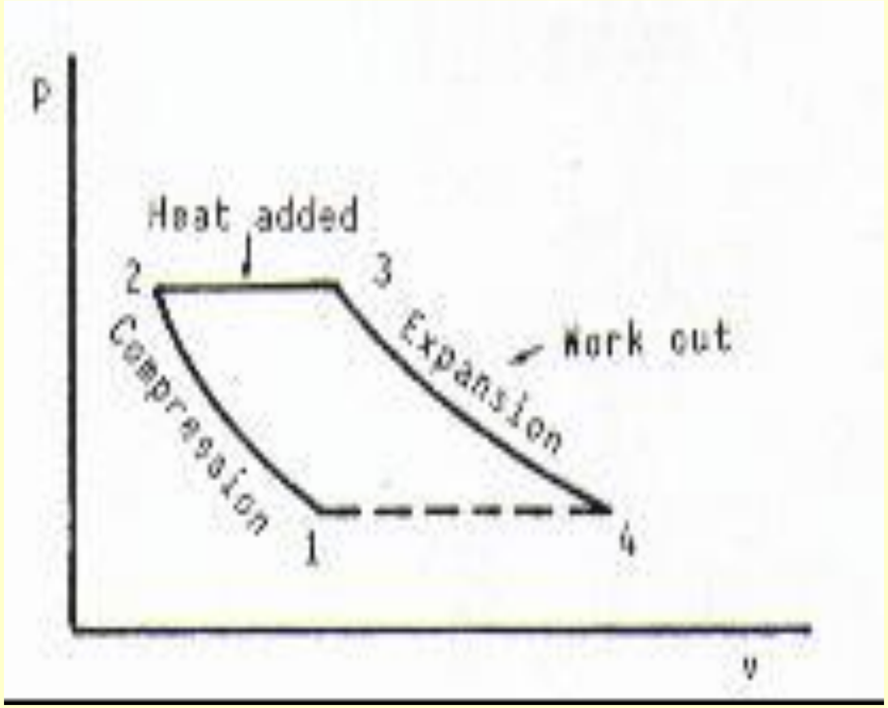
- Unlike diesels, operate on STEADY-FLOW cycle
- Open cycle, unheated engine

1-2: Compression

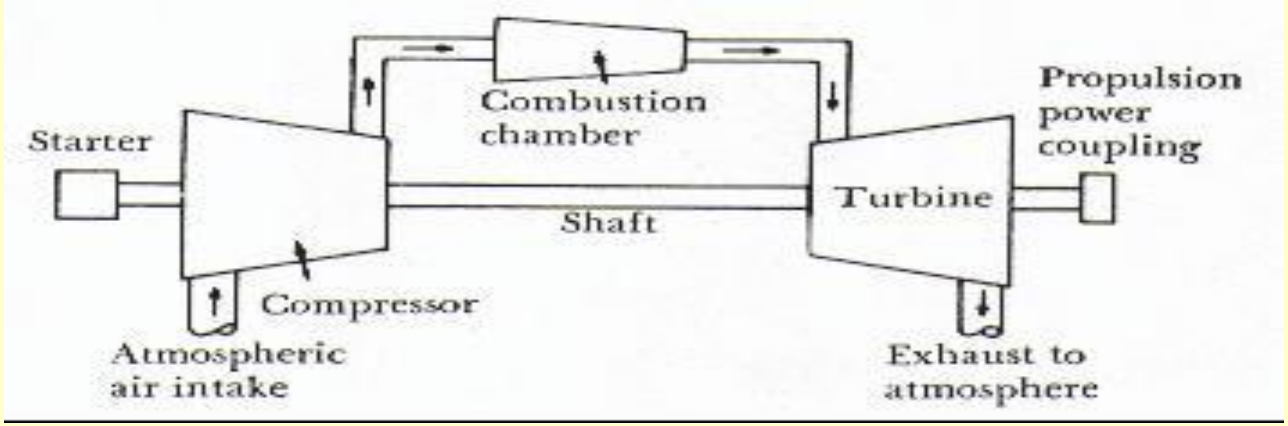
2-3: Combustion

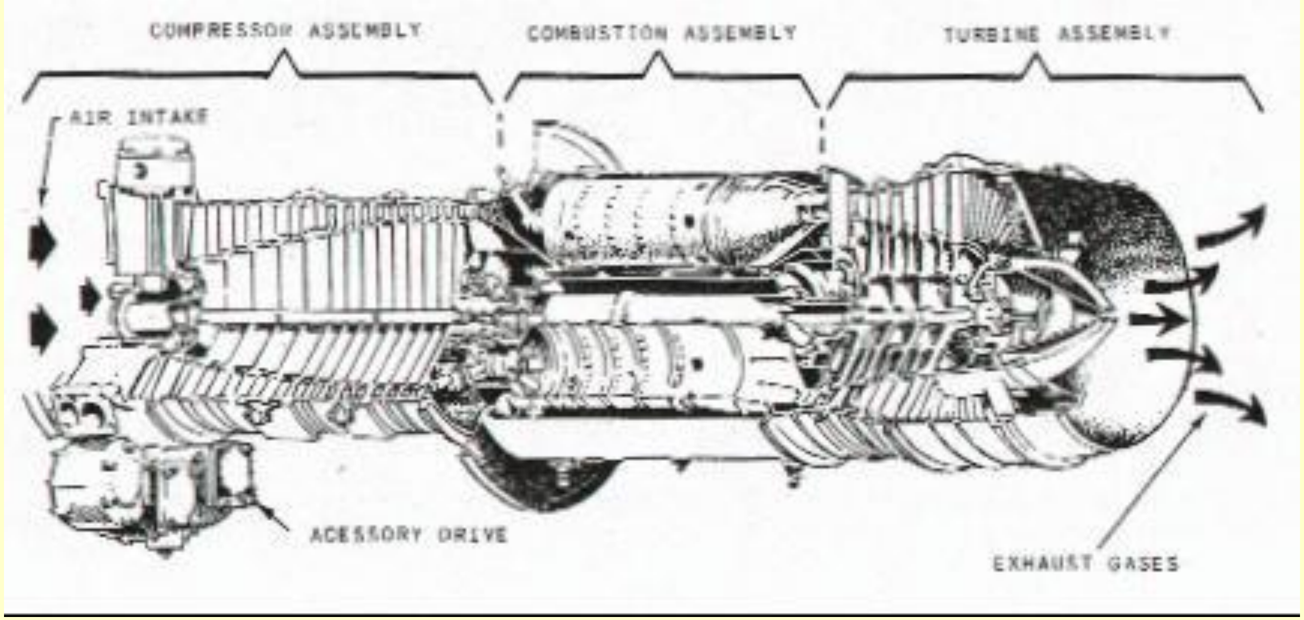
3-4: Expansion through Turbine and Exhaust Nozzle

(4-1: Atmospheric Pressure)



Basic Components





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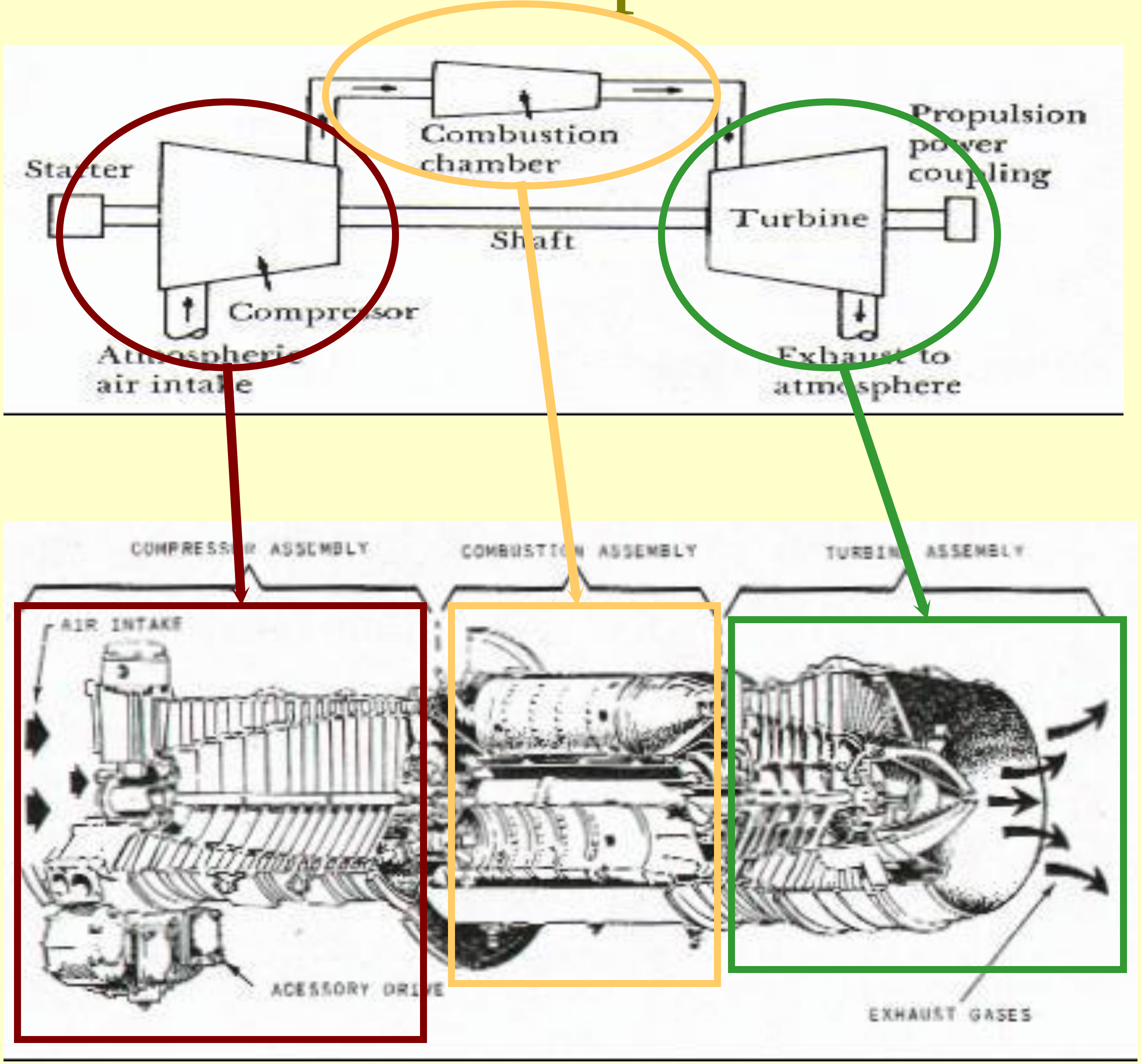
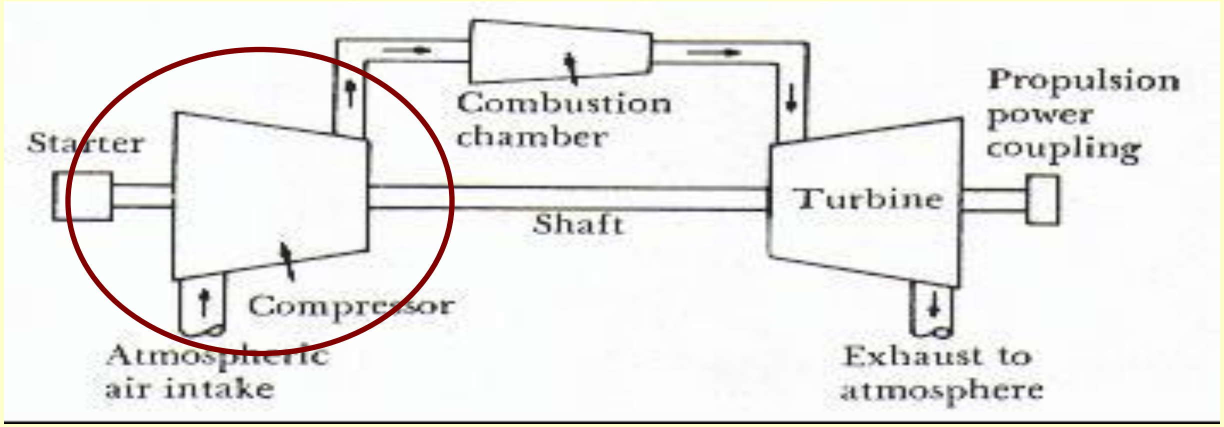


Basic Components

- Compressor
  - Draws in air & compresses it
- Combustion Chamber
  - Fuel pumped in and ignited to burn with compressed air
- Turbine
  - Hot gases converted to work
  - Can drive compressor & external load



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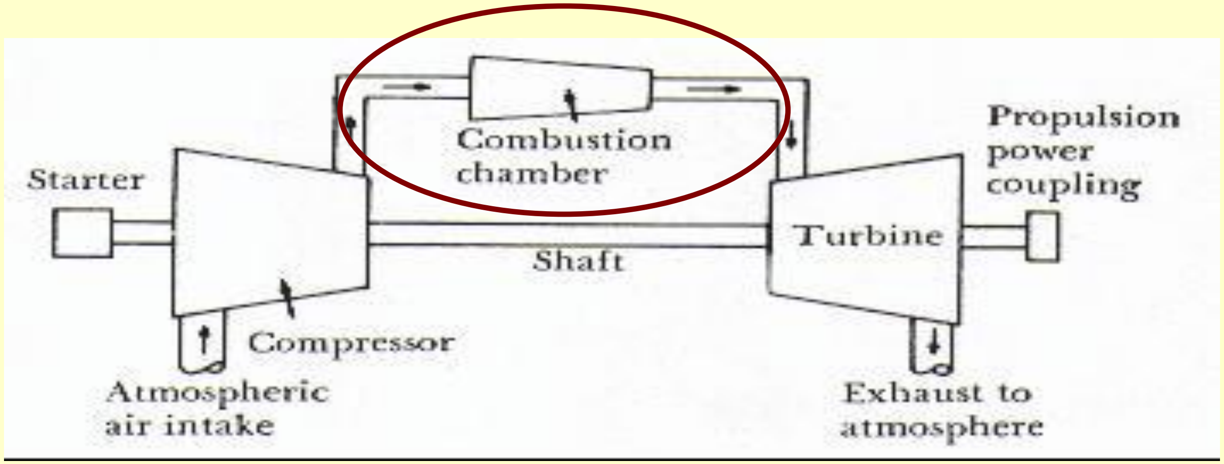

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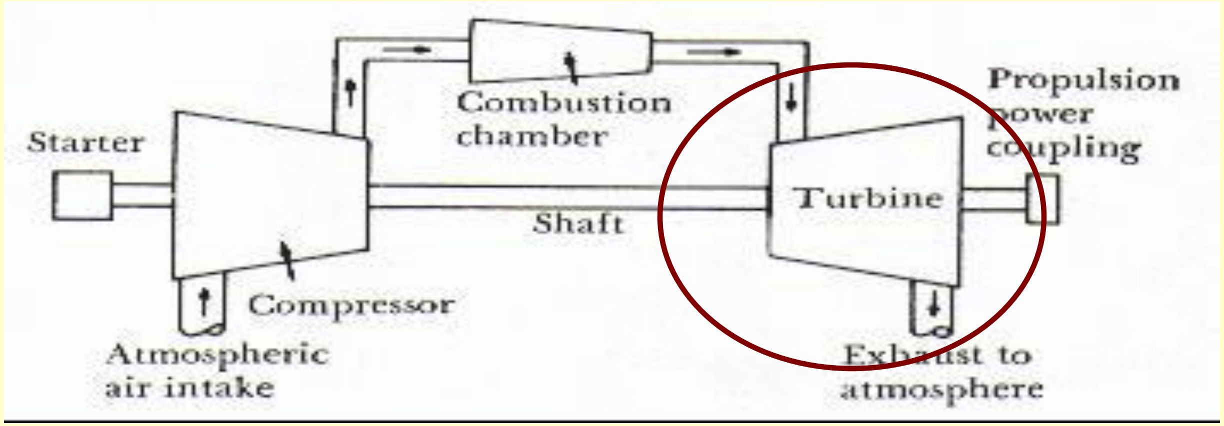
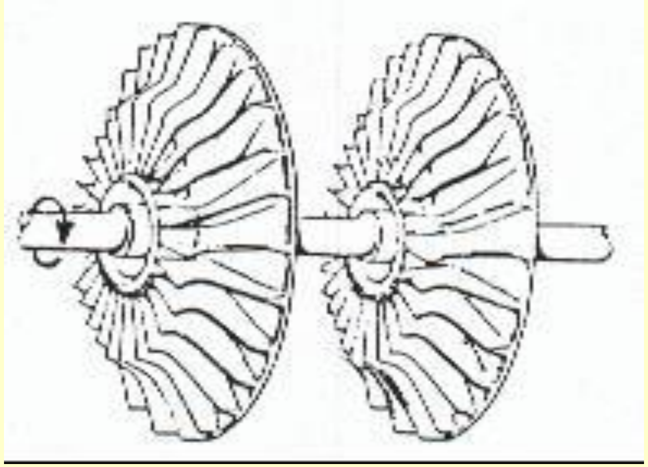


Compressor

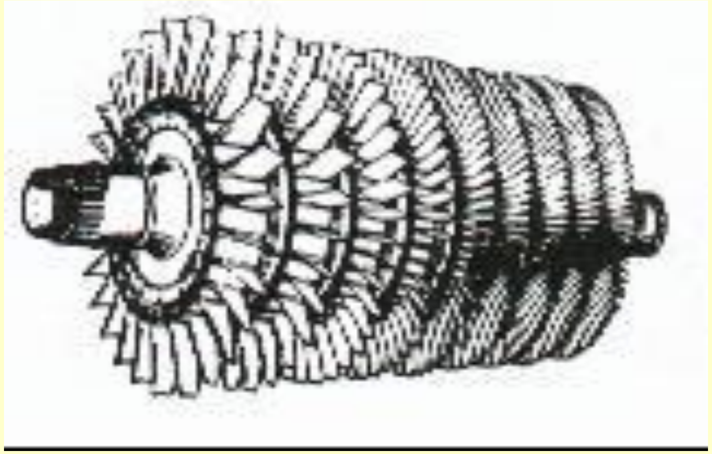
- Supplies high pressure air for combustion process
- Compressor types
  - Radial/centrifugal flow compressor
  - Axial flow compressor

Compressor

- Radial/centrifugal flow
  - Adv: simple design, good for low compression ratios (5:1)
  - Disadv: Difficult to stage, less efficient



- Axial flow
  - Good for high compression ratios (20:1)
  - Most commonly used



Compressor

- Controlling Load on Compressor
  - To ensure maximum efficiency and allow for flexibility, compressor can be split into HP & LP sections
  - Vane control: inlet vanes/nozzle angles can be varied to control air flow
- Compressor Stall
  - Interruption of air flow due to turbulence

Use of Compressed Air

- Primary Air (30%)
  - Passes directly to combustor for combustion process
- Secondary Air (65%)
  - Passes through holes in perforated inner shell & mixes with combustion gases
- Film Cooling Air (5%)
  - Insulates/cools turbine blades

Combustion Chambers

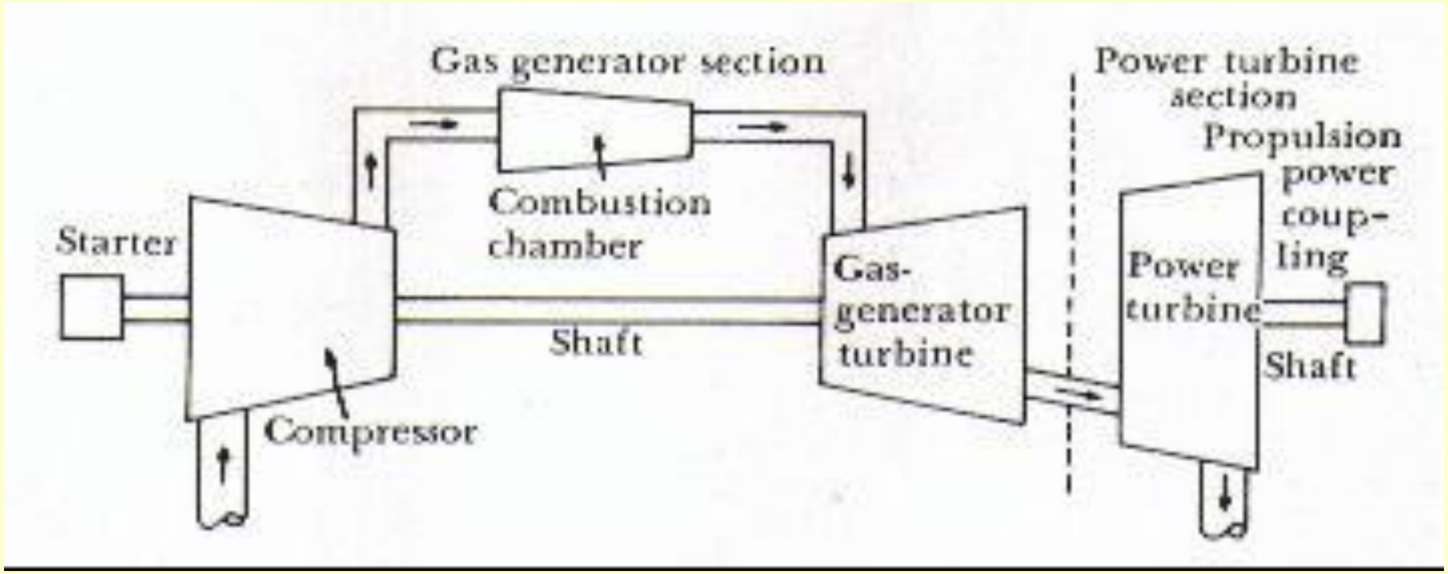
- Where air & fuel are mixed, ignited, and burned
- Spark plugs used to ignite fuel
- Types
  - Can: for small, centrifugal compressors
  - Annular: for larger, axial compressors
  - Can-annular: for really large turbines

Turbines

- Consists of one or more stages designed to develop rotational energy
- Uses sets of nozzles & blades
- Single shaft
  - Power coupling on same shaft as turbine
  - Same shaft drives rotor of compressor and power components

Turbines

- Split Shaft
  - Gas generator turbine drives compressor
  - Power turbine separate from gas generator turbine
  - Power turbine driven by exhaust from gas generator turbine
  - Power turbine drives power coupling



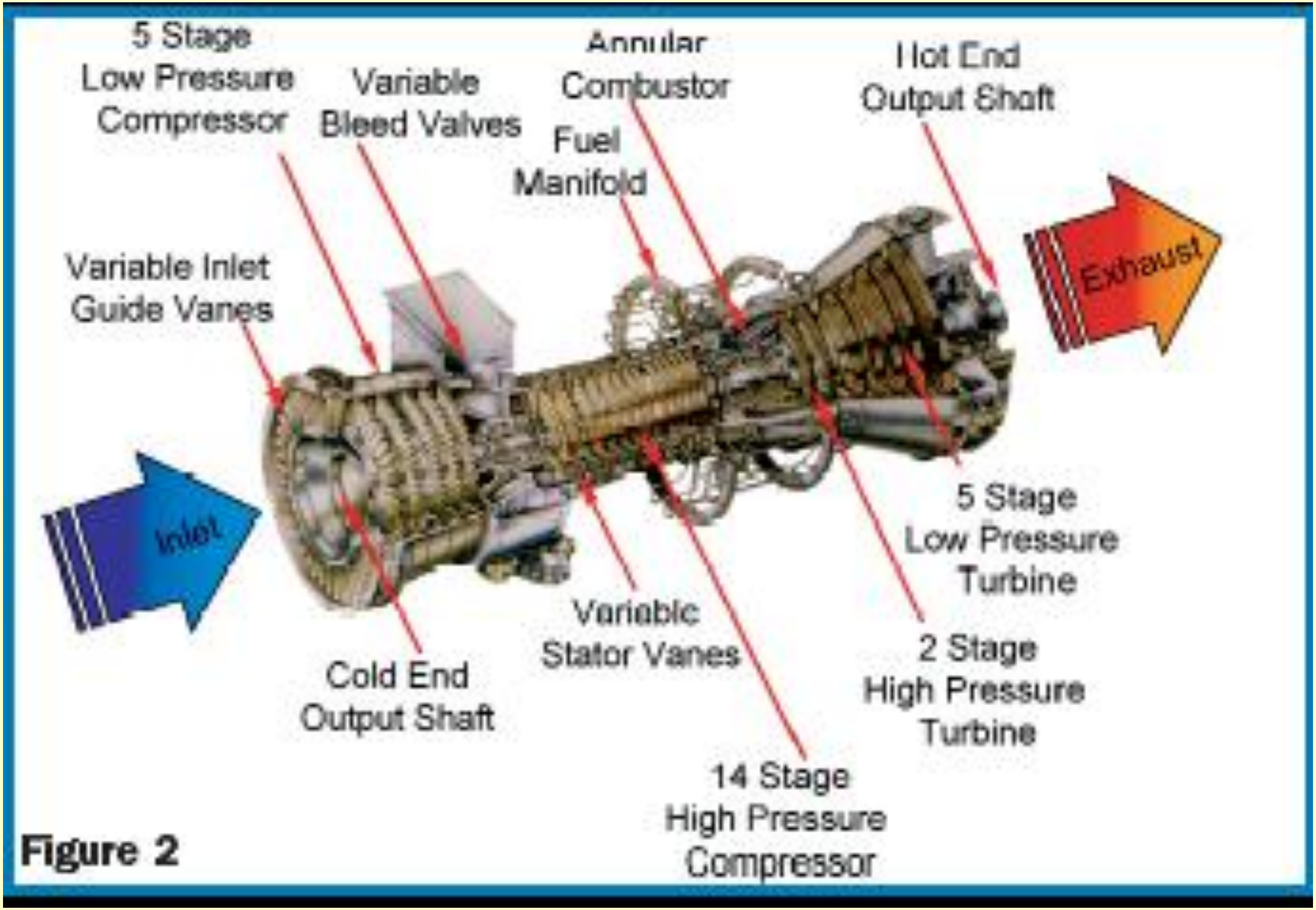
Gas Turbine Systems

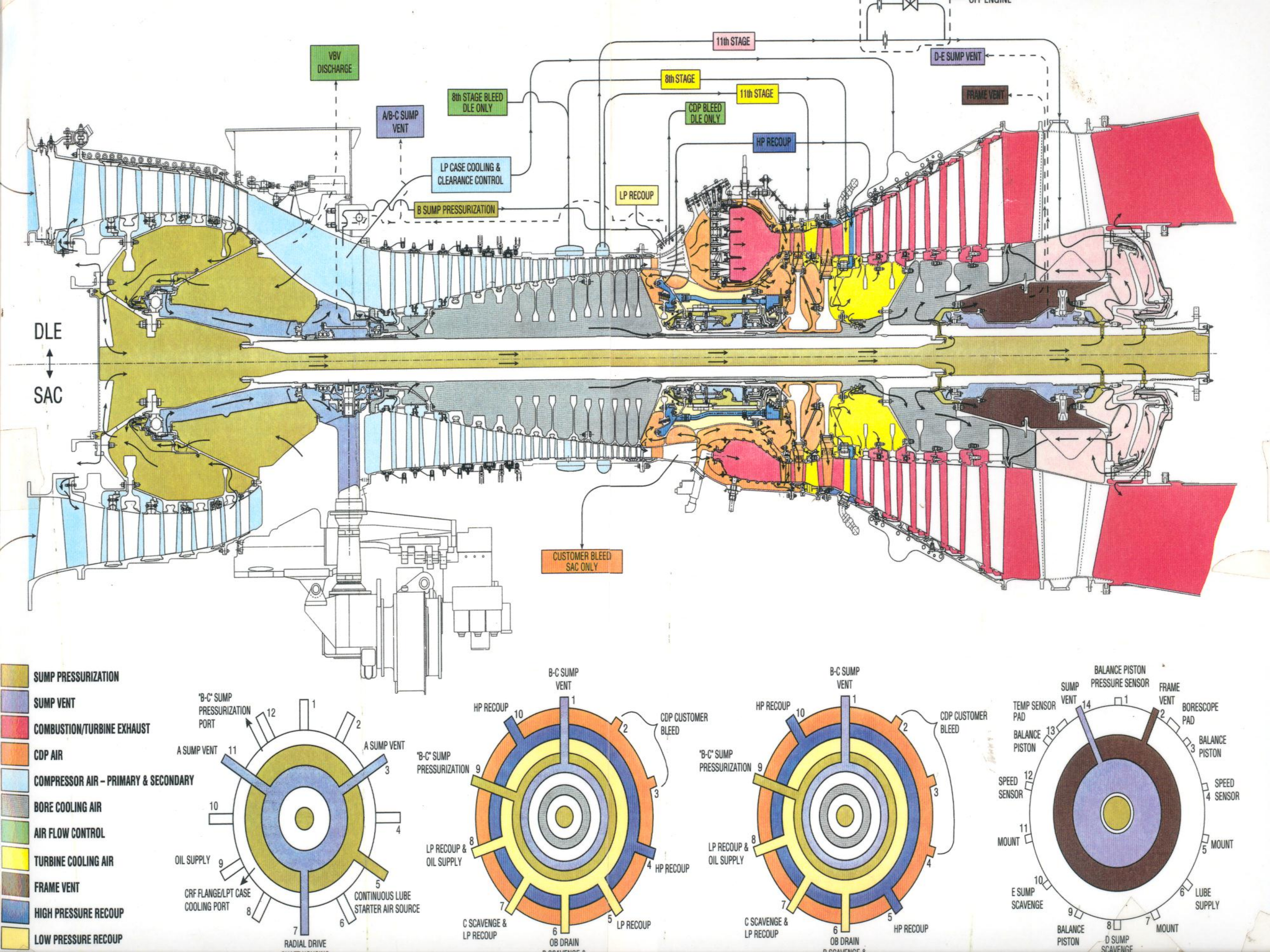
- Air System
  - Air intakes are located high up & multiple filters
  - Exhaust discharged out stacks
- Fuel System
  - Uses either DFM or JP-5
- Lubrication System
  - Supply bearings and gears with oil

Gas Turbine Systems

- Starting System
  - To get compressor initially rotated, HP air used (can use electrical also)
  - Once at certain RPM, fuel injected and spark ignited
- Power Transmission System
  - Reduction gears used to transfer torque
  - With split shaft, turbines can run @ different speeds

Aero derivative Gas turbine





VBV DISCHARGE
A/B-C SUMP VENT
8th STAGE BLEED DLE ONLY
11th STAGE
8th STAGE
11th STAGE
CDP BLEED DLE ONLY
HP RECOUP
D-E SUMP VENT
FRAME VENT
LP CASE COOLING & CLEARANCE CONTROL
B SUMP PRESSURIZATION
LP RECOUP
DLE
SAC
CUSTOMER BLEED SAC ONLY
SUMP PRESSURIZATION
SUMP VENT
COMBUSTION/TURBINE EXHAUST
CDP AIR
COMPRESSOR AIR – PRIMARY & SECONDARY
BORE COOLING AIR
AIR FLOW CONTROL
TURBINE COOLING AIR
FRAME VENT
HIGH PRESSURE RECOUP
LOW PRESSURE RECOUP
"B-C" SUMP PRESSURIZATION PORT
A SUMP VENT
A SUMP VENT
OIL SUPPLY
CRF FLANGE/LPT CASE COOLING PORT
CONTINUOUS LUBE STARTER AIR SOURCE
RADIAL DRIVE
B-C SUMP VENT
HP RECOUP
CDP CUSTOMER BLEED
"B-C" SUMP PRESSURIZATION
LP RECOUP & OIL SUPPLY
HP RECOUP
C SCAVENGE & LP RECOUP
OB DRAIN
LP RECOUP
B-C SUMP VENT
HP RECOUP
CDP CUSTOMER BLEED
"B-C" SUMP PRESSURIZATION
LP RECOUP & OIL SUPPLY
C SCAVENGE & LP RECOUP
OB DRAIN
HP RECOUP
BALANCE PISTON PRESSURE SENSOR
SUMP VENT
FRAME VENT
TEMP SENSOR PAD
BORESCOPE PAD
BALANCE PISTON
BALANCE PISTON
SPEED SENSOR
SPEED SENSOR
MOUNT
MOUNT
E SUMP SCAVENGE
LUBE SUPPLY
BALANCE PISTON
D SUMP
MOUNT

GE Aero derivative gas turbine

Aeroderivative Gas Turbines

		Output (kW)	Heat Rate (Btu/kWh)	Heat Rate (kJ/kWh)	Pressure Ratio	Turbine Speed (rpm)	Exhaust Flow (lb/sec)	Exhaust Flow (kg/sec)	Exhaust Temp. (°F)	Exhaust Temp. (°C)
50 Hz Power Gen	LM6000PC Sprint*	49,500	8,471	8,935	30.0:1	3,627	297	135	821	438
	LM6000PC	43,000	8,538	9,006	30.0:1	3,627	285	129	787	419
	LM6000PD Sprint	46,900	8,262	8,715	30.0:1	3,627	292	132	834	446
	LM6000PD	41,700	8,366	8,824	30.0:1	3,627	279	127	838	448
	LM6000PD (liquid fuel)	40,417	8,443	8,721	28.5:1	3,627	272	123	853	456
	LM2500PK	29,300	9,625	10,152	22.8:1	3,000	197	89	911	488
	LM2500PV	33,500	8,920	9,409	23.0:1	6,100	197	89	907	486
	LM2500PH	26,500	8,673	9,148	18.2:1	3,000	167	76	927	497
	LM2500PE	22,800	10,008	10,556	18.9:1	3,000	158	72	956	513
	LM2000	17,600	9,600	10,129	15.6:1	3,000	139	63	885	474
	LM1600PA	13,700	9,760	10,295	20.1:1	7,900	110	50	894	478
60 Hz Power Gen	LM6000PC Sprint*	49,500	8,451	8,914	30.0:1	3,627	300	136	826	441
	LM6000PC	43,500	8,485	8,950	30.0:1	3,627	284	129	792	422
	LM6000PD Sprint	46,800	8,235	8,686	30.0:1	3,627	290	132	837	447
	LM6000PD	42,300	8,308	8,763	30.0:1	3,627	278	126	846	452
	LM6000PD (liquid fuel)	40,212	8,415	8,878	28.1:1	3,627	268	122	857	458
	LM2500PK	30,900	9,288	9,797	22.9:1	3,600	197	89	906	486
	LM2500PH	27,700	8,402	8,862	17.8:1	3,600	167	76	922	494
	LM2500PE	24,000	9,716	10,248	19.0:1	3,600	157	71	955	513
	LM2000	17,600	9,715	10,247	15.4:1	3,600	136	62	917	492
	LM1600PA	13,700	9,760	10,295	20.1:1	7,900	110	50	894	478

		Output (hp)	Heat Rate (Btu/shp-h)		Pressure Ratio	Turbine Speed (rpm)	Exhaust Flow (lb/sec)	Exhaust Flow (kg/sec)	Exhaust Temp. (°F)	Exhaust Temp. (°C)
Mechanical Drive	LM6000PC	60,000	5,938	—	29.1:1	3,600	281.9	127.8	825	440
	LM2500PK	40,044	6,702	—	22.6:1	3,000	193.5	87.7	967	519
	LM2500PE	30,400	7,017	—	18.1:1	3,000	153.3	69.5	994	534
	LM2000PA	24,300	7,117	—	16.0:1	3,600	141.9	64.4	894	479
	LM1600PA	19,100	7,016	—	20.2:1	7,900	104.3	47.3	915	491

GE Frame machine ratings

Gas Turbine Type	**MW**	**Cycle**	**Hz**	**Heat Rate KJ/KWH**	**Efficiency**	**Air Inlet Mass Flow(KG/sec**	**Exhaust Temperature ^{o}C**	**Pressure Ratio**
9H	480	CC	50	6000	59.91			
7H	400	CC	60	6000	59.91			
9FB	412.9	CC	50	6205	57.93			
7FB	280	CC	60	6280	57.24			
9FA	390.8	CC	50	6350	56.61	624	609	15.4:1
	255.6	SC	50	9757	36.84			
7FA	262.6	CC	60	6425	55.95	432	602	15.5:1
	171.7	SC	60	9936	36.18			
9E	193.2	CC	50	6930	51.87	418	543	12.6:1
	126.1	SC	50	10653	33.74			
7EA	130.2	CC	60	7175	50.10	292	537	12.6:1
	85.4	SC	60	10991	32.71			
6FA	117.7	CC	50	6580	54.63			
	118.3	CC	60	6590	54.55			
	75.9	SC	50	10300	34.90	203	605	15.6:1
	75.9	SC	60	10330	34.80	204	604	15.7:1
6B	64.3	CC	50/60	7340	48.98	141.1	548	12.2:1
	42.1	SC	50/60	11227	32.02			
6C	62.8	CC	50	6667	53.92	117	574	19.0:1
	62.8	CC	60	6667	53.92			
	42.3	SC	50	9930	36.20			
	42.3	SC	60	9930	36.20			

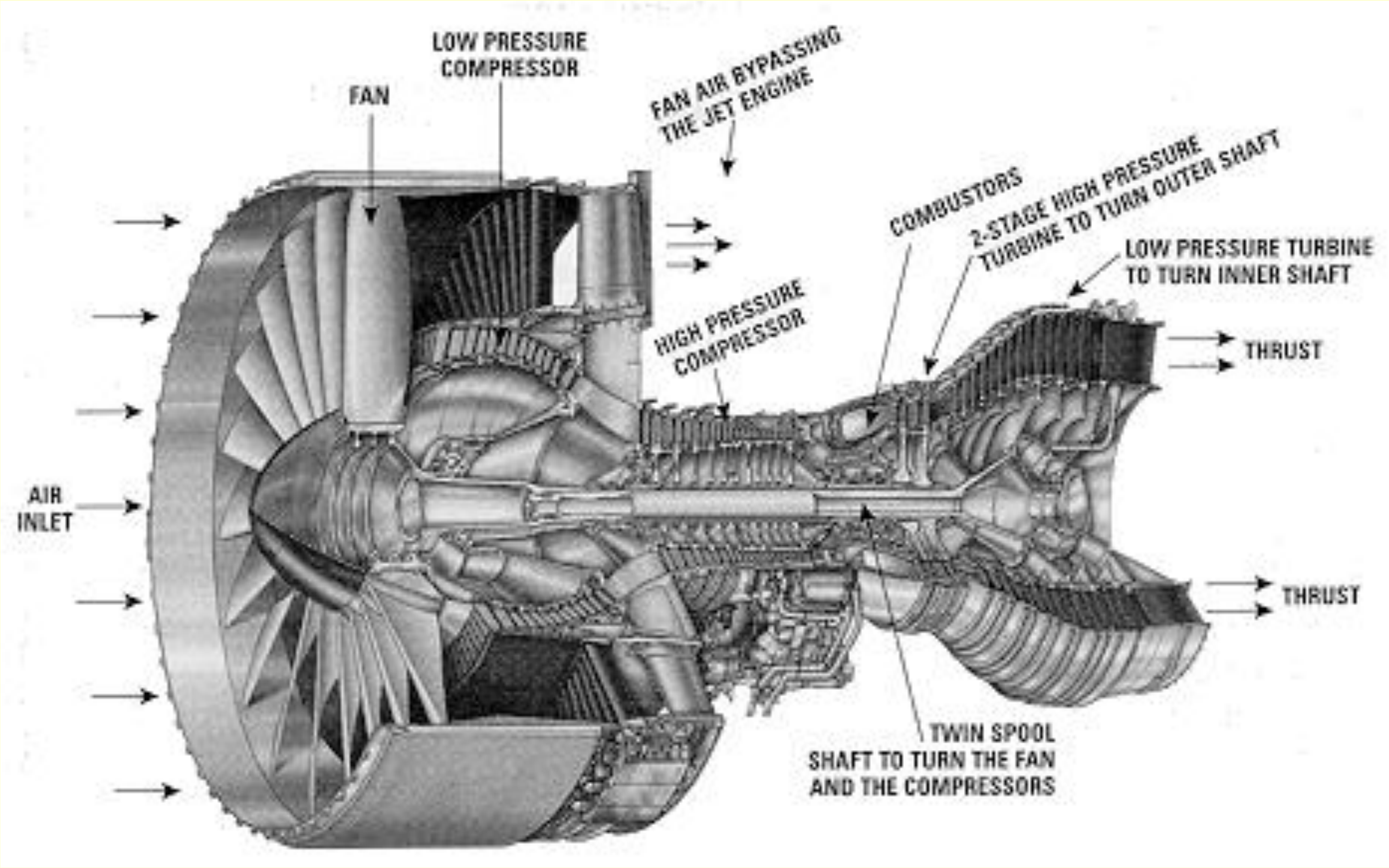
Siemens –Machine rating

Turbine Type	W501D5A	W501F	W501G	V64.3A	V94.2	V94.2A	V94.3A
Combined cycle	1+1 multi	1+1 multi	single	single	1+1 multi	single	single
Grid frequency (Hz)	60	60	60	50/60	50	50	50
Net power output (MW)	172	274	365	100	233	294	390
Net efficiency (%)	50.2	55.5	58.0	52.4	51.5	55.2	57.3
Net heat rate (KJ/KWh)	7174	6489	6204	6870	6990	6522	6283
Net heat rate (Btu/kWh)	6800	6150	5880	6512	6626	6181	5955
Combined Cycle	2+1 multi	2+1 multi	2+1 multi	2+1 multi	2+1 multi	2+1 multi	2+1 multi
Net power output (MW)	346	550	730	202	468	585	780
Net efficiency (%)	50.4	55.8	58.0	52.8	51.7	55.0	57.3
Net heat rate (KJ/KWh)	7143	6457	6204	6818	6930	6545	6283
Net heat rate (Btu/kWh)	6770	6120	5880	6462	6600	6204	5955

Mitsubishi Machine ratings

MODEL	Cycle	50 100 150 200 250 300 350
MF-61	50/60 Hz	6MW
MF-111	50/60 Hz	15MW
MF-221	50/60 Hz	30MW
M251	50/60 Hz	37MW
M501D	60 Hz	114MW
M701D	50 Hz	144MW
M501F	60 Hz	185MW
M501G	60 Hz	254MW
M701F	50 Hz	270MW
M701G	50 Hz	334MW

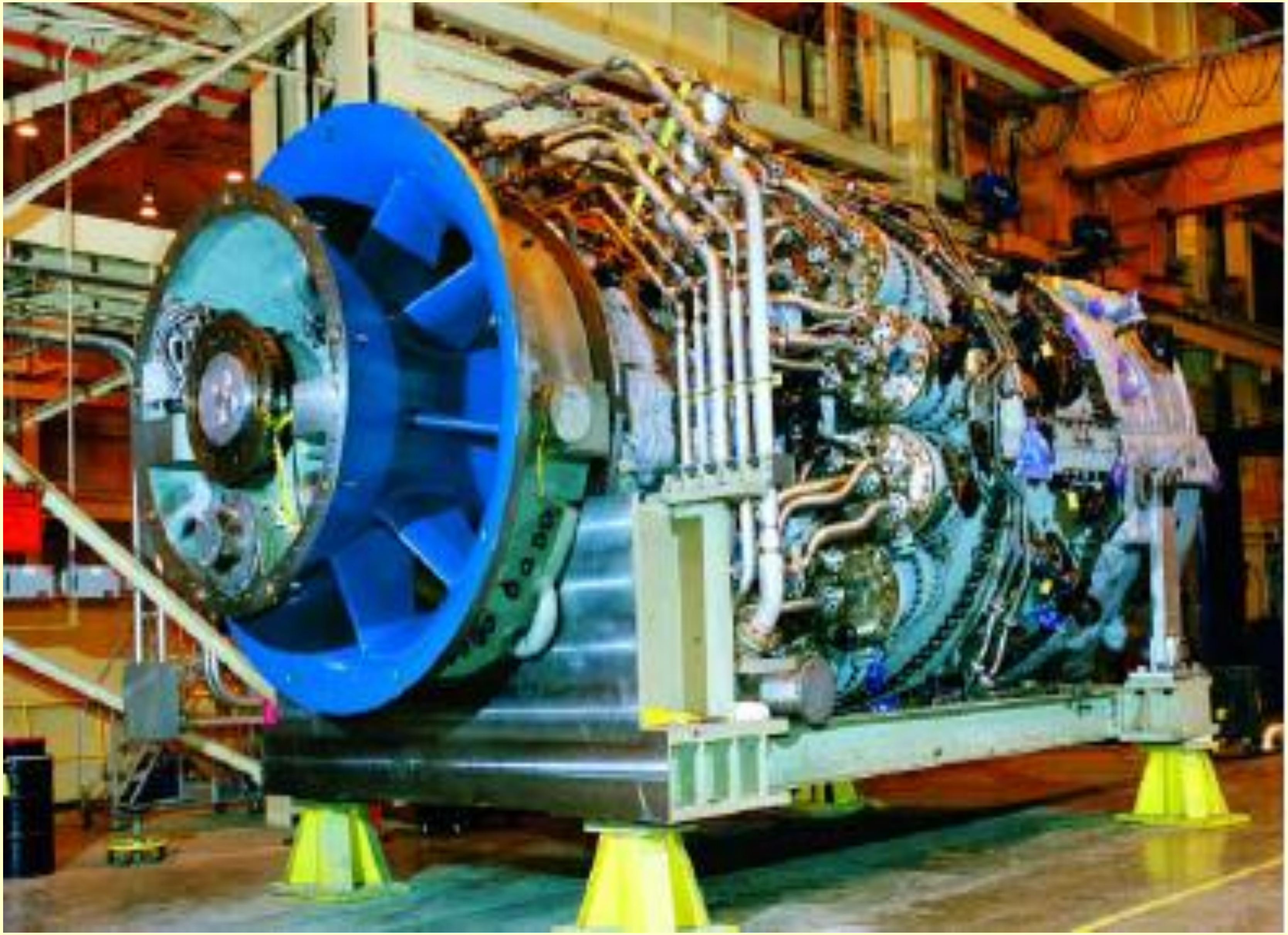
Jet Engine


LOW PRESSURE COMPRESSOR
FAN
FAN AIR BYPASSING THE JET ENGINE
COMBUSTORS
2-STAGE HIGH PRESSURE TURBINE TO TURN OUTER SHAFT
LOW PRESSURE TURBINE TO TURN INNER SHAFT
HIGH PRESSURE COMPRESSOR
THRUST
AIR INLET
THRUST
TWIN SPOOL SHAFT TO TURN THE FAN AND THE COMPRESSORS

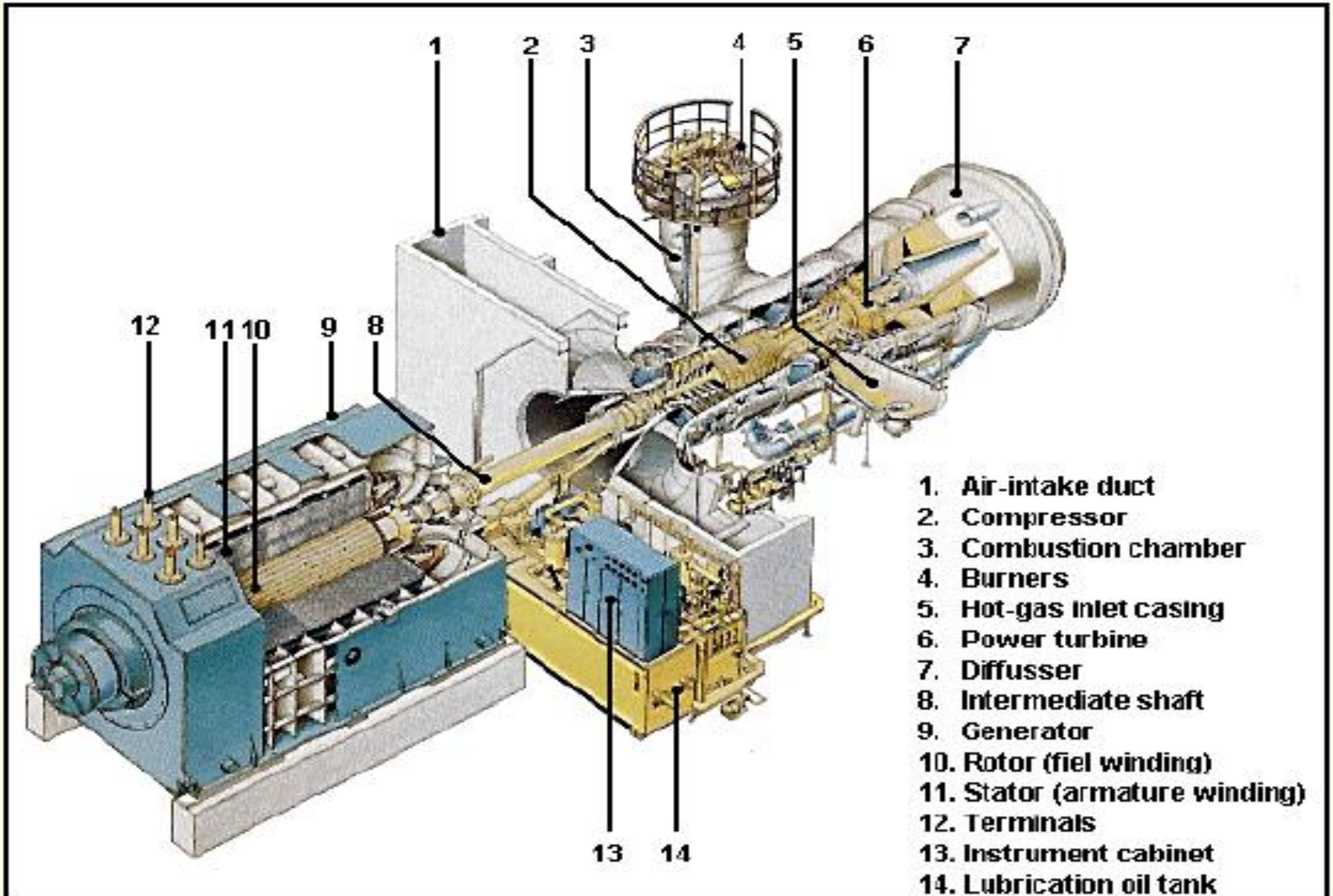
Gas Turbine(Frame type) -Cross Section

Gas Turbine Cross section

Frame Machines



Heavy duty gas turbine generating unit

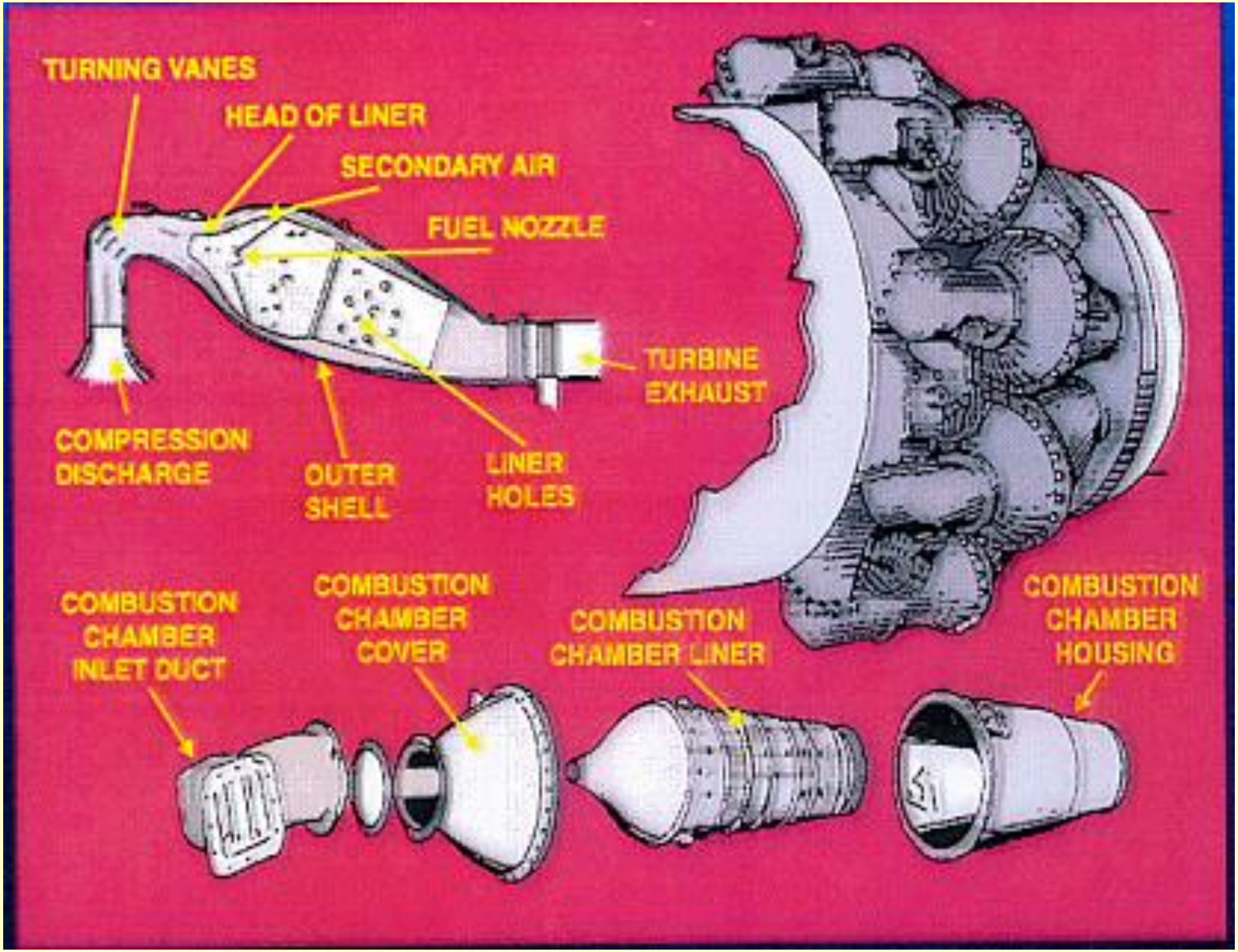


Combustion Chambers

The Basic Elements of Combustion Chamber are

- Casing
- Perforated inlet Liner
- Fuel Injection System
- Initial Ignition System
- Fuel drainage System to Drain off Unburned Fuel after Engine Shutdown

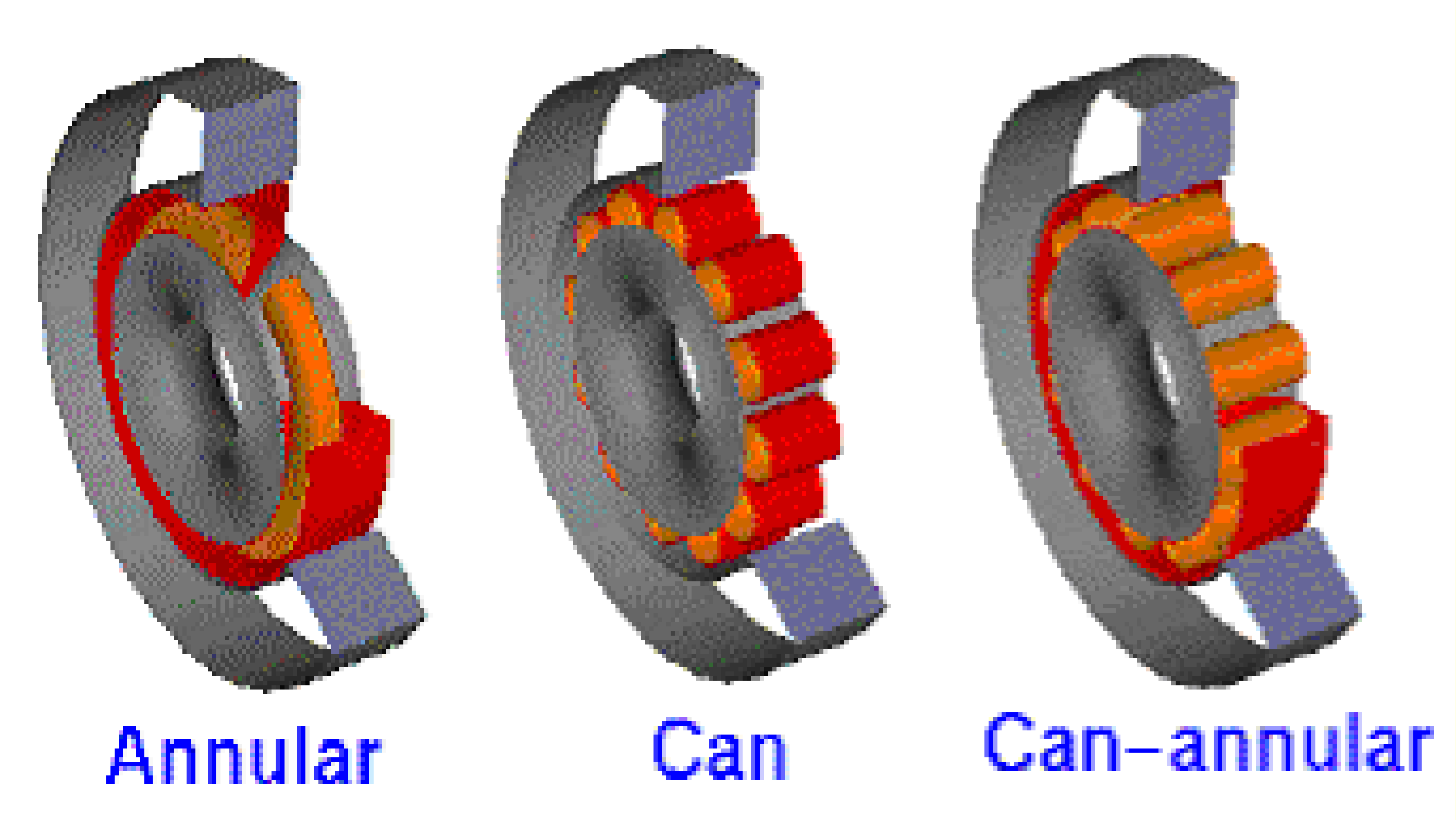
Combustion chamber



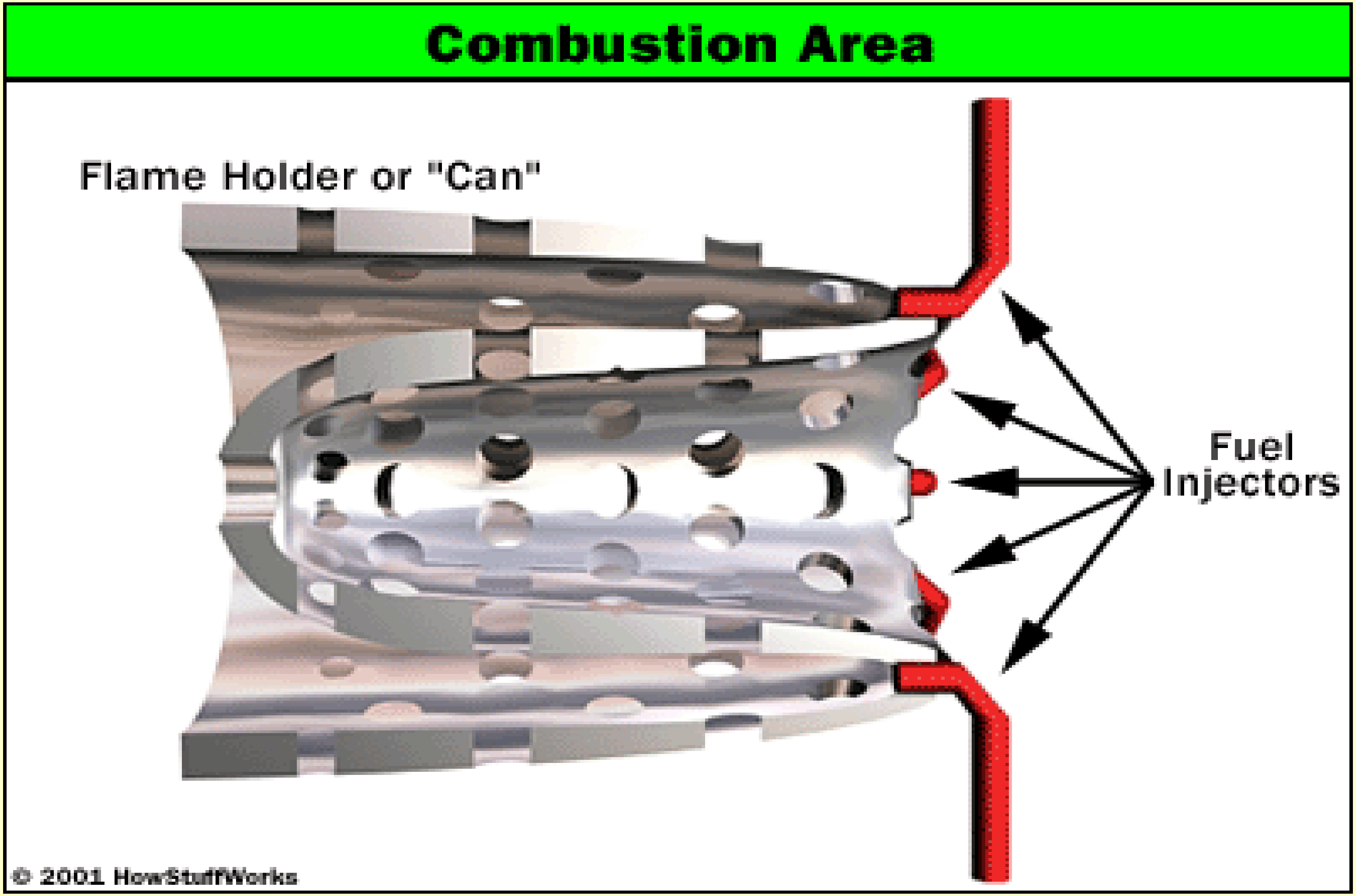
Types of Combustion Chamber

- Multiple Chamber or Can Type
- Annular or Basket Type
- Can Annular Type

Gas turbine combustor-Types



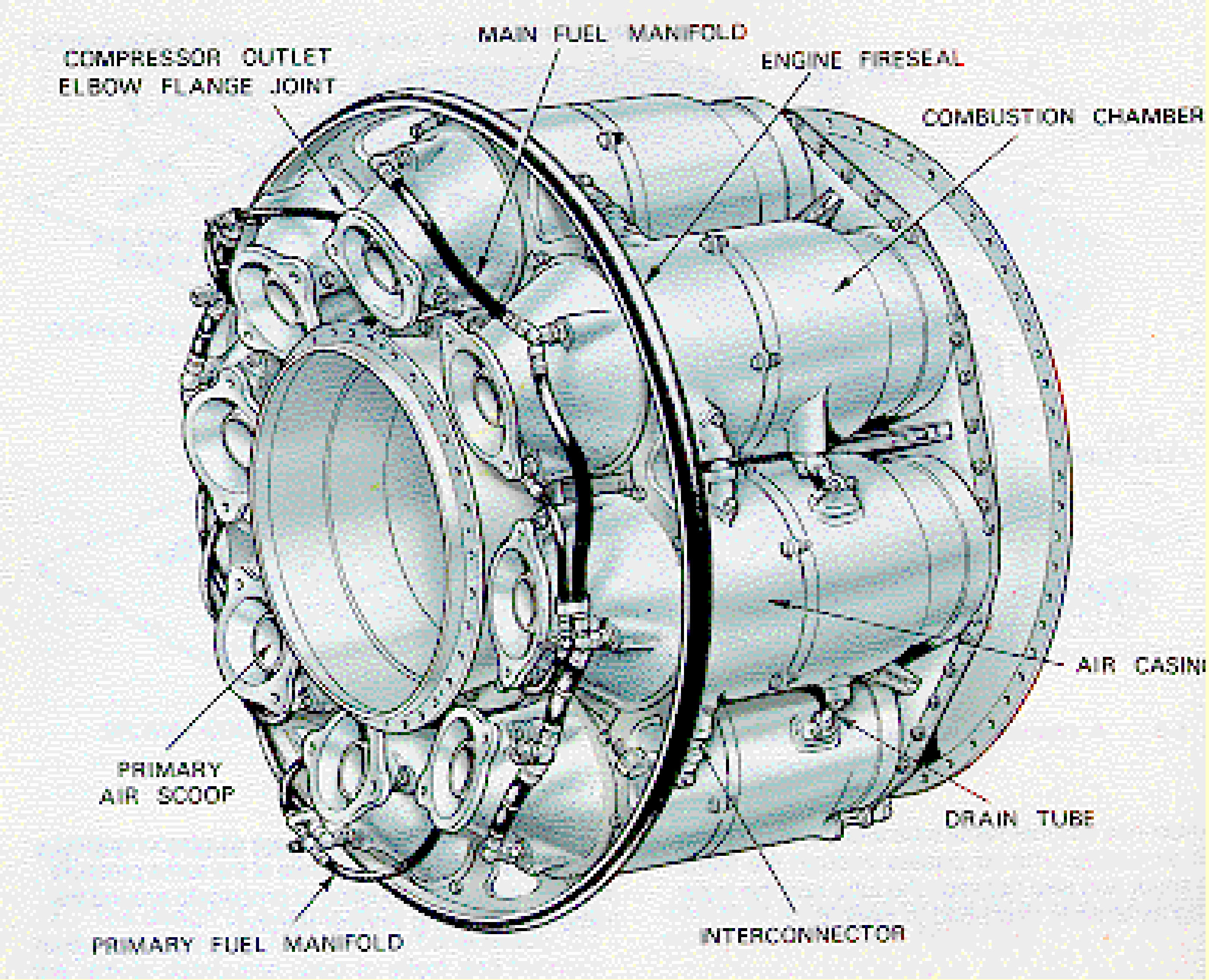
Combustion area-Can



Can Type

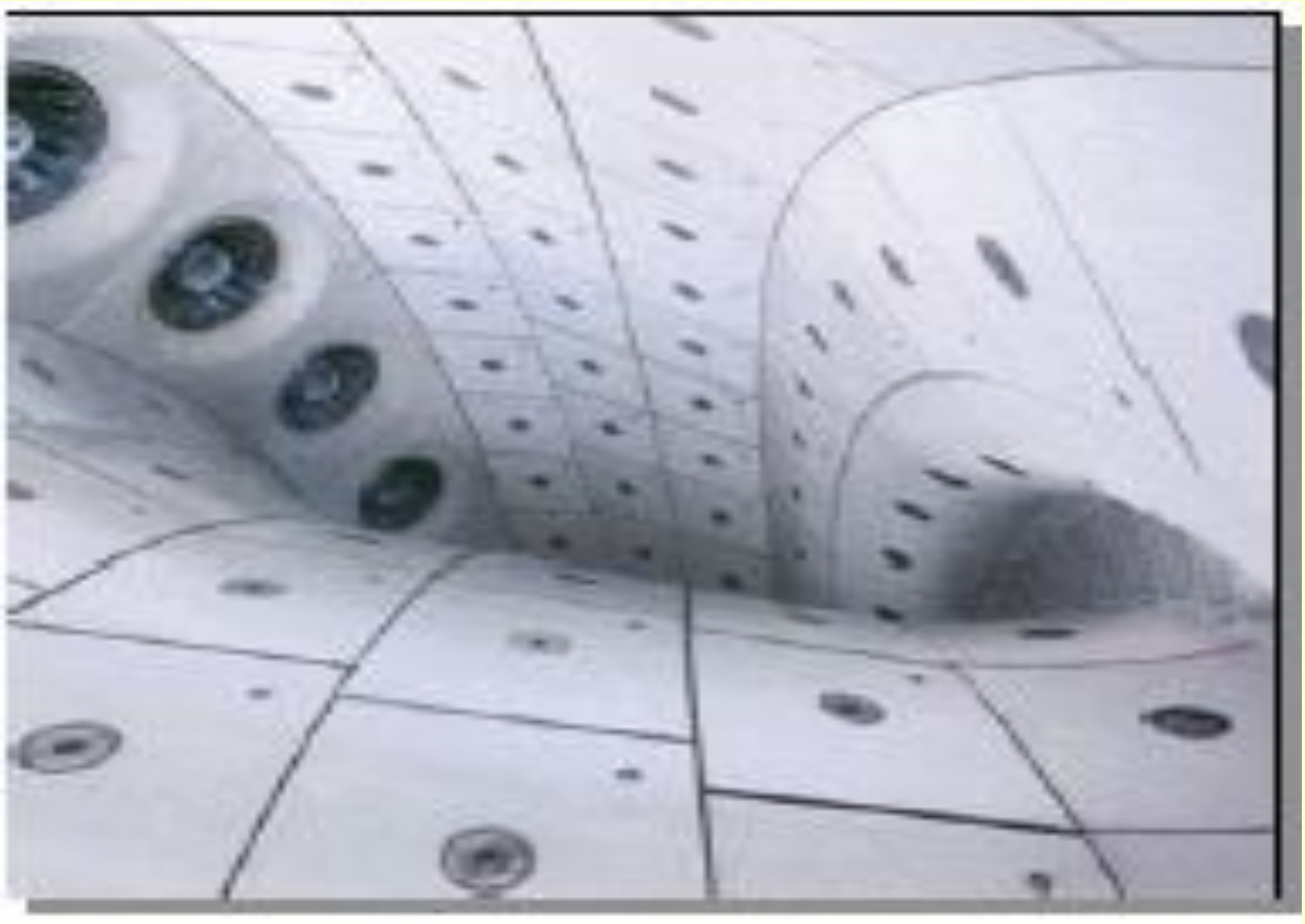
- Used in both axial and centrifugal flow Engines
- It is most suited for Centrifugal compressor since air gets divided equally by diffuser vanes which can be used in respective combustion chambers arranged radially around the axis of the engine.
- Usually 8 to 10 combustion chambers are provided.
- It has outer case with perforated stainless steel combustion chamber liner.
- Inter connector tubes are necessary for Flame propagation in Can type combustors
- Flame is started by two spark igniters at two of the lower chambers,it passes through tubes and ignites combustible mixture in the adjacent chamber.

GT Combustor-Multiple Chamber



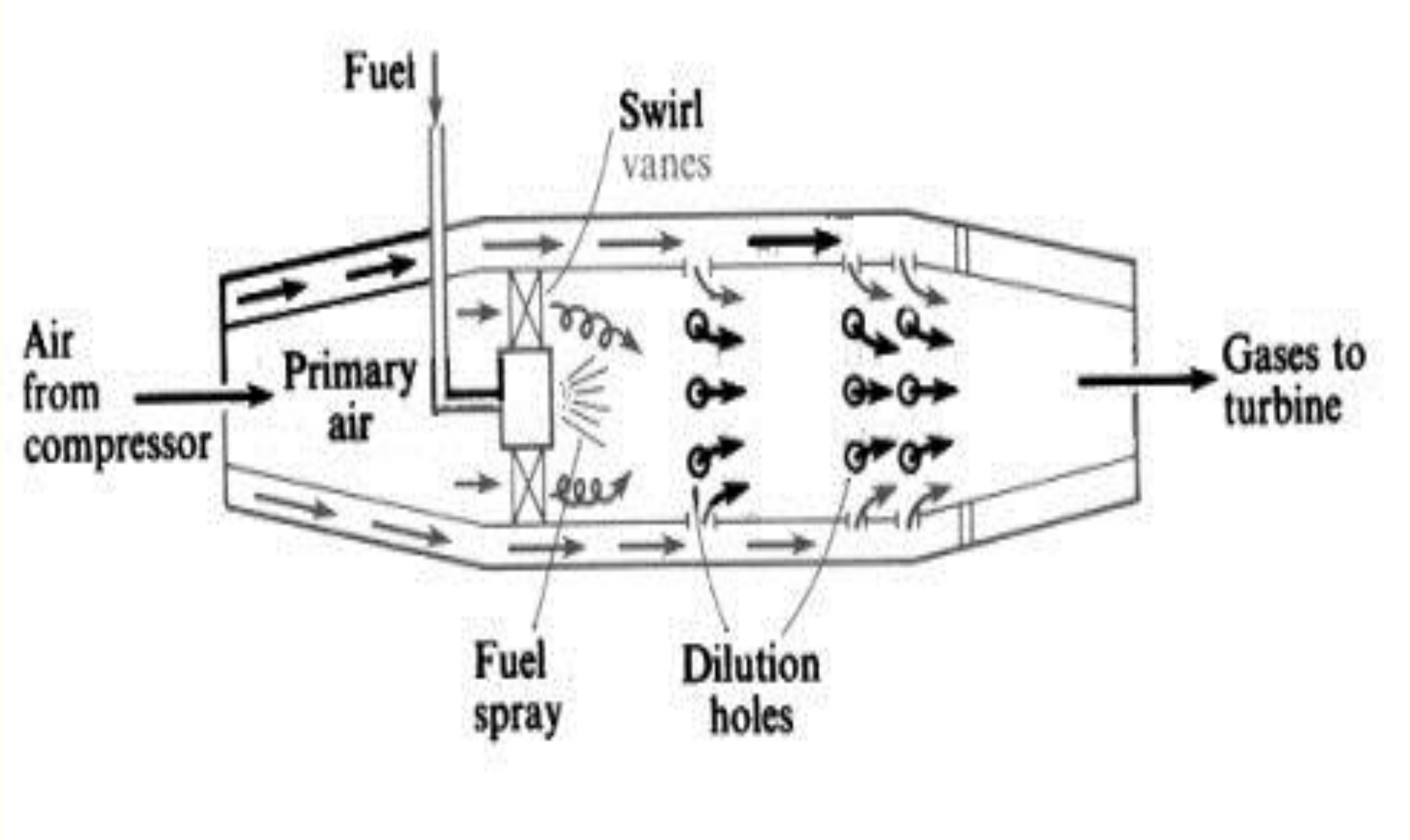
Combustor Can

Annular combustor



Can annular Combustor

Combustor Types-Can



Combustor Type-Can

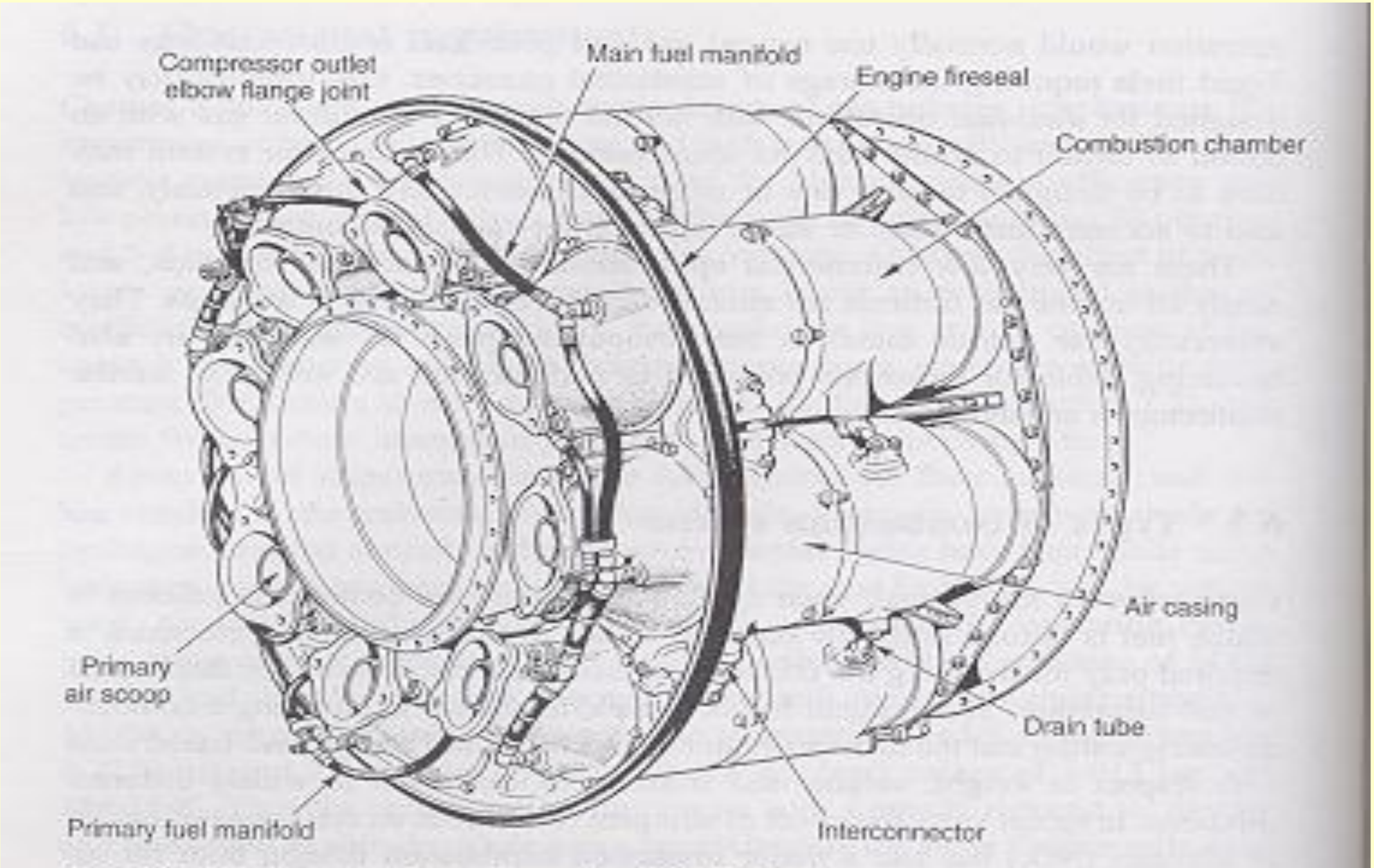
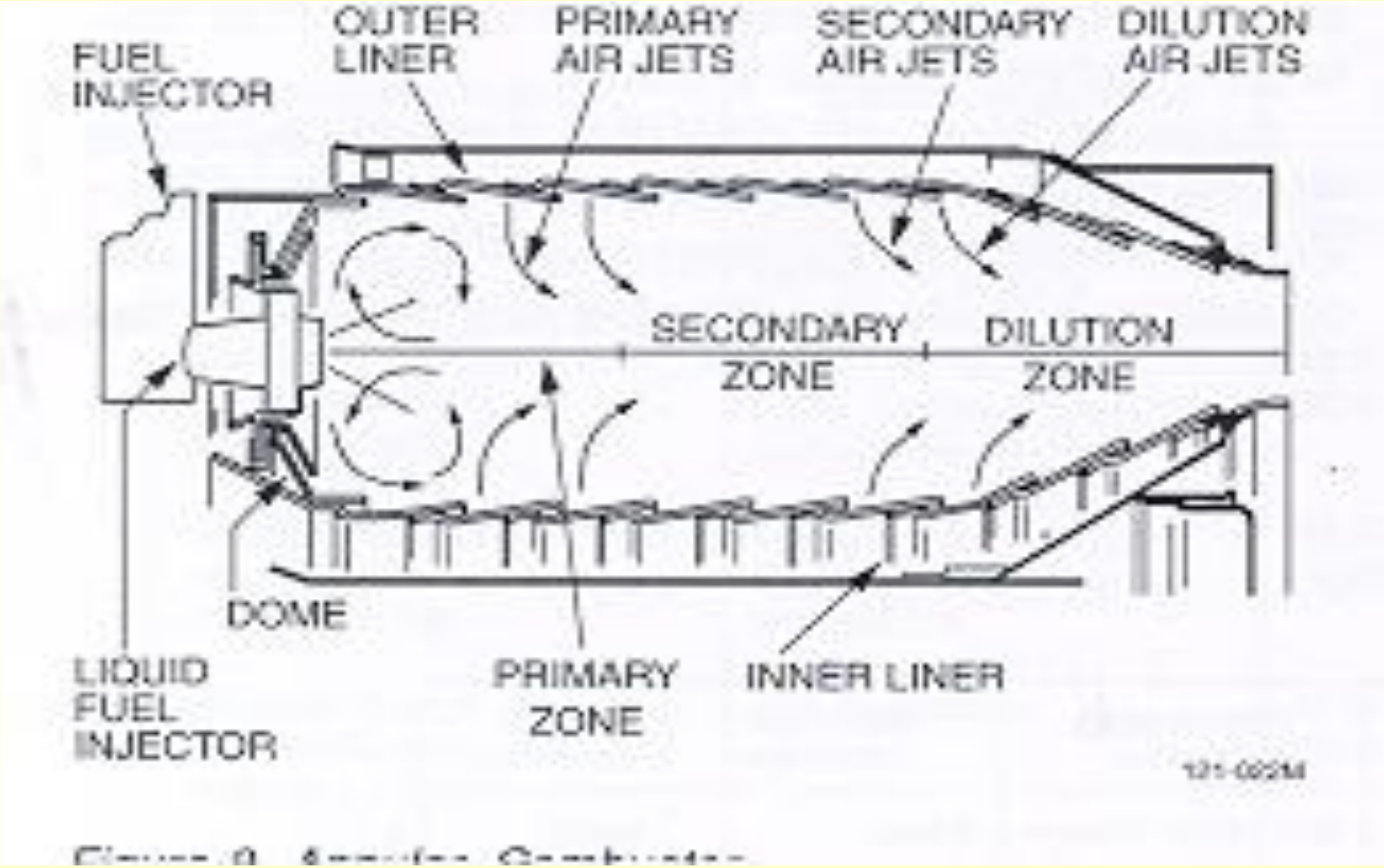


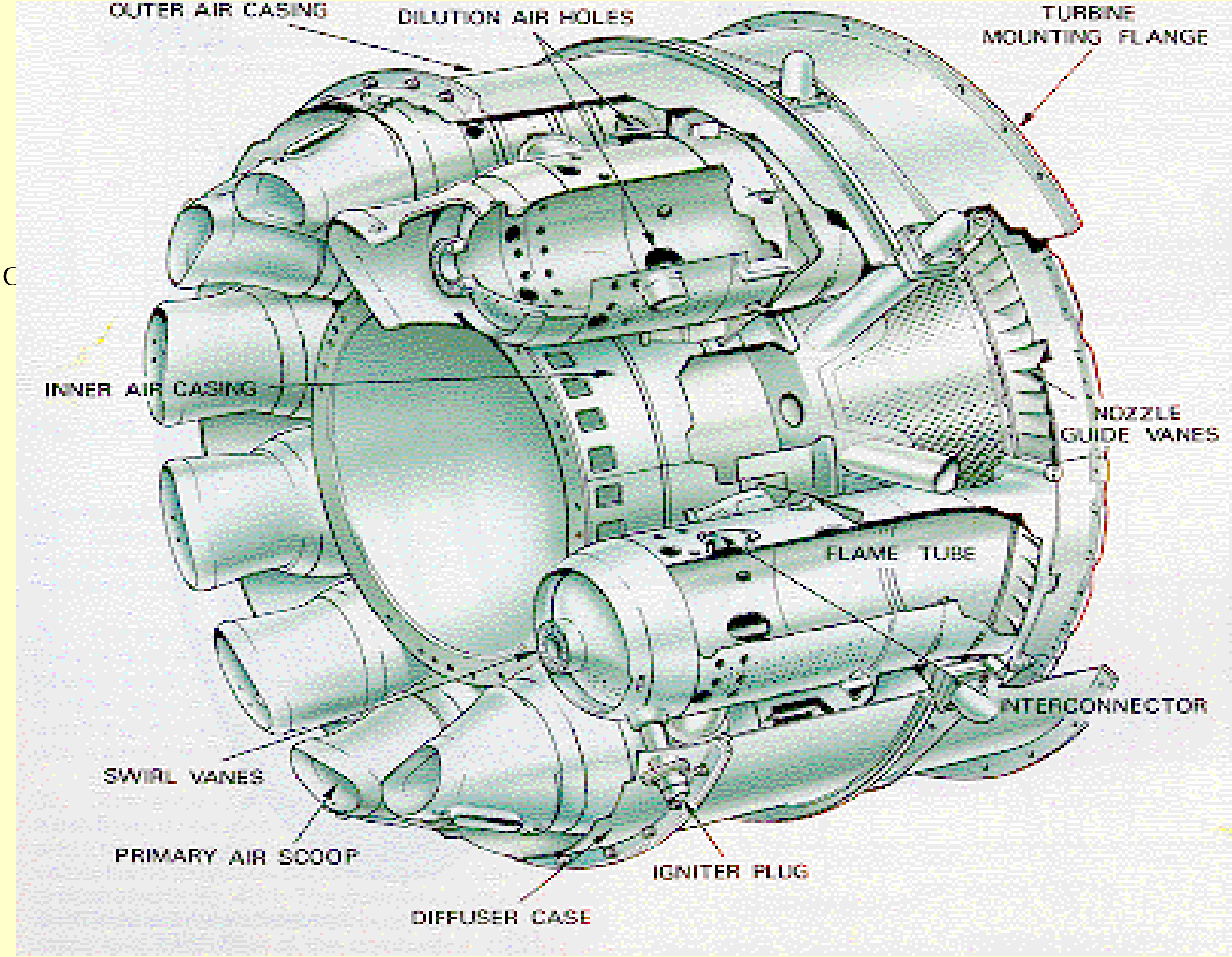
FIG. 6.1 Can type combustor [courtesy Rolls-Royce]

Combustor Type -Annular

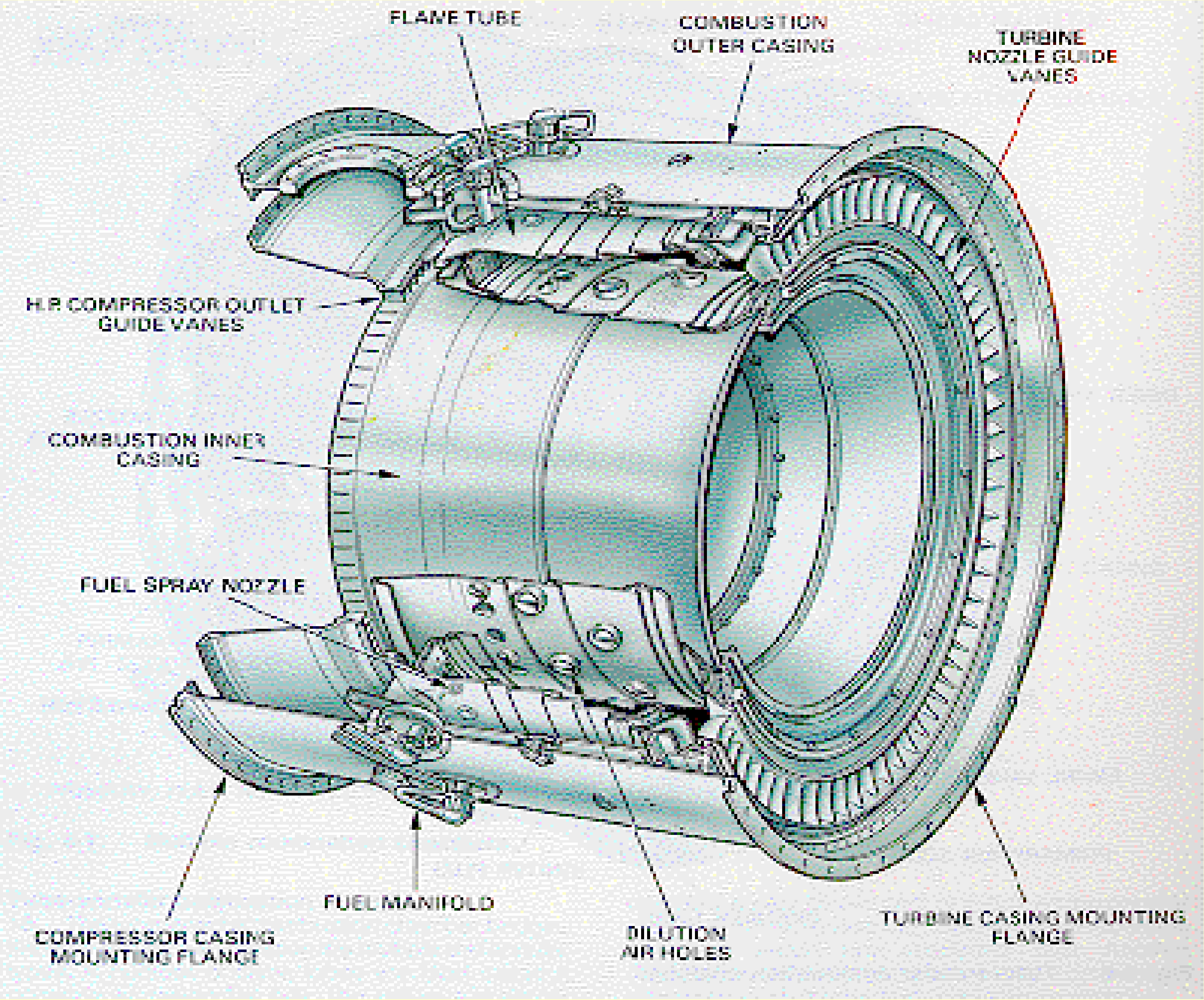


GT Combustors-Can annular

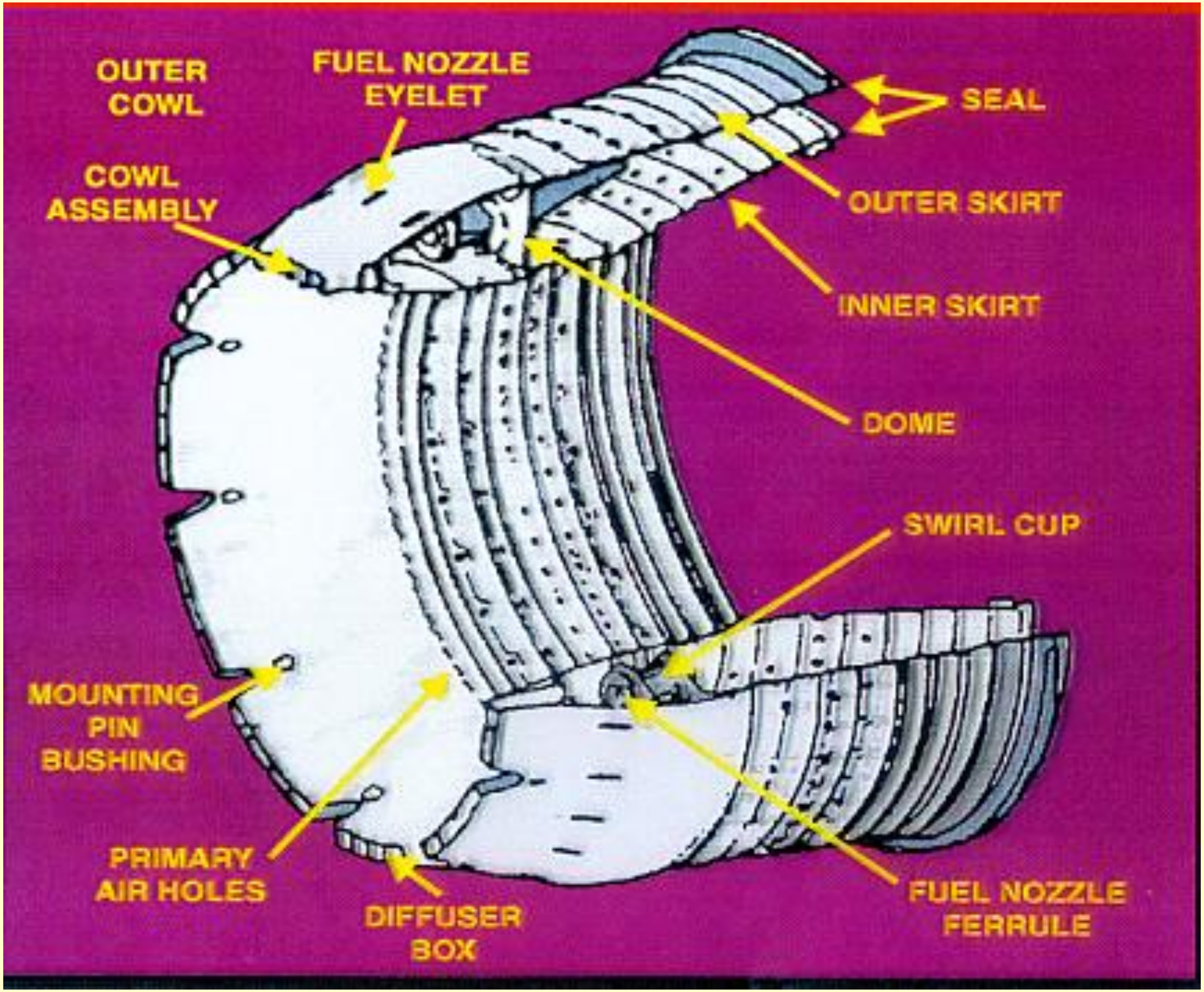
C



GT Combustors-Annular



Annular combustor



Annular or Basket Combustor

- Annular combustor consists of Housing and Liner
- The liner consists of an undivided circular shroud extending all the way around the outside of turbine shaft housing
- The chamber has two or more Baskets, If two or more chambers are used one is placed outside the other in the same radial plane called Double Annular combustor.
- Annular combustor is used in engines designed for axial flow

Combustor-Design requirements

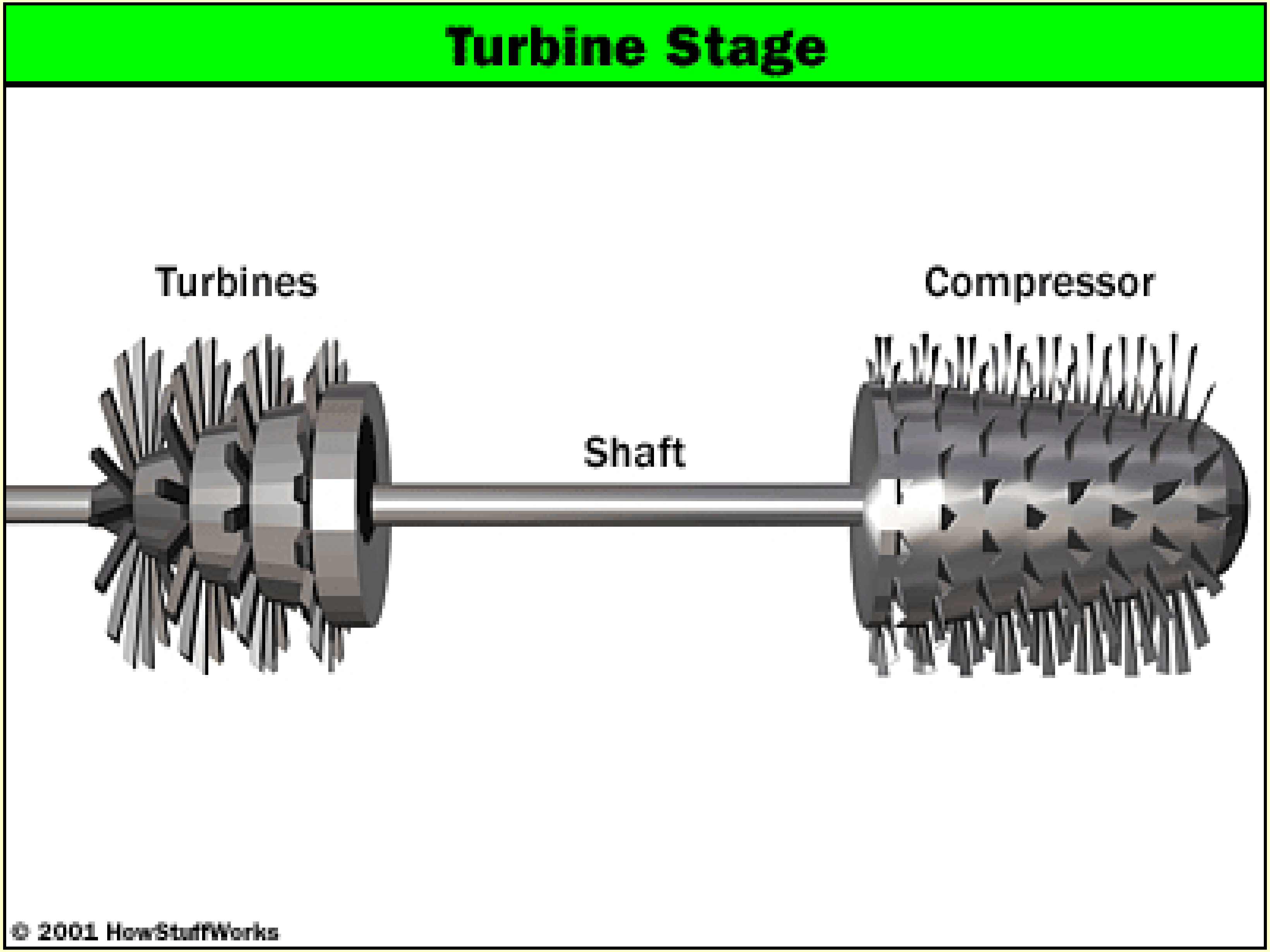
1. High combustion efficiency at all operating conditions.
2. Low levels of unburned hydrocarbons and carbon monoxide, low oxides of nitrogen at high power and no visible smoke for land-based systems. (Minimized pollutants and emissions.)
3. Low pressure drop. Three to four percent is common.
4. Combustion must be stable under all operating conditions.
5. Consistently reliable ignition must be attained at very low temperatures, and at high altitudes (for aircraft).
6. Smooth combustion, with no pulsations or rough burning.

Contd.

Combustor-Design requirements

7. A low temperature variation for good turbine life requirements.
8. Useful life (thousands of hours), particularly for industrial use.
9. Multi-fuel use. Characteristically natural gas and diesel fuel are used for industrial applications and kerosene for aircraft.
10. Length and diameter compatible with engine envelope (outside dimensions).
11. Designed for minimum cost, repair and maintenance.
12. Minimum weight (for aircraft applications).

Turbine

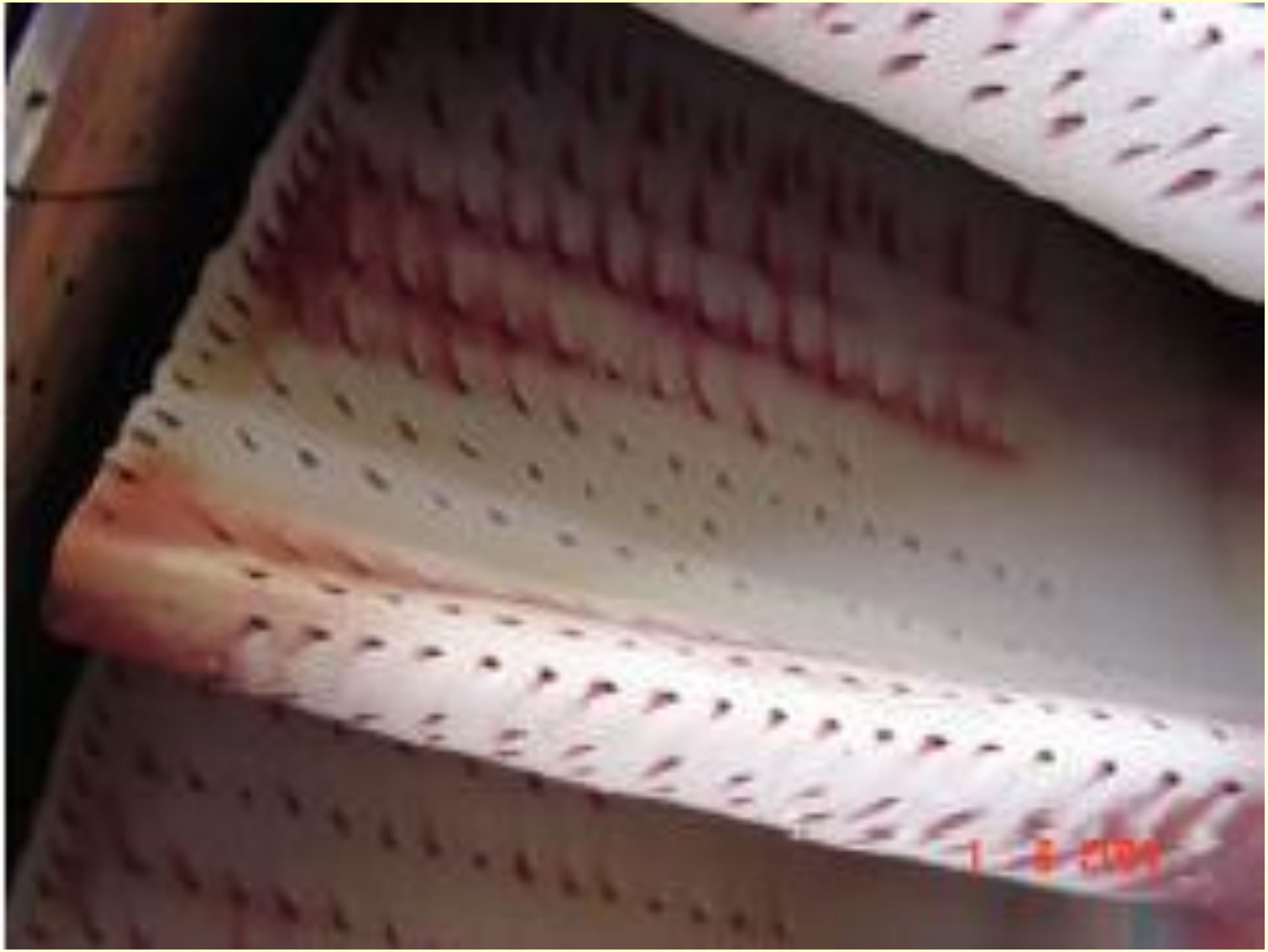

Turbine Stage
Turbines
Shaft
Compressor
© 2001 HowStuffWorks

Gas turbine Blade Assembly

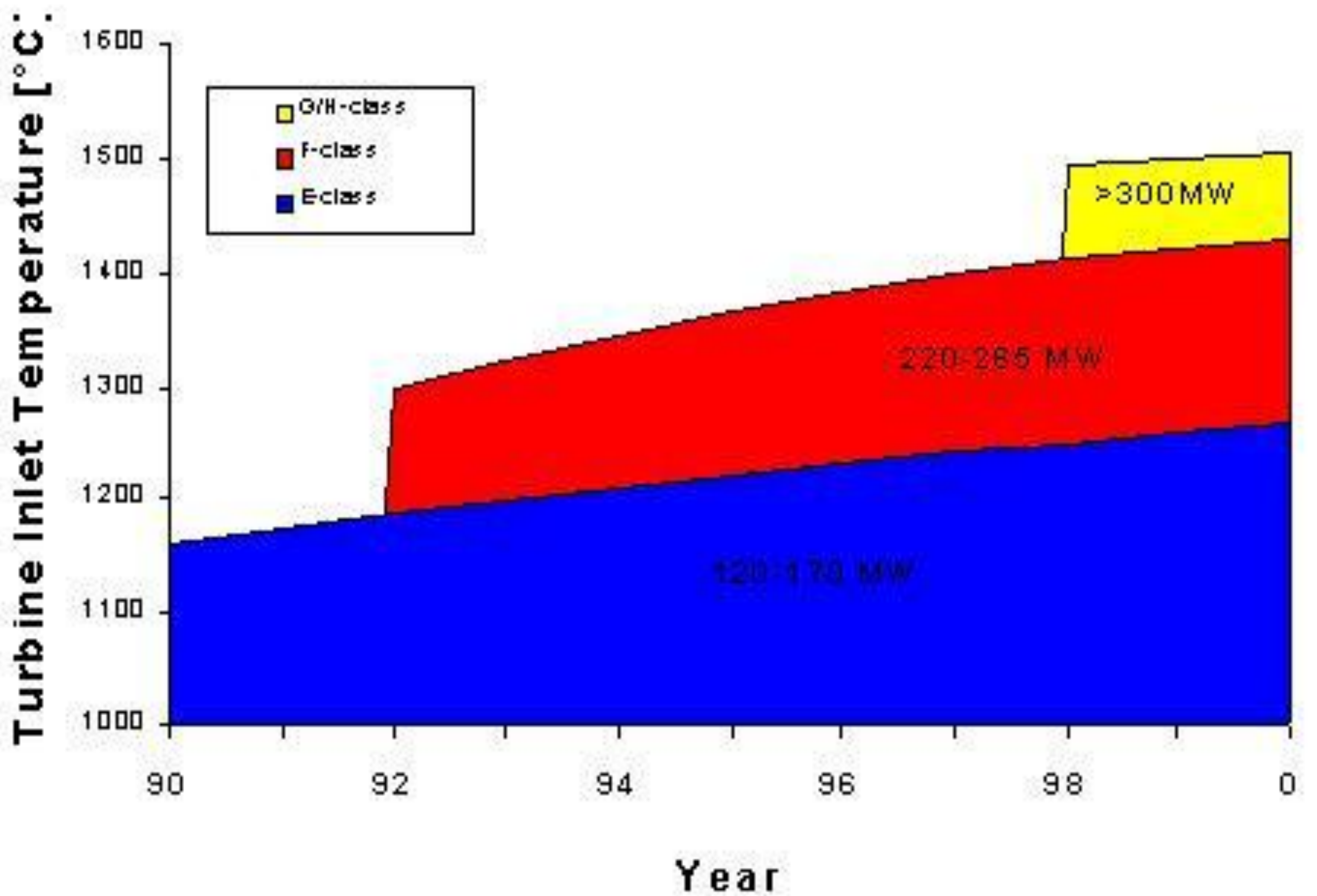
Gas turbine Blade Assembly

Gas Turbine Nozzle Assembly

Gas turbine Blade



HPT Rotor Assembly



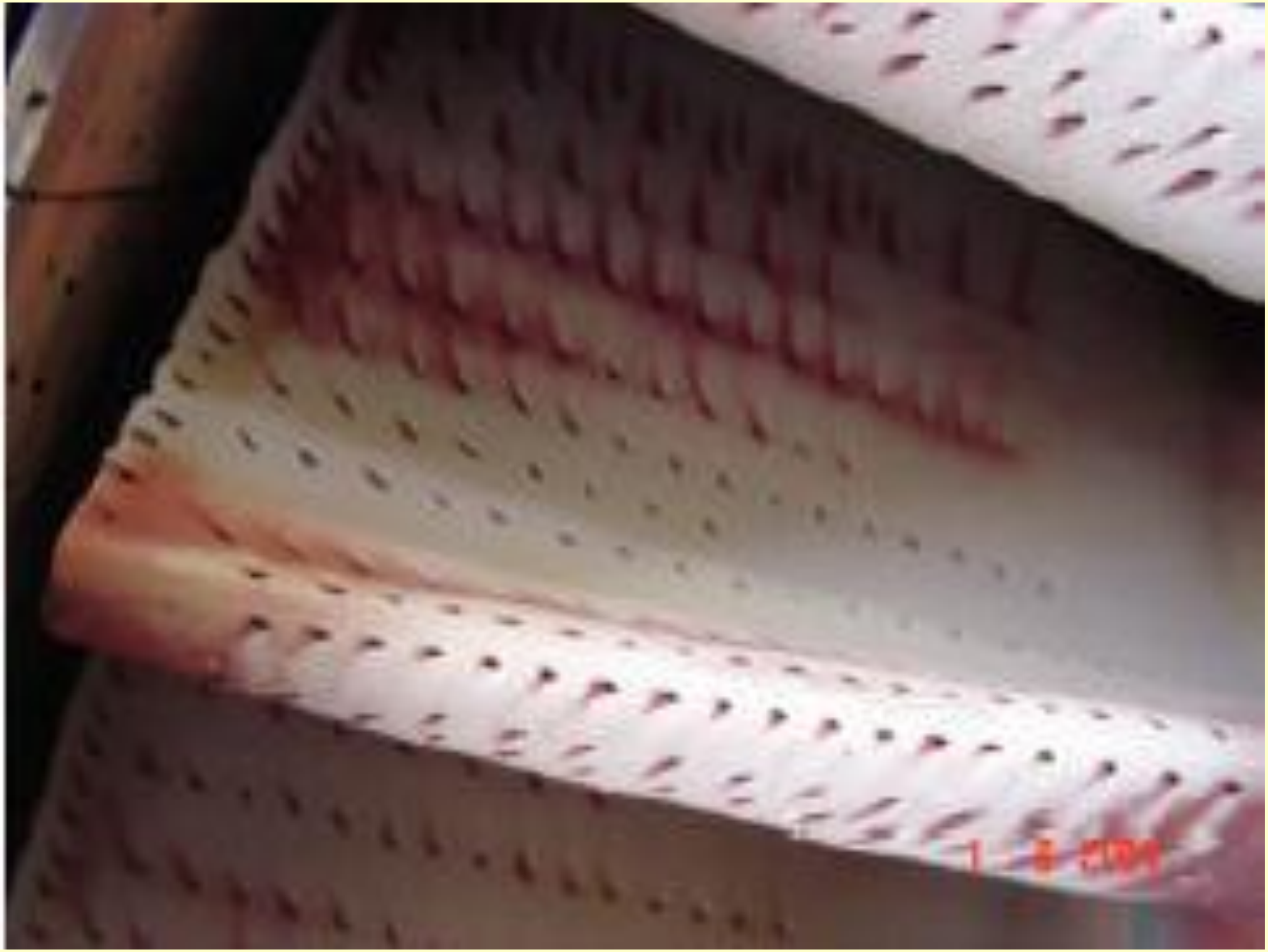
Turbine Inlet Temperature [°C]
1600
1500
1400
1300
1200
1100
1000
G/H-class
F-class
E-class
>300MW
220-285 MW
120-170 MW
90
92
94
96
98
0
Year

Gas turbine Blade Assembly

Gas turbine Blade Assembly

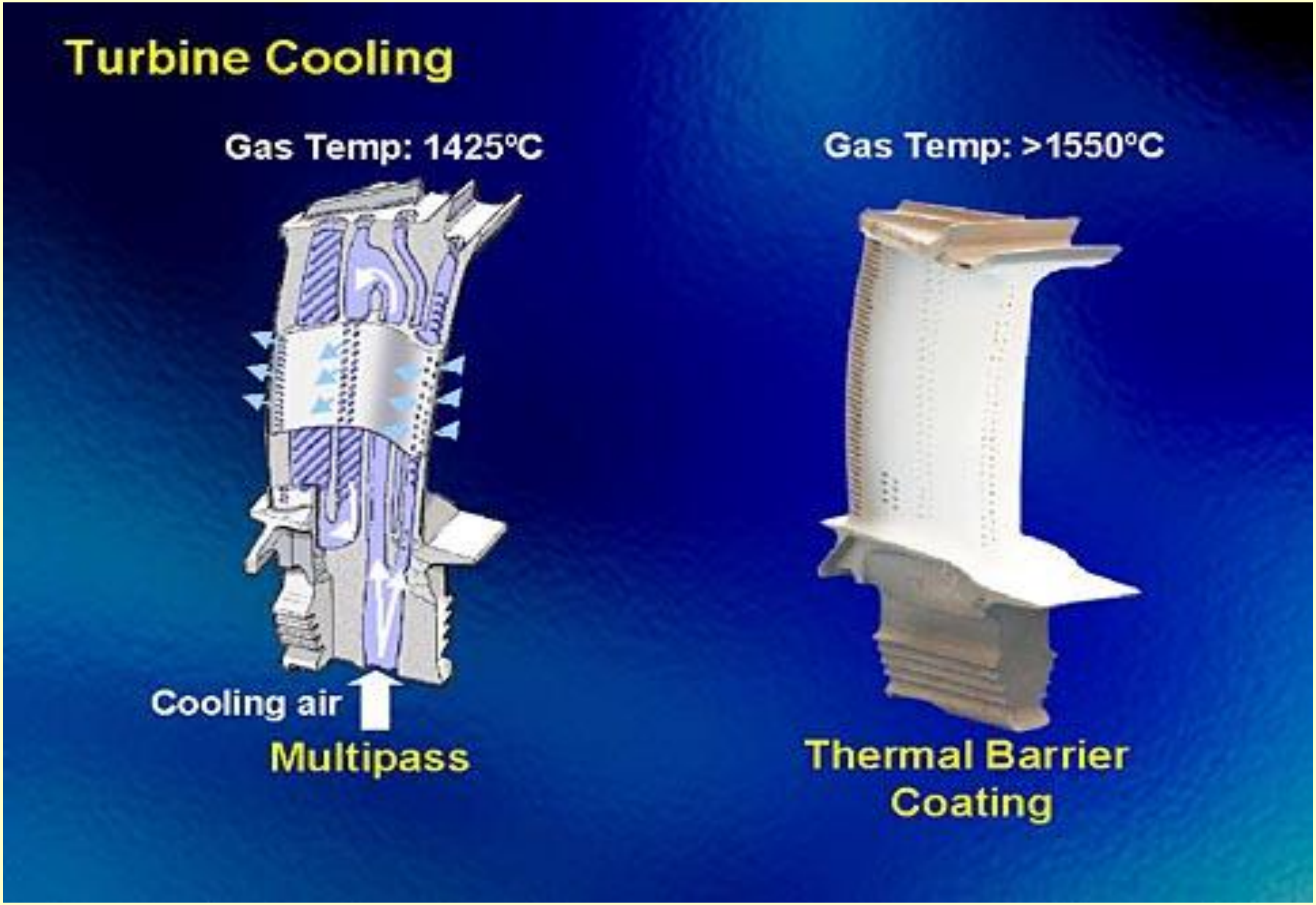
Gas Turbine Nozzle Assembly

Gas turbine Blade

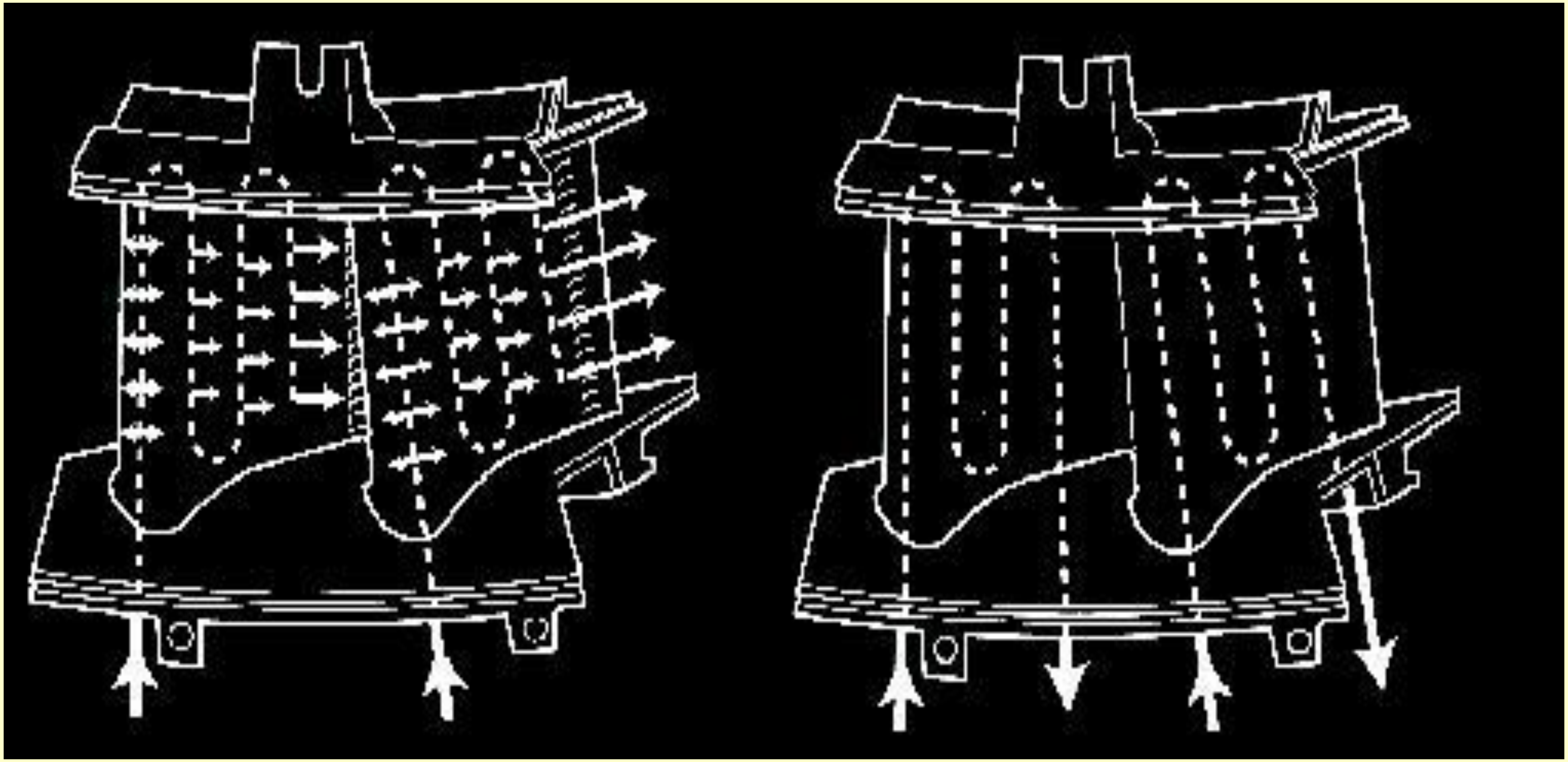


HPT Rotor Assembly

Turbine Blade Cooling



Gas turbine vane cooling techniques



Open loop air cooled

Vane 1 dT gas = 155°C

Closed loop steam cooled

Vane 1 dTgas = 44°C

Gas turbine blading materials

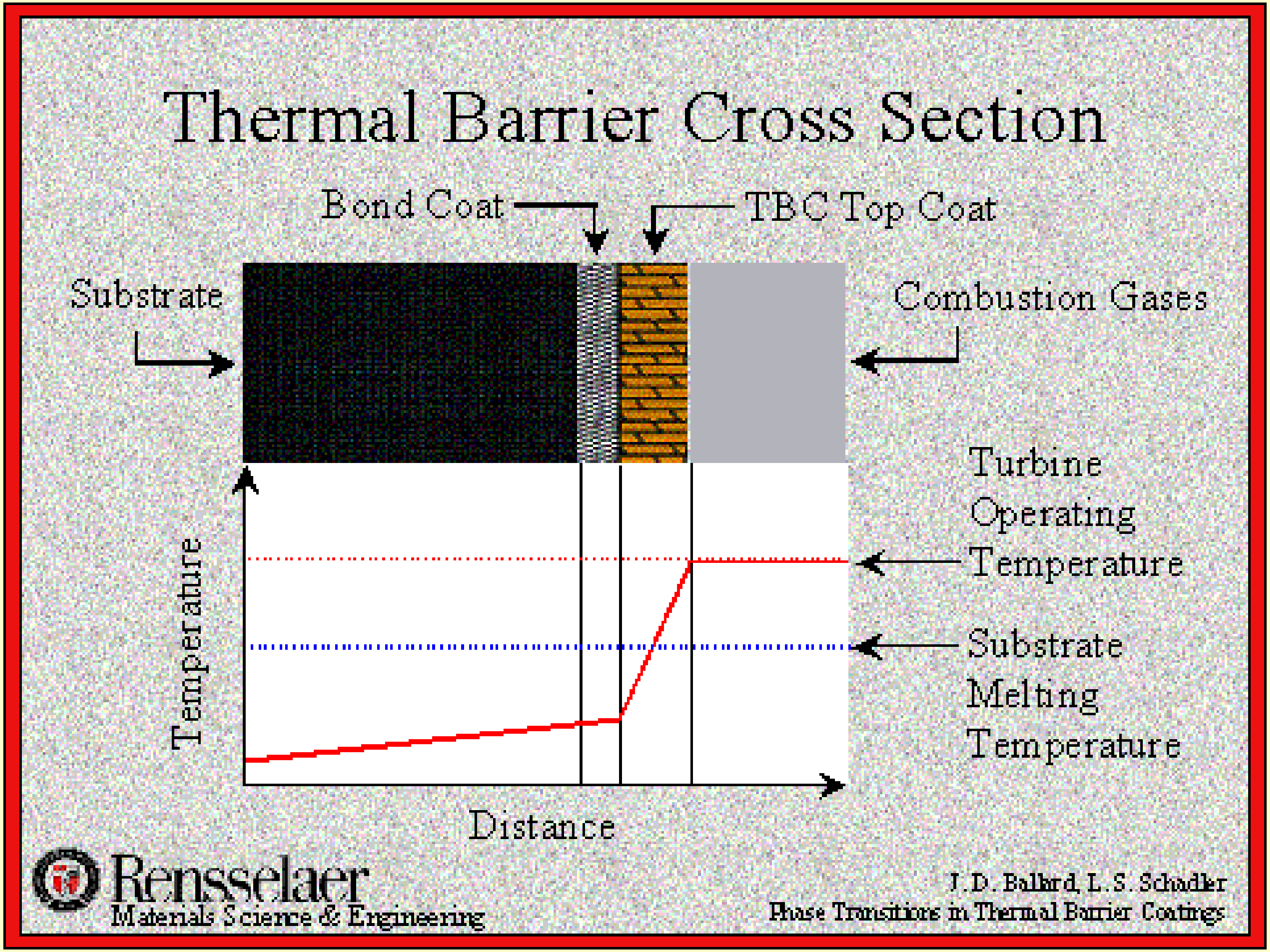
- Turbine blading is subjected to high temperature /stress
- Materials –Predominantly Nickel-Cobalt alloys
- Actual metal temperatures in excess of 80% of melting temperatures
- Lowest metal melting temperature-1300 Deg c
- Nickel alloys –Highest combination of stress/temperature durability
- Cobalt –Higher temperature capability,improved hot corrosion ,thermal fatigue resistance

Turbine Blade Coatings

- To combat hot corrosion and oxidation
- Principle coating groups

    1. Aluminium
    2. Aluminium with additives such as Chromium or Silicone
    3. Platinum Aluminides
    4. MCrAlY –M –Nickel/Cobalt/Iron
    5. MCrAlY+Thermal Barrier Ceramic
    6. Ceramic -Zirconia

Illustration of a thermal barrier coating



Factors affecting gas turbine output

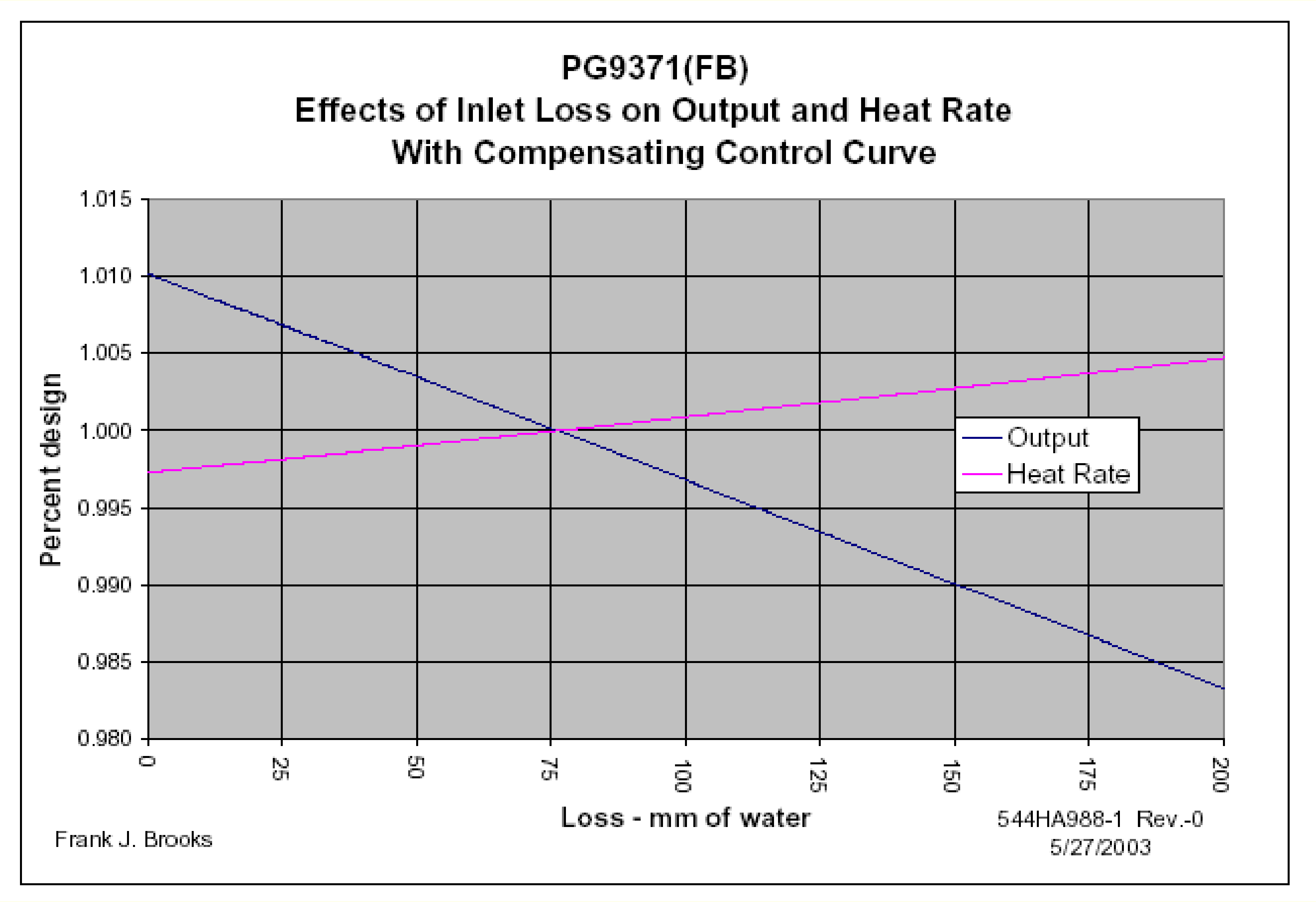
- The energy used by the air compressor - if less energy is used to compress the air, more energy is available at the output shaft;
- The temperature of the hot gas leaving the combustors - increased temperature generally results in increased power output;
- The temperature of the exhaust gas - reduced temperature generally results in increased power output;

Contd.

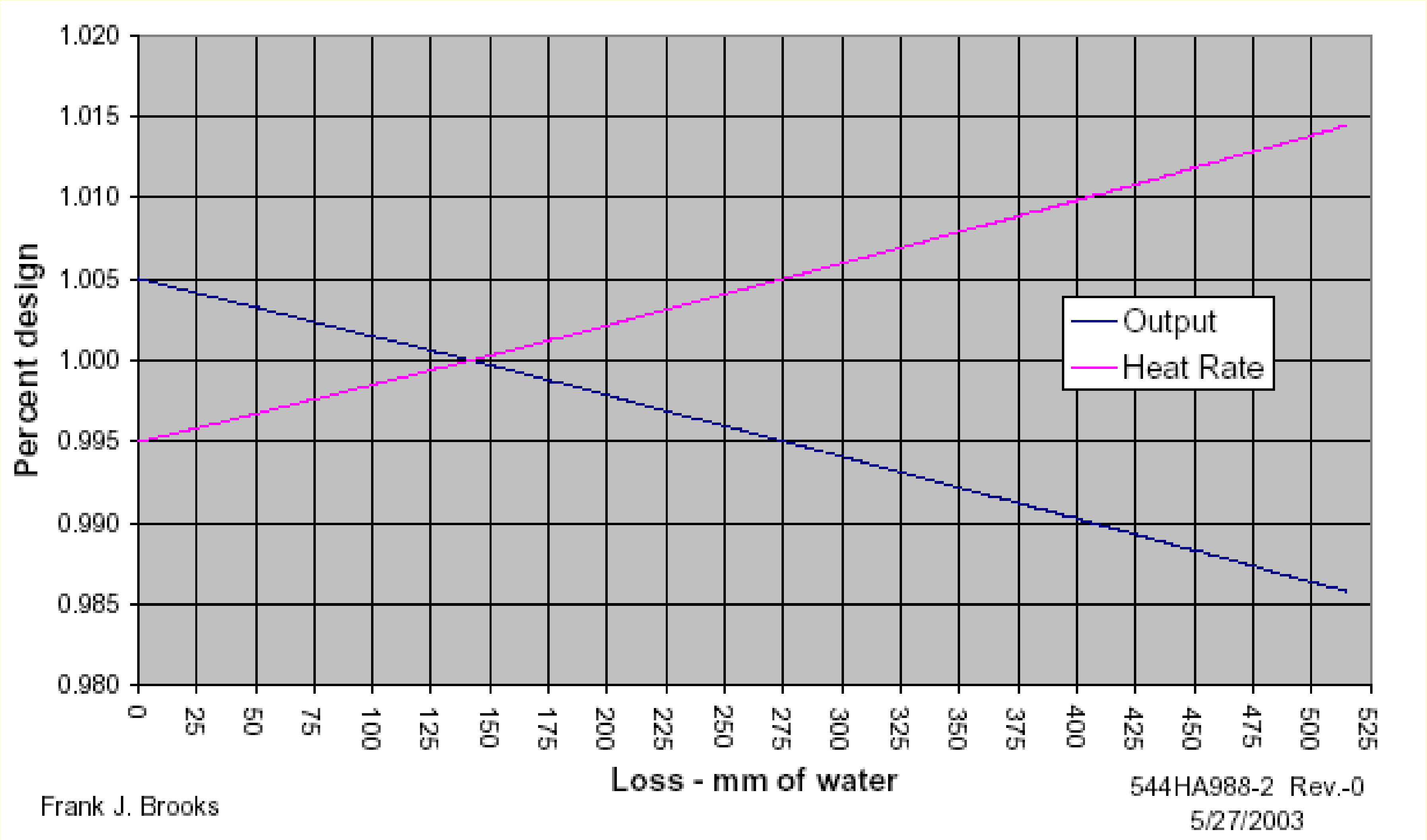
Factors affecting gas turbine output

- The mass flow through the gas turbine - in general, higher mass flows result in higher power output;
- The drop in pressure across the inlet air filters, silencers and ducts - a decrease in pressure loss increases power output;
- The drop in pressure across the exhaust gas silencers, ducts and stack - a decrease in pressure loss increases power output; and
- Increasing the pressure of the air entering or leaving the compressor - an increase in pressure increases power output.

Effect of inlet losses on GT output and heat rate



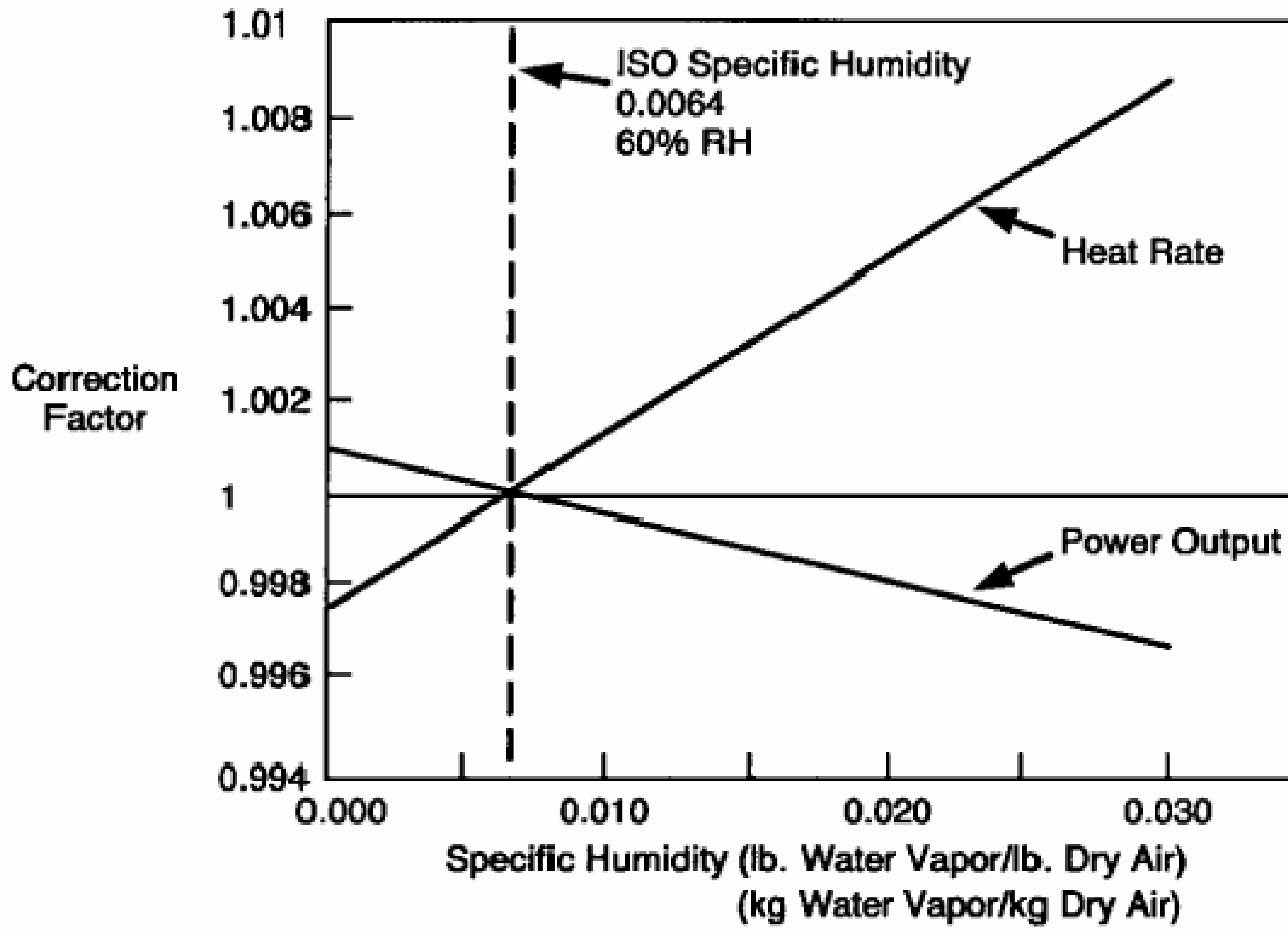
Effect of exhaust losses on GT output and heat rate



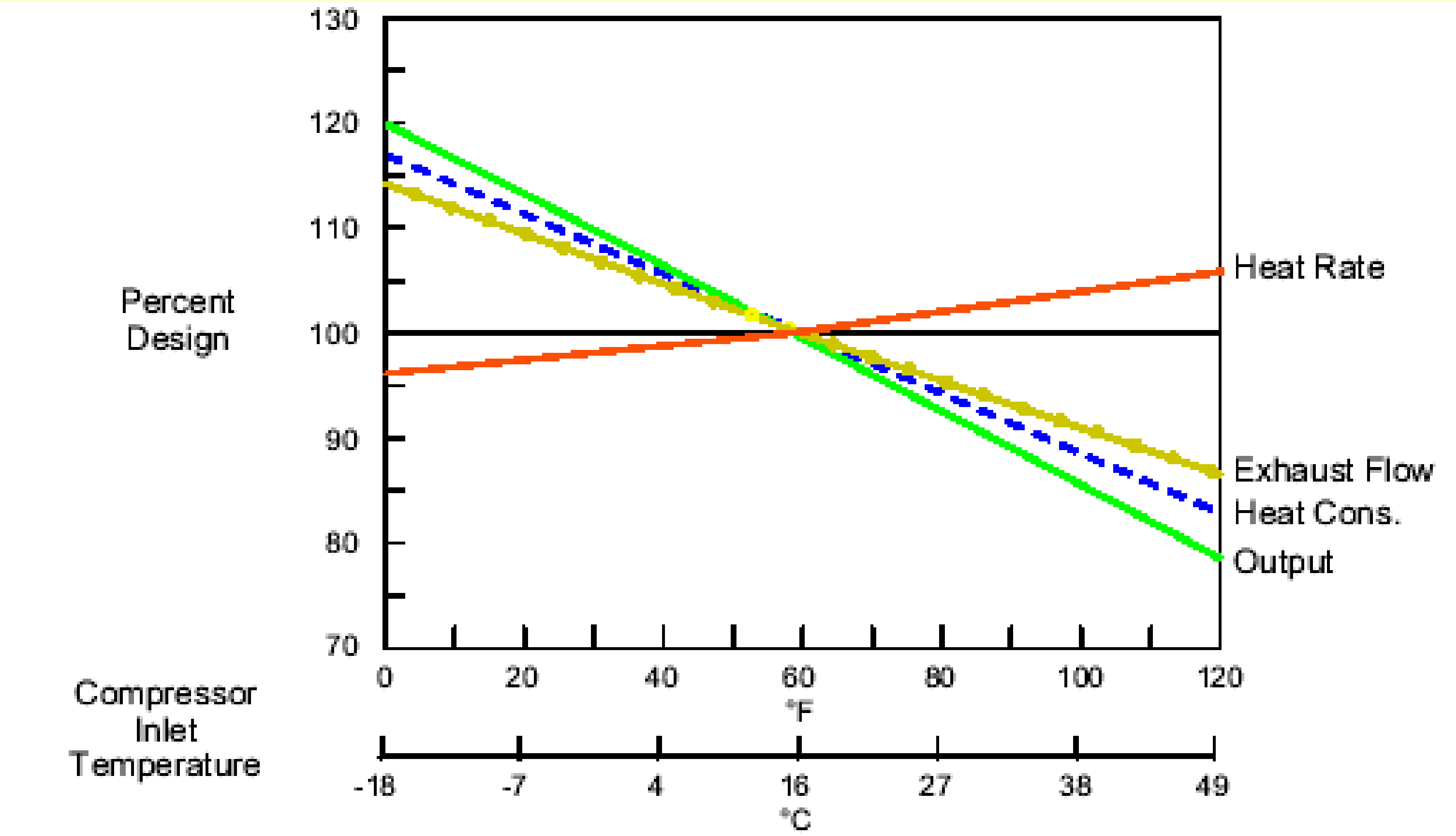
Pressure drop effect on GT

- 4 Inches (10 mbar) H_2O Inlet Drop Produces:
  - 1.42% Power Output Loss
  - 0.45% Heat Rate Increase
  - 1.9 F (1.1 C) Exhaust Temperature Increase
- 4 Inches (10 mbar) H_2O Exhaust Drop Produces:
  - 0.42% Power Output Loss
  - 0.42% Heat Rate Increase
  - 1.9 F (1.1 C) Exhaust Temperature Increase

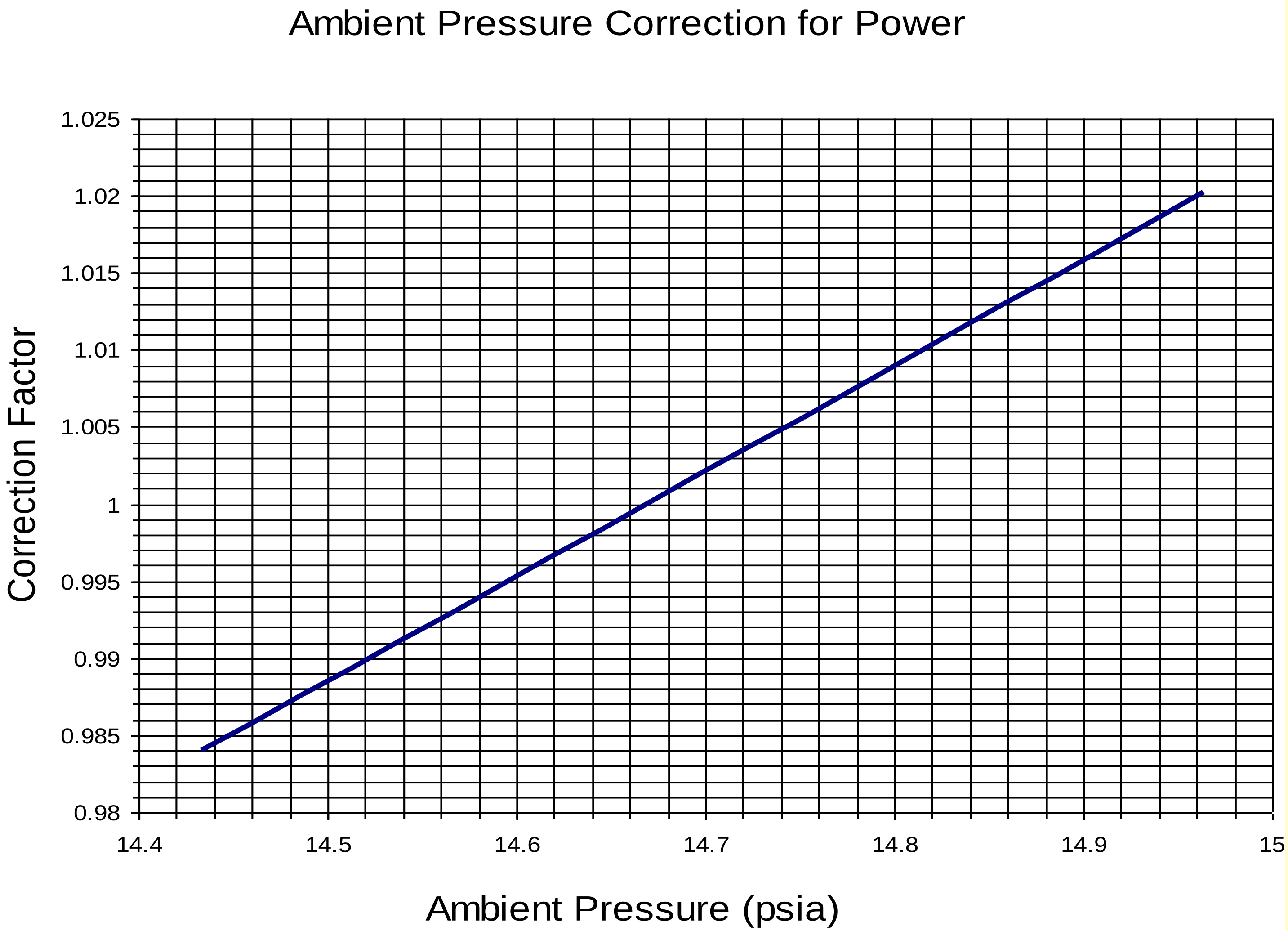
Humidity effect curves



Effect of ambient temperature on GT Performance



Ambient Pressure Vs GT Output



Basis of guar 14.67 psia

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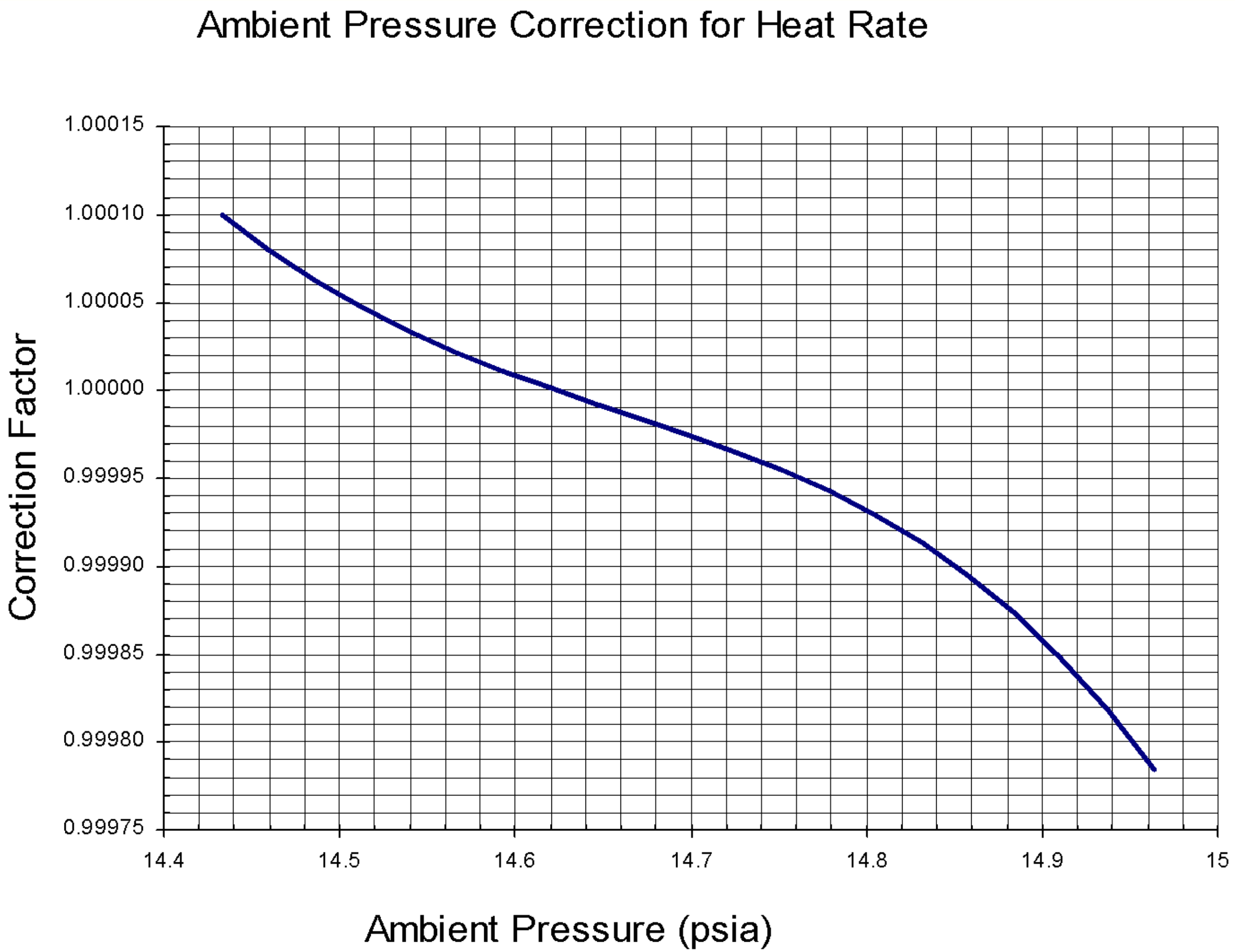
Ambient Pressure Vs GT Heat rate



Basis of guar 14.67 psia
Do not use for other site elevations - corrections valid for named site only.

Factors influencing Gas turbine thermal efficiency

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Factors influencing Gas turbine thermal efficiency

- The mass flow through the gas turbine - in general, higher mass flows result in higher efficiencies;
- The drop in pressure across the inlet air filters, silencers and ducts - a decrease in pressure loss increases efficiency;
- The drop in pressure across the exhaust gas silencers, ducts and stack - a decrease in pressure loss increases efficiency.

Factors influencing gas turbine reliability

- Design of the components
- Selection of materials used in critical components
- Operational factors such as the cleanliness of the fuel and inlet air
- The way gas turbine is operates
- Quality of maintenance factors

Augmenting GT output-Options

- Using the exhaust gas to heat the air from the compressor (mainly used in cold weather conditions);
- Divide the compressor into two parts and cool the air between the two parts;
- Divide the turbine into two parts and reheat the gas between the two parts by passing the gas through additional burners and combustors located between the two parts;
- Cooling the inlet air - mainly used in hot weather conditions;

Augmenting GT output-Options

- Reducing the humidity of the inlet air;
- Increasing the pressure of the air at the discharge of the air compressor;
- Inject steam or water into the combustors or turbine;
- Wash or otherwise clean the fouling from the blades of the air compressor and turbine at regular intervals; and
- Combinations of the above methods.

Gas turbine Performance Enhancement by Inlet air cooling

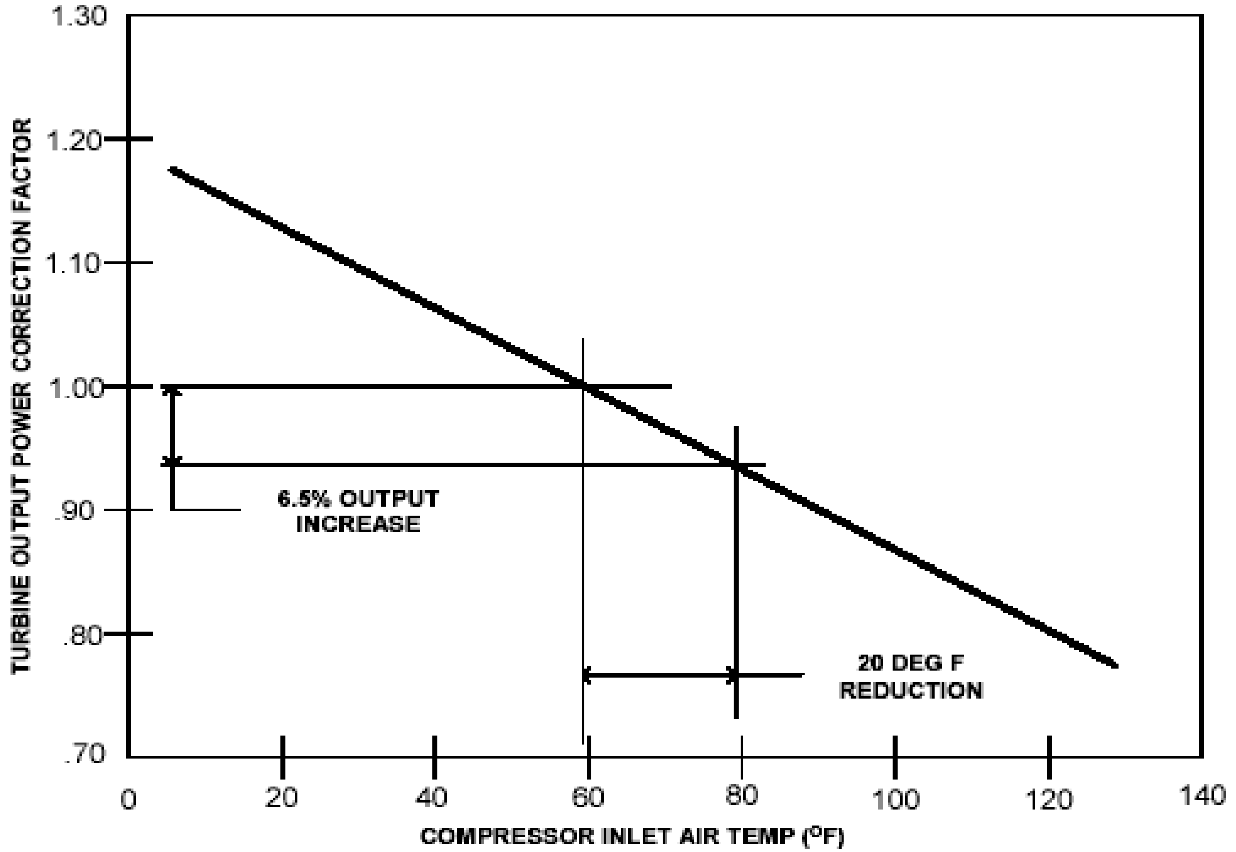
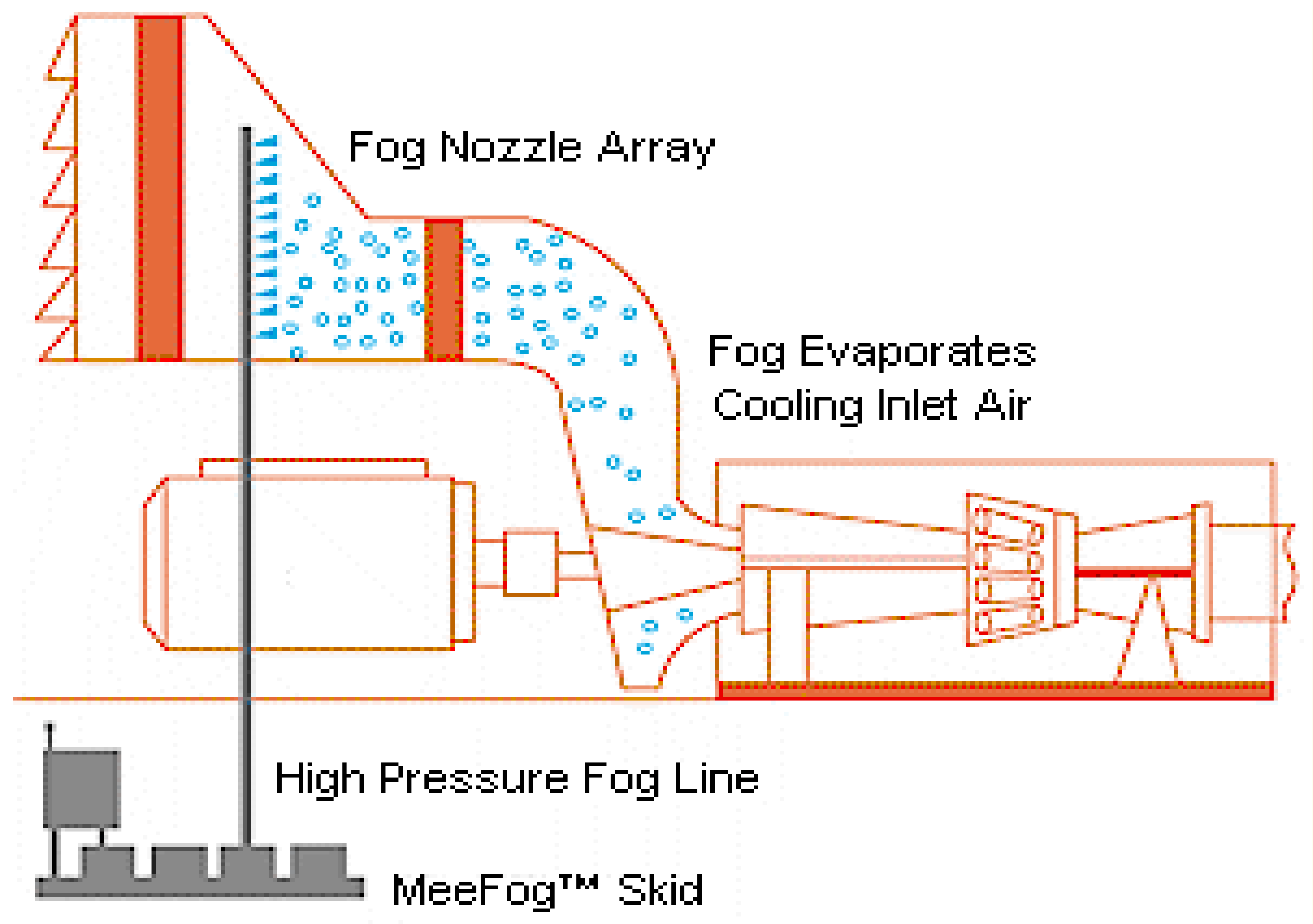
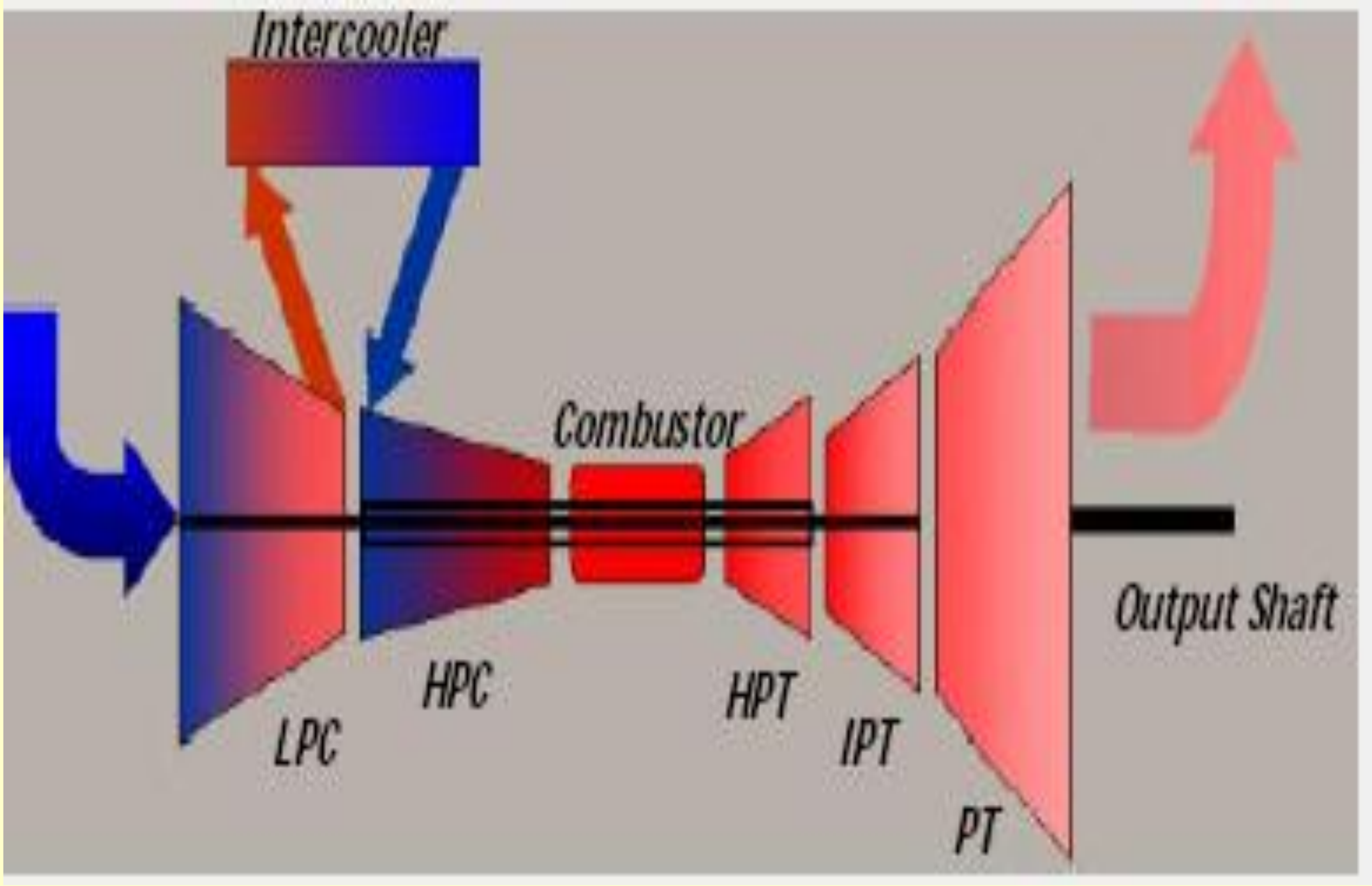


FIGURE 1 SYSTEM PERFORMANCE CURVE

GT Output enhancement –Inlet Fogging



LMS 100



LMS 100 ISO Performance Data

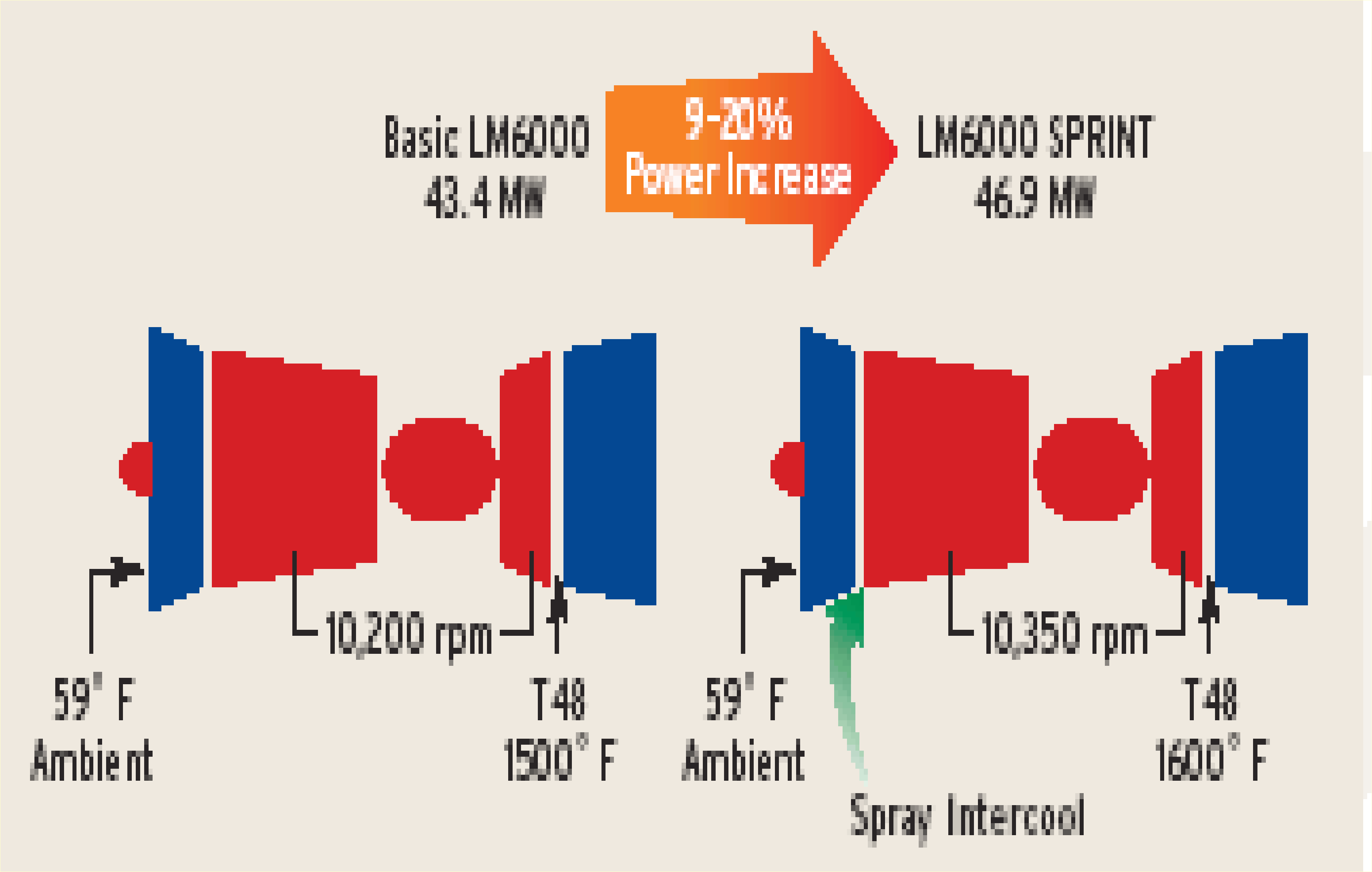
Simple Cycle Gas Turbine 50Hz Applications

Model	Output (MWe)	Heat Rate (KJ/KWH)	Efficiency %
DLE	99	7921	45
SAC (w/Water)	102.5	8247	44
SAC (w/Steam)	102.2	7603	47
STIG	110.8	7263	50

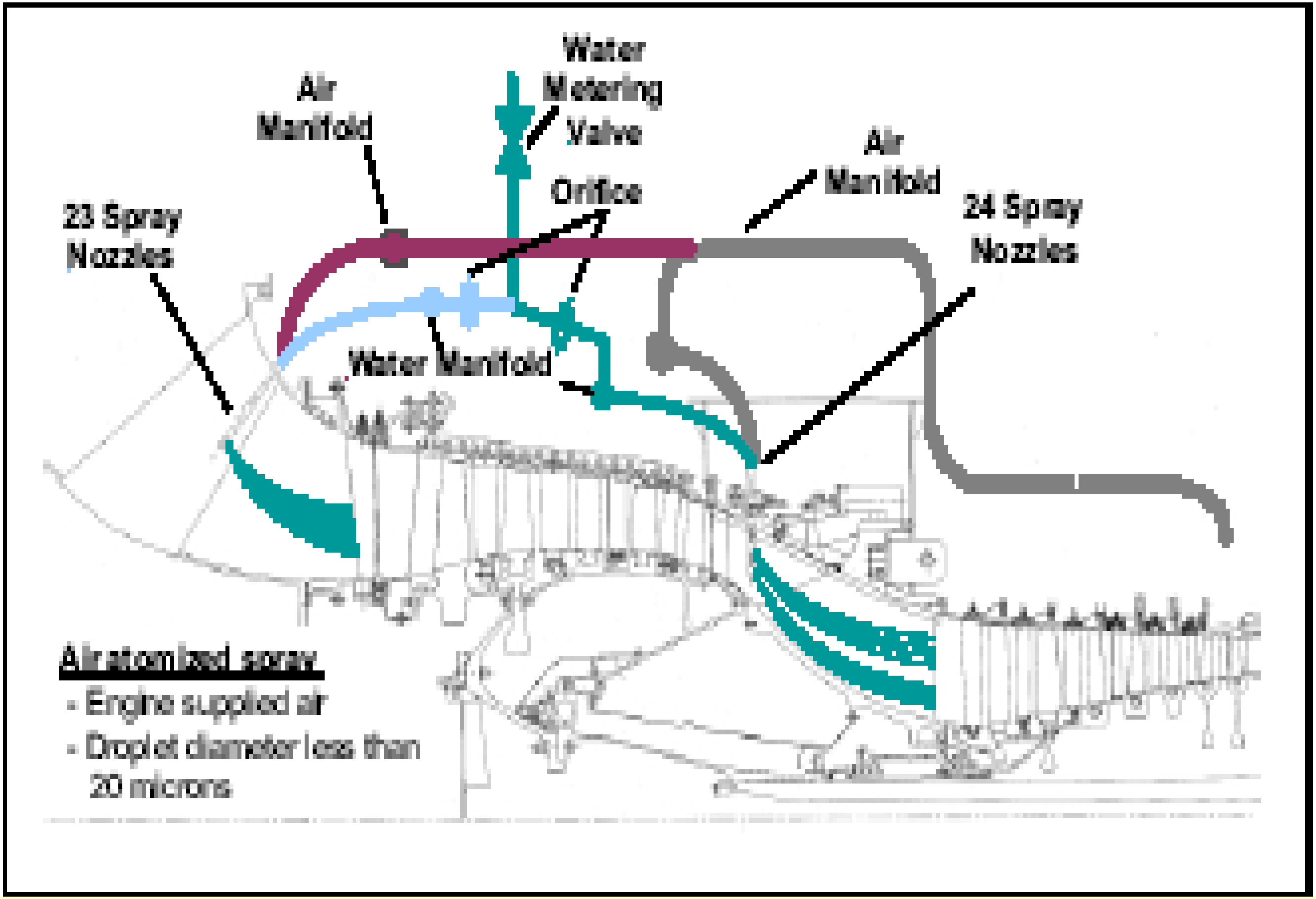
Conditions:

Performance at the generator terminals
NOx = 25 ppm
15°C, 60% Relative Humidity
Losses: 0mm/0mm inlet/exhaust
Fuel: Spec Gas (LHV = 44.2MJ/KG)

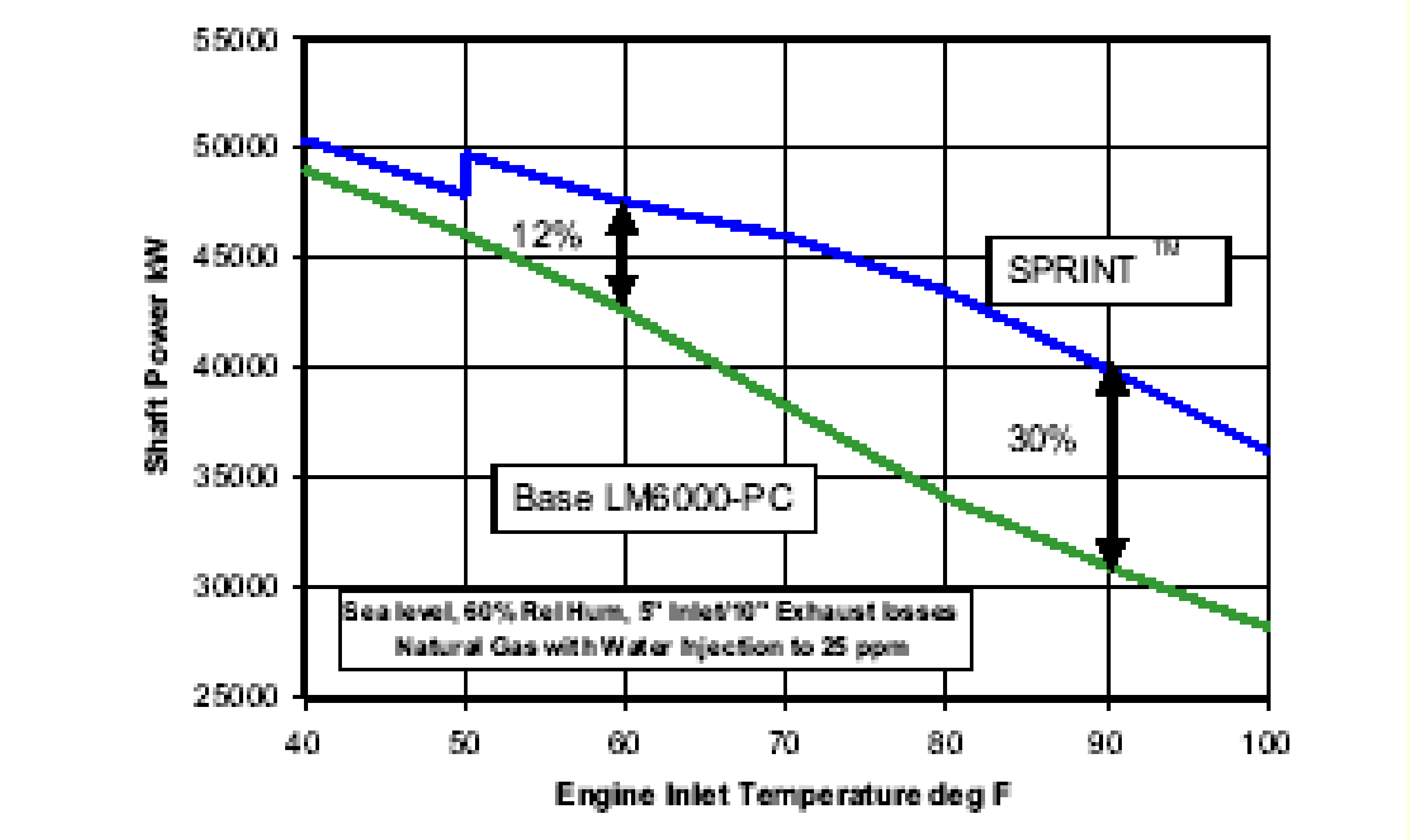
GT Output enhancement -SPRINT



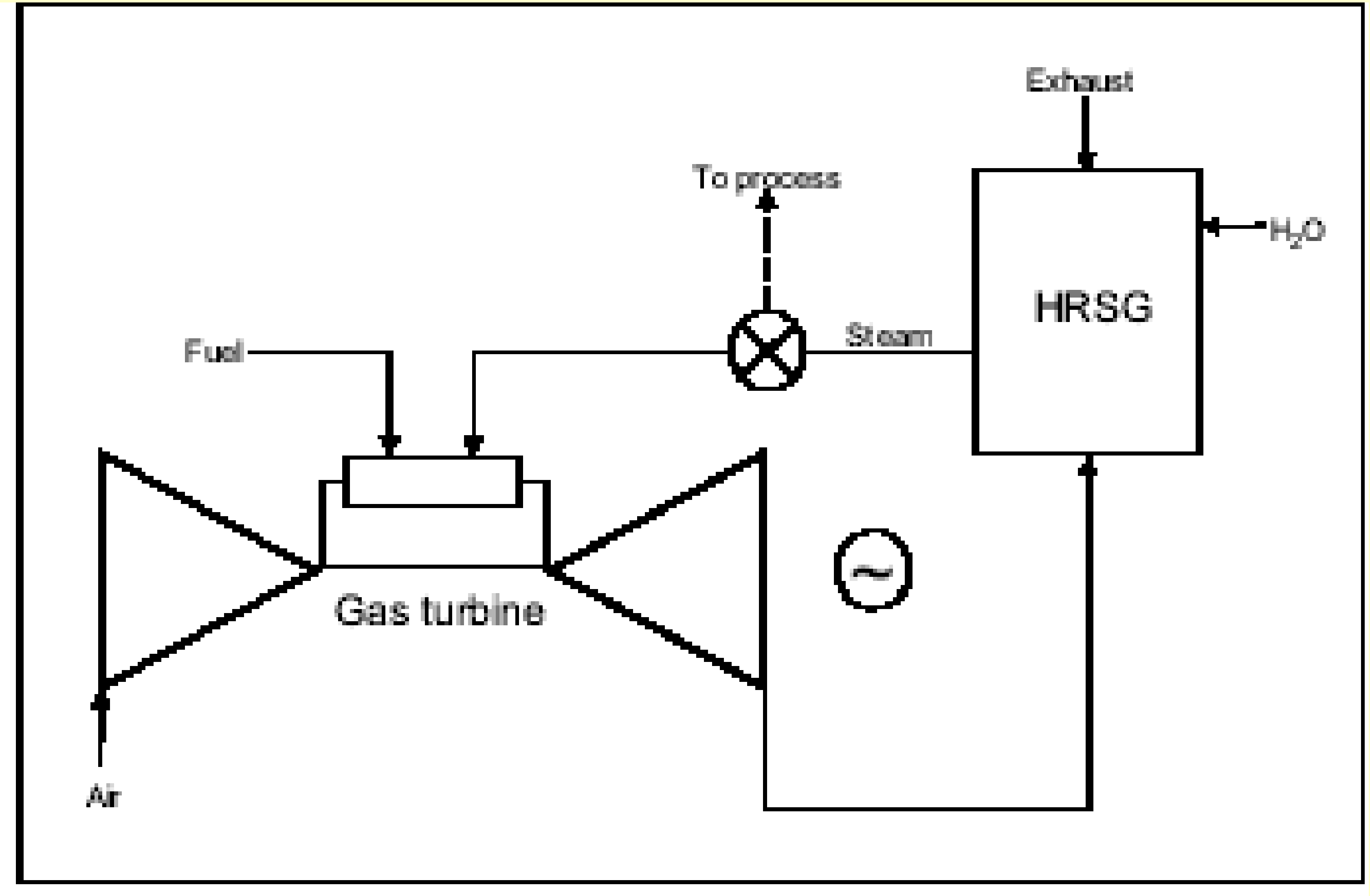
LM6000PC SPRINT Cross Section



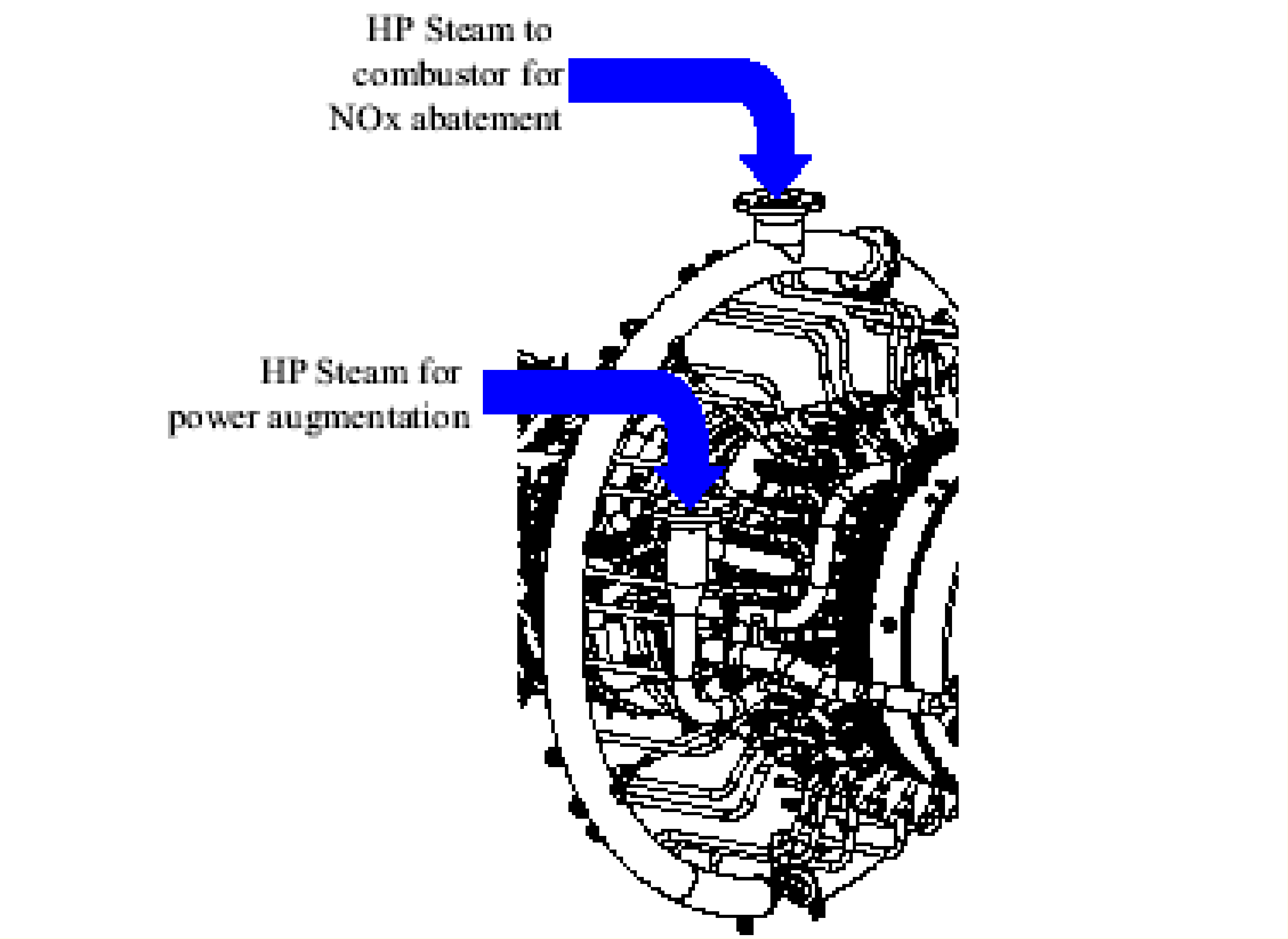
LM6000PC vs LM6000PC SPRINT



GT output enhancement -STIG



Steam injection ports -STIG



System performance enhancement- STIG

Standard Base Load, Sea Level, 60% RH, - Natural Gas - 60 Hertz - 4 in. (102mm) Inlet/10 in. (254mm) Exhaust Loss - Average Engine at the Generator Terminals*				
Model	Dry Rating (MWe)	%Thermal Efficiency (LHV)	STIG Rating (MWe)	%Thermal Efficiency (LHV)
LM1600	13.3	35	16	37
LM2000	18	35	23.2	39
LM2500	22.2	35	27.4	39

*3% margin on Eff. Included

GT Performance Degradation

- By contaminants in the air ,fuel ,steam and water
- Contaminants cause degradation by
  - Deposition
  - Erosion
  - Corrosion
- Degradation can be reversed by
  - Washing (partial reversal)
  - Overhauling /replacing the gas path components

Gas turbine Nozzle before and after washing

GT Performance Testing

- Performance test code –ASME PTC 22
- Testing by input /output method
- Input –Fuel flow rate
- Output –Electrical generation
- PTC 22 specifies
    - Test instrumentation
    - Data reduction
    - Correction methods
    - Test reporting requirements

GT Performance Testing-Parameters to be established

- Ambient dry bulb temperature
- Ambient wet bulb temperature (or RH)
- Barometric pressure
- Test fuel characteristics(heating value ,analysis ,temperature etc)
- Water injection rate ,pressure and temp
- Inlet and exhaust losses

Contd.

GT Performance Testing-Parameters to be established

- Point where electrical output to be measured and what aux electrical loads are to be included
- Condition of the gas turbine unit (if a new unit ,a definition of new and clean unit)
- Local point or points at which the test is to be conducted

Gas turbine fuels

- Gaseous fuels
- Liquid fuels
- Non conventional fuels
  - Crude oil
  - Refinery gas
  - Propane
  - Condensates
  - Orimulsion
- Synthetic fuels
  - Synthetic natural gas (SNG)
  - Synthetic liquid fuel

Gas fuel -Specifications

Fuel properties

- Heating Values
- Modified Wobbe Index (MWI)
- Superheat Requirement
- Hydrocarbon Dew Point
- Moisture Dew Point
- Flammability Ratio
- Gas Constituent Limits
- Gas Fuel Supply Pressure

Contd.

Gas fuel -Specifications

Contaminants

- Liquid
- Sulfur
- Particulates
- Trace metals

Gas fuel properties -Modified Wobbe Index

- Measure of interchangeability of fuel
- Relative measure of the energy injected into the combustor at a fixed pressure ratio
- Calculated using fuel low heating value and specific gravity
- MWI range is established to ensure that required fuel nozzle pressure ratios are maintained at all combustion /turbine modes of operation

Gas fuel properties -Superheat

- To ensure that gas supply to the turbine is 100% free of liquids
- It is the difference between gas temperature and respective dew point temperature
- Condensation of moisture must be avoided to prevent the formation of gas hydrates and collection of water in low points of the gas fuel system
- The superheat requirements take into account the gas temperature drop and the relationship of the moisture and hydrocarbon dew point lines to the gas fuel pressure.
- The superheat requirement is specified to provide enough margin to compensate for the temperature reduction as the gas expands across the gas fuel control valves.

Liquid fuel Properties

- Density and LHV
- Reid Vapor pressure
- Bubble Point
- Cloud and pour point
- Flash point
- Distillation end points
- Aromatic content
- Contents of olefins and diolefins
- Carbon residue
- Ash content
- Water and sediment contents
- Copper strip corrosion
- Corrosive contaminants

Liquid fuel Properties

- Ignition performance based on
  - Volatility measured by Reid vapor pressure
  - Total surface area which is proportional to viscosity
- Free carbon determines the luminosity of the flame.Heavier the fuel greater the emissivity and resulting wall temperatures
- Warm enough to be capable of flowing under gravity-Pour point
- Not too warm to exceed flash point

Contd.

Liquid fuel Properties

- Capability to corrode fuel system components – Copper corrosion
- Ash content –Cause fuel system erosion
- Excessive content of olefins/diolefins can cause fuel decomposition and fuel system blockage
- Carbon residue more –Causes carbon deposit in the combustion system
- Solids in the fuel –Causes clogging of the fuel system especially fine flow passages in the injection system
- Certain components like Na,Li,K,Ca,V can cause hot corrosion of the hot section

Contd.

Liquid fuel Properties

- Bubble point –Temperature at which first bubble of gas appears.
  - Bubble point has to be considered for the following reasons
  - To supply the minimum fuel pressure for a liquid system
  - Fuel pressure must be high enough to allow for fuel turn down ratios and pressure drops in injector
  - To determine the size of the metering orifices
  - If bubble temperature is less than 0 Deg C at any combustor operating condition icing around injectors are likely.

LM600PC -Liquid Fuel specs

PARAMETER	UNIT	LIMIT
SODIUM+POTASSIUM+LITHIUM	PPM	0.2
VANADIUM	PPM	0.5
CALCIUM	PPM	2
WATER+SEDIMENT	PPM	1000
ASH	%	0.01
SULPHUR	%	1

LM600PC -Liquid Fuel specs

PARAMETER	UNIT	LIMIT
LEAD	PPM	1
CARBON RESIDUE	%	0.25
PARTICULATE	Mg/gal	10
FLASH POINT	^{0}F	200
DEMULSIFICATION	minutes	20

DM water quality for NOX Suppression

PARAMETER	UNIT	LIMIT
PH		6 to 8
CONDUCTIVITY	micro siemens /cm	<1
TDS	ppm	<3
TOTAL MATTER	ppm	<5
SODIUM	ppm	<0.1
SILICA	ppm	<0.1

Gas turbine Emission

Emission Products

- Nitrogen oxides
- Carbon monoxide
- Volatile Hydrocarbon Compounds(VHC)
- Sulphur oxide(Sox)
- Particulate matter

NOX Emission

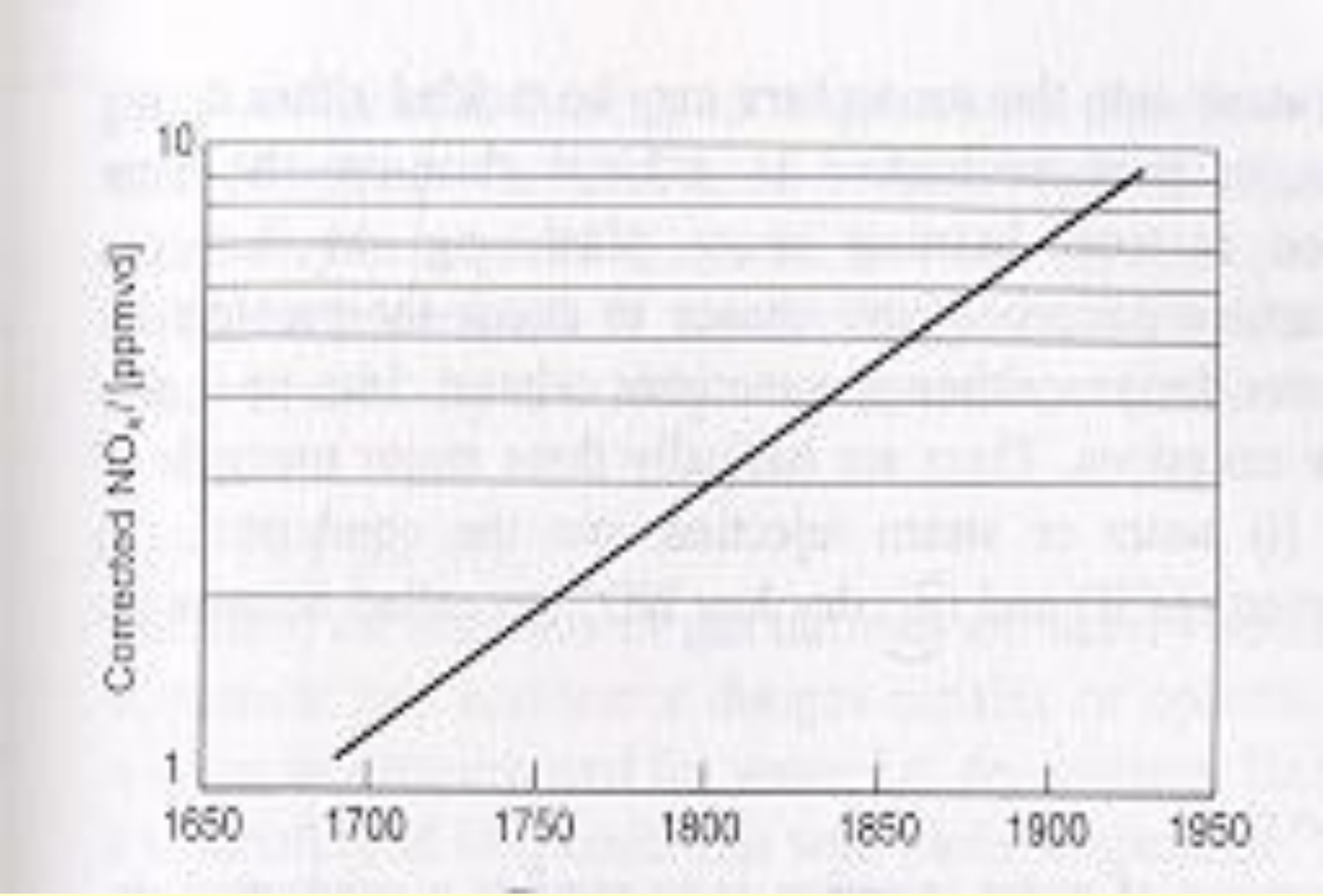
Oxides of nitrogen from gas turbine are of two types

- **Fuel NOX** –Oxidation of nitrogen in the fuel.Independent of combustion temperature
- **Thermal NOX-**High temperature reaction between Nitrogen and Oxygen in the combustion air.Dependent on combustion temperature.

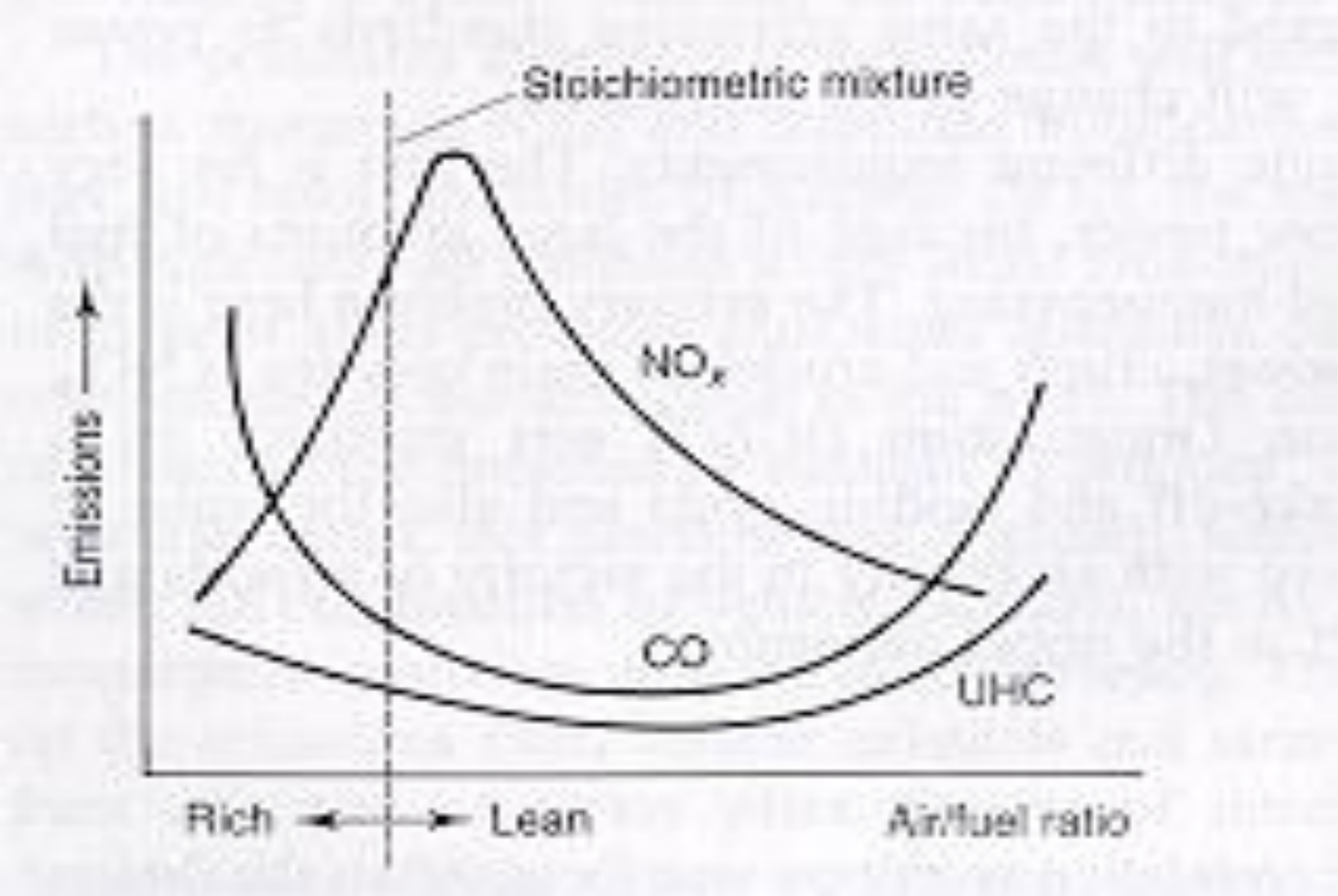
NOX Emission-Contributing factors

- Combustion chamber design
- Turbine operating parameters such as flame temperature
- Residence time
- Fuel/Air ratios in the primary combustion zone

NOX Emission Vs Combustion temperatures



NOX Emission Vs Air-fuel ratio



NOX Control

- NOX formation can be limited by lowering combustion temperatures and staging combustion.
- How to control?
  - Water or steam injection in the combustion zone
  - Improved low NOX combustors
    - Lean premixed
    - Rich/quench/lean combustion
    - Catalytic combustion
  - Selective catalytic reduction

CO and VOC control

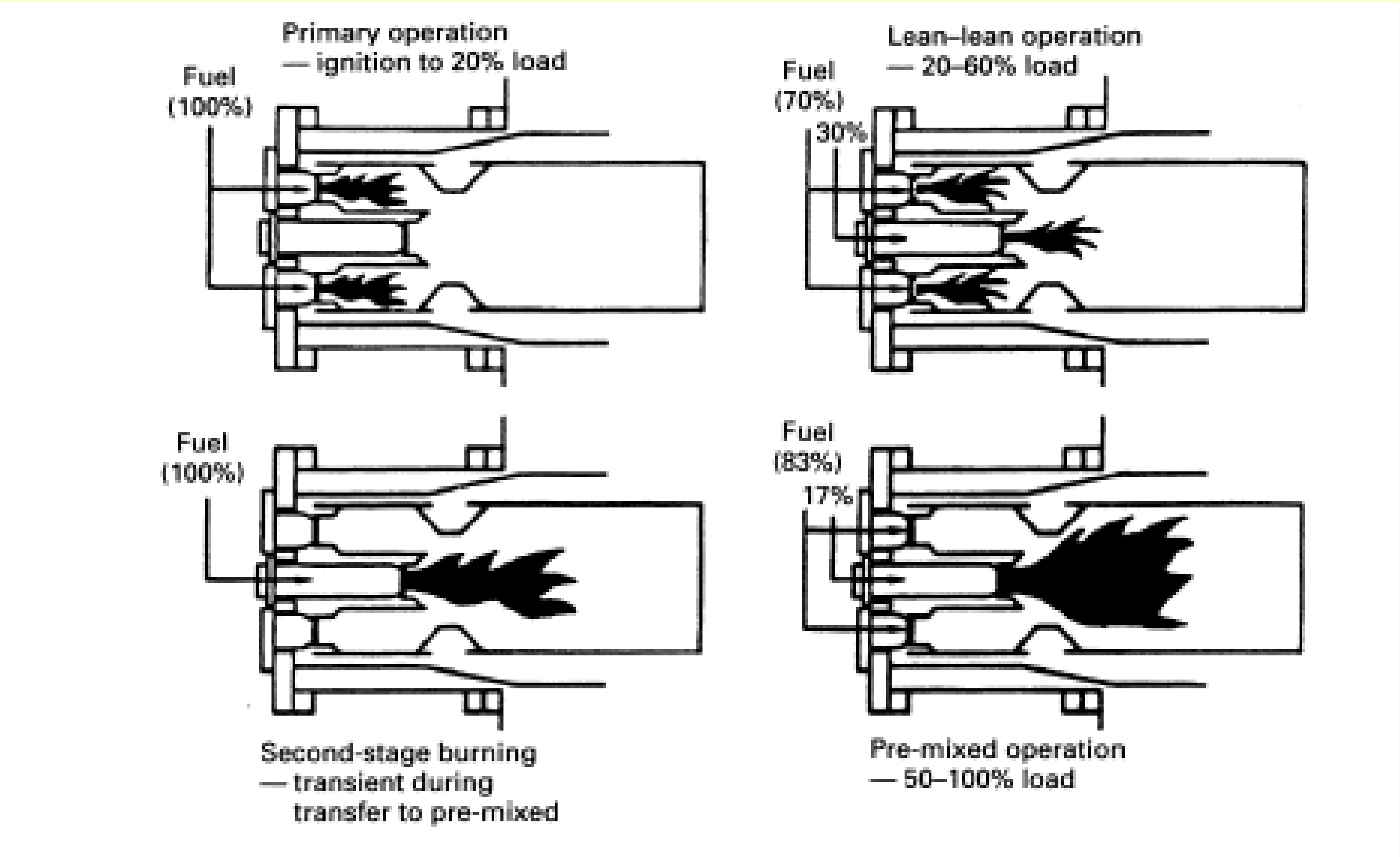
Catalytic oxidation

- CO to CO_2
- VOC to CO_2 and H_2O

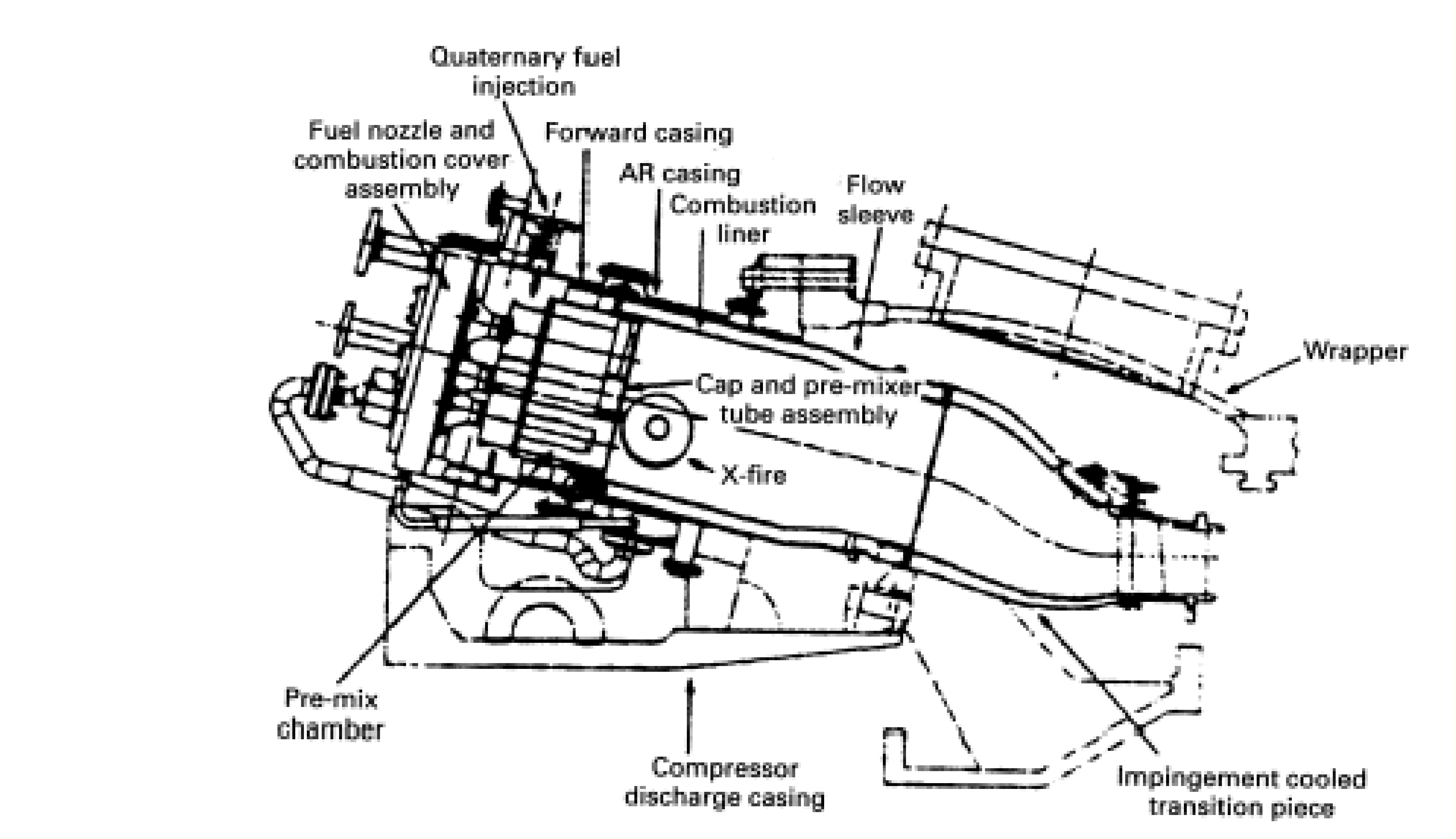
Disadvantage of catalytic oxidation

- SO_3 production with sulphur bearing fuels

DLN Combustor Operating sequence



DLN Combustor



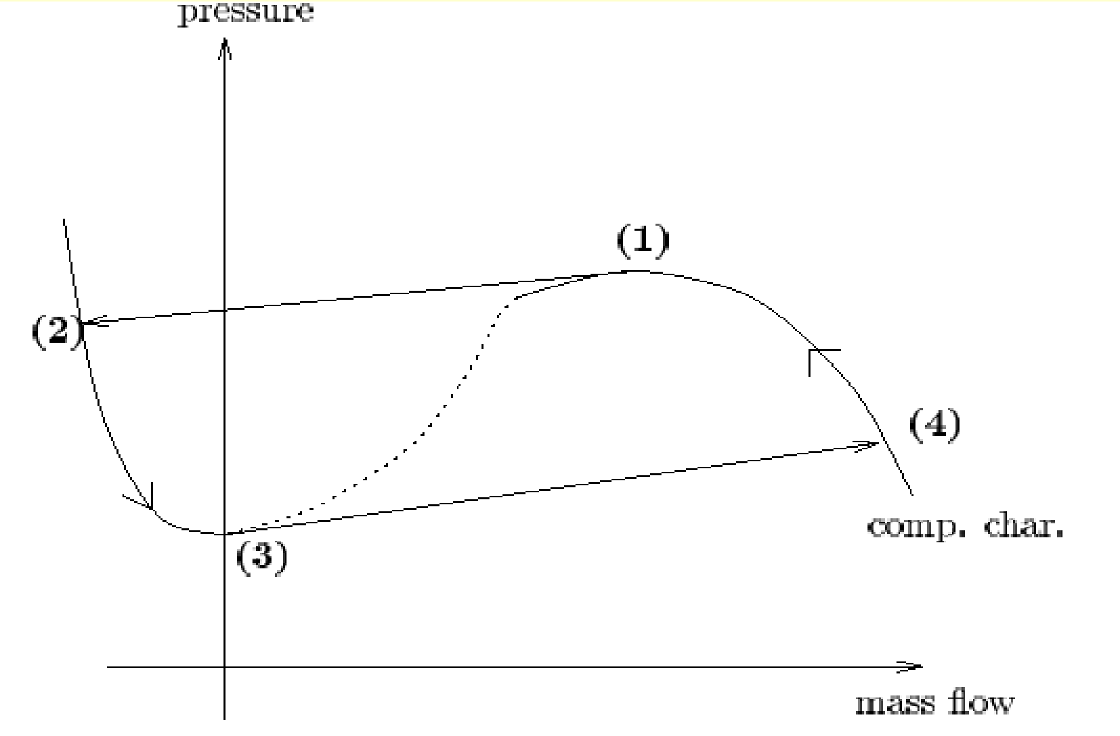
Emission control results

- Water injection reduces NOX from >200 ppm to 25 ppm
- Adding an SCR can further reduce NOX to <5 ppm
- DLN combustors can reduce NOX to <10 ppm without SCR
- SCONOX purports to achieve <2 ppm NOX and < 1ppm CO

Gas turbine off design operation - Surge

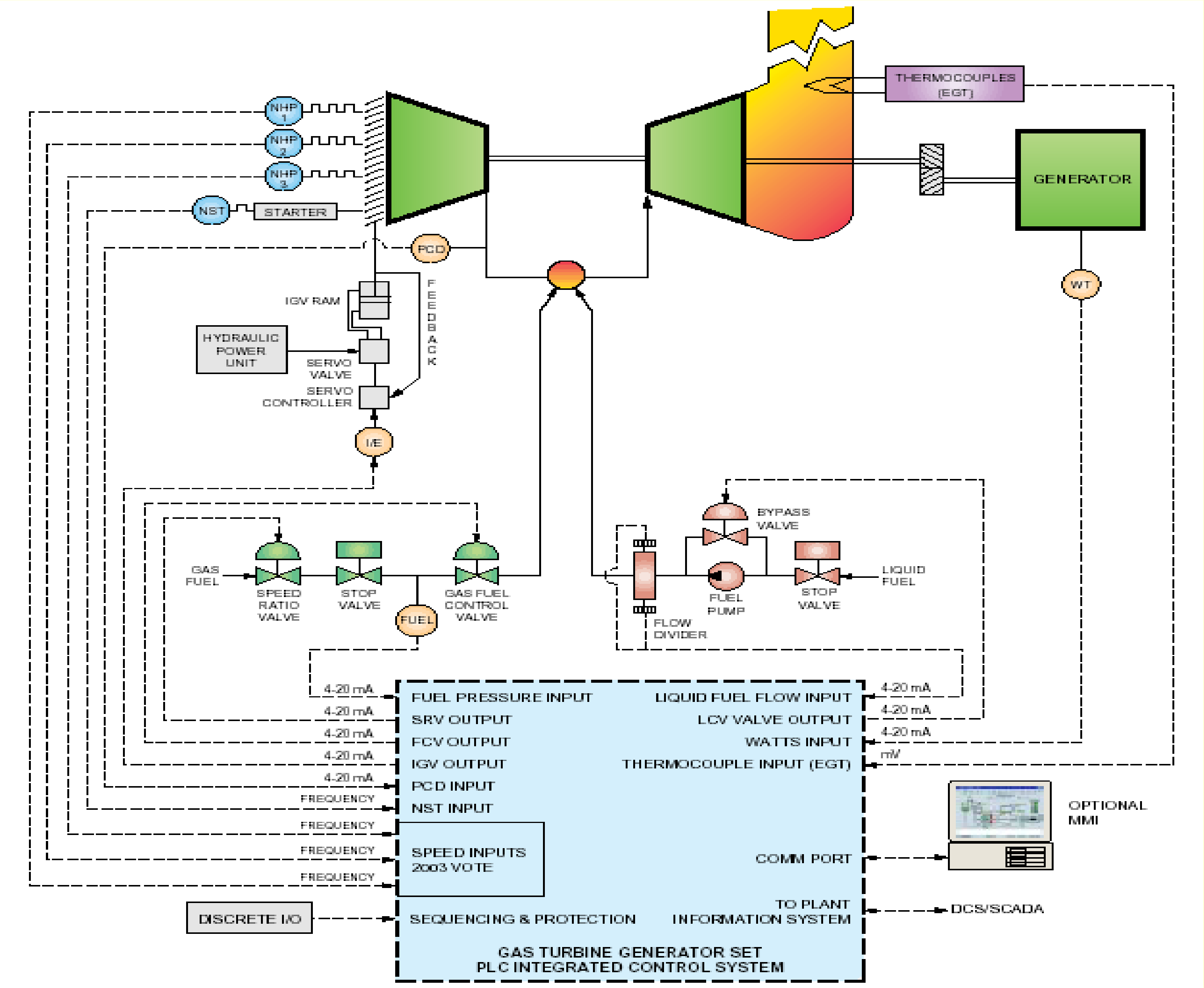
- Complete reversal of air/gas flow causing inlet temperature to rise

Compressor Off Design Operation -Surge



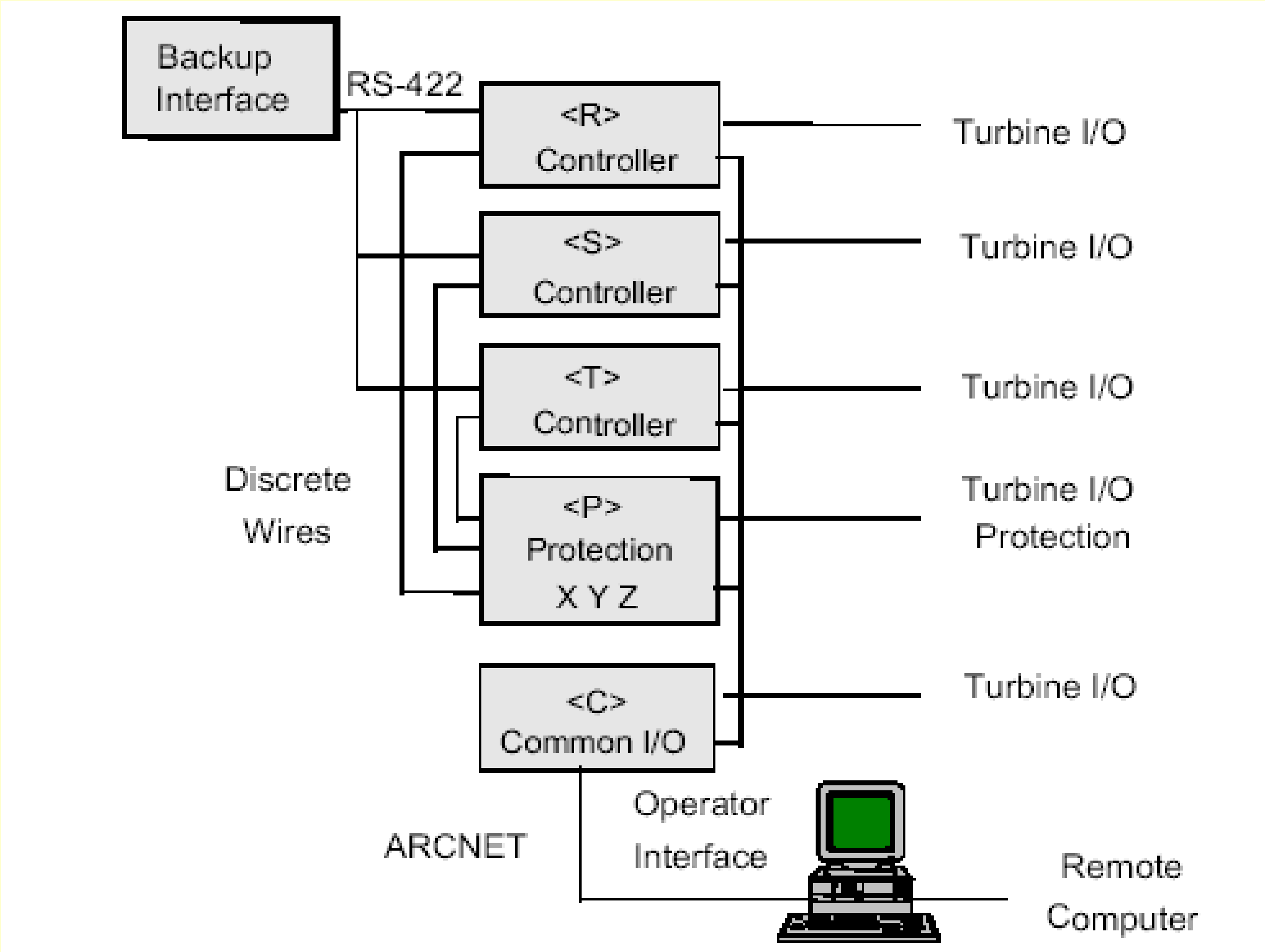
The cycle starts at (1) where the flow becomes unstable .It then jumps to the reverse flow characteristic (2) and follows this till zero flow at point (3) and then jumps to (4) where it follows the characteristic to (1)

Schematic of PLC based control system for GTG

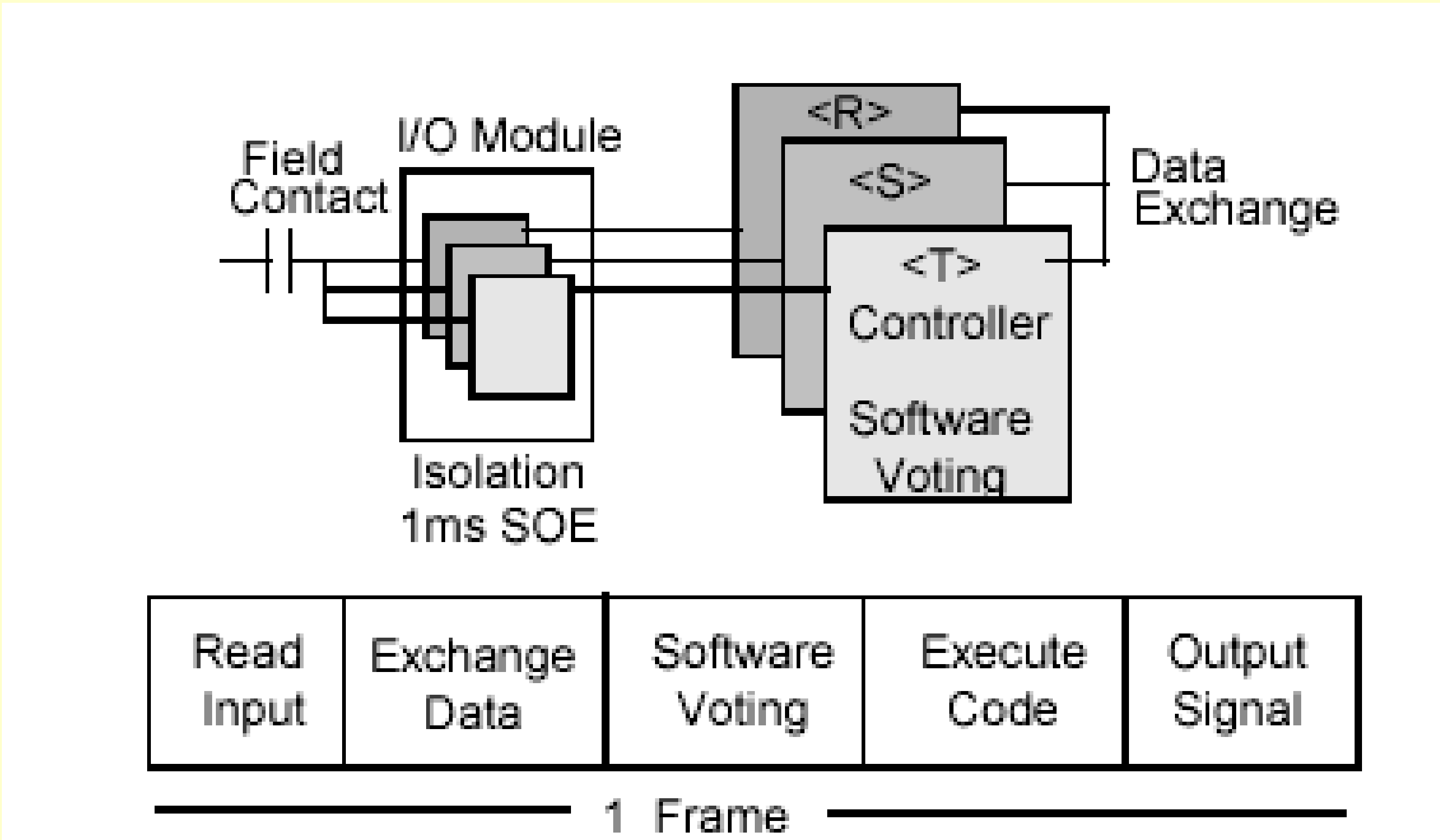


Gas Turbine control systems –Speedtronic

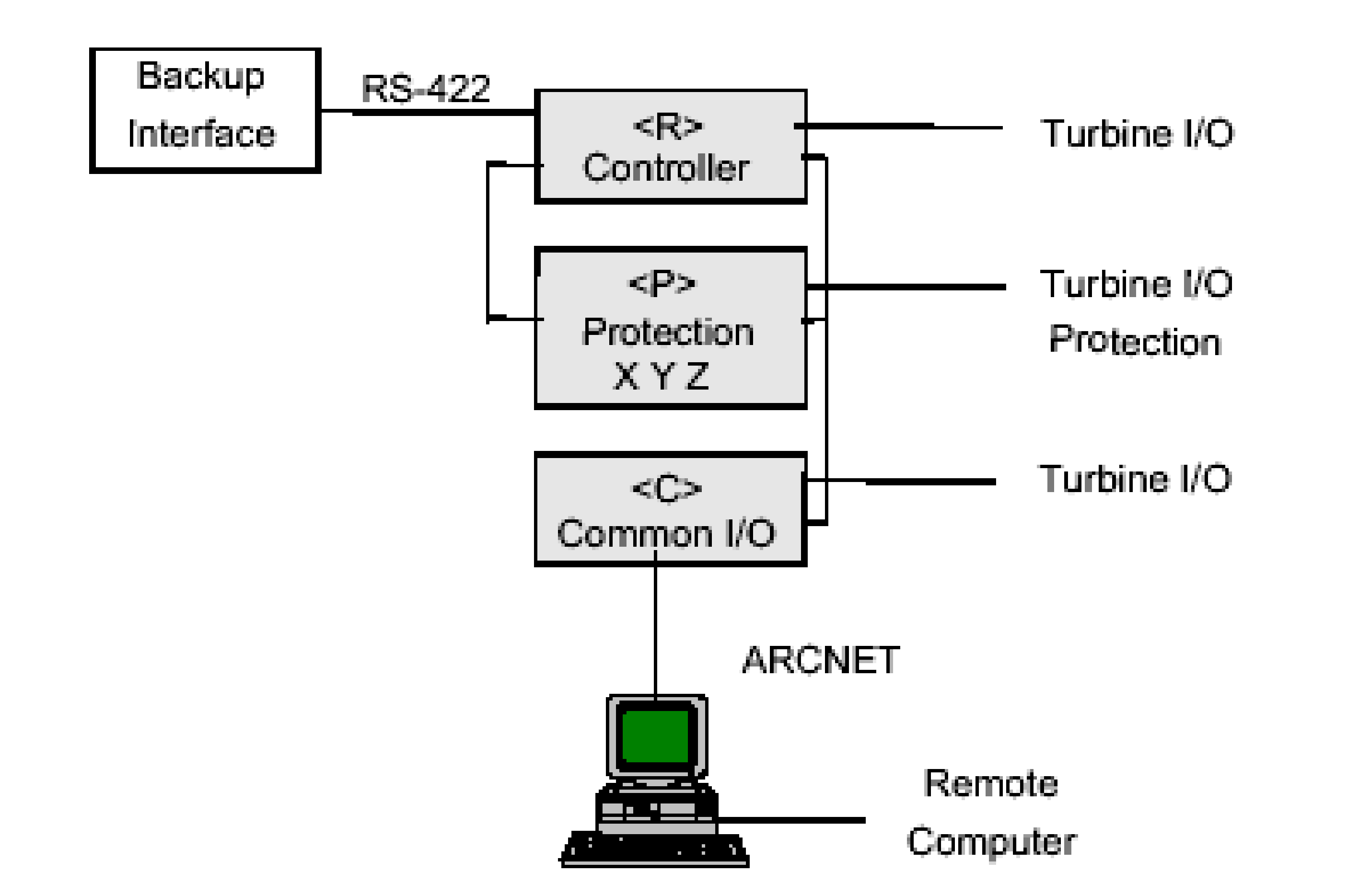
Mark V Control TMR Configuration



Mark V TMR Control Sequence



Mark V Simplex Control Configuration



Speedtronic Mark V Hardware Inputs/Outputs

The Mark V I/O is designed for direct interface with

the following turbine and generator devices:

- magnetic speed pickups
- servos and LVDT/Rs
- vibration sensors
- thermocouples
- Resistive Temperature Devices (RTDs)

Speedtronic Mark V control-Features

- software-implemented fault tolerance
- triple modular redundant (TMR) architecture
- online maintenance
- direct sensor interface
- built-in diagnostics
- common hardware platform for gas and steam applications

Woodward- NetCon control

- A programmable control system
- Used in gas turbine ,steam turbine ,hydraulic turbines
- Can control
  - Speed
  - Load
  - Pressure
  - Level
  - Flow
  - Any system parameter that can be sensed either by a transducer and converted to an analog signal or by a switch or contact
  - Perform start /stop sequencing

Netcon control system

- Simplex system – one CPU
- Fault tolerant system-Triple Modular Redundancy (three CPUs with own power supply)
- Dual I/O copper redundancy allowing each set of I/O boards to receive own operating power I/O signals
- Triple I/O copper redundancy

Netcon control system-Inputs

- Can receive inputs from
- Speed sensors
- Magnetic pick up/Proximity switches
- Temperature sensors
  - J,K,T,S,R,E,N type thermocouples
  - RTDS
- Cold junction sensors
- Position transducers
  - Rotary Variable Differential Transformer
  - Linear

Contd.

Netcon control system-Inputs

- Pressure sensors
  - 4 to 20 ma signals
- Load sensors
  - 4-20 ma
  - 0-5 V dc
  - 0-10 V dc
- Switch or relay contacts

Netcon control system-Outputs

- Four types of output modules
  - Actuator driver module
    - Proportional –4 actuator driver channels
    - Proportional or integrating-2 actuator driver channels
  - Discrete output module –32 or 64 channels
  - Current output module –8 outputs
    - 0-1 and 4-20 mA
  - Voltage output module –8 outputs
    - 0-5 and 0-10 Vdc

Netcon control system

- Communications
  - Can communicate with other devices using RS-232 ,RS-422 or RS-485 communication protocol and ModBus
  - Can be part of LAN
- Power supply
  - Single source or redundant
  - Main power supply –24 V dc
  - I/O power supply-24 V dc provides 5 Vdc for CPU and I/O module
- Cooling
  - By forced air

Netcon control system-Modules

- **CPU** –Follows the instructions of application program control the circuits .Processor –Motorola 68030 with a math co processor or Motorola 68040
- **CPU Aux module-**Used in FT control systems to power each CPU
- **FTIO module** –Handle communication with I/O racks
- **SIO module -**Interfaces communication ports to the VME bus
- **Ethernet module** –Connects to LAN

Netcon control system-Modules

- **Actuator driver module**(2 channel) –Receives digital information from CPU and generate two integrating or proportional actuator signals
- **Actuator driver module** (4 channel) –Receives digital information from CPU and generate four proportional actuator driver signals
- **RTD input module-**Four models of RTD input module**-**Each handles a different type of RTD ,converts analog data to digital data and send to CPU
- **Thermocouple input module** –Receives signals from 8 thermocouples and converts analog to digital and sends to CPU

Netcon control system-Modules

- **Digital speed sensor module** –Receives signals from as many as four magnetic pick ups and sends a digital speed signal and a derivative signal for each channel to the system CPU
- **Discrete input module-**Receives signals from 48 separate switches or relay contacts and sends the data to CPU.Isolated from NetCon's balance circuitry .The module provides 24V dc for these external contacts.
- **Discrete output modules** –Receives digital data from CPU and generates either 32 or 64 relay driver signals.All discrete output modules interface with one or more Woodward relay boxes each with 16,28 or 32 relays.The contacts of these relays then connect to field wiring.

Netcon control system-Modules

- **Voltage input module** –Receives eight 0-10 V signals from the controlled system ,converts analog to digital data and sends to CPU
- **Voltage output module** –Receives data from the CPU and generates eight 0-5 Vdc/0-10 Vdc output signals
- **Current input module -**Receives eight 4-20 mA signals from the controlled system ,converts analog to digital data and sends to CPU
- **Current output module** –Receives data from CPU and generates 0-1 / 4-20 Ma output signals

Netcon control system-Modules

- **LinkNet controller module** –Communicates with the various I/O modules on the LinkNet I/O networks.Both analog and discrete information from the networks are received by this module and shared with main CPU.Information from CPU is also received by this module and then sent to appropriate I/O modules on the network
- **Pressure transducer Module -** Receives information from Smart Pressure transducers and data is shared with main CPU
- **Vibrometer digital vibration module** –Six channel monitoring module.Four channels for monitoring vibration and two for speed input

Netcon control system

- **Service Panel-**Consists of a keyboard ,a digital display .Used by operator to monitor and change system values and by the diagnostic software to display fault messages
- **Software** –Independent of hardware that is minor changes or upgrades do not require changes to the program
- **OS-**
- **Application programme** –Designed using GAP and loaded to UVPROM or flash memory chip and installed on the CPU

Thermocouple ranges

T/C type	Low end	High end
J	-40 ^{0}C	1050 ^{0}C
K	-40 ^{0}C	1600 ^{0}C
E	-40 ^{0}C	800 ^{0}C
R	-40 ^{0}C	1750 ^{0}C
S	-40 ^{0}C	1750 ^{0}C
T	-40 ^{0}C	1050 ^{0}C
N	-40 ^{0}C	1051 ^{0}C
CJ	-40 ^{0}C	150 ^{0}C

Typical Engine Instrumentation (LM6000PC)

Device	Parameter	Function*	Device Type	Qty
P0	Atmospheric Pressure	C	Press transducer	1
T2	LP Compressor Inlet Temperature	C	RTD	2
P2	LP Compressor Inlet Pressure	C	Press transducer	2
T25	HP Compressor Inlet Temperature	C	RTD	2
P25	HP Compressor Inlet Pressure	C	Press transducer	2
N25	HP Shaft Speed	C/P	Magnetic pick	2
PS3	HP Compressor Discharge Pressure	C/P	Press transducer	2
T3	HP Compressor Discharge Temperature	C/P	TC	4
PTB	Thrust Balance Pressure	C/P	Press transducer	2
P48	HP Turbine Discharge Pressure	C	Press transducer	1
T48	HP Turbine Discharge Temperature	C/P	TC	8
NSD	LP Shaft Speed	C/P	Magnetic pick	2

contd

Typical Engine Instrumentation (LM6000PC)

Device	Parameter	Function*	Device Type	Qty
IGV	Inlet Guide Vanes	C/M	LVDT	2
		C	Servo	1
VBV	Variable Bleed Valves	C/M	LVDT	2
		C	Servo	1
VSV	Variable Stator Vanes	C/M	LVDT	2
		C	Servo	1
TBV	Thrust Balance Valve	C/M	LVDT	2
		C	Servo	1
GFMV	Gas-fuel-metering Valve	C	Servo	1
LFMV	Liquid-fuel-metering Valve	C	Servo	1
PGAS	Gas-fuel Supply Pressure	C/M	Press transducer	1
TGAS	Gas-fuel Supply Temperature	C/M	RTD	1
PLIQ	Liquid-fuel Supply Pressure	C/M	Press transducer	1
TLIQ	Liquid-fuel Supply Temperature	C/M	RTD	1
28FD	Flame Detectors	C/P	UV scanners	2

Frame Machines-Details

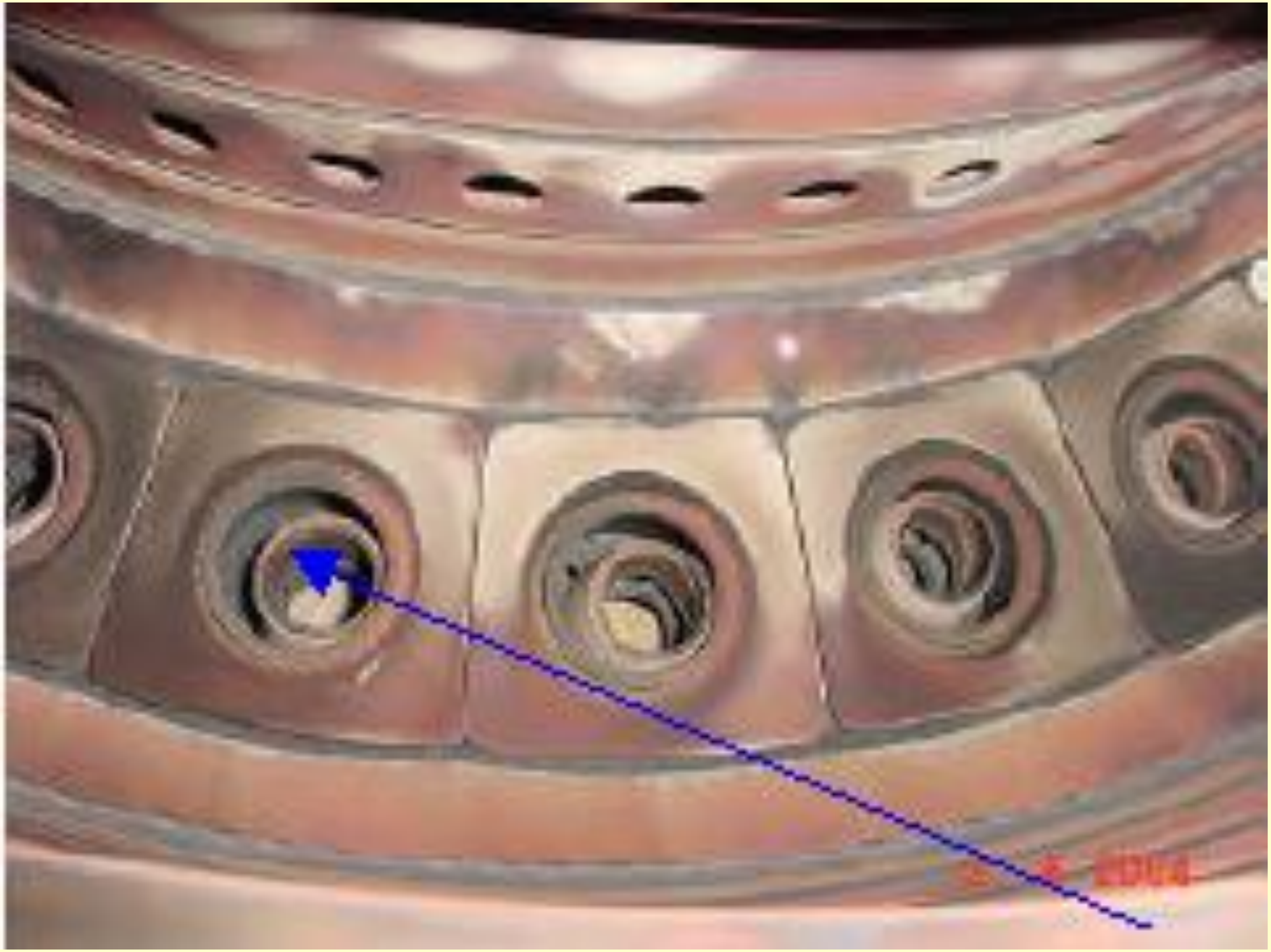
- Horizontally split casing
- Two walk-in combustion chambers for hot-gas-path inspection without cover lift
- Combustion chambers lined with individually replaceable ceramic tiles
- 16-stage axial-flow compressor with variable-pitch inlet guide vanes
- Optional fast inlet guide vanes for peak load operation and frequency stabilization

Frame Machine -Details

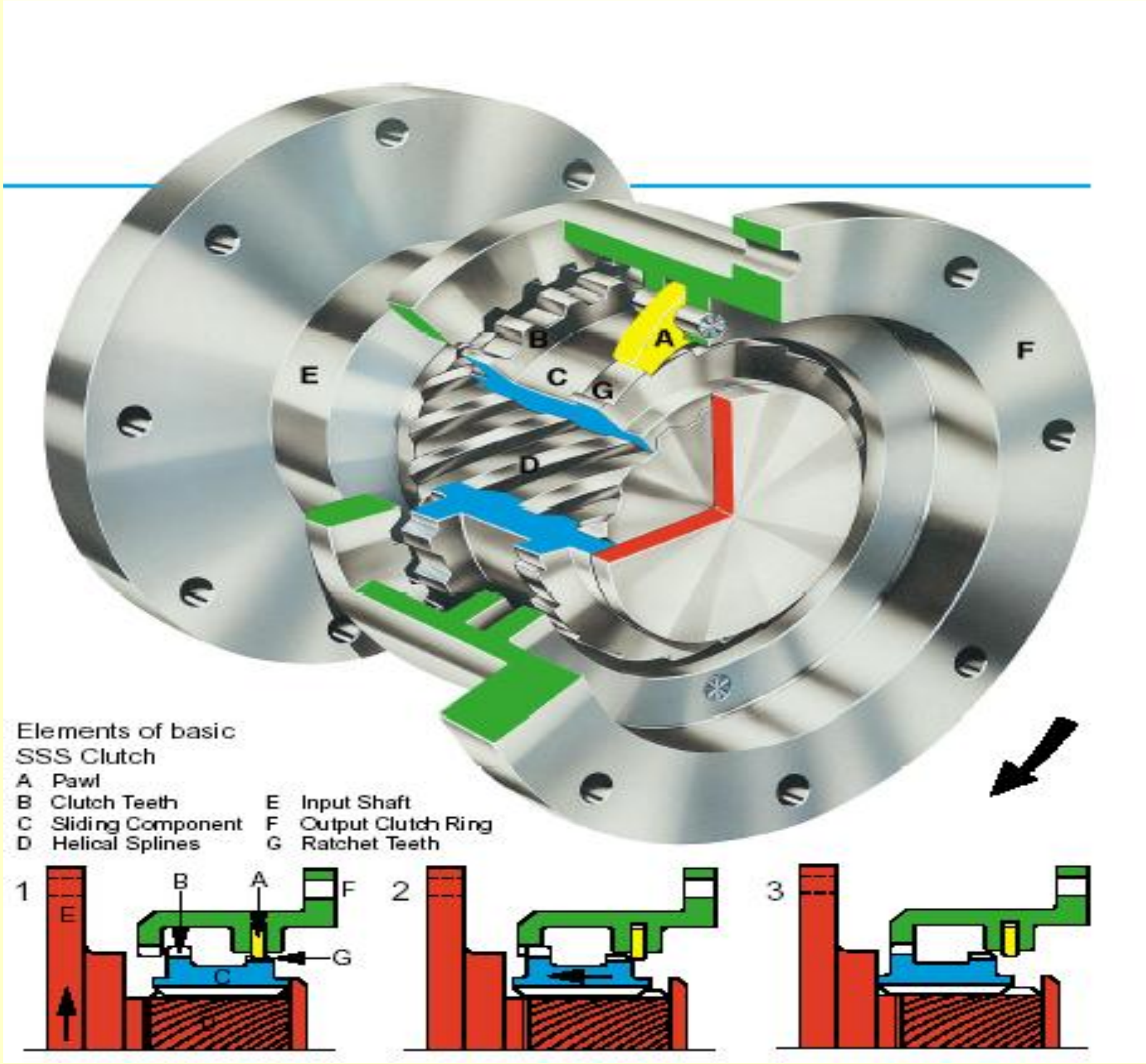
- Four stage turbine
- All blades removable with rotor in place
- Hybrid burners for premix and diffusion mode operation with natural gas, fuel oil and special fuels such as heavy oil and refinery residues
- Low-NOx combustion system

Fuel Nozzles

Combustor Swirler

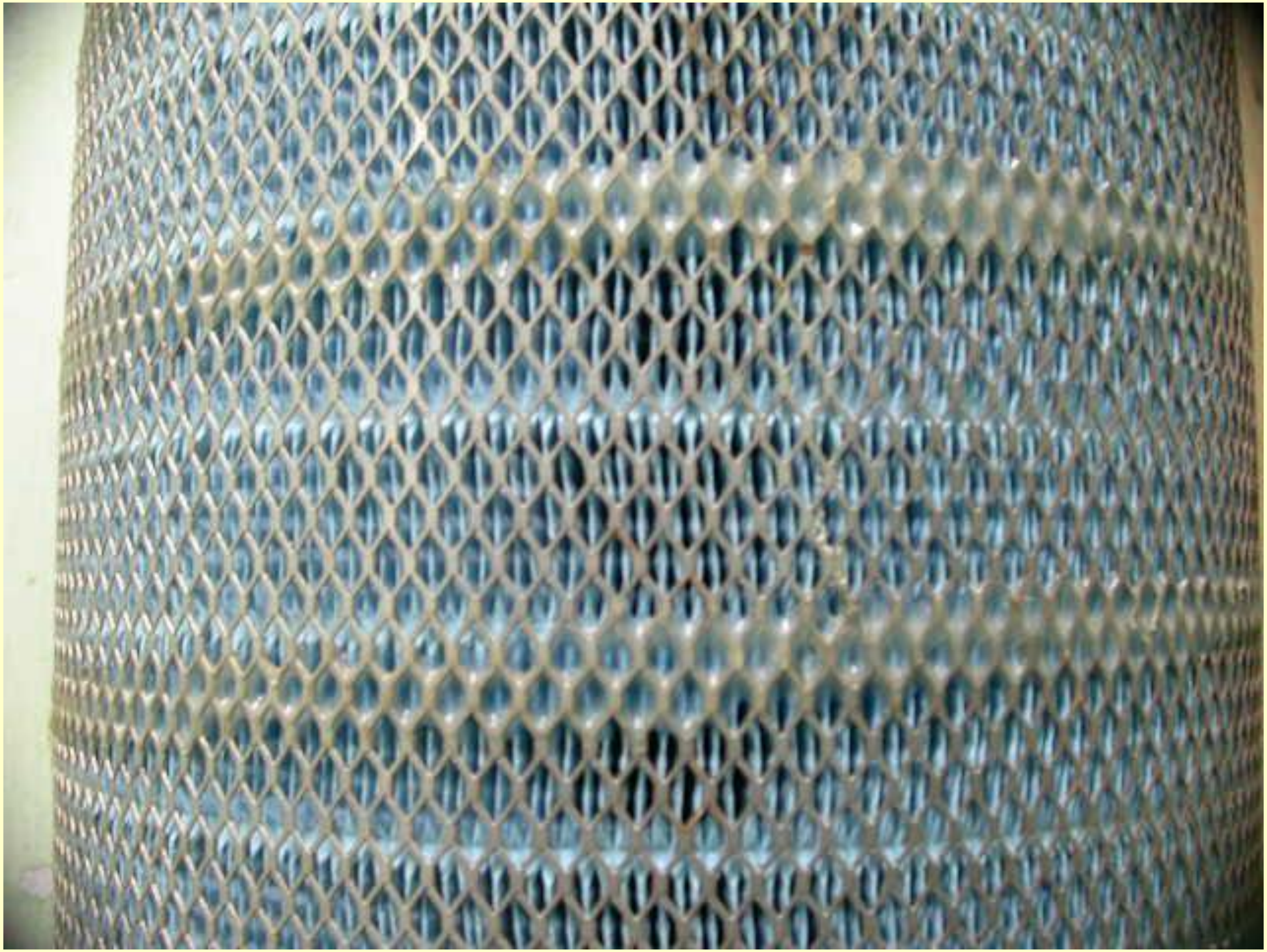


SSS Clutch


A
B
C
G
E
D
F
Elements of basic
SSS Clutch
A Pawl
B Clutch Teeth
C Sliding Component
D Helical Splines
E Input Shaft
F Output Clutch Ring
G Ratchet Teeth
1
2
3
E
C
G

Gas turbine Filter

Gas turbine filter



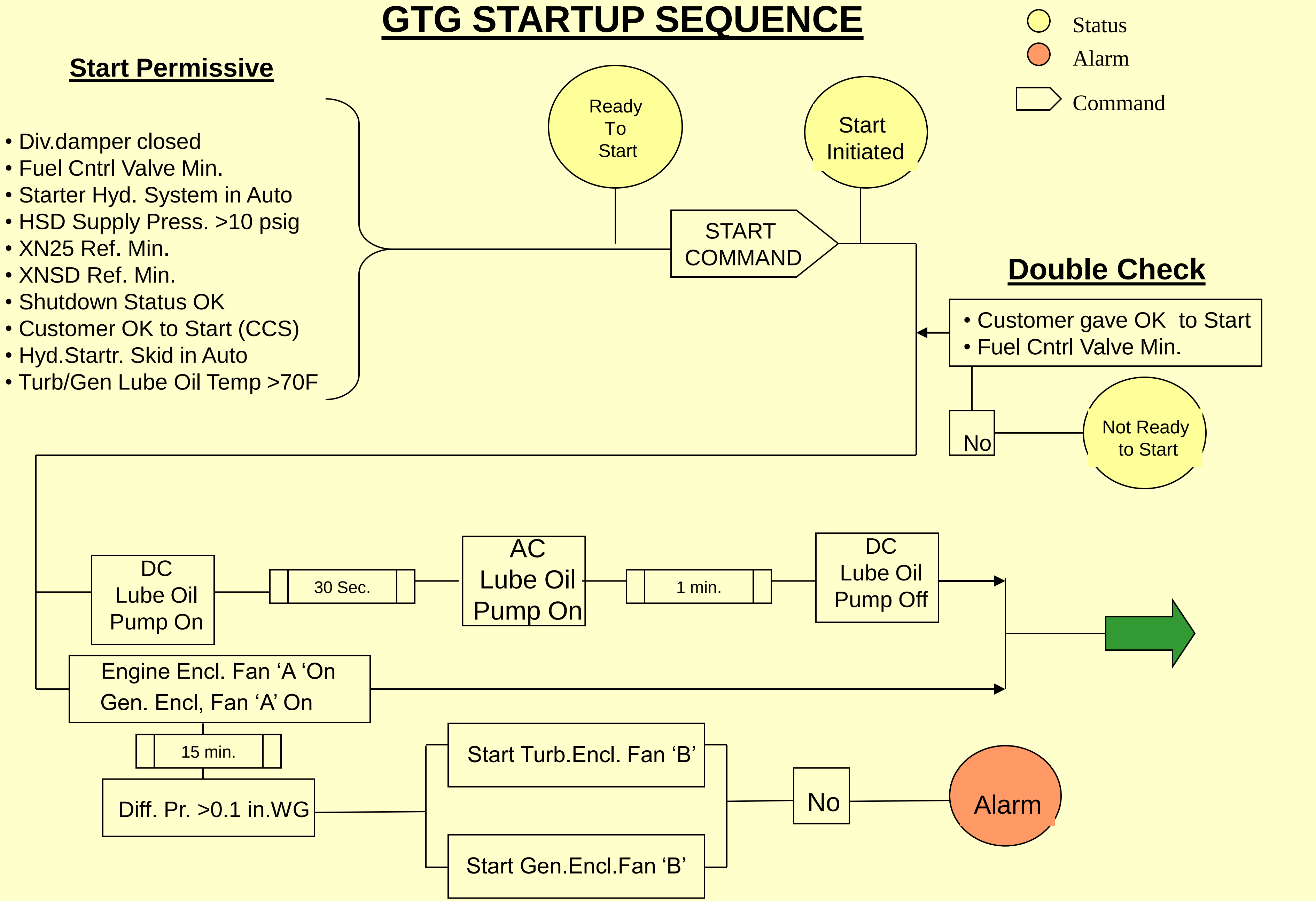
Typical Alarm and trip requirements for gas turbines

		Alarm and
Indication	**Alarm Only**	**Shutdown**
Engine System		
Impending High Blade Temperature	X	
High Blade Temperature		X
Impending High Engine Temperature	X	
High Engine Temperature		X
High Gas Producer Thrust Bearing Temperature	X	X
High Power Turbine Thrust Bearing Temperature	X	X
Fail to Crank		X
Fail to Start		X
Ignition Failure		X
Starter Dropout Failure		X
Backup Overspeed Power Turbine		X
Overspeed Power Turbine		X
High Vibration – Engine	X	X
High Vibration – Accessory Gearbox	X	X

Typical Alarm and trip requirements for gas turbines

Indication	Alarm Only	Alarm and Shutdown
Engine System		
Lube System		
High Oil Temperature	X	X
Low Oil Pressure		X
Low Prelube Oil Pressure	X	X
Low Oil Level	X	X
High Oil Level	X	
Lube Filter High Differential Pressure		
Fuel System		
Liquid Fuel Filter High Differential Pressure	X	
Low Liquid Fuel Pressure	X	X
Gearbox Systems		
High Gearbox Output Bearing Temperature	X	X
High Vibration – Gearbox	X	X
Generator Systems		
High Generator Bearing Temperature	X	X
High Generator Winding Temperature	X	X
High Vibration – Generator	X	X
Ancillary Systems		
Low Battery Voltage	X	
Battery Charger Failure	X	
Inlet Air Filter – High Differential Pressure	X	X

GTG STARTUP SEQUENCE



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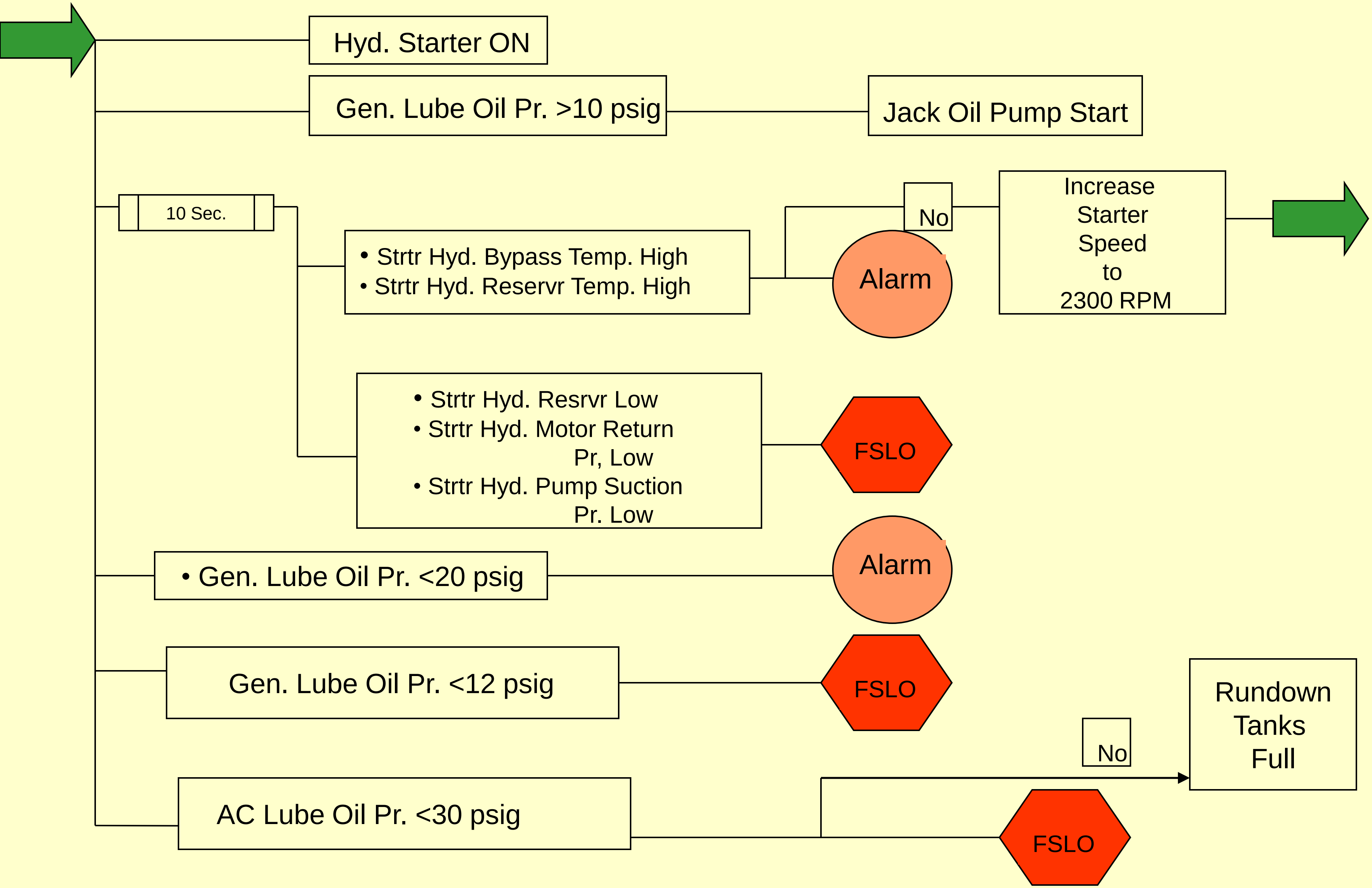

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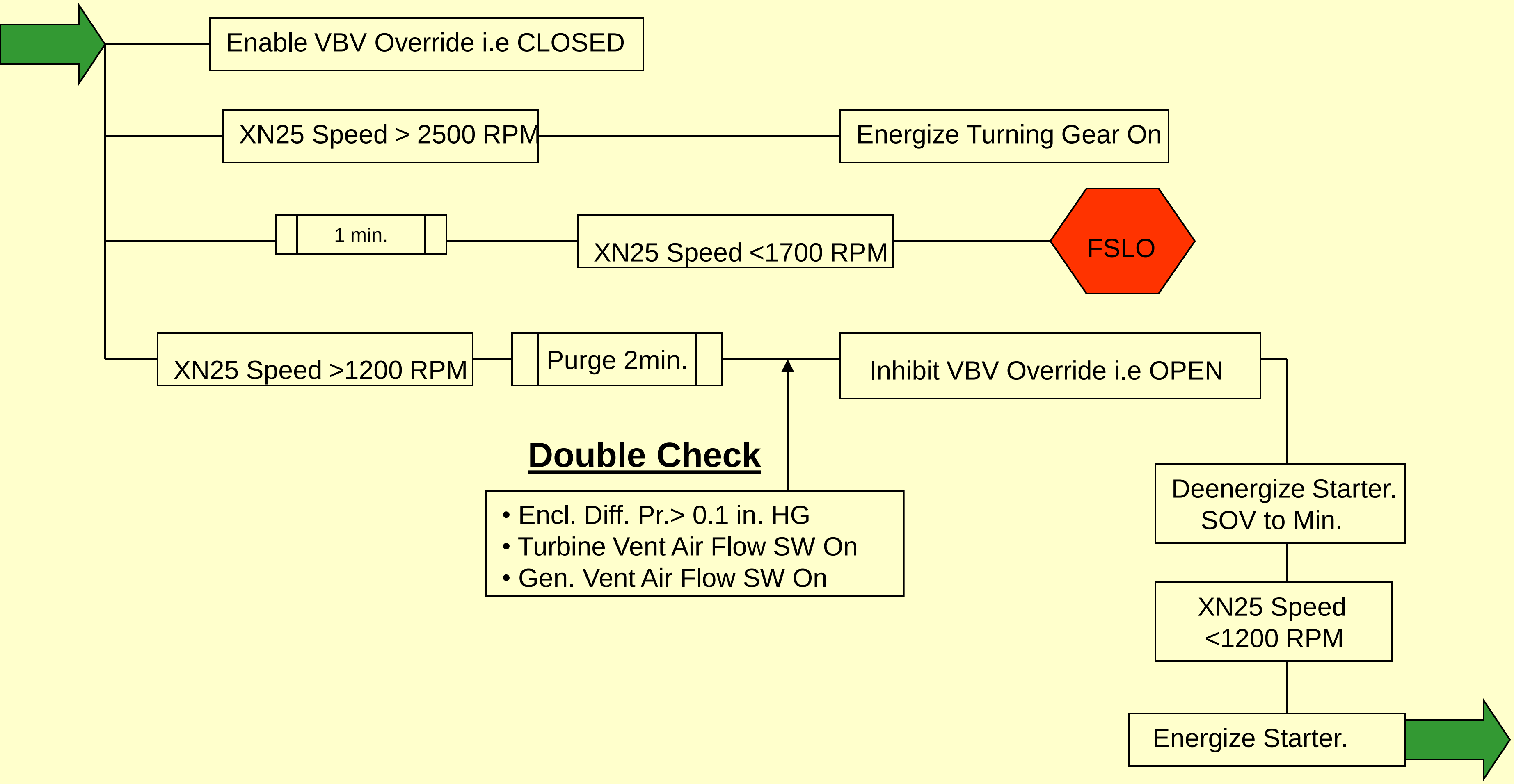

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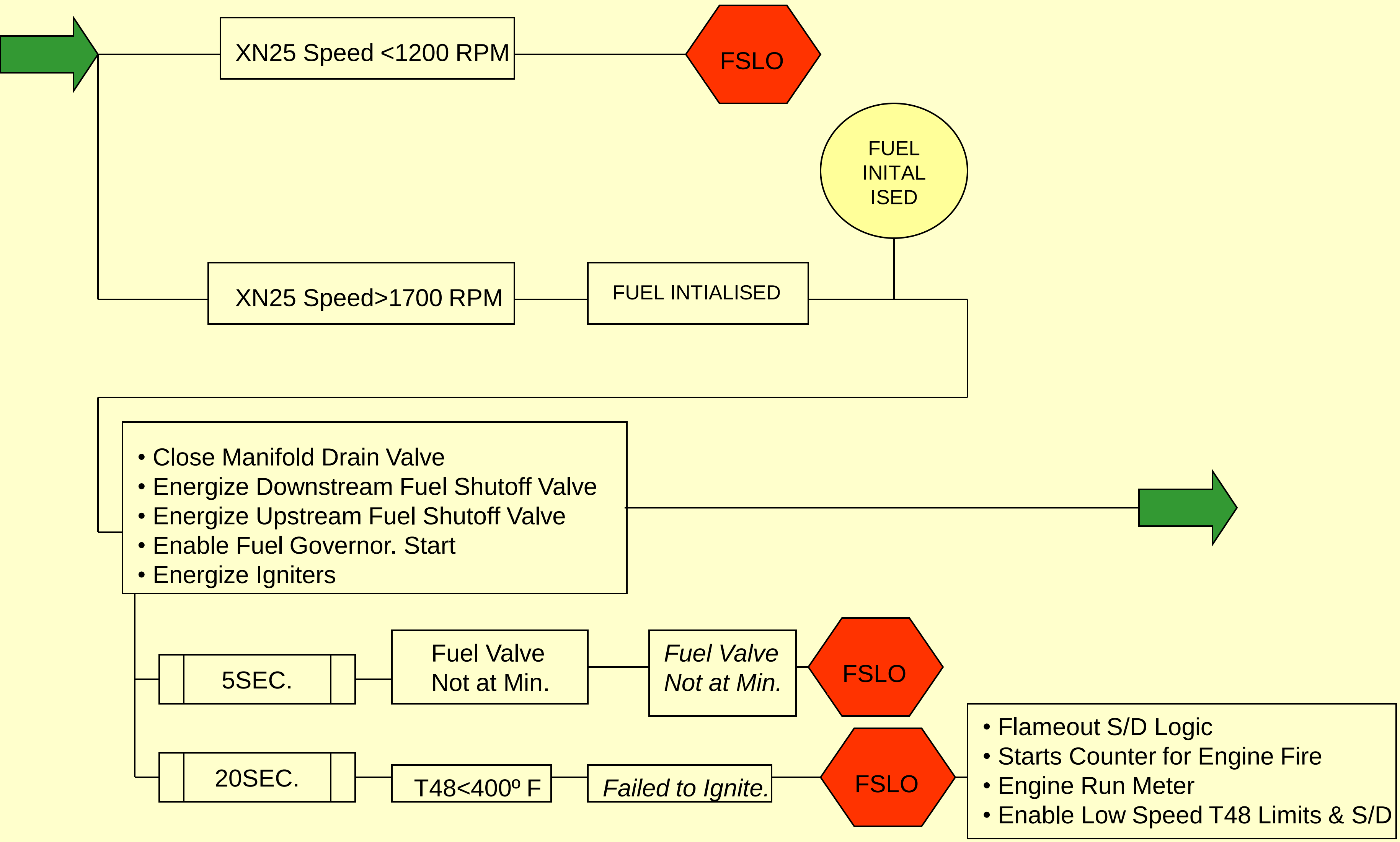

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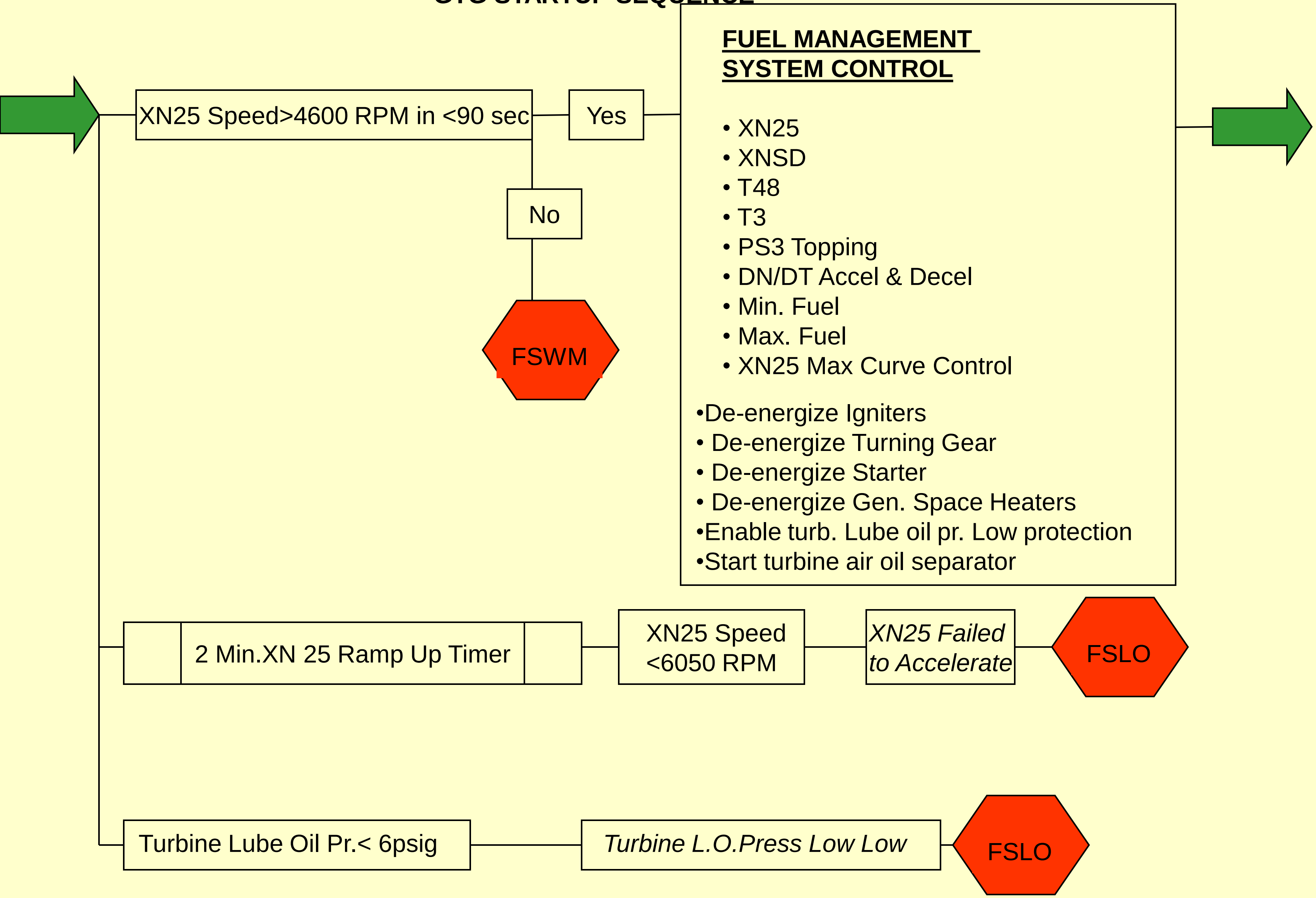

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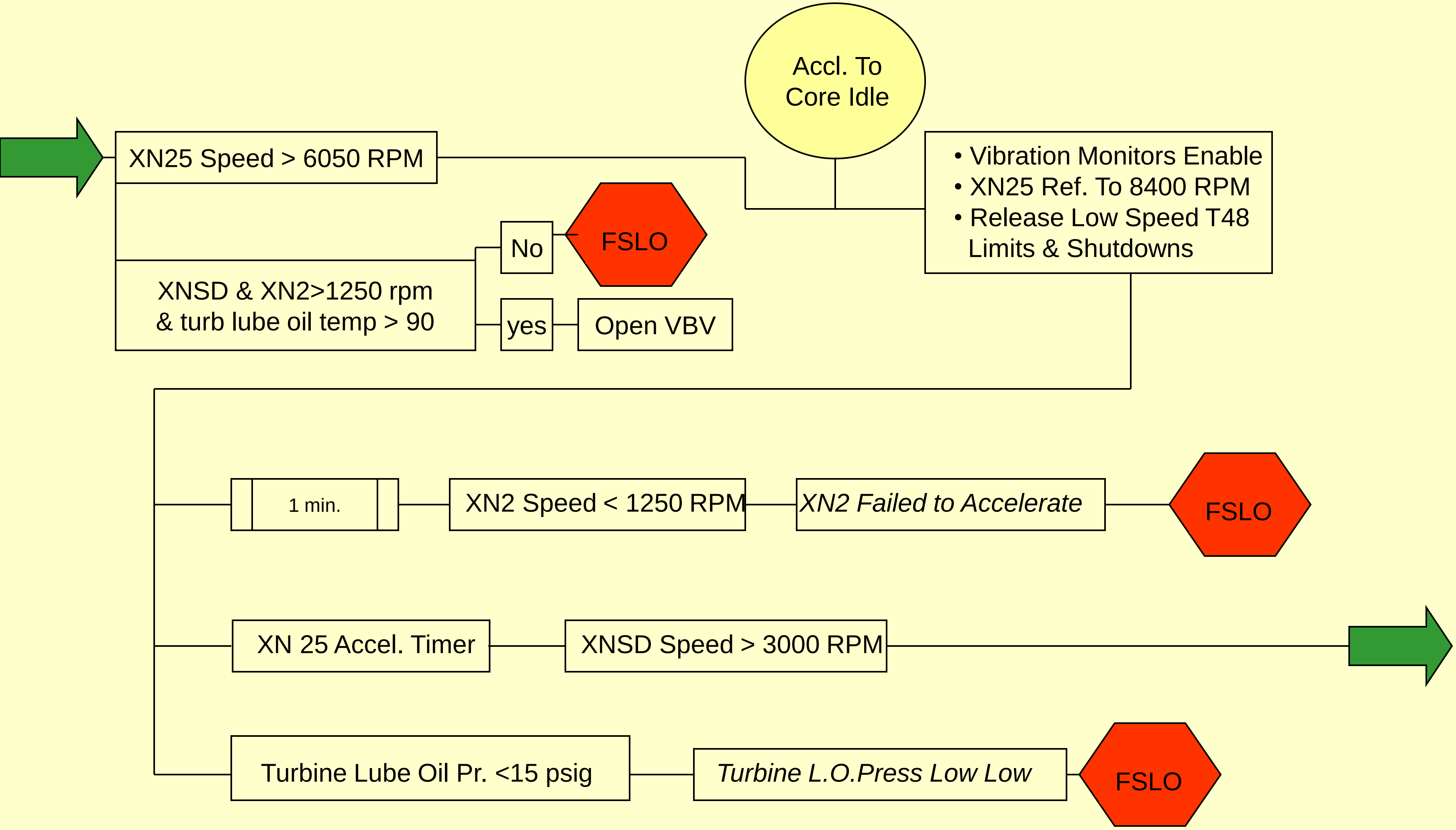

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