DESIGN AND DEVELOPMENT OF A NEW 30,000 HP CLASS TWO SHAFT TYPE GAS TURBINE

by

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ABSTRACT

A description of the application of advanced technology, high temperature, gas turbine design technique to a new model two-shaft type gas turbine to achieve a high efficiency, high reliability, regen cycle and simple cycle gas turbine with a wide range of performance optimization.

INTRODUCTION

The genesis of Westinghouse two shaft gas turbines for mechanical drive units goes back to 1955 with the W52 and has advanced through the NEMA output ranges via the W52, W62 to the W92 frame size of 10,000 HP.

Design work then concentrated on the single shaft unit designed primarily for electrical power generation drives through the W171, W191 to the W251 and W501 frame sizes.

Some three years ago a study of the world market demands showed a growing need for two shaft mechanical drive gas turbines in the 30,000 HP range and a design investigation was undertaken to examine how such a need could be filled.

The areas of demand could be delineated as:

a. Prime movers for Pipeline operation in Gas Pumping duties.

b. Prime movers for Process Plant operation in Gas or Oil Pumping duties.

c. Main Propulsion units for Marine application.

and tabulating the major requirements of each area was a necessary beginning to setting the guide lines for design.

	Gas Pipe Line Duty	Process Plant Duty	Marine Applications
Duty	Base load continuous	Base load continuous	Intermittent base load
Location	World wide - sea level to say 5,000′	World wide - sea level to say 5,000′	World wide - sea level
Climate	Arctic to Tropical	Arctic to Tropical	Arctic to Tropical
Environment	Snow and icing conditions to dust and sand conditions	Snow and icing conditions to dust and sand conditions	Marine with snow and ice
Fuel	Natural Gas	Process Gas and/or Distillate Oil	Distillate, Crude or Residual Oil, Natural Gas
Control	Automatic and unattended	Manual/automatic	Manual/automatic

The major requirements of all users are:
Good reliability
Minimum maintenance
Accessibility for maintenance
High efficiency
Emissions to meet local and central government laws.

The major requirements of the firm are:
A reasonable return on the design and development outlay
Competitive in cost and performance
Ability to ship to market.

Each of the major requirements mentioned above can be further broken down to form the envelope within which the design must occur and whilst it is not the intention of this paper to fully explore all the checks and controls that are laid upon the design it is hoped that the paper will show the sequences of work that had led to the latest Westinghouse two shaft mechanical drive gas turbine design.

DESIGN CONCEPT

The major target to aim for is of course the maximum overall thermal efficiency for converting heat into mechanical work that is obtainable. The possibilities are conditioned by two major criteria, the aerodynamic and thermodynamic expertise available for the design of compressors, combustion systems, turbine and ducting, and the expertise available to provide materials that will withstand the demands made by the thermodynamic and aerodynamic requirements.

Figures 1 and 2 illustrate the relationship between the cycle thermal efficiency and the compressor pressure ratio for a range of firing temperatures and the resulting exhaust temperature. Two cycles of operation are illustrated, the simple cycle and the regenerative cycle.

The choice here is whether to opt for the high efficiency simple cycle requiring pressure ratios of 16:1 and above, or to go with the regenerative cycle requiring much lower pressure ratios and utilize the basic regenerative design in a combined cycle for non regenerative applications. The regenerative cycle has a better cycle efficiency than the simple cycle for a given firing temperature, but requires a regenerator.

The combined cycle in which a waste heat boiler would generate steam is shown in Figure 3. The simple cycle unit HP has been reduced to near the regenerative cycle value so that a direct comparison of efficiencies may be made. At ISO the regenerative cycle produces about 31,000 HP whilst the combined cycle produces 32,000 plus 16,000 HP. Current steam turbines and associated boiler equipment using carbon steel require a steam quality of 600 psia and 825°F and this demands a minimum turbine exhaust temperature of about 900°F.

The power requirement of 30,000 HP revealed by the market survey prompted examination of the W251 frame size as a starting point for the concept. Studies had showed that the basic W191 compressor with some stage rearrangement would produce a flow and pressure ratio compatible with power requirements and a regenerative cycle, and the firing temperature of the W251, *i.e.*, 1,850°F was suitable for both efficiency in the regenerative cycle and use in a combined cycle.

Using the actual firing temperature of 1,850°F of the W251 and the pressure ratio, flow and efficiency for a W191 rearranged compressor, it was possible to compare more closely the merits of the various cycles at ISO conditions.

	Medium Pressure Ratio Unit		High Pressure Ratio Unit
	Regenerative	Simple Cycle	Simple Cycle
Firing temp. °F	1850	1850	1850
Power output	30750	37600	34500
Pressure ratio	7.9:1	8.7:1	20.1
No. of compressor stages	16	17	?
Heat rate BTU/HP. HR.	6720	8720	7550
Turbine exhaust temp. °F	1034	996	780
Overall thermal efficiency	37.9	29.2	33.7
Combined cycle power output		54500	42600
Combiued cycle efficiency		42.3	41.7

The overall thermal efficiency is higher for the medium pressure ratio regenerative cycle, and there is adequate exhaust temperature to produce the requisite steam quality for a combined cycle using the medium pressure ratio simple cycle.

Preliminary matching calculations showed that the first stage of the W251 turbine could be adapted as a single stage to drive the modified W191 compressor, utilizing the technology and field experience of existing units.

The concept that finally emerged utilized a modified W191 compressor within the modified carcass of a W251 having an overhung single stage compressor turbine.

The gas generator was to be a completely separable component from the rest of the unit. A new design of power turbine having a single overhung stage with shrouded rotating blading, and a combined inter-turbine vane assembly, to prevent diffusion and losses between the compressor and power turbines, with a variable power turbine nozzle. The power turbine and its interturbine vane assembly also to be a complete entity separable from the gas generator.

The combustion system would utilize the basic W251 combustors suitably modified for regenerative and simple cycle duties.

To ensure alignment and centralization of the gas generator rotor assembly, the structural loads of the gas generator were carried from the compressor through to the exit flange

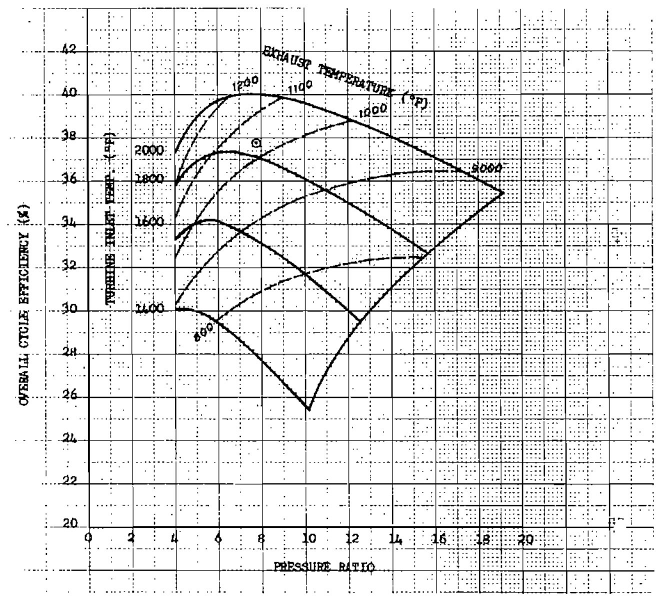

Figure 1. Overall Gas Turbine Efficiency — Regenerative Cycle

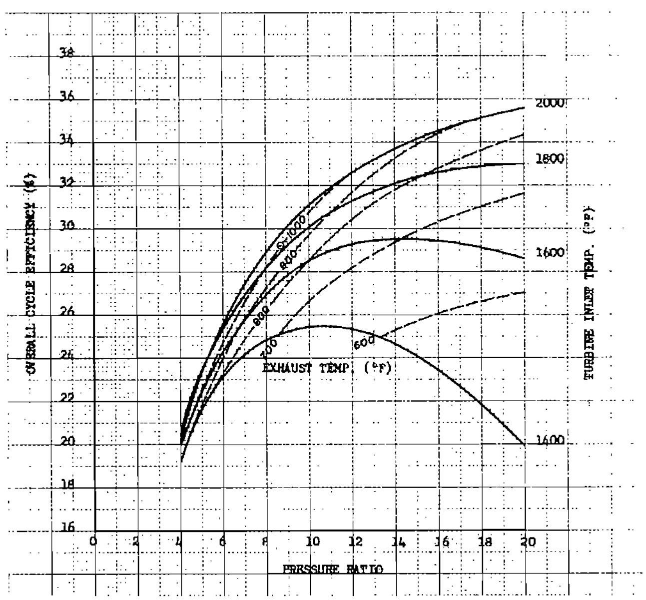

Figure 2. Overall Gas Turbine Efficiency — Simple Cycle

by internal struts which would also serve as the support for the rear bearing housing. The combustor casing would incorporate a central wall for regenerative duties and be suitably insulated on the internal surfaces to minimize thermal gradients between the section carrying the compressor delivery air to the regenerator piping and the section seeing the regenerated air. The removal of the structural loads from the combustor casing allowed a light flexible construction that leads to a gas tight assembly.

Overhanging the turbine stages allows close coupling between the gas generator and power turbine.

The major design work to be carried out can be summarized as follows:

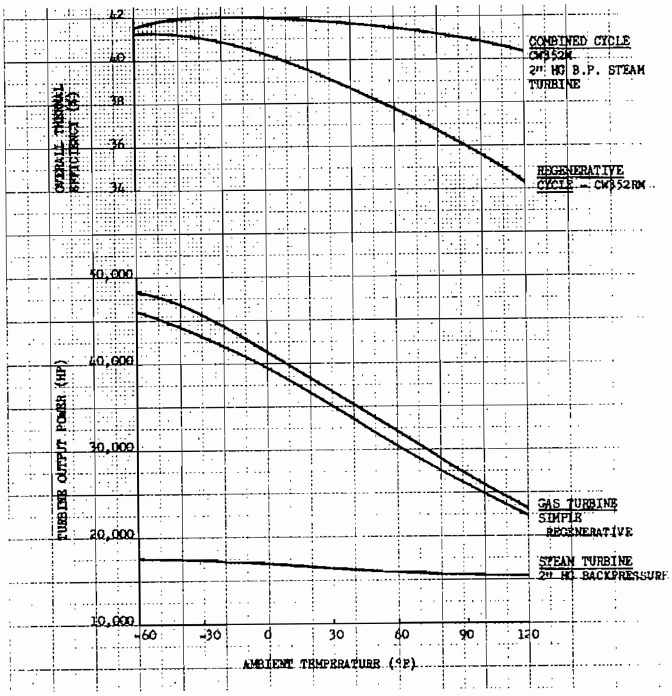

Figure 3. Power and Efficiency Comparison: CW-352

1. Develop structural concepts of:
   a. Combustor shell subjected to large thermal gradients due to difference in temperature of compressor delivery air and regenerator return air.
   b. An intermediate bearing support system.
   c. An overhung gas generator turbine.
   d. The gas generator turbine disc and blade cooling scheme.
   e. The gas generator spindle and disc design.
   f. The variable area turbine vane and transition section at inlet to the power turbine.
   g. The power turbine overhung disc and shrouded blade system.
2. a. Check that an existing turbine stage could be adapted to the requirements of the gas generator.
   b. Develop a Power Turbine shrouded blade design.
3. a. Carry out cycle and performance calculations having regard to the effect of components, cooling flows, pressure losses, on engine performance.
   b. Calculate expected thrust loads over the engine operating range.
   c. Calculate limiting temperatures and pressures over the engine operating range at various radial and axial stations.
   d. Determine the performance envelope for fixed and variable power turbine inlet vanes.
4. Make a first cut design of the engine cooling system using a flow network program.
5. Carry out a cost study of the design concept longitudinal.
6. Develop a regenerator specification.
7. Specify and plan the required test programs, engine design tasks and schedules required for a full design.

PROVING THE CONCEPT

The concept occupied a period of six months during which time certain precepts were developed. The work done in that time now needed to be subjected to the design investigation proper and to the production of the thousands of drawings necessary to manufacture both the turbine and its auxiliary equipment, as well as production specifications which included the full performance, and all items both necessary and optional for operation anywhere in the world and in any climatic condition.

The design team consists of mechanical designers, aerodynamicists, thermodynamicists, heat transfer specialists, metallurgists, combustion engineers, planning, manufacturing and cost engineers, layout, assembly and detail drafting personnel, and of course, a manager. The starting point for all these people is the information arising from the aerodynamic and thermodynamic investigations that result in the required performance. The preliminary information provided by the concept is first utilized to start firming structures whilst the aerodynamicists and thermodynamicists subject the concept to a complete investigation of the performance attainable by each item starting with the compressor intake and running through the compressor, turbines, interturbine vanes and exhaust manifolds.

The matching characteristics of each item at the design point are examined and then checked for off design point operation. As these investigations proceed, changes in the initial information become available and the design team can establish the mechanical criteria. This process results in recycling and attaining the compromises that eventually lead to the final design.

The final results are shown in Figures 4 and 5 which illustrate the longitudinals of the regenerative and simple cycle designs.

DESCRIPTION

The model CW352RM gas turbine consists of two sections, namely the gas generator and power turbine which are self-contained and separable structures. (Figure 6.)

The gas generator section consists of the inlet, compressor, combustor and compressor turbine casings supporting the compressor/compressor-turbine rotor in two bearing assemblies. The rotor consists of a sixteen stage axial flow compressor with a single overhung compressor turbine stage having cooled stationary vanes and cooled rotating blades.

The power turbine section consists of the power turbine and exhaust diffuser casings, supporting the overhung single stage turbine rotor on two bearing assemblies mounted in a common bearing housing.

GAS GENERATOR

Inlet Casing Assembly

The carbon steel inlet casing performs a dual function. It provides a smooth air flow passage to the inlet of the axial flow compressor and supports the outboard bearing assembly. The bearing housing is held concentric within the inlet casing by use of radial struts.

The bearing housing contains a radial bearing of the tilting pad type and a dual tilting pad thrust bearing to absorb thrust in either direction as well as hold the rotor within its design axial position under all conditions.

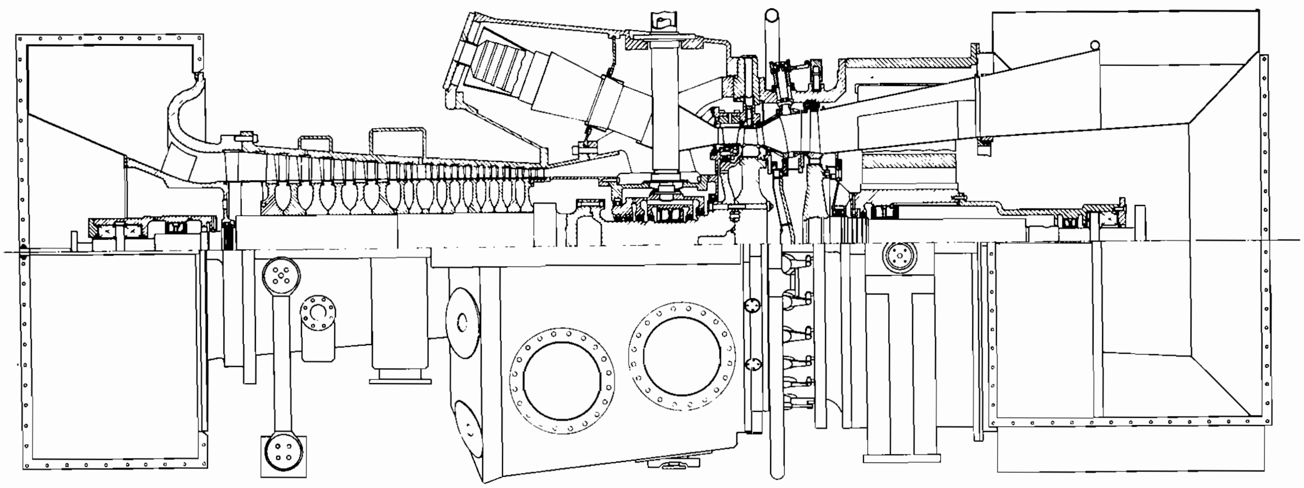

Figure 4. Longitudinals of the Regenerative Cycle Design: CW-352RM Turbine Engine

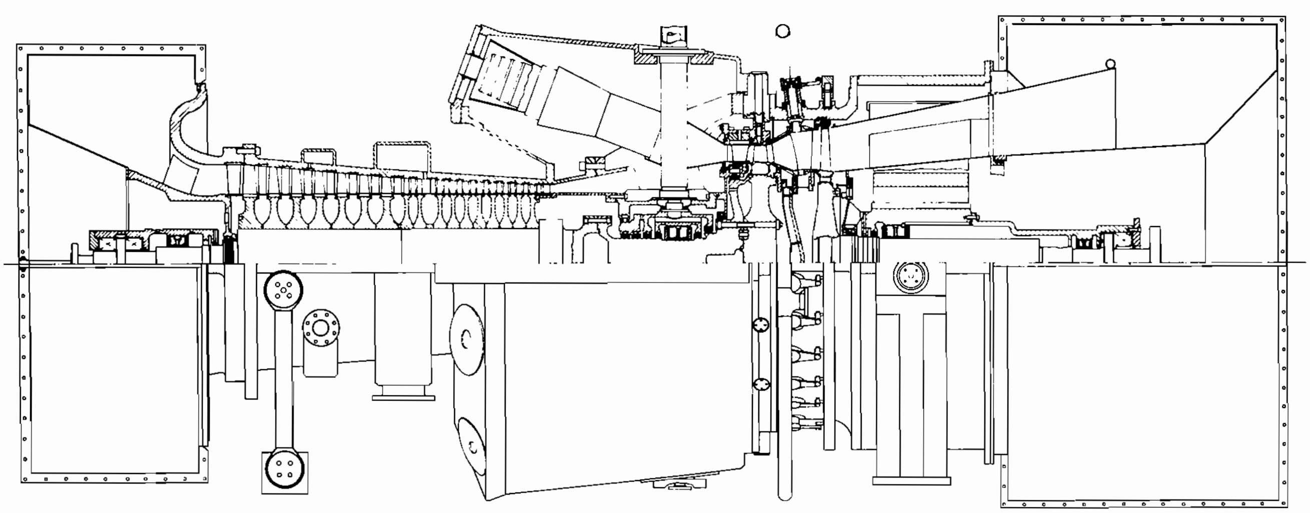

Figure 5. Longitudinals of the Simple Cycle Design: CW- 352M Turbine Engine

The inlet casing supports the inlet guide vane assembly of the compressor.

An option feature available is:

Heated inlet guide vanes to prevent ice accumulation.

Compressor Casing Assembly

The carbon steel compressor casing is arranged to accommodate 16 stages of stationary vane assemblies. The casing is assembled with a bolted horizontal joint. The top cover is removable for easy access.

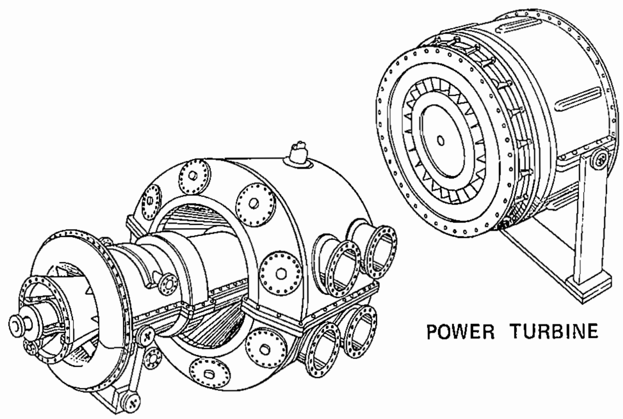

Figure 6. Gas Generator and Power Turbine

The double trunnion type of casing support is attached to the forward end of the compressor casing. This system provides true centerline support of the gas turbine in the transverse and vertical directions while allowing free thermal expansion in the axial direction relative to the fixed support at the turbine end of the unit.

The stationary vane assemblies are fabricated in halves utilizing stainless steel vanes and carbon steel shrouds.

Combustor Casing Assembly

The combustor assembly consists of three main structural components namely, the strut system, combustor shell and compressor turbine assembly.

The strut system consisting of six ribs is bolted to the discharge end of the compressor casing and to the end of the compressor turbine casing. The central portion of these ribs is extended radially inwards to the inboard compressor-turbine bearing housing support casing. The strut system provides the strength and rigidity to this portion of the cylinder assembly and maintains concentricity of the inboard bearing with the compressor-turbine casing.

The bearing housing is mounted within the strut support casing, and contains a tilting-pad type radial bearing. A seal air system contains oil vapours within the bearing housing and provides cooling for the bearing and its housing.

Venting of the seal air is provided in the drain portion of the co-axial oil supply and drain piping and as well in the bearing housing vent pipe which is co-axial with the supply air pipe.

The compressor-turbine cylinder which forms the aft end of the gas generator section, supports a horizontally split blade ring. The blade ring is held concentric within the cylinder via radial guide pins.

The individual cast alloy vane segments are provided with internal air cooling. Replacement of these vanes is possible by removing the top half of the combustor shell and the combustor basket assemblies. Provision is made for borescopic inspection of the compressor-turbine vanes and rotating blades.

The horizontally split combustor shell is designed to contain the hot pressurized gas yet be flexible, because the strut system provides the strength and rigidity to the turbine casing.

The shell is provided with regenerator supply and return outlet pipes. Internally, the hot and cold zones of the shell are separated by a floating wall.

The combustion system comprises eight can type combustion baskets which are conically disposed along the longitudinal axis of the unit, four in the upper and four in the lower casing between the compressor and turbine. This provides for accessibility and compact unit length. Each basket assembly includes liner shields around the primary and the secondary sections, a transition piece assembly, cross flame tubes and a gas fuel nozzle.

Compressor/Compressor-Turbine Rotor

The rotor consists of a sixteen stage axial flow compressor with a single stage overhung compressor-turbine.

The compressor section of the rotor comprises a solid, forged alloy spindle, forged alloy compressor discs shrunk on the shaft and chrome steel blading with dove-tailed side entry roots. The blades are held in place with spring-loaded pins, to permit ease of replacement. Any blade can be replaced without disturbing any other blade row, or requiring removal of the rotor.

The compressor-turbine section of the rotor consists of a spindle with integral seal air wall and a separate disc which is keyed and bolted to the spindle. A central spigot maintains concentricity of the assembly. Both components are of forged alloy steel construction.

The compressor-turbine blades are cast from alloy steel and have extended side-entry, serrated roots for high strength. Internal cooling passages are incorporated to cool the entire blade. A locking plate system is used to secure the blades in the disc and provide passages for disc root and blade cooling. The blades can be removed and replaced without removing the rotor.

POWER TURBINE

Turbine Casing Assembly

The turbine casing supports the variable power turbine vane assembly and encloses the single stage turbine blades. The horizontally split steel casing allows access for inspection of power turbine vanes and rotor blades. Access for borescopic inspection of the turbine blades and vanes is provided in the casing.

The fixed portion of the vanes are cast in pairs from alloy steel. The variable vanes are connected to an externally mounted unison ring which is actuated in response to control signals.

The unique arrangement of the fixed and rotatable vane assembly allows close gas coupling between the compressor-turbine and power turbine rotors, for improved cycle efficiency.

A central floating diaphragm assembly supported from the vanes separates the cooling paths to the rear face of the compressor turbine disc and to the front face of the power turbine disc.

Exhaust Diffuser Casing Assembly

The integral exhaust diffuser assembly consists of a steel outer casing supporting the bearing housing via a tangential strut system. Access for borescopic inspection of the struts is provided. The exhaust diffuser cone assembly shields the casing components from the hot exhaust gases. The assembly is horizontally split.

The power turbine bearing housing supports two radial tilting pad bearings and a double thrust bearing. The thrust bearing inboard side is of the single pad type while the outboard side is a six-shoe tilting pad type. The horizontally split bearing housing is arranged for inspection and removal of any bearing without the necessity for dismantling the outer casing or removing the rotor. Fixed turbine supports attached to the exhaust diffuser casing provide centerline support transversely and vertically while restricting axial motion.

Power Turbine Rotor

The single stage power turbine rotor with overhung disc is arranged for counter-clockwise rotation when viewed in the direction of gas flow. It is designed to operate over a speed range from 2,500 to 5,250 RPM.

The integral disc and shaft is made from forged alloy steel. The precision forged alloy steel blades have extended shanks and serrated side entry roots. The extended shank helps to isolate the disc and blade roots from the hot gas path.

Integral with the blades are interlocking tip shrouds to reduce tip leakage and dampen out blade vibration.

A locking plate system is used to axially position the blades in the disc and provide passages for disc and blade serration cooling.

INLET AND EXHAUST MANIFOLDS

Inlet Manifold

The horizontally split inlet manifold is fabricated from steel with either left or right-hand side entry. It has been designed to produce a uniform air flow distribution at the inlet to the compressor and to prevent ice formations.

Exhaust Manifold

The horizontally split exhaust manifold with integral diffuser is fabricated from steel, and again is oriented for left or right-hand side exhaust.

INSULATION

The turbine casing including all horizontal and vertical joints is insulated using removable-type blankets. These blankets consist of kaolin clay fibre mat covered with an aluminized fabric.

COOLING AIR SYSTEM

In the cooling air system of the CW352, air is extracted from three locations in the axial compressor and fed to appropriate hot parts of the gas turbine. The major features of the cooling system are as follows:

High Pressure Cooling System

High pressure air is taken from the compressor discharge and used to cool the compressor turbine vanes, the compressor turbine rotating blades, and the front face of the compressor turbine disc.

a. The compressor turbine vane aerofoil is a hollow design with tubular cooling air holes running radially in the aerofoil walls both on the pressure and suction sides. It also has trailing edge holes through which the cooling air exits from the blade and re-enters the turbine gas path.

b. The compressor turbine rotating blade is an extended root design with a series of tubular, radial cooling holes running from the bottom of its fir-tree root to the outer tip of its aerofoil. Some high pressure cooling air is fed up the front face of the compressor turbine disc where it enters the radial cooling air holes in the blades and is exhausted to the turbine gas path at the blade tips. Additional high pressure cooling air follows a path which brings it axially past the root extensions of the blade, re-entering the turbine gas path downstream of the compressor turbine.

Intermediate Pressure Cooling System

Intermediate pressure air is taken from the compressor bleed air extraction chamber and used to cool both the rear face of the compressor turbine disc and the front face of the power turbine disc.

The air is fed into the turbine cylinder, through the hollow fixed portion of the power turbine vanes, and between the walls of a double skinned diaphragm to reach the centerline, where the air is metered both forward to the compressor turbine disc and aft to the power turbine disc. The air which cools the rear of the compressor turbine disc re-enters the turbine gas path when it reaches the disc perimeter. The air which cools the front of the power turbine disc is directed axially when it reaches the disc perimeter and cools the extended roots of the power turbine blades before re-entering the turbine gas path downstream of the power turbine.

Low Pressure Cooling System

Low pressure air is taken from the second stage of the axial compressor and used to seal and cool the compressor turbine radial bearing in the combustor cylinder, to cool the rear face of the power turbine disc, and to seal the other turbine bearings against oil leakage.

a. To prevent hot axial compressor discharge air from leaking along the rotating shaft into the radial bearing in the combustor cylinder, cool, low pressure sealing air is introduced to a chamber that separates the bearing from the compressor discharge air. This chamber is vented to atmosphere to effectively carry off any axial compressor discharge air that leaks past the shaft seals. The low pressure air provides a cool environment for the bearing housing.

b. Low pressure air is introduced to the cavity behind the power turbine disc along the shaft and cools the power turbine disc as it moves out to the disc perimeter where it re-enters the turbine gas path (Figure 7).

DESIGN FEATURES

a. Wide speed range of the power turbine; from 50% to 105% of design speed.

b. Single overhung rotor assemblies for the compressor turbine and power turbine provide unrestricted gas flow passage to the turbine blading.

c. Variable power turbine vane assembly, allowing close coupling of the compressor-turbine and power turbine blading with no loss due to diffusion.

d. Single, tangential strut system downstream of the power turbine blading maintains concentricity of the power-turbine rotor within its casing.

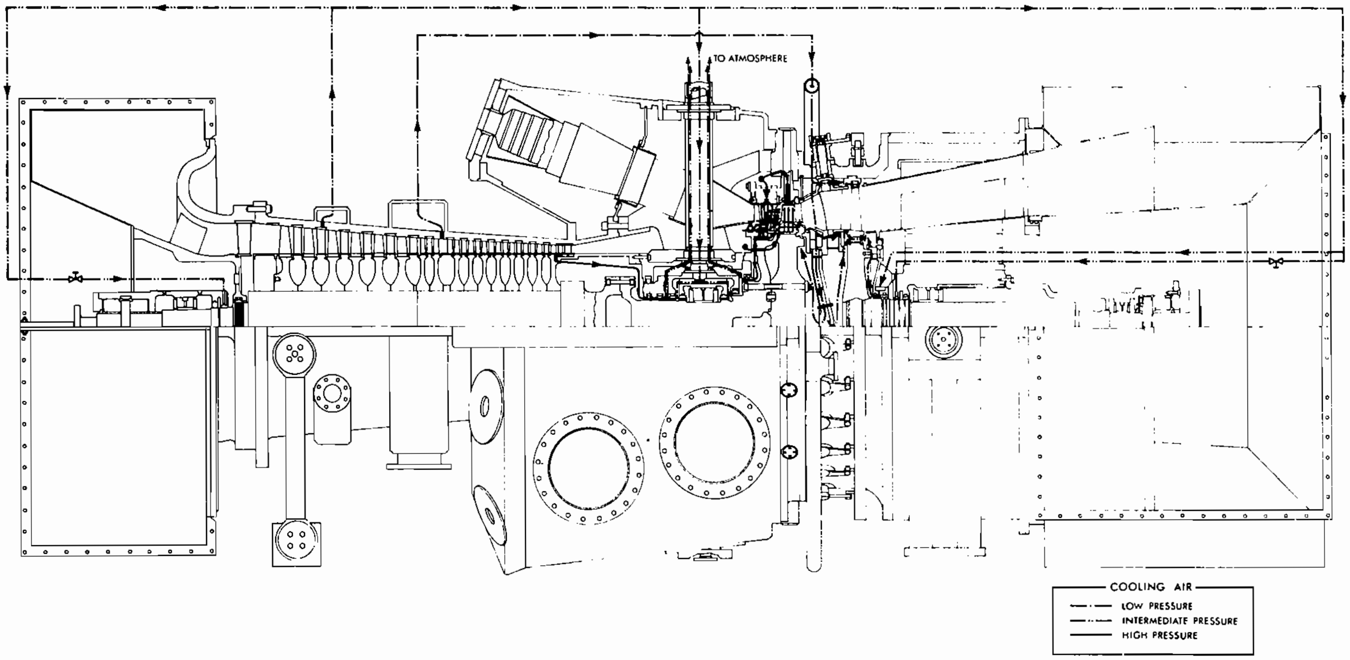

Figure 7: Cooling Air Systems: CW-352

e. True centerline support of the turbine structure on two sets of supports, arranged to minimize thermal growth at the power turbine load coupling.

f. Tilting-pad radial bearings for stable operation over a wide speed range.

g. Seal and cooling system for the compressor-turbine bearing assembly.

h. Two major separable structures, the compressor turbine assembly and the power turbine assembly.

i. Internal strut support system of the compressor turbine assembly maintains rotor bearing alignment and isolates the hot combustor section from the main structure.

THE REGENERATOR

The flow, temperature and regenerator effectiveness required a new design of regenerator, and a detailed specification was issued to manufacturers. Three companies responded with varying designs, all of which met the specification. The problem of thermal shock which has in the past, reduced the useful life of some units used in gas turbine peaking applications, has been recognized and given emphasis in design criteria, and the increased gas side temperature of 1,050°F together with a high regenerator effectiveness has been met by stainless steel materials and improved heat transfer characteristics.

COMPONENT TESTS

Many parts of the new design such as compressors, compressor turbine blading, tangential supports, and the compressor turbine inboard bearing have been operating in similar or more onerous circumstances in previous Westinghouse frame sizes and have been proven in both mechanical and aerodynamic performance.

Where components are the result of new ideas or operating in areas where previous field experience is scanty or non existent, tests were arranged to ensure that every part of major importance will be proven before the unit is finally built.

The combined interturbine vane and variable power turbine nozzle assembly, which is considered to be a major advance in two shaft industrial gas turbine practise, will undergo full annulus scale model testing to verify their efficiency as a flow distributor and efficiency in preventing loss between the turbines.

The power turbine shrouded blades have been the subject of comprehensive finite element analysis for stress and dynamic response. This dynamic response will be verified by rig excitation testing prior to the initial build. The rig will consist of using the complete power turbine blade, disc and rotor shaft running in its own bearings and steam jets will be directed on the rotating blades to examine excitation effects. The rig will also allow checks on the critical speed and bearing behavior.

Model airflow tests have been carried out on the inlet of the compressor verifying entry conditions seen by the compressor to be excellent both circumferentially and radially.

The speed and power range of the unit results in large variations in outlet swirl from the power turbine. Airflow tests will be carried out on a model of the exhaust diffuser and manifold to ensure minimum loss and turbulences in the final design.

The combustion system has been developed by extensive investigations, utilizing water model techniques and full scale single basket tests over the operating range of the unit. The final system has to meet the specifications of ignition, stability, temperature gradients and basket metal temperature for natural gas, distillate oil, and dual fuel systems.

PROTOTYPE TEST

Loaded and unloaded tests will be carried out on the initial build to demonstrate performance and verify the correct operation of all systems. These tests will be made at the factory prior to delivery of the units to customers.

AUXILIARY SYSTEMS

Layout

The turbine sits on a one-piece bedplate at one end of which is the lube oil reservoir. The auxiliary systems which are mounted on the bedplate are all situated on top of the lube oil reservoir.

These systems include the lube oil system, fuel system, starting system, auxiliary drives and hydraulic system.

Lube Oil System

This will be similar to that used on previous Westinghouse units and will be offered in two versions. The regenerative cycle, pipeline version will have an auxiliary gearbox driven screw type main lube oil pump with AC motor driven centrifugal auxiliary pump. A DC motor driven emergency centrifugal pump will also be provided. Duplex oil filters and a separately mounted oil/air cooler will be offered as standard.

The simple cycle, process version will have steam turbine and/or AC motor driven centrifugal main and auxiliary pumps again with a DC motor driven centrifugal emergency pump. Duplex oil filters and duplex oil/water coolers mounted on the lube oil reservoir will be standard.

Lube oil will be available for the driven compressor at a range of pressures and flows.

Lube oil system components will be grouped together on one side of the lube oil reservoir.

Optional lube oil coolers for the regenerative cycle machine will be hot climate oil/air cooler and a cold climate oil/glycol/air cooling system.

Fuel System

The standard fuel for both regenerative and simple cycle machines will be natural gas. As an option on the simple cycle machine either distillate fuel oil or a dual fuel system will be available.

Both fuel gas and fuel oil valves will be grouped together on one side of the lube oil reservoir with AC motor driven fuel oil pumps, filters, etc., on a separate fuel oil skid.

Electro-hydraulic actuators will be used on the fuel valves as on the rest of the control system.

Starting System

A gas expansion starting turbine driving through the auxiliary gearbox will be standard. On the simple cycle machines this can be powered with steam and a starter/helper turbine will be available as an option. An overrunning SSS clutch will allow the starting turbine to be disengaged during running. This system along with a DC motor driven turning gear has been used reliably on many previous Westinghouse machines. The gas expansion turbine will be suitable for use on refrigerated natural gas.

Electro-hydraulic actuation of the starting turbine governor valve will permit a flexible and closely controlled start up cycle.

Auxiliary Drives

Both regenerative and simple cycle machines will have an auxiliary gearbox driven from the inlet end of the compressor turbine shaft.

On the regenerative cycle machine this gearbox, as well as having the starting system driving through it, will drive the main lube oil pump, a customer supplied seal oil pump for the driven compressor, an overspeed trip and two hydraulic pumps.

On the simple cycle machine the auxiliary gearbox will drive a seal oil pump, overspeed trip and one hydraulic pump with a shaft driven screw type lube oil pump as an option.

Hydraulic System

Two separate hydraulic systems will be used on the CW352 both having auxiliary gearbox driven pumps. One system will supply control oil to the fuel valve actuators, overspeed trip system, vapour extractor and various linear actuators. This system will have a second DC motor driven hydraulic pump for use during starting and shutdown.

The second hydraulic system which will be offered only with regenerative cycle machines powers the lube oil/air cooler fans to allow continued operation during an AC power outage.

Inlet System

An inlet system with inertial filters will be offered as standard. These filters remove rain, snow and any large and medium size particles from the airstream while requiring minimal maintenance.

As an option, a media filter or both inertial + media will be available. The inlet housing also incorporates a blow in door to bypass the filter should the pressure drop exceed a preset value.

For cold climate operation an anti-icing system will be available which includes snow hoods over the inlet filter, heated seals on the blow in door and heated I.G.V.'s.

Exhaust System

The exhaust configuration will depend on whether regenerators or waste heat boilers are fitted but in all cases will be silenced to level A or better.

OPERATING CHARACTERISTICS

The performance of the CW352 gas turbine at I.S.O. is tabulated below:

CW352 PERFORMANCE

MAXIMUM CONTINUOUS RATING
I.S.O. CONDITIONS (50°F, SEA LEVEL)
ZERO DUCT LOSSES
POWER TURBINE VANE AT NOMINAL POSITIONS

VERSION	CW352RM	CW352M	
Type of Fuel	Natural Gas	Natural Gas	Distillate Oil
Output Power (HP)	30,750	37,600	36,750
Heat Rate (BTU/HP.HR.)	6,720	8,720	8,800
Power Turbine Speed (RPM)	5,000	5,000	5,000
Exhaust Flow (LB/HR)	——	949,200	950,000
Exhaust Temperature (°F)	——	996	995

The simple and regenerative cycle versions are designed to operate efficiently over the ambient range of 120°F to -60°F from 0 to 6,000 feet altitude. Within this range, the variable power turbine vanes allow rematching with the gas generator portion to provide a range of power at rated turbine inlet temperature. (Figure 8.)

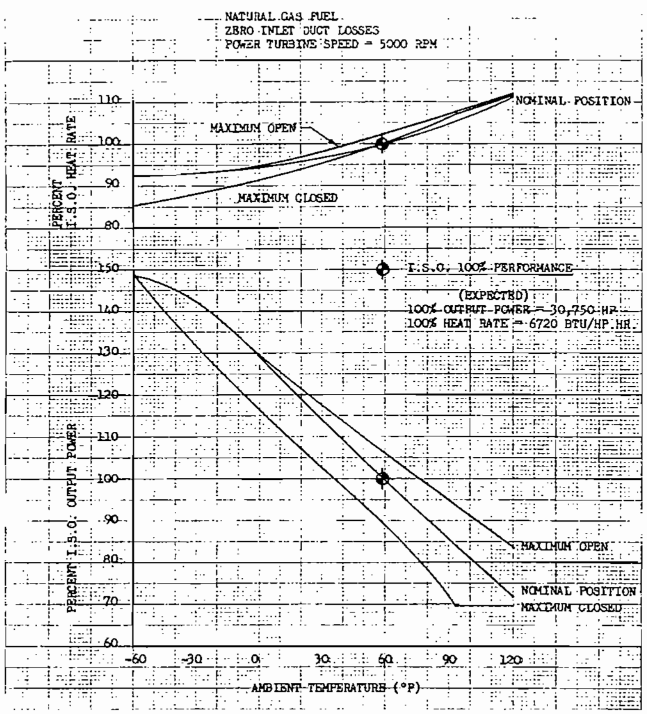

Figure 8. Full Load (expected) Performance Vs Ambient Temperature; With Range of Power Turbine Vane Position: CW-352RM

The vairable power turbine vane is utilized to enable the regenerative version to achieve its maximum possible overall efficiency at every part load power.

Variable inlet guide vanes allow a constant exhaust temperature to be maintained at constant power for combined cycle applications. Variable I.G.V.'s are an option.

A helper turbine may be used with the simple cycle version to increase the shaft power available at high ambients.

TURBINE CONTROL SYSTEM

Basic Control System for the gas turbine consists of:
Sequencing logic
Fuel Scheduling
Protection

Sequencing Logic is concerned with starting and stopping the turbine. This is fundamentally a conventional system in that certain events have to occur at given time intervals.

Specific requirements of the station status have to be satisfied prior to starting the turbine; examples being:
AC power available
DC power available
Fuel gas pressure available

Turbine unit functions also have to be satisfied, such as:
Lube oil temperature satisfactory
Compressor side valve positions correct
Fuel governing valve in closed position

The normal starting sequence to be followed, involves:
Scheduling gas to the starting turbine
Purging the turbine and gas compressor
Monitoring flame light-off
Scheduling fuel
Accelerating the turbine up to idle speed

Fuel Scheduling is an electrohydraulic system, using a Woodward type electronic governor. The governor receives its signal from the station control system and responds by changing the speed of the gas compressor. The governor also maintains the load within the speed and temperature limits of the gas turbine.

Speed probes measure pulses from toothed wheels, mounted on the power turbine shaft and on the gas generator coupling at the auxiliary gearbox.

Temperature is measured by thermocouples mounted in the gas path between the gas generator and the power turbine, and also by thermocouples located between the regenerator and the combustor shell.

The variable power turbine vanes are controlled in conjunction with the governor, to optimize available power with minimum fuel consumption.

Protection comprises several independent sub-systems. Overspeed protection is via hydraulic trip mechanisms on both the power turbine and gas generator shafts, operating directly on the fuel shut-off valve.

Temperature protection uses thermocouples in the hot gas path. Vibration protection consists of proximity probes on all four radial bearings. Bearing protection utilizes temperature detectors in the bearing shoes.

Station interface module is a feature designed in close cooperation with the customer. It is anticipated that, with unmanned stations, a considerable amount of data would be telemetered to the pipeline control centre.

Redundancy is being given careful consideration. Where a protective system has had a history of very good reliability, redundant systems are not required. However, where instrumentation has proved less reliable than the component it is protecting, redundancy is of real benefit. Systems where this concept is being applied are vibration, temperature monitoring, bearing oil supply, and certain areas of sequencing logic.

Hardware has been defined as basically solid state, utilizing electro-hydraulic valve operators for turbine functions.

SHIPPING, INSTALLATION, MAINTENANCE

Shipping

Charts have been prepared to show the breakdown for shipping the turbine and associated equipment to the field. Further charts illustrate replacement component weights for maintenance purposes by air if necessary. Typical charts are shown in Figures 9 and 10.

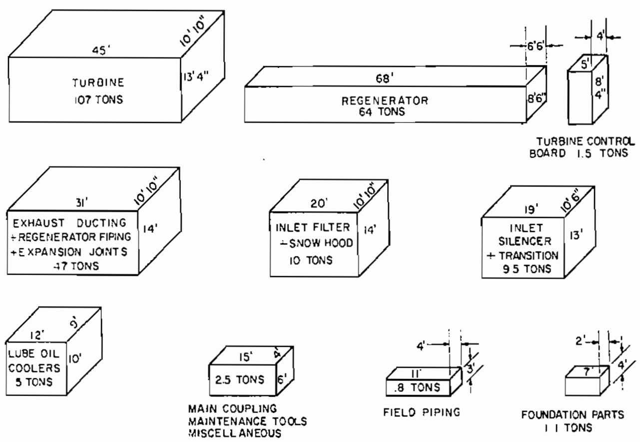

Figure 9. CW-352 Shipping Dimensions and Weights

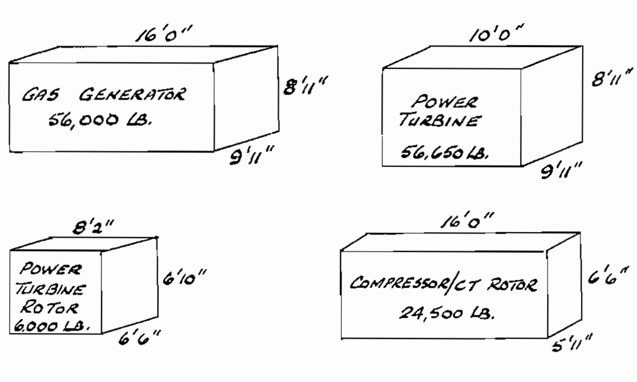

Figure 10. Shipping CW-352 Components for Maintenance by Air

The CW352 regenerative gas is designed for shipment by normal rail transportation. Standard methods of packaging include the cocooning of the turbine assembly, and boxing of the controls, piping and foundation parts.

Packaging methods are finalized when shipment routing and installation timing are decided.

Shipping Weights

Turbine on bedplate	107 tons
Lube oil cooler	5
Inlet filter	10
Inlet silencer and ducting	9.5
Foundation parts	1.1
Miscellaneous piping and supports	0.8
Coupling and tools	2.5
Exhaust ducting and regenerator piping	47
Regenerator	64
TOTAL	247 tons

Installation

Dimensioned sketches utilizing two types of regenerators are shown for a twin unit gas compressor station in Figures 11 and 12.

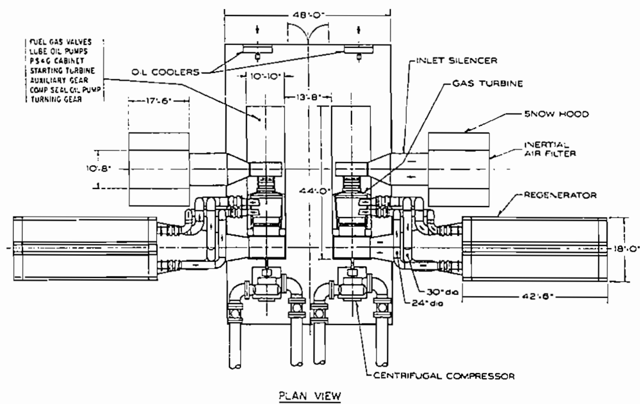

Figure 11. Twin Unit CW-352RM Gas Compressor Station Layout type I

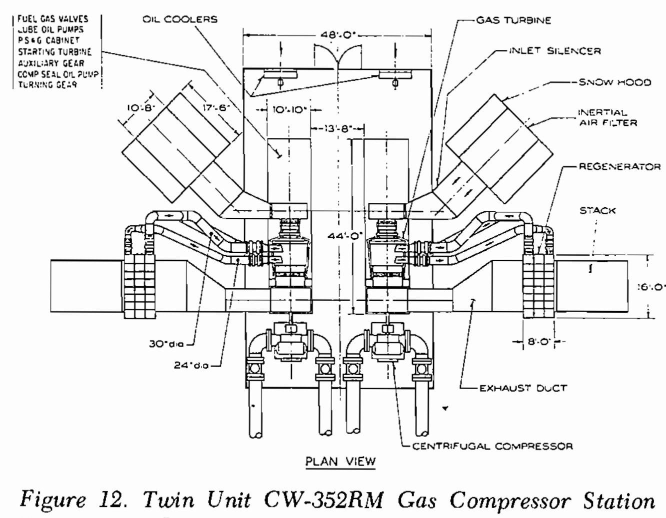

Figure 12. Twin Unit CW-352RM Gas Compressor Station Layout type II

Maintenance

In designing the CW 352 Gas Turbine, one of the major criteria has been ease of maintenance. Maintenance has been considered from several standpoints, depending on the inspection and/or replacement objectives.

1. *Replacement of Gas Generator and Power Turbine assemblies.*

   Both the gas generator and the power turbine assemblies can be replaced as single units, with each assembly consisting of the rotor inside its cylinders.

   If heavy cranes are not available, these two components can be jacked and skidded into place.

2. *Replacement of rotors.*

   The heaviest component is the compressor/CT rotor at 22,000 lb. which, together with its lifting beam, would give a required crane capacity of 12 tons.

3. *Replacement of compressor turbine rotating blades, vane segments, and compressor blades.*

   These can be replaced on an individual basis, at site, without removal of the rotor and the rotors can be field trim balanced.

4. *Replacement of power turbine rotating blades.*

   This is not a field maintenance procedure. The complete power turbine has to be returned to the factory or maintenance shop for overhaul because of the special fixtures required to remove and replace shrouded blades.

5. *Replacements of power turbine vane segments.*

   The vane segments can be replaced on an individual basis, at site.

6. *Borescopic Inspection.*

   The hot blade path can be inspected without disassembly of the turbine. Figure 13 illustrates the borescopic inspection areas.

CONCLUSIONS

Westinghouse have designed and are developing a two shaft gas turbine that has:

a. The highest published thermal efficiency.

b. Variable speed mechanical drive in a large power size.

c. Heavy duty long life features.

d. Been designed to facilitate maintenance with minimum down time.

e. Been packaged for simple installation.

f. Hot blade path with significant proportion of proven components.

ACKNOWLEDGEMENTS

My thanks are extended to members of the Gas Turbine Engineering sections of Westinghouse Canada and Westinghouse Electric Corp., Lester, and to members of the Marketing Section of Westinghouse Canada.

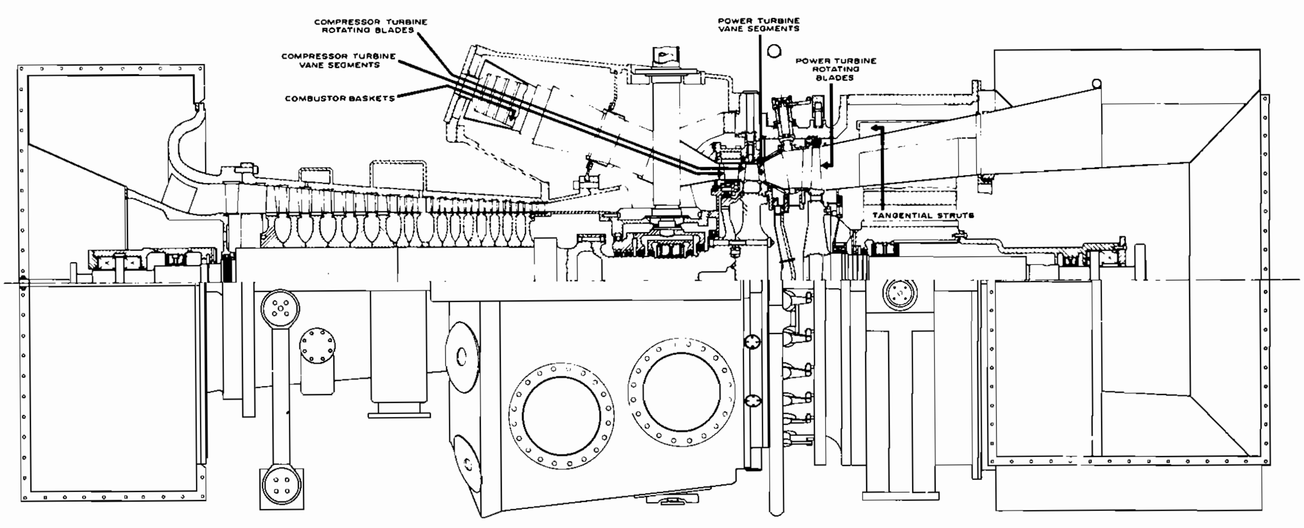

Figure 13. Borescope Entry Locations CW-352