

Wood Group Pratt & Whitney Industrial Turbine Services, LLC

FT4A-9 POWER PAC

TYPICAL TECHNICAL PACKAGE

EQUIPMENT DESCRIPTION AND SCOPE OF SUPPLY

111907

TYPICAL FT4A-9 POWER PAC

Proprietary Information Notice

Typical FT4A-9 Power Pac General Description

Estimated FT4A-9 Performance

- 60 HZ MW vs. ambient temperature curve - Inst 41315

- 60 HZ MW vs. heat rate – IPC 2638

- 50 HZ MW vs. ambient temperature curve – IPC 6007

- 50 HZ MW vs. heat rate – IPC 1329

- Estimated Exhaust Emissions

- Typical 60 HZ Electric Generator Performance – EM EE 13456

- Typical 50 HZ Electric Generator Performance – EM EE 13457

Scope of Supply and Purchaser's Responsibilities

Typical FT4-A9 Power Pac General Arrangement and Elevation – IPR 2865

Typical 60 HZ One Line Diagram – EM 361D067

Dimension Sheet EM Generator – EM 104D304

Appendix A

Introduction to Wood Group Pratt & Whitney Industrial Turbine Services

- History

- Field service capabilities

- Engine and free turbine overhaul shops

- Engine test facility

- Technical support

The Pratt & Whitney FT4

Fuel Specifications FR-1 LF and FR-2 GF

PROPRIETARY INFORMATION NOTICE

NOTICE

The information contained herein represents confidential and proprietary information owned or controlled by Wood Group Pratt & Whitney Industrial Turbine Services LLC (WGPW) and is being supplied to RECIPIENT solely for RECIPIENT'S information. And evaluation of WGPW's quotation to RECIPIENT for services and/or parts as called for in this PROPOSAL and subsequent modifications thereto.

By acceptance of this PROPOSAL, RECIPIENT expressly agrees to maintain in confidence all such information made available by WGPW and further agrees not to disclose such to others outside of RECIPIENT organization, either during the course of the RECIPIENT'S evaluation or subsequent thereto, without the prior written consent of WGPW.

Nothing contained herein shall be construed as implying that WGPW has granted, or that RECIPIENT has accepted any rights or license to any WGPW information other than that specifically set forth above.

RECIPIENT shall, at any time and at WGPW request, return all WGPW proprietary information (including all copies thereof).

In the event that this PROPOSAL shall result in the award of an order to WGPW, RECIPIENT expressly agrees to accept the inclusion of the following provision as a condition of order award:

CONFIDENTIALITY AGREEMENT

The information contained herein is proprietary information owned or controlled by WGPW and is furnished solely for use by RECIPIENT and shall be maintained in confidence and not be disclosed to any third party, or used or reproduced either wholly or in part except in connection with such use, without the prior written consent of WGPW. Upon the conclusion of WGPW's Work, all WGPW proprietary information (and all copies thereof) shall be returned to WGPW upon WGPW request.

TYPICAL FT4A-9 POWER PAC GENERAL DESCRIPTION

GENERAL

This information applies specifically to an FT4A-9 LF series and model gas turbine repackaged by WGPW. The FT4A-9 LF is a gas turbine engine consisting of a gas generator and a free turbine that uses the hot gases produced by the gas generator to develop shaft horsepower. The free turbine is coupled through an output shaft to an electric generator manufactured by the Electric Machinery Manufacturing Company. The complete unit is called a Turbojet Power Pac and is operated by liquid fuel. Gas fuel or dual fuel operation is available as an option.

The unit is designed to generate power for peaking operation. Power output will vary because of changes in the inlet air conditions. Performance assumes that the gas turbine will be operated on clean distillate fuel or natural gas fuel conforming to the PWA Fuel Specifications provided in Appendix "A".

OPERATIONAL FEATURES

The Power Pac may be operated manually or automatically from either the Local Control Panel located in the Power Pac control house or from an optional Remote Control Panel.

The Power Pac may be synchronized in parallel with other electric generators already on the line, or operated alone as an isolated power source. Battery power is provided to start and operate the Power Pac in complete independence of external sources of power for black starts.

The Power Pac can be automatically started, synchronized and loaded to full output in approximately three minutes. On a normal shutdown, the unit is automatically unloaded, sequenced through the breaker opening, reduction-to-idle and cool-down phase of operation after which the gas generator rotors and the free turbine coast to a stop. In the event that an electrical fault or a mechanical malfunction should occur in any of the Power Pac equipment, the unit is protected by alarms and automatic shutdown devices.

GAS GENERATOR

The gas generator has the characteristics described for dual compressor gas turbines in Pratt & Whitney Aircraft General Operating Instructions for Gas Generators and Turbine Engines for Industrial and Marine Use, PWA Oper. Instr. 194, to which reference should be made for complete information pertaining to how an engine of this type operates. A full description of the gas generator may

be found in the Pratt and Whitney Aircraft FT4A-9 Service Manual. The material presented in the Service Manual is supplemented by the information in the specific operating instructions.

Ignition System – Ignition of the gas generator is furnished by a dual, 125 volt DC, 4-joule ignition system. The two independent ignition systems, each with its own igniter, operate simultaneously when energized. The ignition system operates only during the gas generator starting cycle. The speed mechanism in the PLC circuit limits the time the system is energized.

Gas Generator and Free Turbine Speed Control – The speed of the free turbine prior to synchronization, and the speed of the gas generator to provide loading following synchronization, is controlled by a new Allen Bradley Controllogix PLC and fuel control designed to WGPW specifications. This control senses gas generator high rotor speed (N2) free turbine speed (N3) gas generator exhaust gas temperature and load, and positions a fuel modulating valve to regulate gas generator fuel flow.

Free Turbine over speed is sensed by a mechanical over speed control and the fuel control. Either control will close the fuel shutoff valves in the event free turbine speed exceeds $4,125 \pm 25$ rpm (less in 50 HZ applications)

Air Inlet Anti-Icing System – The system consists of an ice detection unit, hollow gas generator inlet guide vanes and a hollow nose cone. Hot, high pressure air is circulated through the guide vanes and nose cone whenever icing conditions exist. The system may be operated either manually or automatically from the Gas Turbine Panel in the Power Pac control house; however, for normal operation, the control switch on the ice detection unit should remain in the Automatic position. In the Automatic position, the anti-icing air valves are opened automatically whenever icing conditions occur in the gas generator inlet plenum chamber during operation. When operating in Automatic-Parallel, the sequencer prevents operation of the anti-icing relay until after synchronization. The anti-icing system is automatically turned off when the Power Pac is shut down.

A temperature and humidity transducer, located on the inlet plenum door adjacent to temperature sensor for the fuel control, supplies the signals to the anti-icing system. Icing is considered likely whenever the gas generator inlet temperature is below 46°F and simultaneously the relative humidity of the inlet air is greater than 90%.

Free Turbine – The free turbine is connected to the exhaust case of the gas generator, but rotates independently of the gas generator compressors and turbines. It is directly coupled to the electric generator and rotates at a speed of 3,600 rpm (or 3000 rpm in 50 HZ applications) when synchronized to the line frequency.

ELECTRIC GENERATOR AND EXCITATION SYSTEM

The Electric Machinery Air Cooled Open Type AC generator is rated at 21,875 kva, 0.85 power factor, 13,800 volts, 3-phase, 60 hertz, (3,600 rpm). Excitation and voltage regulation is controlled by a Cutler Hammer static excitation/voltage regulation system.

LUBE OIL SYSTEMS

Gas Turbine Lube System – The gas turbine has separate lube systems for the gas generator and free turbine. For a full description of the internal lube oil systems for the gas generator and the free turbine, refer to the applicable PWA FT4A Service Manual. The two external lube systems are shown schematically in Figure 1-1.

The lube oil used in both the gas generator and the free turbine lubrication systems must be a Type II synthetic gas turbine oil conforming to the latest revision of PWA Oil Specification No. 521. Refer to P&WA Turbo Power Service Bulletin No. 6, latest revision, for a listing of approved oils that are commercially available.

Synthetic oils for the gas turbines can be manufactured from any of several different basic materials. Since some of these materials are not compatible with one another and since synthetic oils of different brands are not necessarily derived from the same basic materials, even though they meet the same specifications, it is important to ensure that the synthetic oils produced by different manufacturers are not mixed, or indiscriminately used together, in the same gas generator or free turbine lube oil system.

The battery, making DC power available at all times to both the DC auxiliaries and to the inverter, which supplies the essential AC auxiliaries, enables the Power Pac to be started without an external power source (except when equipped with a hydraulic start system). Once the Power Pac is in operation and the generator main circuit breaker (52G) is closed, the non-essential AC auxiliaries, such as the battery charger, space heaters, cooling fan motors, etc., are furnished AC power directly from Power Pac output.

FIRE EXTINGUISHING SYSTEM

The gas turbine enclosure is provided with a fire extinguishing system that consists of five 75 pound (content weight) CO₂ bottles, a 5 pound (content weight) pilot N₂ bottle, a one pound (content weight) manual release remote bottle and two Fenwall fire detectors. The fire detectors are located above the gas generator and are set to activate at 450°F, which is approximately 250°F

higher than the highest temperature normally encountered at the detector locations.

In the event of a fire within the gas turbine enclosure, the detector unit opens the solenoid valve on the pilot N2 bottle and releases control pressure to operate the discharge heads on the CO2 storage bottles. Although the entire system is discharged, the valves on two of the bottles are pilot-operated discharge heads and are opened first. Pressure from the two pilot-operated discharge heads then passes through the manifold to open the discharge heads on the remaining three CO2 storage bottles. A total of 375 pounds (content weight) of CO2 is discharged in approximately two minutes through two shower heads located in the gas turbine enclosure.

The system may be manually discharged from the fire system remote manual release station (fire box), located on the outside of the electric generator enclosure, by removing the safety pin from the small one pound (content weight) actuator bottle and depressing the handle. The system may also be manually discharged by removing the safety pin from either one or both of the pilot-operated discharge heads and opening either one or both of the red handwheels.

The gas turbine enclosure is normally cooled by air that enters the enclosure through the secondary air inlets. In the event of a fire, the discharge pressure of the fire extinguishing system will close the dampers of the secondary air inlets. Also, a pressure switch energizes a relay which will initiate the following:

1. The 4-1 master start lockout circuit will open, making it impossible for the Power Pac to be started.
2. The quick-acting fuel shutoff valve (fire valve) for the gas generator will automatically close.
3. The 86G-1 relay will be automatically tripped, which will initiate an emergency shutdown of the Power Pac. Refer to Section V, Protective and Auxiliary Devices.
4. An alarm will sound and the Gas Turbine Enclosure Fire annunciator will illuminate.

NOTE: The secondary air inlet dampers and the pressure switch in the electric generator enclosure must be manually reset prior to further Power Pac operation. To reset switch, push plunger located at the bottom of the switch to the In position. Reset dampers by installing release cable end in pressure line sockets located on enclosure roof. The Power Pac

may be electrically locked out without discharge of the CO₂ system by pulling the plunger to the Out position

START SYSTEM

The gas generator is equipped with a hydraulic starter which operates on hydraulic pressure provided by an electric hydraulic pump skid.

The PLC controls the starter speed which normally engages the engine at zero rpm and drives the compressor up to speeds necessary to sustain operation after light off. An additional feature of this starting system provides for controlling the rate of flow to permit reengagement of the rotating engine at about 800 rpm without damage to the starter bearings or shear coupling.

INSTRUMENTATION AND CONTROLS

The Power Pac can be operated locally from the Power Pac Control House or from an optional remote panel

This unit is offered with a Powell control house repackaged into the unit in 1999. It includes a new Allen Bradley Controllogix PLC and fuel controller, Cutler Hammer motor controls, engine and generator control panels and 125 VDC battery bank with charger.

ENGINE AND GENERATOR ENCLOSURES

The gas turbine engine is housed in an acoustically treated engine enclosure including inlet and exhaust silencing and an inlet vandal hood. The generator enclosure is also acoustically treated with air inlet and exhaust silencing.

Turbo Power & Marine Systems

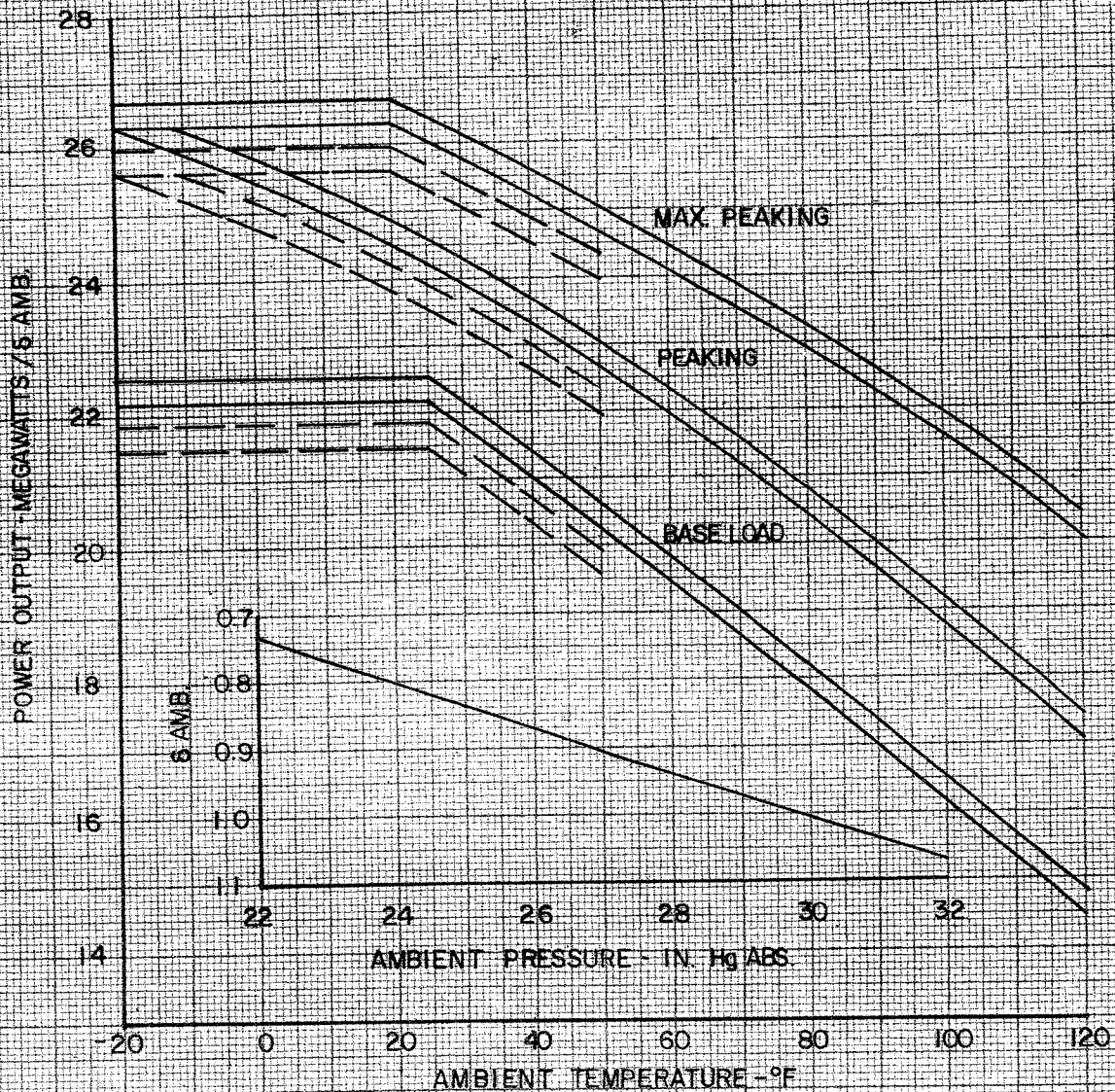
Operating Instructions T-324

SEA LEVEL

$N_3 = 3600$ RPM

- NOTES:
1. INLET AND EXHAUST DUCT PRESSURE LOSSES OF 3" AND 1" H₂O RESPECTIVELY AND 97% GENERATOR EFFICIENCY ARE INCLUDED.
 2. TRIM TO LOWER LINE OF SOLID BAND. DO NOT EXCEED UPPER LINE FOR NORMAL OPERATION.
 3. TRIM TO LOWER LINE OF DASHED BAND WHEN TRIMMING WITH ANTI-ICING AIR SYSTEM IN OPERATION. DO NOT EXCEED UPPER LINE.

REFERENCE CURVE NO.
IPC 806 N/C (4-11-69)



DATE 5-15-69

INST 41315

Estimated Installed Trim Curve

PRATT & WHITNEY AIRCRAFT

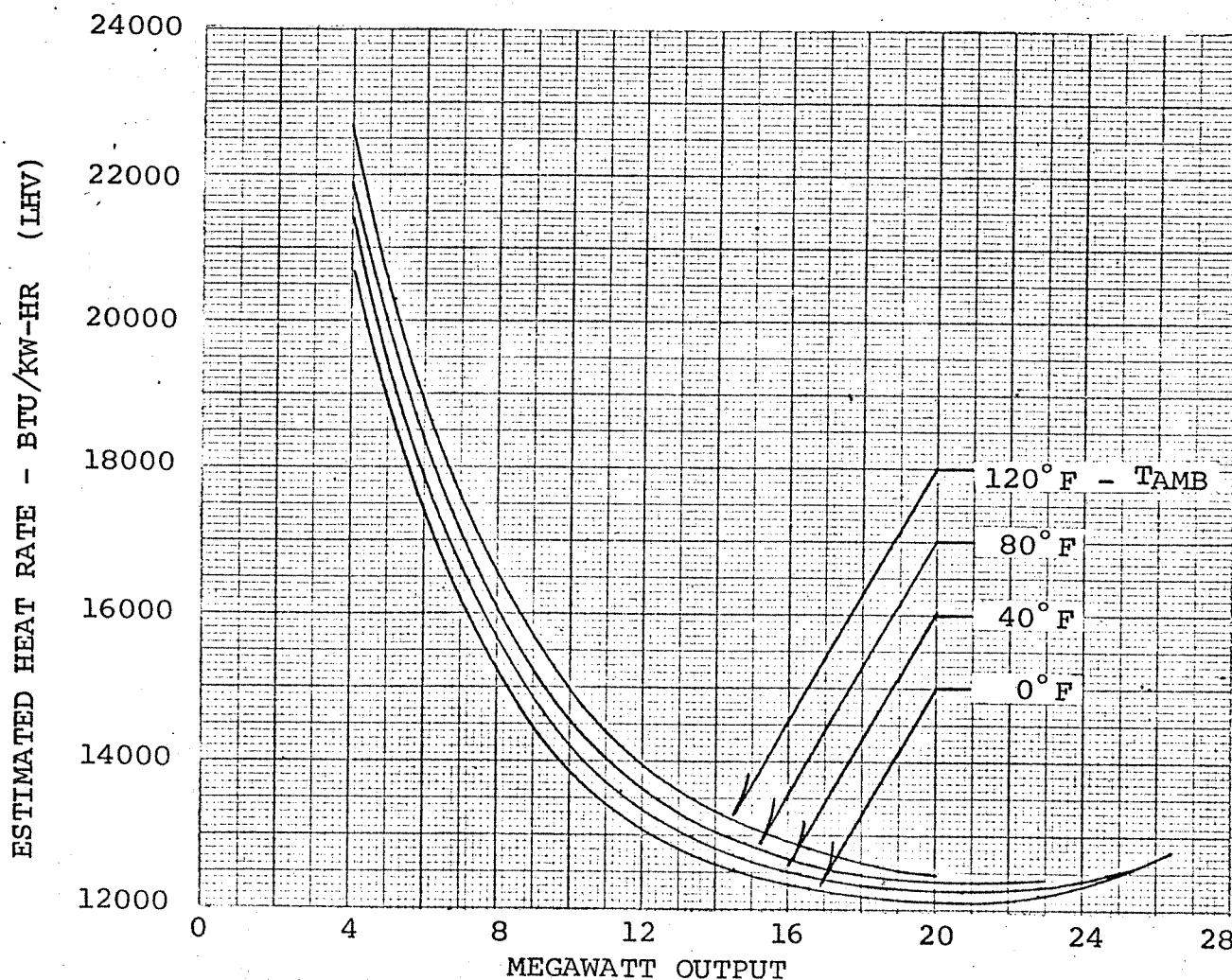
FT4A-9 GAS TURBINE POWER PAC
ESTIMATED HEAT RATE VS. MEGAWATT OUTPUT

3" H₂O INLET DUCT PRESSURE LOSS
1" H₂O EXHAUST DUCT PRESSURE LOSS

SEA LEVEL

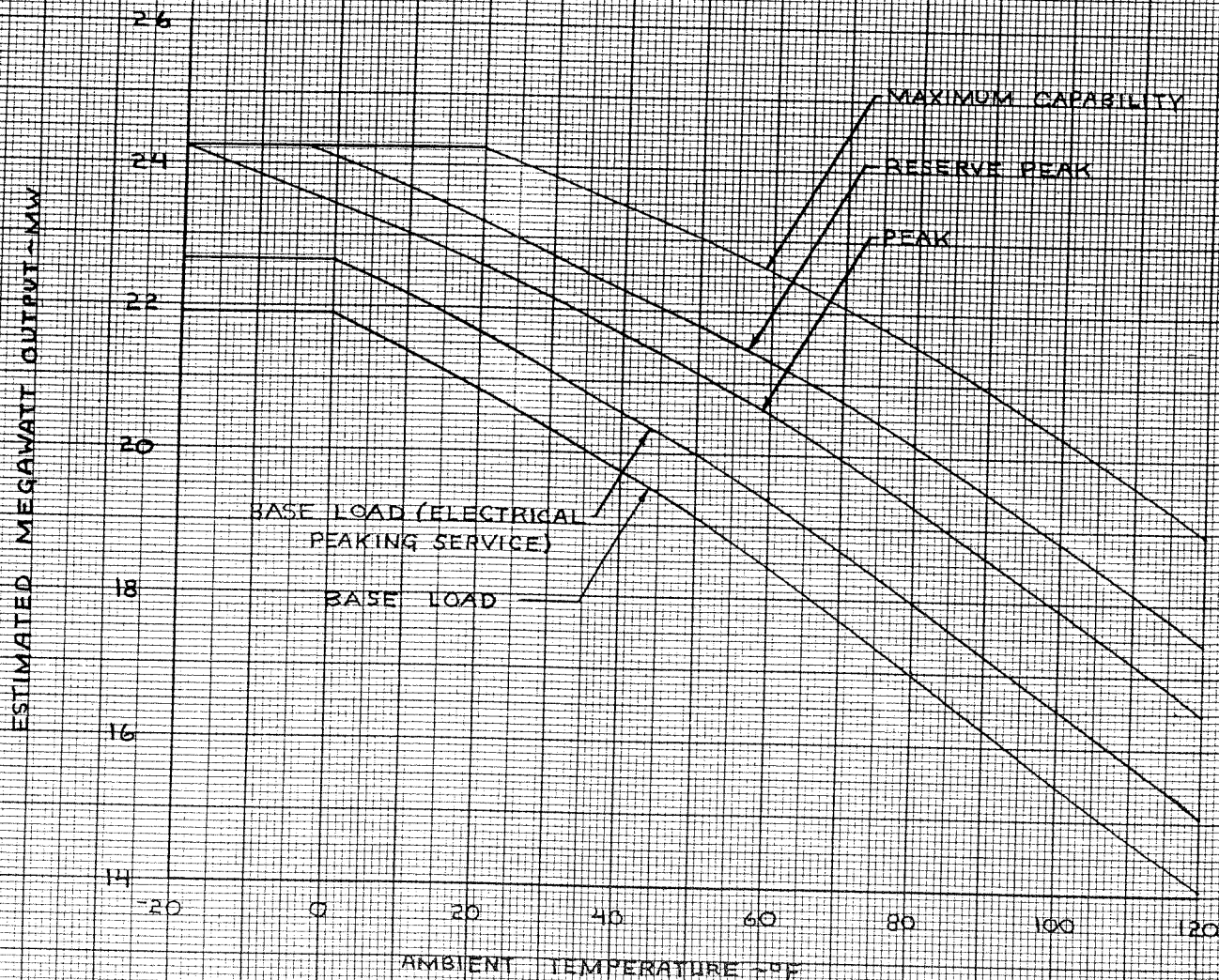
$\eta_{\text{GEN.}} = 97\%$

N₃ = 3600 RPM



TURBO POWER AND MARINE SYSTEMS, INC.

FT4A-9A GAS TURBINE POWER PAC
ESTIMATED MEGAWATT OUTPUT VS. AMBIENT TEMPERATURE
3" H₂O INLET & 1" H₂O EXHAUST DUCT PRESSURE LOSSES
SEA LEVEL
N₃ = 3000 RPM



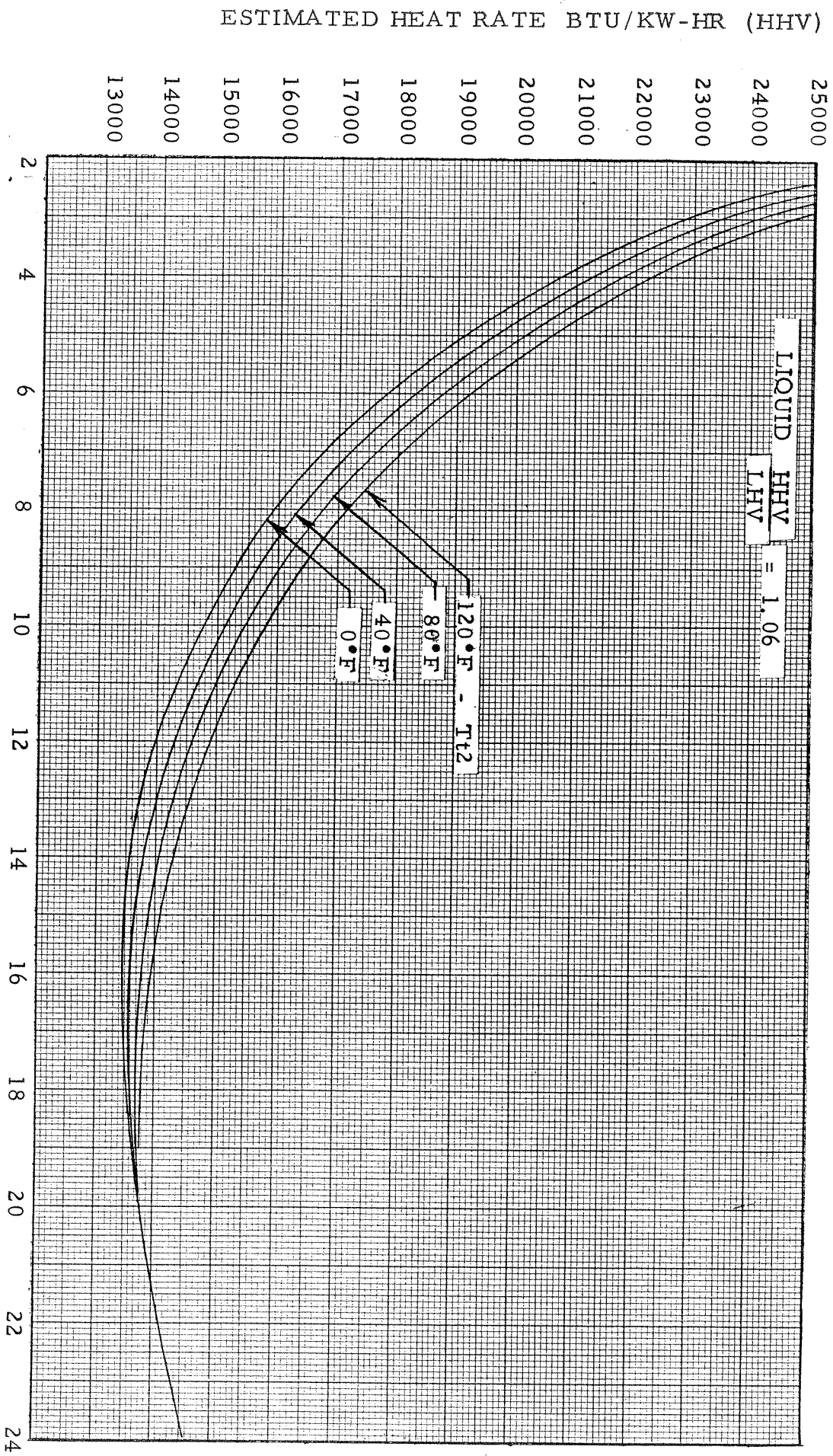
Z-1-72 KRL

IPC-6007

PRAATT & WHITNEY AIRCRAFT

FT4A-9 GAS TURBINE POWER PAC
 ESTIMATED HEAT RATE VS. GENERATOR OUTPUT FOR LIQUID FUEL
 3" H₂O INLET DUCT PRESSURE LOSS
 1" H₂O EXHAUST DUCT PRESSURE LOSS

$\eta_{GEN} = 97\%$ SEA LEVEL $N_3 = 3000 \text{ RPM}$



FT4A-9,-11 Estimated Emissions
Dry and with ~1:1 H2O Injection

110907

Model	Load Setting	Fuel	NOx PPMVD @15% O2	CO PPMVD @15% O2
FT4A-9,-11	Ind base	No 2 LF Dry	192	84
FT4A-9,-11	Ind base	No 2 LF ~1:1 H2O	42	332
FT4A-9,-11	Ind base	Gas Dry	102	126
FT4A-9,-11	Ind base	Gas ~1:1 H2O	25	298

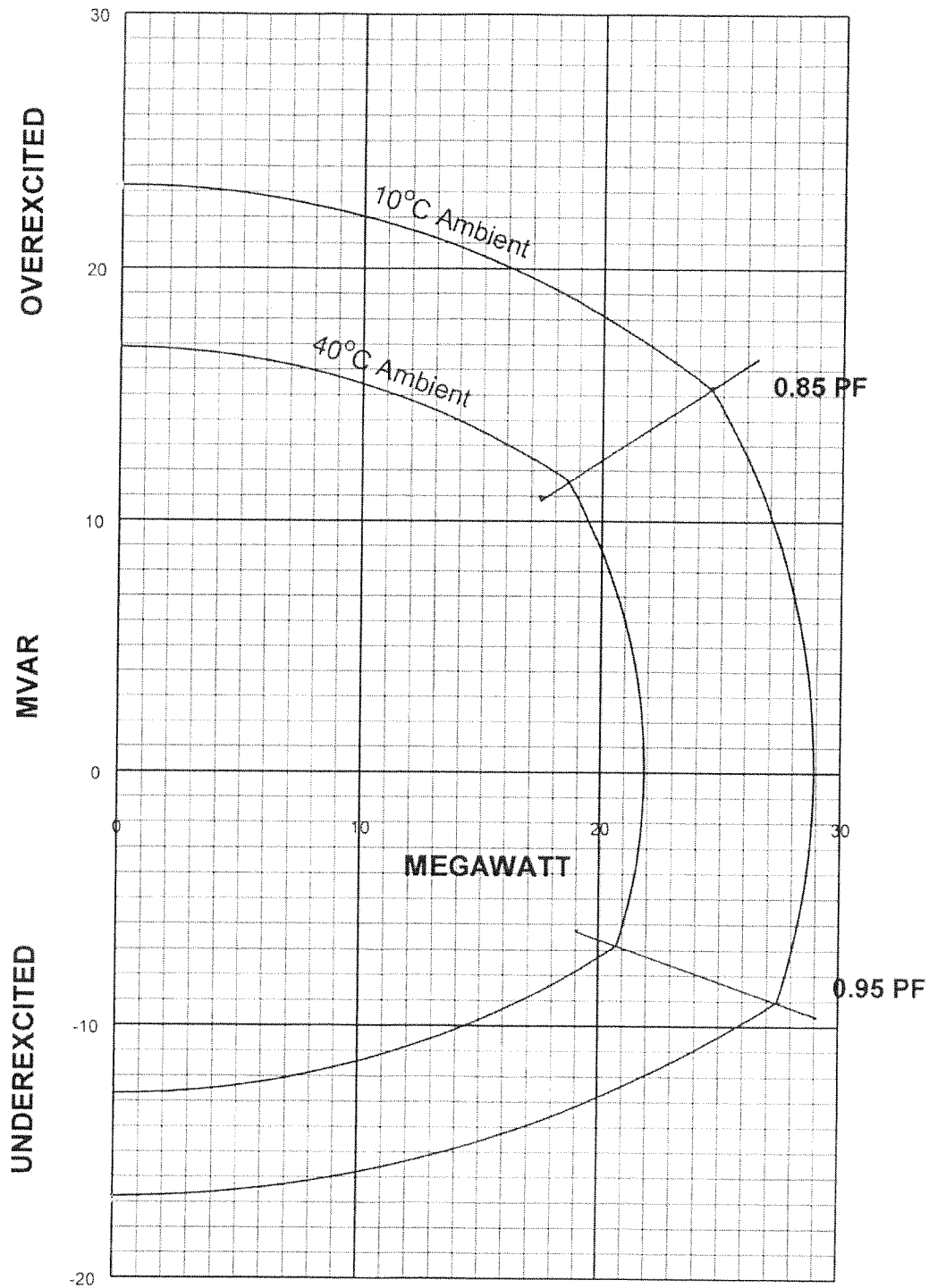


Electric Machinery Company
800 Central Avenue
Minneapolis, MN 55413

Reactive Capability Curves

13800 Volt, 0.85 PF, 3600 RPM

For Serial Numbers: 168178011, 268178011, 368178011



EE 13456

RS 1/10/07

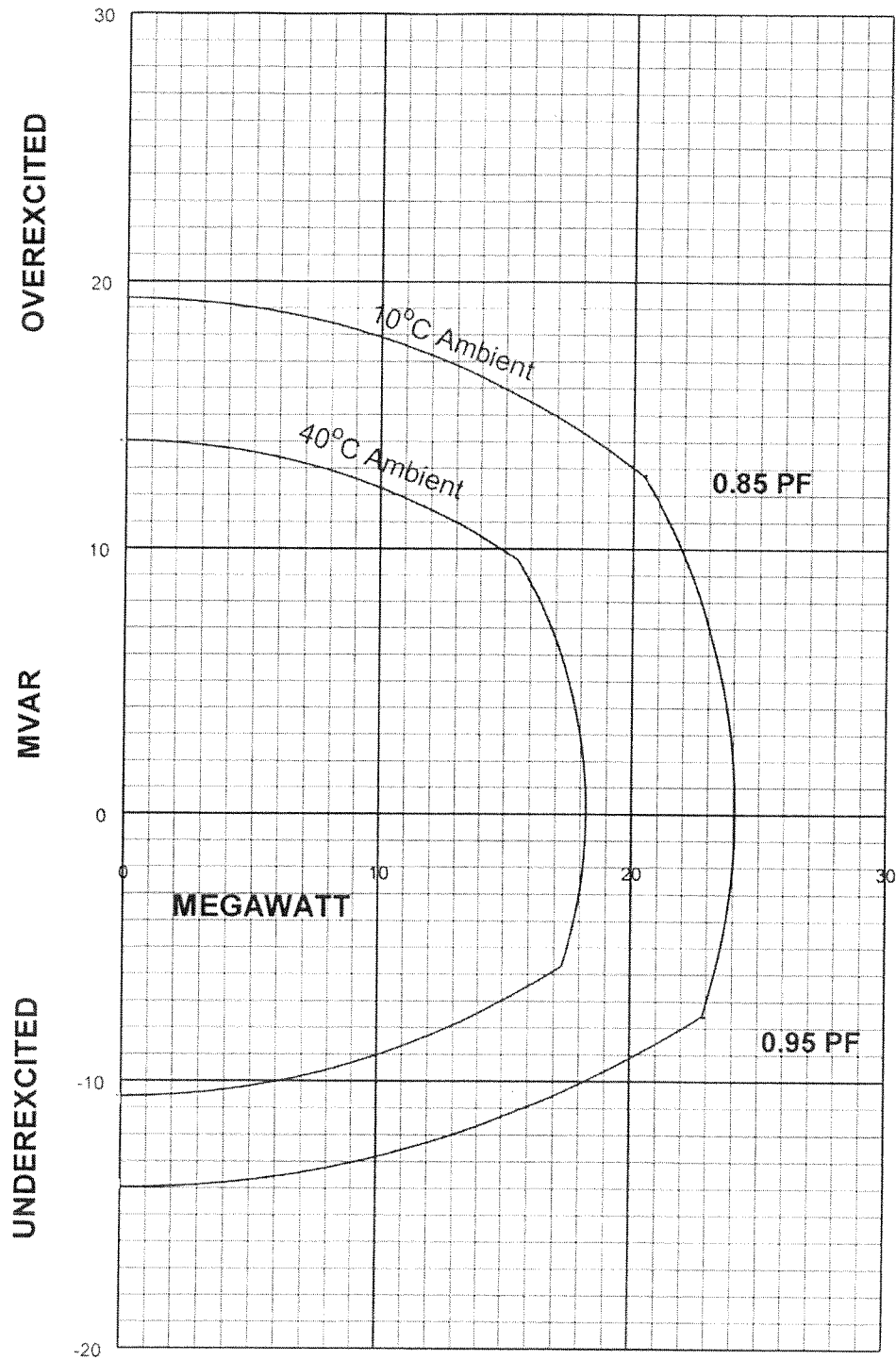


Electric Machinery Company
800 Central Avenue
Minneapolis, MN 55413

Reactive Capability Curves

13800 Volt, 0.85 PF, 3000 RPM

For Serial Numbers: 168178011, 268178011, 368178011



EE 13457

RS 1/10/07

Scope of Supply and Purchaser's Responsibilities					
					WOOD GROUP PRATT & WHITNEY INDUSTRIAL GAS TURBINE SERVICES
FT4A-9 POWER PAC POWER ISLAND					
EQUIPMENT ONLY					
LIQUID FUEL		Qty: 1			WGPW
Item	Description	Quantity	Design	Supply	Installation
					Notes
I.	GAS TURBINE POWER ISLAND				
1	GAS TURBINE PACKAGE	1		W	C
	Gas Generator (GG4A-9 Core Engine)			W	C
	Power Turbine			W	C
	Exhaust Elbow			W	C
	Exhaust Transition			W	C
	Fabricated gas turbine base and mount			W	C
	Coupling connecting power turbine and			W	C
	Hydraulic Starter			W	C
	Ignition System			W	C
	GG & FT Lube Oil Systems			W	C
	* Oil-to-air Coolers			W	C
	* Motor Driven Pumps			W	C
	* Carbon Steel Piping			W	C
	* Enclosure			W	C
	Fuel Supply System			W	C
	* Liquid Fuel Filter			W	C
	* Liquid Fuel Fire Valve			W	C
	Gas Turbine Enclosure			W	C
	* Secondary cooling air system with louvers			W	C
	* Vents and Drains			W	C
	* Interior AC/DC Lighting			W	C
	* CO ₂ Fire Suppression System			W	C
	* Sound Attenuation Estimate			W	C
	Air Inlet Vandal Hood			W	C
	Inlet Silencing			W	C
	Exhaust Stack			W	C
	Hydraulic Start Pac			W	C
2	GENERATOR PACKAGE	1		W	C
	EM Open Ventilated Air Cooled Synchronous Generator			W	C
	Static Exciter Assembly			W	C
	Stator Heaters			W	C
	Neutral Ground Transformer/resistor			W	C
	Current Transformers			W	C
	Stator Temperature Detection			W	C
	Bearing Temperature Detection			W	C
	Generator and exciter air temperature detection			W	C
	Rotor Ground Detection			W	C
	Lube Oil System			W	C
	* Oil Filter			W	C
	* Motor Driven Pumps			W	C
	Enclosure			W	C
	* Inlet Air Filter			W	C
	* Inlet and Exhaust Silencing			W	C

W=WGPW
C = Customer

		Quantity	Design	Supply	Installation	
Item	Description					Notes
	* Interior AC/DC Lighting			W	C	
	* Sound attenuation to 85 dBA) @ 3 ft			W	C	Inlet and Exhaust silencing
	* Fire Detection System			W	C	
3	CONTROL PACKAGE	1		W	C	
	Prefabricated Steel Enclosure			W	C	
	* HVAC			W	C	
	* Fluorescent Lighting			W	C	
	* DC Emergency Lighting			W	C	
	* AC Power Outlets			W	C	
	* Smoke Detector			W	C	
	Operator Control Cabinet			W	C	
	* Starting and Operating Controls			W	C	Manual and automatic
	* Speed Indication			W	C	
	* Voltmeters and Frequency Meters			W	C	Bus and generator
	* Ammeter			W	C	
	* Watt Meter			W	C	
	* VAR Meter			W	C	
	* Synchroscope			W	C	
	Instrument Cabinet			W	C	
	* Automatic Voltage Regulator			W	C	
	* Synchronizer			W	C	
	* Vibration Monitor			W	C	Gas turbine
	* Fire protection system power supplies			W	C	
	Unit Control Cabinet			W	C	
	* PLC system for automatic starting, running, loading, unloading and shutdown of the unit.			W	C	Allen Bradley Controllogix
	* Fuel Controller with Woodward Fuel Valve			W	C	
	Generator Protective Relay Panel			W	C	
	* Generator Protective Relays			W	C	
	* Lockout Relays			W	C	
	* Watt hour Meter			W	C	
	Motor Control Center			W	C	
	* AC and DC Distribution Panels			W	C	
	* Motor Starters			W	C	
	* AC Distribution Transformer			W	C	
	* Breakers as required			W	C	
	* Automatic Transfer Switch			W	C	
	* Field Termination Blocks			W	C	
	* Power Supplies			W	C	
	Ventilated cubicle with rack mounted lead acid batteries			W	C	125 VDC
	Battery Charger			W	C	
	Switchgear Module 15 kV Class			W	C	
	* Metal Clad Switchgear Compartment			W	C	Mounted in control enclosure
	* Circuit Breaker			W	C	1200 Amp/ 750 MVA, 15kV class totally enclosed
	* Non-segregated Insulated 3 Phase Bus Duct			W	C	
	* Lightning Arresters and Surge Capacitors			W	C	
	* Current Transformers and Potential Transformers			W	C	
	* 3 Phase Station Auxiliary Transformer			W	C	
4	INSTALLATION HARDWARE					
	Site interconnecting piping		C	C	C	

W=WGPW
C = Customer

Scope of Supply
112107
Page 2 of 6

			Quantity	Design	Supply	Installation	
Item		Description					Notes
		Foundation embedded material		C	C	C	Including all anchor bolts, shims and plates, and grout for WGPW supplied equipment.
		Interconnecting electrical cables			W	C	Between WGPW supplied equipment
	5	STARTUP AND COMMISSIONING SPARE PARTS AND CONSUMABLES			W		For WGPW Scope of Supply
II.		ADDITIONAL RESPONSIBILITIES DURING CONSTRUCTION AND START-UP					
		Technical Representatives to advise Customer Supervisory Personnel during FT4 equipment erection checkout, and startup					Optional
		Instruction Manuals and Plant Documentation provided: Construction Manual, Commissioning Manual & Sign-off Sheets, TPM Drawing Package, Vendor Manuals & Drawings, FT4 Maintenance Manual, FT4 Illustrated Parts Catalog, FT4 Service Bulletins, Operating Instructions, Bill of Material, As Built Drawings, General arrangement drawing, Foundation interface drawing, Loading diagram			W		
		WGPW training					Optional, includes customer training on site. Training description can be found in the WGPW Customer Training Document version 21-0802. Travel and lodging for customer's personnel not included.
		Performance Testing			C		The customer is responsible for providing all necessary support to install, calibrate, and remove all temporary and plant instrumentation/equipment necessary for performing the acceptance test. WGPW provides technical support and manages the test plan for this work.
III.		PROJECT DEVELOPMENT AND OWNER'S RESPONSIBILITIES					Owner is responsible for compliance with WGPW operating, installation, and maintenance instructions.
	1	SITE DEVELOPMENT		C	C	C	Owner is responsible for all areas of site development and are not limited to the items listed in this document.
		Adequate Title and Interest, Permanent Facility Permits, Construction Permits and Licensing			C		To permit the installation of such units and their operation for at least the period contemplated by the contract. Provide WGPW representatives unrestricted access at all times as may be reasonably necessary in the performance of their duties.

W=WGPW
C = Customer

			Quantity	Design	Supply	Installation	
Item	Description						Notes
	Sub-Soil Investigation & Report			C	C	C	Minimum sub-foundation bearing capacity of 2500 psf (120 kPa) and limits differential settlement of the main foundations equal to or less than 0.0005 times the foundation length.
	Foundations for all Equipment			C	C	C	WGPW will provide Loading Diagrams for WGPW supplied equipment.
	Below Grade Electrical Raceway			C	C	C	Includes Conduit, Duct Bank, Trenches, etc.
	Provision of Secure Field Office . Furnished with electricity, Heating and Air Conditioning, Drinking Water, Desks, Chairs, Parking Area, Lockers and others which are necessary for Field Works, Services & Sanitary Facilities of Office Personnel.			C	C	C	Including 10' x 40' (3 m x 12 m) area for a field office. This field office needs to be able to accommodate 3-4 WGPW individuals.
	Provision of First Aid and Medical Services - OSHA Approved			C	C	C	
	Provisions of Local Communication Facilities			C	C	C	Including radio, telephone (local and long distance) with international direct dialing and fax machine. This should be a minimum of 3 lines in the WGPW field office. A separate dedicated phone line shall be provided to each turbine control system in the control house.
	Temporary Construction Staging & Secure Inventory Area				C		A minimum area of approximately 115' by 136' is recommended per Power Island. A minimum of two shelved conex boxes and one non shelved or enclosed equivalent per Power PAC prior to delivery of equipment.
	Access Roads), Interior Roads, and Parking Areas			C	C	C	All-weather and unobstructed
	Transmission System			C	C	C	
2	ENGINEERING AND CONSTRUCTION						
	Plant Engineering				C		
	All Labor for complete off-loading, Inventory, Inventory control, Storage, Erection, Installation, Checkout, Testing, and Start-up of all WGPW and non-WGPW supplied equipment and material.				C		
	Maintaining and Guarding all Facilities, Equipment, and Materials during construction				C		Including security fence
	Site Organization During Construction				C		Including Resident Field Construction Manager; Supervision & Manpower for Erection Works, Checkout, Trouble Shooting, Start-up & Commissioning, Test Operation & Trial Operation, Plant Start-Up Engineering
	Emissions and Acoustic Testing				C		
	Worker's Compensation, Employer's Liability, or any other Local Insurance Required				C		WGPW will cover all WGPW personnel.
	Consumable Material for Erection Works				C		As required

W=WGPW
C = Customer

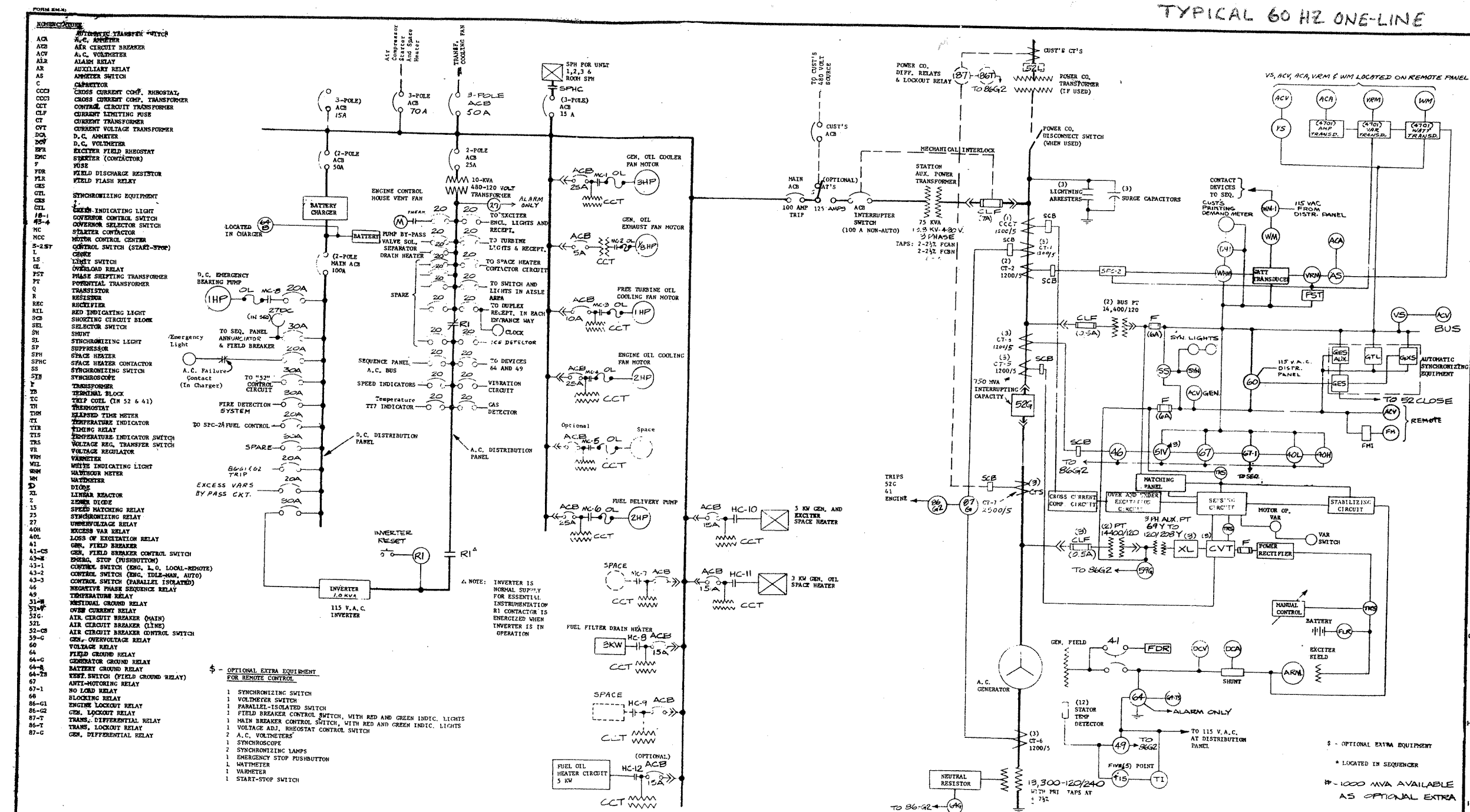
			Quantity	Design	Supply	Installation	
Item	Description						Notes
	Construction Equipment, Tools and Aids				C		Including but not limited to the following: Cement Mixers, Loaders, Trucks, Cranes of varying capacities, Power Generators, Air Compressors, Welders, Drilling Equipment, Pipe Working Facilities & all hand tools required for expeditiously and competently completing all phases of the work under the contract.
	Required Tests Prior to Startup: Including but not limited to:				C		
	* Resistance ratio and polarity tests				C		Generator and Transformer CTs and PTs
	* All high voltage dielectric tests				C		All WGPW supplied protective relays and circuits. The WGPW Commissioning and checkout manual further clarifies the Customers responsibilities.
	* Field check and calibration	*					
	Protective Relay Calibration						
	Phasing and Synchronizing the Generator to Purchaser's system				C		
3	POWER ISLAND INTERFACES						
	BOP Motor Control Centers				C		
	Control System Interface				C		Customer is responsible for all-interconnecting hardware, software and documentation for all BOP I/O communication and control.
	Natural Gas for Start-up, Testing and Operation 445 psig (30 bar), Approximately 4700 scfm (2.2 m3/sec) per gas turbine (Optional fuel)		N/A				Interface Point: Flange on WGPW Power Island. Per TPM Natural Gas Fuel Specification FR-2. Fuel to be tested by a certified lab and the results provided to WGPW prior to start-up.
	Liquid Fuel for Start-up, Testing and Operations						Interface Point: Flange on WGPW Power Island. Per TPM Liquid Fuel Specification FR-1. Fuel to be tested by a certified lab and the results provided to WGPW prior to start-up.
	Potable Water for Gas Turbine Off-line Water Wash 50 psig (3.4 bar) min., Approximately 300 gallons (1150 liters) per gas turbine water wash at 110 gpm (415 liters/m)				C		Interface Point: Flange on WGPW Power Island. Per TPM Potable Water Quality Specification
	Demin water for injection per AR-1				C		Required with optional water injection
	Vent and Drain. Maximum flow on Oily Waste drain is 35 GPM for water wash.				C		Interface Point: Connections on WGPW Power Island.
	High Voltage Power				C		Interface Point: Generator Terminals.
	Backfed Electrical Power Supply 75 kVA per Power Island, 13.8 kV, 60 Hz, 3 phase for lighting, heating and intermittent auxiliaries				C		Plus as required for BOP and optional equipment loads
	Construction Power-Including distribution to the WGPW supplied equipment				C		480 V, 3 phase, 24 hours per day to electric generator upon arrival of the generator. Reliable temporary 480 V, 100 amp power at the control house for checkout and start-up at least 21 days prior to the first fire date of the first unit to be commissioned.

W=WGPW
C = Customer


			Quantity	Design	Supply	Installation	
Item		Description					Notes
	4	OTHER OWNER RESPONSIBILITIES					The following list of items is provided for your convenience and gives examples of the types of equipment and/or services that are outside the WGPW Scope of work, and if required, are the sole responsibility of the Owner.
		Site Survey/Plot Plan		C	C	C	
		Excavation for Foundations, Pipes, Roads, Cabling & Grounding Grid		C	C	C	
		Site Leveling		C	C	C	
		Backfill		C	C	C	
		Finish Grading		C	C	C	
		Foundation embedded material		C	C	C	Including all anchor bolts, shims and plates, and grout for WGPW supplied equipment.
		Surface Drainage to and including any Collection Pond		C	C	C	
		Oily Water Separator		C	C	C	
		Sanitary Waste Disposal		C	C	C	
		BOP and Plant Fire Protection Systems- Hydrants Panels and Extinguishers		C	C		Including Fire Protection during construction
		Plant Lighting		C	C		
		Intra-communication system		C	C		
		Site Fencing and Gates		C	C		
		Construction Water			C		
		Builder's All Risk Insurance (BAR)			C		
IV.		OPTIONS					
	1.	Spares Parts and Consumables			W		
	2.	Long Term Maintenance Agreement			W		
	3	Off-line compressor internal water wash system			W	C	Includes piping system, nozzles, valves, etc internal to the Gas Turbine Enclosure. Excludes Water Wash Skid
	4	Gas turbine heating system			W	C	For condensation control
	5	60 to 50 HZ Conversion			W	W	
	6	Dual Fuel Conversion			W	W	
	7	Gas Fuel Conversion			W	W	
	8	Gas Fuel Filter			W	C	
	9	Gas Fuel Fire Valve			W	C	
	10	Gas Detection System			W	C	
	11	Water Injection System			W	C	
	12	Inlet Filtration			W	C	
	13	Construction & Startup Technical Supervision			W	C	
	14	Training			W	C	
	15	Liquid Fuel Forwarding Skid			W	C	
	16	Black Start Capability			W	C	Requires extra equipment

W=WGPW
C = Customer

TYPICAL 60 HZ ONE-LINE



NO. REF. 358D517
FIRST USED
68-1780-28

CONTROL CERTIFIED FOR CUSTOMER															POST # WHITNEY AIRCRAFT ON USER															COMMONWEALTH EDISON															 Electric Machinery Mfg. 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UNDER SHORT CIRCUIT CONDITIONS THE FOUNDATION LOADING VARIES FROM ZERO TO 120,000^{LB} AT EACH GENERATOR SOLEPLATE

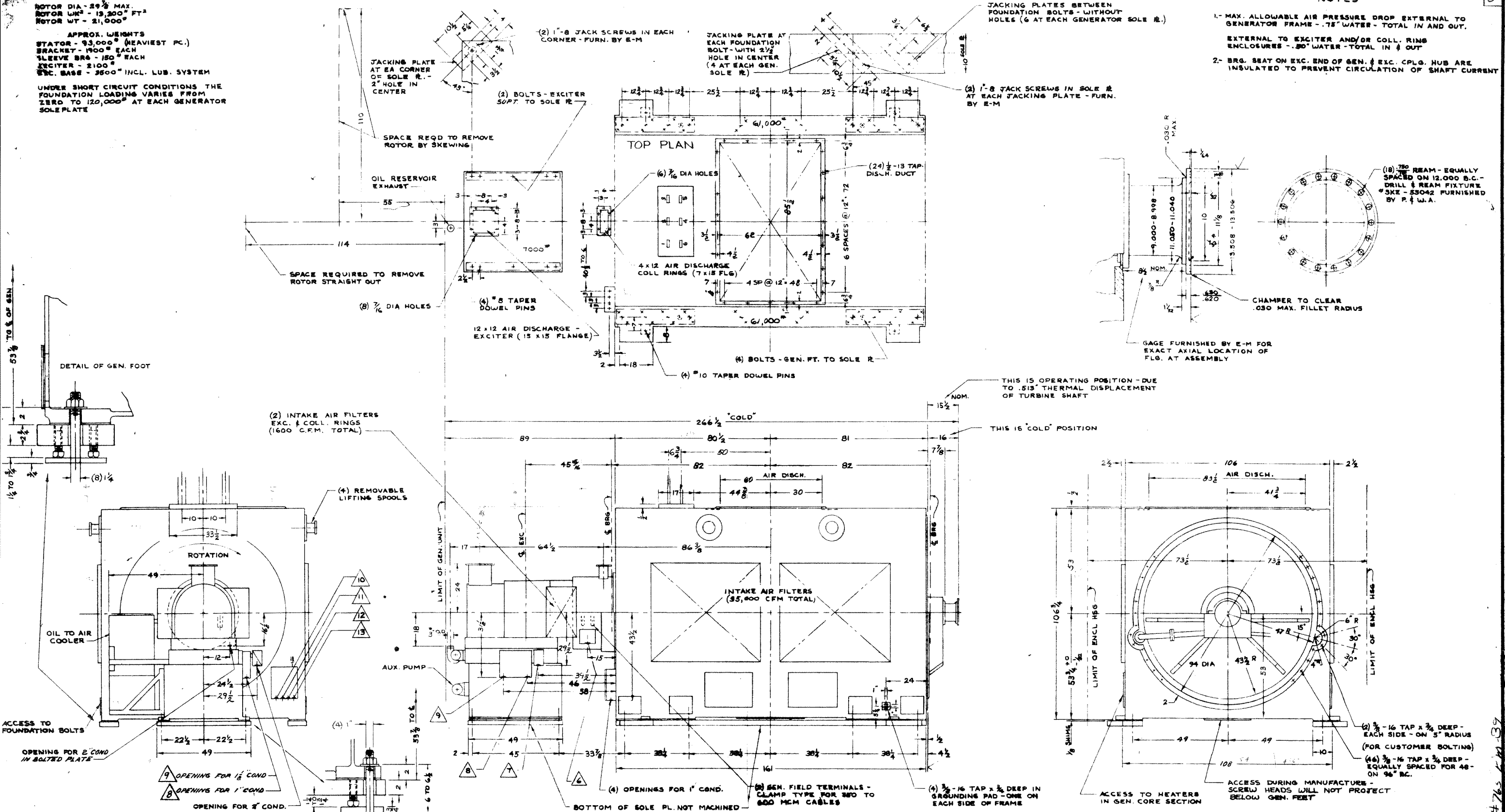
NOTES

3

1.- MAX. ALLOWABLE AIR PRESSURE DROP EXTERNAL TO GENERATOR FRAME - .75" WATER - TOTAL IN AND OUT.

EXTERNAL TO EXCITER AND/OR COLL. RINGS
ENCLOSURES -.50" WATER - TOTAL IN & OUT

2- BRG. SEAT ON EXC. END OF GEN. & EXC. CPLG. HUB ARE INSULATED TO PREVENT CIRCULATION OF SHAFT CURRENT



TP-235	TP-235 *	TP-215	767449	767410	767410	767410	767410	767410	767410
68-1770-11&91	68-1700-11 & 91	68-1625-11 & 91	67-1508-12 & 91	67-1507-12 & 91	67-1478-11 & 91	67-1360-12 & 91	67-1360-12 & 91	67-1360-12 & 91	67-1360-12 & 91
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3600	3600	3600	3600	3600	3600	3600	3600	3600	3600
60°C	60°C	60°C	60°C	60°C	60°C	60°C	60°C	60°C	60°C
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325	325	325	325	325	325	325	325	325	325
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CERTIFIED FOR SPARE & REPAIR AIRCRAFT
DIVISION OF UNITED AIRCRAFT CORPORATION
THREE GENERATOR-CLOCKWISE ROTATION
PLACING END OPPOSITE TURBINES

Electric Machinery Mfg. Company
MINNEAPOLIS, MINNESOTA

MENTION SHEET

14-00000

6-23-67 6-27-67 101D306

104D304

WOOD GROUP PRATT & WHITNEY

HISTORY

Wood Group Pratt & Whitney (formerly Wood Group Turbine Engine Services) currently operates from a 53,000 square foot facility located on five acres adjacent to Bradley International Airport, in Windsor Locks, Connecticut (USA). Founded in 1977, we have grown in both capability and capacity while establishing a solid reputation as a customer oriented, quality conscious and cost competitive service organization.

Our strategic location, within minutes of Pratt & Whitney (P&W), the Original Equipment Manufacturer (OEM), allows us to utilize the P&W approved supplier base for specialized services and expertise. Many of these companies have over three decades of experience in fabrication and refurbishment of GG3, GG4 and FT4 parts and assemblies.

Since 1993, we have been designated by the OEM as the service facility for their newest industrial model, the GG8. We have successfully repaired over 120 GG8s for Pratt & Whitney. As of June 18, 1998 – Pratt & Whitney Turbo Power & Marine Systems, Inc. (TPM) and Scotland based John Wood Group PLC formed a joint venture company (Wood Group Pratt & Whitney) for the overhaul, repair and service of industrial gas turbines, focusing on the TPM built GG3 and FT4 gas generating units.

Also located at the main facility is our field service group which includes well-trained electrical and mechanical engineers. Our electronics lab repairs and calibrates all types of OEM power generating ancillary equipment from SPC electronic fuel controls to base plate solenoid valves. Our service engineers are trained to perform hot section inspections, unit audits, on-site module changes, trouble shooting tasks, vibration analyses, trim balancing, alignment, generating bearing change outs, electrical system audits, card exchange programs and many other services required in the maintenance of GG3 and GG4 engines.

Our maintenance philosophy, procedures, methods and work programs are modeled after the Original Equipment Manufacturer's recommended guidelines. Strict adherence to the OEM's quality systems assures our customers that they will be receiving the highest standards as stipulated by the OEM. Our Quality Control Plan has been reviewed by the U.S. Military and was found to meet the requirements of MIL-I-45208(A). Additionally, WGP&W's Quality Control System meets or exceeds the following specifications:

- Quality Program Requirements – MIL-Q-9858A (Paragraphs 3.3, 3.5, 5.1 and 5.2)
- Calibration System Requirements – MIL-STD-45662A
- Qualification of Aircraft, Missile and Aerospace Fusion Welding – MIL-STD-1595A
- Liquid Inspection Penetrant – MIL-STD-6866B

WGP&W have recently adopted quality controls in accordance with our standard corporate policy of ISO 9000.

FIELD SERVICE

Field Service forms the foundation of our capability and commitment to serve the gas generator and free turbine user.

WGP&W dedicated staff of trained and experienced personnel has all of the equipment required to meet the mechanical and electrical service needs of GG3 and GG4 power plants and free turbines.

FIELD SERVICE SUPPORT

- WGP&W offers trained and experienced mechanical and electrical personnel for scheduled or unscheduled GG3/GG4/FT maintenance worldwide.

FUEL CONTROL

- Calibration, test and adjustment (static and dynamic)
- Repairs, upgrades and engineering changes for all electronic cards
- Card exchange program
- Training for user personnel

SEQUENCER

- Calibration, test and adjustment of speed relays, load share, over speed timers and relays
- Training for user personnel
- ***WGP&W developed and manufactured a proprietary replacement PLC sequencer. Field tested and proven, our PLC sequencer is fully capable of interfacing with existing hardware, reducing retrofit costs.***

Please ask for more information.

VIBRATION SYSTEM / BALANCING

- Complete calibration, test and adjustment of vibration monitor and pickups
- Vibration analysis, monitoring and evaluation of mounts / alignment
- Trim balance

UNIT AUDIT

- Full function operational checkout, calibration, test, adjustment of the sequencer, fuel control, vibration monitor and protective devices to ensure maximum reliability of unit controls.

UNIT PERFORMANCE

- Full heat rate, testing and evaluation
- Unit operation capability tests
- Gas generator, compressor and turbine operation evaluation

MECHANICAL SERVICES

- Provide technical direction and/or technicians for hot section inspections and evaluation, including on-site disassembly and assembly, for module exchange/repairs.
- Station refurbishment
- Field weld transition duct repair
- Starting system maintenance/repair
- Exhaust and inlet stack weld repair
- Engine heater installation
- Borescope inspection of compressor and turbines
- Removal/installation of gas generators or free turbines
- Lube oil system flush/cleaning

ELECTRICAL

- **Igniters**
Replace cables

- **Tt7**
Calibrate and test probes
Replace or repair harnesses

- **SPC2A – 2B – 2D – 2E and 2H**
Calibrate, test and adjust
Repairs, upgrades and engineering changes for electronic cards
Card exchange program
Training for user personnel

- **Sequencer**
Calibrate, test and adjust speed relays, load share, over speed timers and relays
We have developed and manufactured a direct replacement for the PLC sequencer.
Please ask for more information.

- **Over speed**
Repair, calibrate and test
Replace mechanical governor in electronic unit

- **Engine Heaters**
WGP&W has designed and manufactured an engine heater unit, which eliminated moisture during unit standby, thus retarding corrosion of internal engine components.
Please ask for further information.

TECHNICAL SUPPORT

Experienced technical resources provide or assist in the selection, installation and consultation for the following:

- Fuel system changeover
- Gas turbine maintenance management

- Preventative maintenance program development and implementation
- Assistance with R&D projects applied to GG/FT operations or maintenance
- Unit refurbishment or retirement
- Unit relocation
- Upgrade and repower gas generators
- Controls upgrades

SPARE PARTS

WGP&W maintains an extensive inventory of parts, components and assemblies to support the service and repair of GG3, GG4 and FT units. In most cases we offer serviceable, overhauled or new parts and components to best meet your specific needs or requirements.

MAJOR FIELD MAINTENANCE

WGP&W have the tooling, equipment and trained personnel to perform removal and installation of the following major components and modules. These include the inlet case, LP compressor, HP compressor, either turbine and exhaust case or the gas generator. Also included are the replacement of either the IGV, #7 / #8 bearing or the accessory drive of the free turbine.

ANNUAL UNIT AUDITS

Perform full functional checkout, calibration, test and adjustment of all engine and free turbine control and protective devices to ensure maximum reliability and proper function. Some related repairs and adjustments are as follows:

- Water and/or detergent wash using customer or WGP&W supplied equipment
- All 86E&G functions associated with gas generator, free turbine and/or associated systems of the Worthington expanders
- All sequencer operating and shutdown functions including integrity of relays and timers
- SPC fuel control, static calibration and dynamic trims. Incorporation of approved "Product Improvements"
- Speed relay assembly (static calibration of units and speed pickups)
- Vibration monitor (static check of monitor, cable and pickups)
- All base-mounted pressure and temperature sensing switches for proper operation at the OEM's specified settings. Adjustment and/or replacements of sensing devices, as required.

- Inspect fire detector sensors and associated equipment (conduct static tests of fire protection system)
- Test proper operation of all fuel valves and components
- Test proper operation of lube oil level alarm and trip sensing switches
- Perform over speed check of mechanical and electrical systems
- Test operating parameters and make necessary power trim adjustment per operating instructions. Perform a three point comparison of compressor and turbine section operation versus design parameters
- Report with findings and recommendations

WGP&W to supply all necessary tooling and instruction to perform audits

HOT SECTION INSPECTION

Provide advisory Technical Services and Instruction to enable client personnel to complete this Inspection/Repair operation.

We will conduct prior consultation with the Maintenance Supervisor to ensure that all anticipated replacement material will be available.

Hot section inspections are performed in accordance with OEM inspection procedures which will include but are not limited to the following items:

- Furnish special tools and borescope
- Inspect and/or borescope low and high compressors
- Borescope third stage turbine
- Remove, inspect and replace combustion chambers, as necessary
- Remove, inspect and replace 1st stage nozzle guide vanes for sulfide or heat corrosion
- Replace fuel manifold and nozzle assemblies with customer supplied material, if necessary
- Pressure check manifolds and pressurizing & dump valve

- Inspect and clean lube oil strainers
- Inspect and clean mod valve and strainers
- Remove and replace main fuel filters with customer supplied elements
- Drain and inspect starter oil foreign material, replenish oil to operating levels
- Inspect and check all Tt7 probes and harnesses, N2 and N3 speed pickups and wiring
- ***Issue final report of findings and recommendations***

APPLICABLE EQUIPMENT

- PWA GG3 and GG4 Gas Generator
- PWA FT4 Two Stage Free Turbine
- Hamilton Standard SPC Fuel Controls and Speed Monitors
- Sequencer and Control System
- Associated Base and Engine Mounted Components
- Gas Turbine Vibration Analysis and Trim Balance Services
- Gas Turbine Lubrication and Fuel Systems (GG4)
- Gas Turbine to End-Driver Alignment (GG4)
- Gas Turbine Relocation and Start-up
- Spare Parts (GG3, GG4 and FT4)
- Shop Overhaul (GG3, GG4, Gas Generator, FT4 and Free Turbines)
- Field Service and Field Repair (GG3, GG4 and FT4)

ENGINE AND FREE TURBINE OVERHAUL SHOP

We staff a fully complemented overhaul shop to support the industrial GG3/GG4/FT market. Our facility has the resources to disassemble, repair, inspect, balance and reassemble engines, free turbines and their associated components. A few of these capabilities include:

- Rotor and/or assembly balance utilizing the latest computerized balance equipment
- Machining capability (up to 52 inch diameter) to aerospace tolerances

- Non-destructive test professionals certified to level II ANT (SNT-TC-1A)
- All welding to MIL-STD-1595A requirements
- Dedicated Quality Assurance Department

We have also been certified to ISO 9002 Standards.

OVERHAUL WORK SCOPE

Low and High Compressor Modules (A & B)

- Disassemble and destack “A & B” modules
- Deblade disks
- Clean parts
- Perform detail inspection
- Provide inspection report and recommendations
- Perform module repairs, as required
- Blade and balance disks
- Assemble rotors and final balance
- Reassemble modules
- Perform final inspection

High and Low Turbine Modules (C & D)

- Disassemble modules and deblade
- Clean parts
- Perform detail inspection
- Provide inspection report and recommendations
- Perform module repair, as required
- Blade and balance disks
- Reassemble modules
- Perform final inspection

N2 and N3 Gearboxes

- Complete disassembly of gearbox

- Clean all material
- Provide inspection report and recommendations
- Repair as required
- Reassemble gearboxes
- Perform final inspection

ENGINE TEST

We have recently opened our new dedicated test cell and have additional capability with a third party, if necessary. WGP&W's own test cell is fully certified to FAA standards, and has a thrust range capable of testing all listed turbine modules.

PRODUCT SUPPORT

WGP&W offers a complete line of repairs, upgrades and overhauls for many of the associated components and assemblies of GG/FT units.

A brief description of these components and our capabilities are listed below:

STARTERS

- Functional test and inspection
- Full overhaul and test

FUEL SYSTEM

- **Mod Valve & Actuator**
Repair, overhaul, calibrate and test
- **P & D Valves**
Repair, overhaul, modify, flow and test
- **Fuel Shut Off Valves**
Repair, overhaul, modify, calibrate and test (gas or liquid)
- **Air/Gas Assist**
Repair, overhaul, modify, calibrate and test

- **Fuel Pumps**
Repair, overhaul, modify, calibrate and test
- **Fuel Manifolds**
Repair, overhaul and test (liquid, gas or dual fuel)
- **Fuel Nozzles**
Repair, overhaul, calibrate, flow match and test
- **Combustion Chambers**
Repair, modify and/or upgrade

THE FT4

The FT4 modular industrial gas turbine is the heart of our power system. It consists of a gas generator that provides high energy gas to the free turbine, which converts it into useful mechanical work.

Operating in harsh conditions ranging from frigid arctic climates to remote desert locations where temperatures can exceed 130°F, the FT4 has proven itself in atmospheres laden with sand, iron oxide, salt and other undesirable elements.

Ongoing engineering studies and improvements have been made over the years, resulting in a proven, durable design, capable of providing users with dependable service in a wide variety of applications.

HISTORY

This efficient aero-derivative engine was originally developed by the Pratt & Whitney division of United Technologies Corporation, where it established a notable record for dependability in both military and commercial aviation. In a joint development program, which started in the early 1960's, TPM and P&W converted the JT4 flight engine into an industrial gas generator and designed a new power turbine which today is the mature, fully developed FT4 industrial gas turbine. Its design concept is based upon proven technology with primary goals of maintainability, efficient operation and low life-cycle costs.

DESCRIPTION

The gas generator consists of a multistage axial flow compressor, a can-annular combustion section and a two-stage axial flow reaction turbine. High pressure ratios are achieved by use of a reliable fixed geometry dual compressor “twin spool” design in preference to the more complex variable geometry stators. The free turbines are two-stage or three-stage axial flow reaction turbines with an exhaust elbow or collector box to redirect the exhaust gas flow, and a drive shaft which includes a flexible coupling to absorb alignment variations.

The twin spool and free turbine concept means that minimum power is required for starting. Only the high compressor needs to be driven by a small starter turbine which operated on compressed air or gas. Black start capability is standard on all units.

ADVANTAGES

The FT4 is a mature, developed gas turbine, whose design is based on proven technology, efficient maintainability, and low overall operating costs:

- **Durability** – The FT4 has been proven in more than 10 million hours of operating experience. As new materials and coatings are developed, modifications are made in the FT4 design to incorporate them. The result has been a continual improvement in operating life and structural integrity. Conservatively designed air-cooled turbine blades and vanes allow low turbine metal temperatures without the risk of clogged air passages due to dirty air.
- **Availability** - Surveys of various gas turbines have consistently revealed the FT4 to have the highest availability. Long periods between maintenance actions, fast change-outs, and module replacement capability are key factors in the FT4's superior availability.
- **Modular Design/Modular maintenance** – A chief advantage of the FT4 is easy maintainability made possible by modular design. The six basic gas generator modules are: Low pressure compressor, High pressure compressor, High pressure turbine, Low pressure turbine, Exhaust case and Gearbox.

The most difficult of these modules can be exchanged in four working days and easiest within four hours. For maximum availability, the complete gas generator can be changed out within eight hours. Hot section inspections are routinely accomplished in less than eight hours.

- **Site Flexibility** – The FT4 does not require an on-site water or electric power supply. Inlet air filters and demister systems are available to adapt the unit to any desert or marine environment.

- Fast Starting – FT4 systems can reach full generating power in less than three minutes from a cold start, and there is no maintenance penalty for starts and shutdowns. The shut-down cycle is sequenced automatically and takes approximately 20 minutes for generator cool down. Except for one-minute period following fuel cut-off, the unit may be restarted during the shut-down sequence.
- Training – A wide variety of courses is available for customer training in the operations and maintenance of the units. This can be accomplished at our Service School in the United States or on site.

Proven reliability, maintenance support, customer training, and technical field support – all are interlocking elements in the successful FT4 modular industrial turbine program, designed to maximize availability, minimize down time, and lower maintenance and operating costs.

Today, as in the past, system support after the sale is a major dimension in the WGPW management and operating philosophy.

INSTALLATION

Erection of an FT4 station has been accomplished in less than two months. The compactness and relatively light weight of the FT4 simplify site selection, and for most soil conditions concrete slab foundations are sufficient.


The modular industrial gas generator can be trucked to the station site or flown in by helicopter. The gas generator and free turbine are factory tested and prepackaged to assure on-time operation.

SUPPORT SERVICES

Wood Group Pratt & Whitney is the only source you will need for total support and maintenance of the FT4 industrial gas turbine. A complete service network is in place to assure maximum availability.


- Spare Parts – Over \$40 million parts inventory. Where expedited delivery is important; parts can be shipped in 24 hours.
- Exchange Program – Components can be exchanged for repair units in our rotatable pool at significant savings.
- Audits – An audit service is available which provides an in-depth on-site inspection and assessment of equipment and a written report of the results to the customer with recommendations.

- Authorized Maintenance – A guaranteed authorized maintenance program is available to provide customer assurance that recommended standards are maintained. This includes work performed in shop as well as on site.
- Modular Shop Design – Should a customer desire a small shop for disassembly of a gas generator into modules, Wood Group Pratt & Whitney can provide technical guidance in the layout of the shop and recommend required equipment.
- Field Service – A 24-hour phone service is available, allowing customers to request assistance or a visit from one of our field service representatives to help solve problems.

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GAS TURBINE LIQUID DISTILLATE FUEL REQUIREMENTS

REV LET	SHEETS AFFECTED	SHEETS ADDED	DESCRIPTION	REV BY & DATE	APPVD & DATE
A	1-4		1) Added 1.7 cs lower limit of viscosity 2) Changed NA + K limit to 0.2 ppm 3) Added sulfur limit to 1.3% max. 4) Changed format to FrameMaker 5) Revised verbiage to put more stringent requirements for fuel management 6) Updated test procedures to current standard	P. Lavendier 8/18/95 EC#8352	
B			Completely re-written and updated to allow the use of Naptha Fuels, lower min viscosities. Max allowable fuel viscosities were changed to be based on actual operating temperatures, rather than a fixed temperature.	EC#9025 T. Fox/D. Dalal 2/11/98	
C	All		Updated Logo to new PWPS Logo. Updated all TPM references to PWPS references.	EC#9925 L. DiSalvo 7/23/01	
D	4		1) Changed Free Water to Combined Free water and sediment. changed limit to 0.1% max by volume. Changed Test Method to ASTM D2709. 2) Changed sediment to Particulate Contamination. Removed metric unit (mg/l) (2.7) from Limit. Changed test method to ASTM D2276 or D5452.	EC#10620 D. Tougas 7/8/03	
	4		3) Added Note 13 to Particle size 4) Removed Test Method IP288.		
	5 & 6		5) Added Test Method ASTM 4809 to Net Heating Valve. 6) Made various typographical changes. Added Note 13 regarding filtering.		

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		REVISE BY : D. Tougas	DATE: 7/8/03	
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GAS TURBINE LIQUID DISTILLATE FUEL REQUIREMENTS

GENERAL

This document provides the requirements and general guidelines for light and medium hydrocarbon liquid distillate fuels which can be burned satisfactorily in PWPS/P&W aeroderivative industrial gas turbines.

Industrial gas turbines are capable of burning a variety of liquid fuels providing they have appropriate fuel delivery, injection and combustion systems for each class of fuel. Distillate liquid fuels are complex hydrocarbon mixtures processed from a wide variety of basic crude oil stocks, and have a broad range of property values. In some cases, such as gasoline, the hydrocarbon fraction may undergo further processing and acquire additives or, as with naphtha, may be offered for use in the as-distilled form.


This document recognizes three general categories of distillate fuels as defined by ANSI/ASME B 133.7M which may be employed in properly configured PWPS/P&W gas turbines. Category a is No. 0-GT fuels such as light naphtha, gasoline, and JP-4/ Jet B fuels which are highly volatile and require special handling and fuel system design. Categories b and c are No. 1-GT and No. 2-GT such as light to medium kerosene and diesel fuels which can be burned in the standard gas turbine, providing all fuel properties specified in the following Table 1 are met. Fuel treatment or conditioning, including heating, may be necessary to satisfy these requirements. Residual, ash bearing fuels, and blends of distillate and residual fuels are not suitable for aeroderivative gas turbines.

Industrial fuels may be obtained from a large number of producers with a broad range of properties. Contamination in transport and deterioration in storage are common problems. Poor and contaminated fuels greatly affect the performance and durability of gas turbines. Therefore, it is imperative for the gas turbine user to install a proper fuel system design and institute an effective fuel quality management program to insure and maintain clean, high quality fuels.

GUIDELINES FOR EFFECTIVE FUEL QUALITY MANAGEMENT

The fuel management system should be designed and in place prior to the site start-up. The following considerations should be addressed:

- 1) The fuel type is generally chosen on the basis of cost and availability, however, the effects of fuel on gas turbine operation and life cycle economics should be considered. Normally, high viscosity fuels such as heavy diesel are less expensive initially, but usually impact engine life and increase overall life cycle costs. Some fuels can be made usable through treatment and/or conditioning, and the cost of these processes should be factored into the overall economics. Possible treatment processes are water wash, heating, filtration, and centrifuge or cyclone separation.
- 2) The transport path between the fuel producing location and the customer's unloading/ storage area should be analyzed for possible contamination potential. Dedicated transport containers are highly

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GAS TURBINE LIQUID DISTILLATE FUEL REQUIREMENTS


recommended.

- 3) The fuel storage equipment should be properly designed and sized and should be free of any contaminating or corrosive materials. Fuel storage time versus tank capacity should be balanced. Sufficient time should be allowed for incoming fuel to settle. The fuel for the gas turbine should not be removed from the bottom of the tanks, so as to avoid picking up heavy bottom ends. Tanks should be regularly drained from the bottom to remove the sediment.
- 4) The on-site conditioning and treatment systems should clean the impurities from the fuel and maintain high quality as it forwards the fuel to the gas turbine. The design should consider the quantity, placement and filtration efficiency of the filters.
- 5) The requirement for fuel preheating, if necessary, should be considered. Preheating is required for viscosity enhancement of heavy fuels and wax removal from high cloud point (waxy) fuels.
- 6) Safety requirements should be considered in the initial design phase, particularly if the fuel is one of the highly volatile Category a type fuels.
- 7) Contaminants brought in with the incoming gas turbine airflow should be considered. Proper air filtration is required. It is the normal practice to subtract the incoming air contaminants from the allowable fuel contaminant limit through a formula given in Note 7 of Table 1.

The operators of PWPS/P&W equipment must comply with all aspects of this specification, and ensure compliance by regularly taking and analyzing liquid fuel samples. Contaminants not normally present in the fuel at the production site may be introduced as a result of contact with sea water, other fuels, or insufficiently cleaned equipment during the transportation, handling and storage phases. If the fuel arriving at the user location falls out of compliance with the specification, and can not be made compliant by treatment, then the fuel supplier should be contacted immediately for a corrective action. Even a short period of operation with fuel of excess contaminants (salts, trace metals, particulates, wax, etc.) could seriously impact the gas turbine life and performance.

To further insure high quality fuel and continuous compliance, a regular maintenance program must be adopted for all on-site fuel handling, storage, conditioning and treatment systems. Regular replacement of filter elements, periodic draining of water, removal of sediments from the tanks, lines and sumps, and replacement of treatment fluids, etc., should be planned for and implemented.

PWPS/P&W requests review of the customer's final overall fuel management system design. PWPS bulletin no. 97M01 entitled "Distillate Fuel System Recommendations" is available for further details on implementing a quality fuel system. Additional guidance can be obtained by contacting your PWPS/P&W Marketing representative.


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GAS TURBINE LIQUID DISTILLATE FUEL REQUIREMENTS

RECOMMENDED DISTILLATE FUELS

The following liquid distillate fuels can be used in the gas turbine, if the fuel property requirements listed in Table 1 are met for the fuel delivered to the inlet of gas turbine.


- Category a (No. 0-GT): Naphtha Fuels, Unleaded gasoline types, wide-cut fuels of the JP-4 (MIL-T-5624), and Jet B (ASTM D 1655) types - SEE NOTE 3
- Category b (No. 1-GT): Kerosene or other distillates of the JP-5 (MIL-T-5624); Jet A and A-1 (ASTM D1655); No. 1-D diesel fuel (ASTM D975); No. 1 fuel oil (ASTM D 396); and No. 1 GT gas turbine fuel oil (ASTM D2880) types.
- Category c (No. 2-GT): Distillates of the No. 2 diesel fuel (ASTM D975) No. 2 fuel oil (ASTM D 396), No. 2 GT gas turbine, and marine diesel (MIL-F-16884) types.

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GAS TURBINE LIQUID DISTILLATE FUEL REQUIREMENTS

TABLE 1: GAS TURBINE LIQUID FUEL PROPERTY REQUIREMENTS

Property	Limit	NOTE(S)	Test Method (Note 1)
Viscosity - cSt: Max. (for category a, b, and c)	6.0 max. for starting, 12.0 max. for operation	2	ASTM D445
Min. at 100 °F (37.8°C) (for category a)	0.5 min.	3	ASTM D445
Min. at 100 °F (37.8°C) (for category b&c)	1.0 min		ASTM D445
Combined Free Water and Sediment, vol. %	0.1 max.	4	ASTM D2709
Particle Contamination, mg/gal.	10.0 max.		ASTM D2276 or ASTM D5452
Particle Size - microns (micrometer)	20 max	13	
Hydrogen - % by weight	12.4 min	5	ASTM D1018
Metal Contaminants - ppm by wt.			ASTM D3605
Vanadium (V)	0.2 max.	6 & 7	
Sodium (Na) + Potassium (K)	0.2 max.	6 & 7	
Calcium (Ca)	2.0 max.	6 & 7	
Lead (Pb)	0.1 max.	6 & 7	
Copper (Cu)	0.02 max.	6 & 7	
Copper corrosion	No.1 max.	8	ASTM D130
Fuel Category a (only)			
Flash Point, °F (°C)	To be reported	9	ASTM D93
Reid Vapor Pressure, psi or	12.5 max.		ASTM D323
Vapor Pressure by Mini- method, psi	12.5 max.		ASTM D5191
Fuel Category b and c (only)			
Flash Point, °F (°C)	100 °F (37.7°C) or local regulatory limit	10	ASTM D93
Cloud Point, °F (°C)	25 °F (14°C) below GT inlet fuel temp.		ASTM D2500
Carbon Residue (on 10% bottoms), %	0.25 max.		ASTM D524
Sulfur, % by mass	1.3	11, 12	ASTM D4294
Ash, % by mass	0.005 max.		ASTM D482
Net Heating Value, Btu/lb (kcal/kg)	To be reported		ASTM D4809
Specific Gravity	To be reported		ASTM D1298

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GAS TURBINE LIQUID DISTILLATE FUEL REQUIREMENTS

NOTES TO REQUIREMENTS (TABLE 1)

NOTE 1

The most recent revision of the ASTM test method should be used insofar as practicable. An equivalent test method may be used in lieu of ASTM test method, if approved by PWPS/P&W.

NOTE 2

Maximum fuel viscosity at gas turbine fuel pump inlet shall be 6.0 cSt for starting and 12.0 cSt during operation. Fuel may be heated, to a maximum of 160 deg F (71C), to meet this requirement.

NOTE 3

In order to operate FT8 with Category a fuels, such as naphtha, specially designed PWPS/P&W fuel system components are required.

NOTE 4

The fuel delivered to the inlet of the gas turbine is to have a sediment level less than 10 mg./gallon of fuel. However, for practical extended fuel filter life, the fuel should have lower sediment levels

NOTE 5

Minimum hydrogen percentage by weight is 12.4; however, for optimum combustion, higher hydrogen percentage is recommended.

NOTE 6

To achieve the level of sensitivity required for the detection of some of these metals, the furnace atomic absorption method may be necessary. Since some trace metals can have harmful effects on gas turbine operation, it is necessary to impose limitations. Higher levels of Table 1 metallic levels, even for short period, will increase the gas turbine maintenance costs.


NOTE 7

Limits of metal contaminants in Table 1 assume no contaminants in the inlet air or injected water. For operation with contaminants in the inlet air or injected water, the maximum allowable limit of any particular contaminant in the fuel must be reduced according to the following formula:

$$A_f = L_f - [C_{air} \times (\text{air/fuel weight ratio})] - [C_{water} \times (\text{water/fuel weight ratio})]$$

where,

A_f	=	Maximum allowable contaminant in the fuel, ppm by wt.
L_f	=	Contaminant Limit as called out in Table 1, for example 0.2 for (Na+K)
C_{air}	=	Contaminant in inlet air, ppm by wt.
C_{water}	=	Contaminant in injection and/or evaporative cooling water, ppm by wt.

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GAS TURBINE LIQUID DISTILLATE FUEL REQUIREMENTS

NOTE 8

Copper corrosion test conditions are 2 hours at 212 deg F (100 deg C).

NOTE 9

No flash point limitation is specified; however, local regulatory limits and safety regulations must be met.

NOTE 10

The cloud point shall be at least 25 degrees F below the anticipated gas turbine fuel inlet temperature. To meet this requirement, additional fuel heating, to a maximum of 160 degrees F (71C), may be needed.

NOTE 11

Sulfur content limits Below 1.3% WT. are imposed when:


- a) The local regulatory limits of sulfur oxides exhaust emissions are exceeded; then the fuel sulfur content must be reduced until the local regulatory limits are satisfied. For instance, the USA EPA limits fuel Sulphur content to 0.8% for SO₂ emissions control, but local codes vary widely.
- b) If exhaust heat recovery equipment is employed; then the equipment manufacturer's limit may apply.

NOTE 12

High sulfur fuels will impact hot section repair interval dependent on the amount of alkali metals present. The combination of high sulfur and high alkalis must be avoided.

NOTE 13

Maximum particle size to be controlled by filtration with a β_{20} ratio of 200.

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GAS TURBINE NATURAL GAS FUEL REQUIREMENTS

GENERAL

This document provides the requirements and application guidelines for natural gas fuels which can be fired satisfactorily in PWPS/P&W gas turbines without fuel system modification.

The term gas fuel can refer to a range of fuels which are normally in the gas state in gas turbine operational use. These range from low BTU content types such as coke oven gas to high BTU types such as propane. Because of the wide variation of gas fuels in ignition and combustion properties, as well as volume throughput requirements, their combustor and fuel delivery systems may differ widely. The fuel specification must be matched to the gas generator design.

The most common gas fuels used are those of the natural gas family. For satisfactory use in gas turbines, these fuels must meet minimum specifications so as to avoid combustion and fuel system problems, as well as hot section corrosive damage.

In addition to reviewing the composition and contaminants of the gas fuels being considered for use, the customer is urged to institute good fuel management, handling and treatment systems. A fuel that might not meet the requirements at the engine fuel inlet location may be treated prior to that location.


Present gas turbine combustion systems are comprised of conventional types which may or may not employ water injection to reduce oxides of nitrogen (NOx) emission, or Dry Low NOx (DLN) types which control NOx emissions without water. The latter are more sensitive to certain fuel properties than conventional systems and therefore have more stringent limits on some properties, as noted in the following specification.

GUIDELINES FOR EFFECTIVE FUEL MANAGEMENT

The first step in designing an effective fuel management system is to identify the composition and contaminants in the gaseous fuels being considered for use in PWPS/P&W aeroderivative gas turbines. The gas analysis performed to analyze the gas composition and contaminants should include, as a minimum, all properties listed in Table 1. Clean, dry fuel is required for safe and durable operation of a gas turbine.

The minimum and maximum limits of gas fuel supply temperature are listed in Table 1. The gas supply to the site should be evaluated to prevent any liquid from accumulating in the off site piping and then flooding the site fuel systems with large volume of liquids.

In reviewing the gas composition, the presence of corrosion-producing substances such as alkali metals (sodium, potassium, etc.), sulfur compounds, etc. should be noted so that proper precautions can be taken to minimize gas turbine and/or fuel system corrosion. When exhaust recovery equipment is utilized, there will be further requirements for fuel sulfur limit to minimize corrosion of the cold end surfaces.

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GAS TURBINE NATURAL GAS FUEL REQUIREMENTS

The contaminants in natural gas are normally introduced as a result of production and transportation processes. These contaminants may include tar, resins, water, salt water, rust (iron oxide), sand, lubricating oil, crude oil, gas hydrates, ice, construction debris, etc. Widely distributed gaseous fuels such as natural gas are usually cleaned prior to distribution. Water with its associated pipeline corrosion and condensate are probably the largest contaminants occurring in the gas distribution systems.

The design of an adequate fuel handling/treatment system is based on the actual gas composition and the contaminants present in the gas fuel delivered to the site. The following considerations should be addressed in the design of an effective gas fuel management system:


- Pressure reducing station
- Type of filtration systems such as inertial separators (scrubbers), gas separator, coalescing filter, or filter separator to remove liquid and/or solid contaminants
- Fuel handling system materials that are compatible with the gaseous fuel properties
- Fuel heating to raise the temperature of the gas sufficiently above the hydrocarbon and moisture dew points
- Safety precautions for handling the fuel

To protect the power plant equipment, a fuel testing program to periodically measure contaminant removal from the fuel and perform maintenance on the fuel filtration system is recommended. This is an important step in ensuring that the proper quality fuel is provided to the gas turbine.

PWPS/P&W fuel requirements of Table 1 are the allowable limits of fuel properties. The operators of the PWPS/P&W equipment must comply with all aspects of this specification, and confirm compliance through analysis of gas fuel samples taken regularly. Additional detailed guidance can be obtained through a PWPS/P&W representative.

OTHER GASEOUS FUELS


The standard model gas turbine is optimized to operate on gaseous fuels within this specification. The gas turbine has the basic capability of operating on a range of fuels outside of this specification, but may require modifications to fit the specific application. Such modifications could include fuel system component re-sizing, additional safety equipment, fuel pre-heating or gasification equipment, and engine controls adjustment. To judge the suitability of other gaseous fuels for a given application, please contact the PWPS/P&W Marketing Department.

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		REFERENCE :	REV:	

GAS TURBINE NATURAL GAS FUEL REQUIREMENTS

TABLE 1: GAS TURBINE GASEOUS FUEL REQUIREMENTS

Property	COMBUSTOR TYPE		NOTE(S)	Test Method (Note 1)
	A	B		
	Conventional	DLN		
Lower Heating Value (LHV) BTU/SCF (MJ/m ³)	800-1200 (30 - 45)	800-1200 (30 - 45)	2	ASTM D3588
Wobbe Index, BTU/SCF (MJ/m ³)	1040-1350 (39 - 50)	1040-1350 (39 - 50)	2, 3	ASTM D3588
Hydrogen Gas (H ₂) Content, % Vol. Max	Note 4	1.0	5	ASTM D1945
Carbon Monoxide (CO) Content,% Vol	Note 6	Note 6	6	ASTM D1946
Total Particulate, PPM WT. MAX.	30	30	5, 7, 10	ASTM D2009
Max Particle Size, Microns (Micrometre)	10	10	-	ASTM D2009
Max Gas Supply Temp, °F (°C)	300 (149)	300 (149)	5	-
Min. Gas Supply Temp, °F (°C)	32 (0)	32 (0)	5	-
Min Gas Fuel Superheat Above Hydrocarbon Dew Pt, °F (°C)	+28 (+16)	+50 (+28) Note 13	5	-
Min Gas Fuel Superheat Above Moisture Dew Pt, °F (°C)	+28 (+16)	+50 (+28)	5	-
Total Sulfur Content,% Wt Max	Note 8	Note 8	5, 10, 8	ASTM D1072 or ASTM D3246
Total Metals, PPM Wt, Max Sodium + Potassium	0.2	0.2	5, 10	ASTM D3605
Water Content	Note 10	Note 10	5, 11	ASTM D1142
Flammability Ratio (UFL/LFL), MIN	Not Applicable	2.2	12	

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GAS TURBINE NATURAL GAS FUEL REQUIREMENTS

NOTES TO REQUIREMENTS (TABLE 1)

NOTE 1

The most recent revision of the ASTM test method should be used insofar as practicable. Equivalent test method may be used in lieu of ASTM test method if approved by PWPS/P&W.

NOTE 2

At standard conditions of 60° F (15.6° C) 1 atm (101.3 KPa).

NOTE 3

Wobbe Index = $LHV / \sqrt{S.G. \cdot (T_{gf} + 460) / 520}$ OR Wobbe Index = $LHV / \sqrt{S.G. \cdot (T_{gc} + 273) / 288.6}$
(corr. to 60° F) (corr. to 15.6° C)

Where:

T_{gf} = inlet gas temperature, °F

S.G = specific gravity relative to air

LHV in BTU / SCF

Where:

T_{gc} = inlet gas temperature, °C

S.G = specific gravity relative to air

LHV in MJ/m³ (note 2)

NOTE 4

Hydrogen content up to 4% vol. may be used. Higher amounts of hydrogen content can be used but should be approved by PWPS/P&W and must satisfy all applicable safety codes for the fuel system.

NOTE 5

At the inlet to the gas turbine fuel plate or at gas turbine enclosure interface, if the enclosure is provided by PWPS.

NOTE 6


Fuel CO content will increase CO output, thus CO fuel content may require control to meet guarantee exhaust emissions levels.

NOTE 7

Particulates are composed of any solids in the gas fuel stream, including sand, rust, clay, coke, tar, iron sulfide, etc.

NOTE 8

Total sulfur includes hydrogen sulfide (H₂S), mercaptans, carbon disulfide (CS₂), carbonyl sulfide (COS), thiophene, sulfur oxides, etc.

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GAS TURBINE NATURAL GAS FUEL REQUIREMENTS

NOTE 9

Limits on fuel sulfur are imposed when:

- a) The local regulatory limits of sulfur oxides exhaust emissions are exceeded, then the fuel sulfur content must be reduced until the local regulatory limits are satisfied.
- b) When exhaust heat recovery equipment is employed, the equipment manufacturer's limits will apply.

NOTE 10

The allowable gas fuel contaminants shall be debited by the amounts of that contaminants entering with the inlet airflow (type A&B combustor) and water injection flow (type A combustor):

Allowable fuel limit = Overall limit - (Air/Fuel x Inlet Air Level) -(Water/Fuel x Water Level)

NOTE 11

Gas Hydrates are not allowed, therefore water content should be below the concentration which would allow gas hydrates to form at the operating temperature and pressure. Fuel heating is allowed to bring gas fuel temperature above the moisture saturation (dew) point.

NOTE 12

Flammability limits at 1 atm (101.3 KPa) and 77 Deg. F (25 Deg. C).

NOTE 13

FOR DRY LOW NO_x (DLN) COMBUSTORS ONLY:

- Hydrocarbon dew points are to be evaluated from ambient pressure up to the maximum gas turbine inlet pressure
- Dew points will be based on extended analysis to C14 level according to method of GPA 2286-95.
- Gas samples shall be taken per method of GPA 2166-86.
- Concentrations should be determined to an accuracy of 10 PPM or less.
- The maximum expected dew point line during the operating period, must be used to establish the minimum required fuel temperature at the gas turbine inlet



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PWPS SPECIFICATION

RELEASED

FR-2

REV D

SHEET 1A
OF 1

ISSUED BY: P. Lavendier

DATE: 7/1/85

REVISE BY: L. DiSalvo/J. Kennedy

DATE: 7/23/01

REFERENCE:

REV:

GAS TURBINE NATURAL GAS FUEL REQUIREMENTS

REV LET	SHEETS AFFECTED	SHEETS ADDED	DESCRIPTION	REV BY & DATE	APPVD & DATE
A	All	3 & 4	Specification completely re-written incorporating Gas Turbine Gaseous Fuel Requirements for "Dry Low Nox". Title was "Gas Turbine Gaseous Fuel Requirements". Proprietary box was removed.	EC#8975 D. J. Dalal 10/28/97	
B	All	5	In table sht 3 deleted "absolute" in max. particle size Changed MJ/nm3 to MJ/m3	EC#9012 D.J. Dalal/T. Fox 12/22/97	
C	3 5		In table sht 3, added note 13 in column B Added note 13 requirements for H/C dew point.	EC#9077 T. Fox 8/20/98	
D	All 3		Updated Logo to new PWPS Logo. Updated all TPM references to PWPS references. In Table1: 1. Change test method for CO from ASTM D2099 to ASTM D1946. 2. Added ASTM D3246 as an alternate test method for total sulfur content.	EC#9925 L. DiSalvo J. Kennedy 7/23/01	