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GE Power Generation

Performance and Reliability Improvements for MS5002 Gas Turbines

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ABSTRACT

Gas turbine technology has advanced significantly since the first MS5002 was introduced in 1970. In 1995 General Electric and Nuovo Pignone continued this trend and began a joint development program to further increase the output of the MS5002 to meet customer demand. The result is the new 43,000 HP model D Frame 5 two shaft gas turbine designated the MS5432D. The MS5432D combines the product development strength of General Electric and Nuovo Pignone with their history of over 30 years of joint development programs. The MS5432D blends the proven design ideas of scaling and evolution with the state of the art in materials, cooling technology and design techniques.

This paper will discuss two main topics. First, this paper provides a summary of the results of the joint Nuovo Pignone and General Electric MS5002D product development program and a description of the new MS5432D, including a description of the introductory MS5002D package and ratings. Secondly, the paper will describe the advanced technology improvements incorporated in the MS5432D and how they achieve increased performance, extend useful life and improve reliability when applied to an existing MS5002 as an uprate. Also described will be the advances in technology that have made the new MS5002 Dry Low NOx system possible, achieving the lowest levels of pollutant emissions at higher outputs and efficiencies. Additionally, this paper will include a history of MS5002 development. Complete tabulations of performance improvement, material changes, emissions data and maintenance interval extensions available from the new MS5342D are also included.

Advanced technology uprate packages are available to upgrade all of the over 550 GE-design MS5002 heavy-duty gas turbines in the world.

INTRODUCTION

Uprate packages are introduced to meet customer demand for increased output, improved efficiency and maintenance interval extensions. Figure 1 lists the main items that the customer and manufacturer both must consider when evaluating a unit for a possible uprate.

- Performance Improvements (Output/Heat Rate)
- Maintenance/Inspection Interval Extensions
- Availability/Reliability Improvements
- Emissions Impact/Regulatory Agencies
- Life Extension
- Thorough Review of Gas Turbine Components and Accessories Systems for Compatibility
- Thorough Review of Load Equipment and Accessories for Compatibility

New Unit Technology/Components

GT25260

Figure 1. Uprate Considerations

Due to strong customer demand, General Electric and Nuovo Pignone embarked on the MS5002D joint development program in 1995 to increase the output of the MS5002. The MS5342D is a multi-generation product that was designed to meet the needs of the new unit and retrofit markets. Thus for the retrofit market the design provides complete uprate packages and, in addition, the components of which an uprate package is comprised can also be applied individually to previous models resulting in the benefits described later in this paper.

Figure 2 illustrates the basic MS5002D configuration. The most significant feature of the MS5002D Uprate is the replacement of the MS5002 compressor section with a new 17 stage compressor derived from the MS6001B design. Figure 3 graphically illustrates this change. The uprate to a modified MS6001B compressor increases airflow, resulting in increased output and pressure ratio. The pressure ratio increase allows firing temperature to be increased resulting in further performance gains, while maintaining the turbine hot gas path temperatures at proven MS5002C levels.

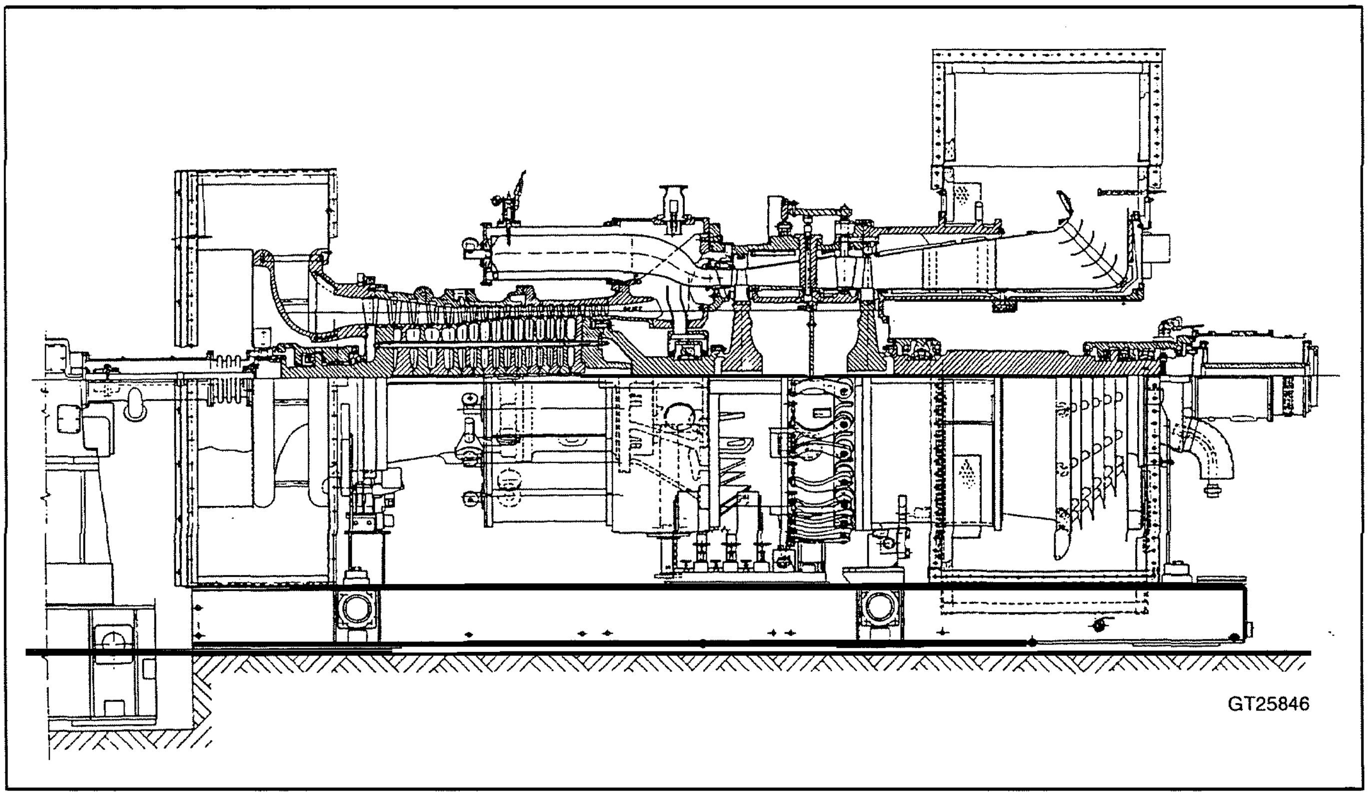

Figure 2. MS5002D

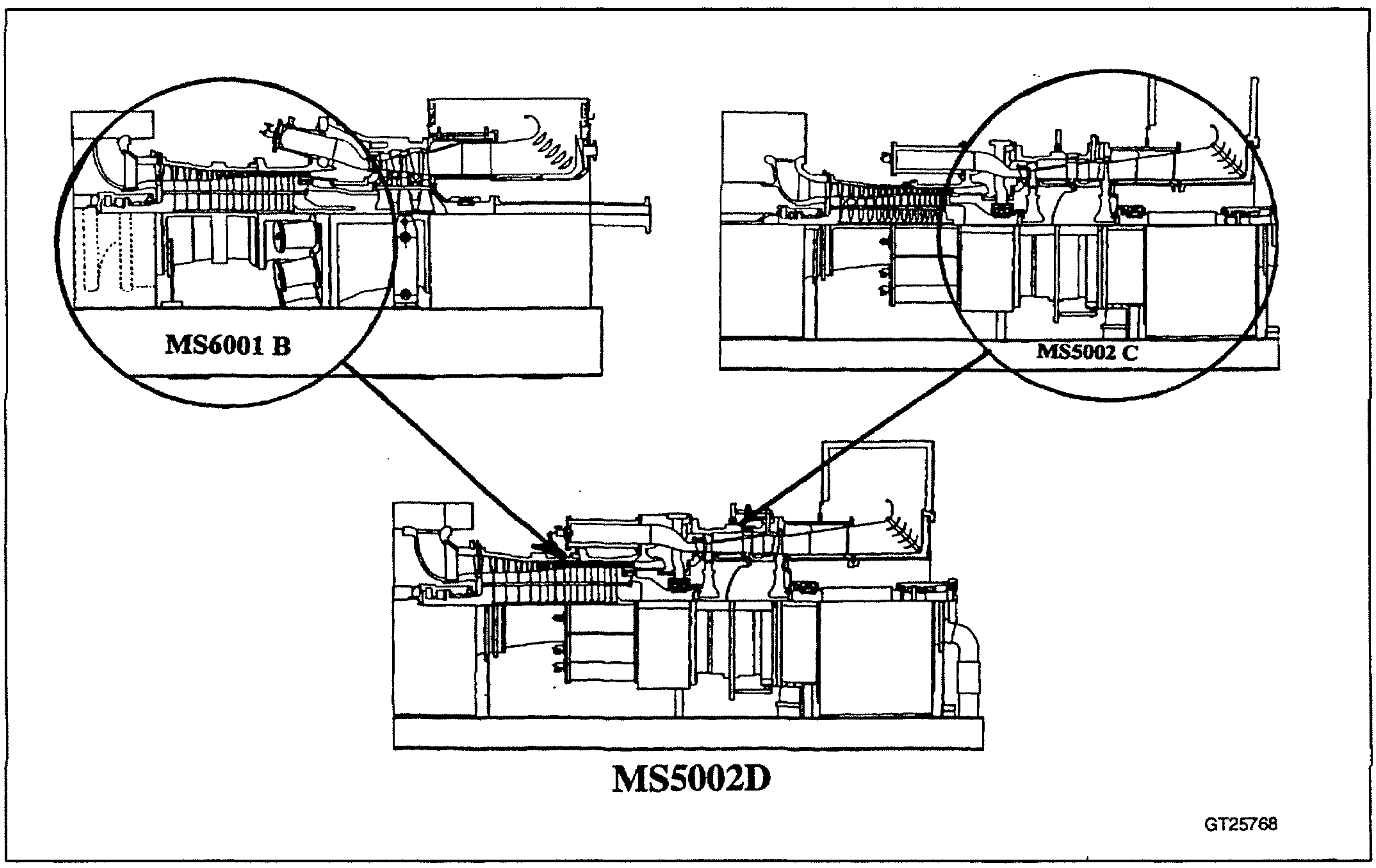

Figure 3. MS5002D Design Derived From MS6001B and MS5002C

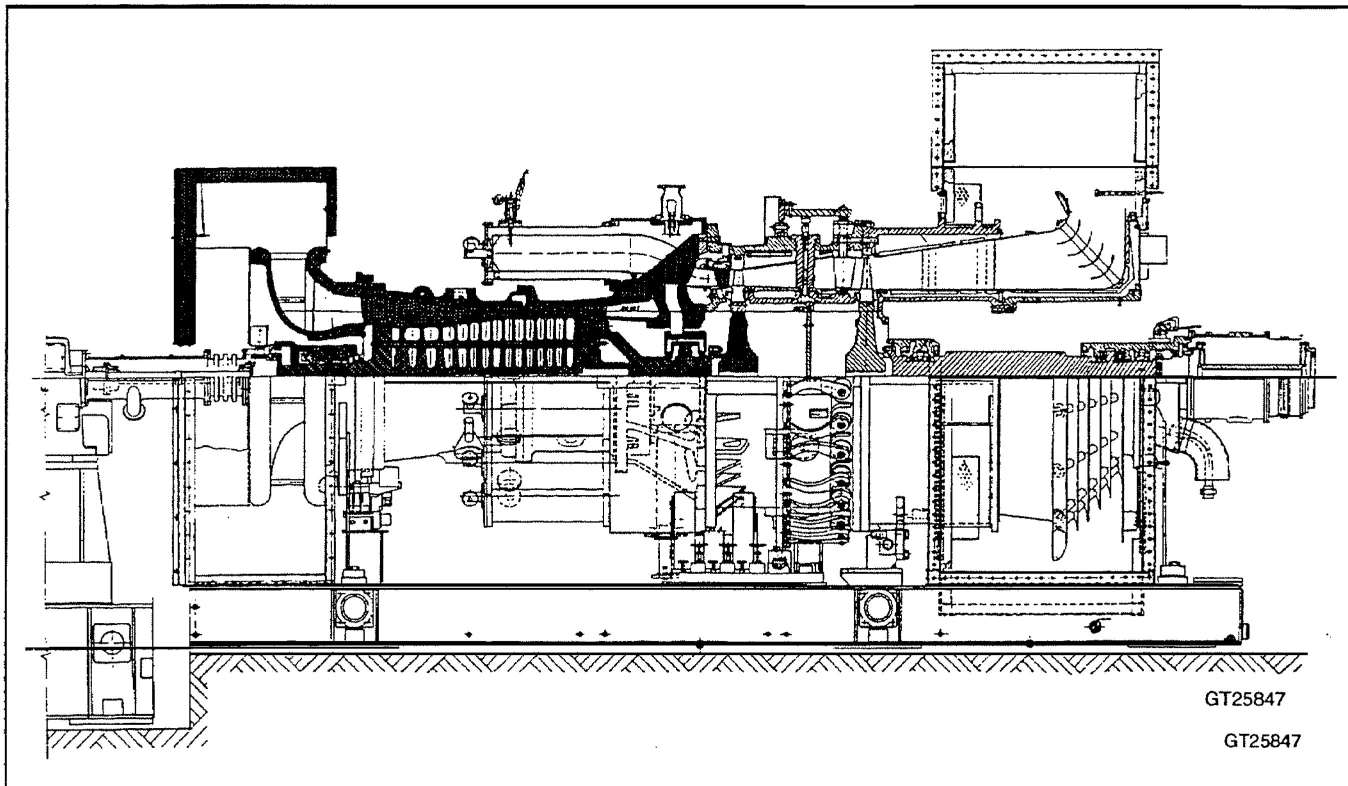

Figure 4. MS5002D Performance Improvement Package

The design change to the new MS5002D 17 stage compressor requires replacement of the compressor rotor, blading and casings as described below. Output is further increased by installing a new first stage nozzle with a reduced throat area designed to optimize compressor performance. The new nozzle slightly increases the compressor pressure ratio on top of that increase achieved by the new compressor which, in turn, allows another increase in firing temperature and performance due, in both cases, to increasing turbine efficiency. Advanced seals on the high pressure packing, No. 2 bearing, and Stage 2 shrouds also provide improved performance. See Figure 4 for graphic outline of new parts required to uprate an existing MS5002B/NT or Model C unit to a MS5342D.

Sourcebook reference codes (e.g., FT2C for an MS5002 Advanced Technology Uprate) have been added to this text and to many of the figures and tables. The Sourcebook is an automated system available to all GE offices. The Sourcebook provides a quick reference for the uprate options listed in this GER and for all other Conversion, Modification and Uprate (CM&U) options available for heavy-duty gas turbines. More detailed information is available through all GE Sales worldwide.

MS5002 HISTORY

General Electric started development of the MS5002 in 1969. The MS5002 was developed primarily to meet the mechanical drive market's demand for a more powerful two-shaft gas turbine to serve as a larger prime mover. The first frame five two shaft models, the MS5262A and MS5322B, were developed simultaneously to take advantage of both the M and N versions of the highly successful MS5001 compressor design. The development work was based on the GE philosophy of scaling and the experience gained through the MS3002H/J development process. Figure 5 shows a comparison of MS5002 ratings for both of these original models and the subsequent improved configurations.

The original compressor designs for the 15 stage 5/2A compressor and 16 stage 5/2B compressor, were derived, respectively, from the highly successful 16 stage MS5001M and 17 stage MS5001N compressor series by removing the last compressor stage. The final compressor stage was removed to create a lower pressure ratio machine to attain higher regenerative cycle efficiencies as the 5/2's original target market was expected to be predominantly regenerative cycle machines. The MS5000 compressor airfoils can ultimately trace their history

	Ship Dates	Output hp (kW)		Heat Rate** Btu/hp-hr (kJ/kWh)		Firing Temp F/C		Air Flow 10^3 lbs/hr (10^3 kg/hr)		Exhaust Temp (F/C)	
		RC	SC	RC	SC	RC	SC	RC	SC	RC*	SC
MS5002A	1970-Present	25,200/ 18,792	26,250/ 19,575	7,390/ 10,455	9,780/ 13,837	1,705/ 929	1,690/ 921	773/ 351	773/ 351	987/638/ 531/337	975/ 524
MS5002B	1970-1975	31,050/ 23,154	32,550/ 24,273	7,480/ 10,583	9,240/ 13,073	1,710/ 932	1,700/ 927	923/ 419	923/ 419	940/660/ 504/349	932/ 500
MS5002B	1975-1978	32,000/ 23,862	33,550/ 24,981	7,180/ 10,158	8,910/ 12,606	1,710/ 932	1,700/ 927	899/ 408	925/ 420	942/679/ 506/359	930/ 499
MS5002B	1978-Present	32,000/ 23,862	35,000/ 26,100	7,070/ 10,003	8,830/ 12,493	1,710/ 932	1,700/ 927	899/ 408	966/ 438	936/667/ 502/353	915/ 491
MS5002C	Present	35,600/ 26,547	38,000/ 28,337	6,990/ 9,889	8,700/ 12,309	1,770/ 966	1,770/ 966	957/ 434	982/ 445	970/693/ 521/367	961/ 516
MS5002D	July 1997	-	43,000/ 32,066	-	8,650/ 12,235	-	1,807/ 986	-	1,113/ 504	-	950/ 510

Includes 0/0 Inches H_2O Inlet/Exhaust Pressure Drops Base Load Operation on Natural Gas Fuel

* First Number Is Turbine Exhaust; Second Is Regenerator Stack

** Heat Rates Are Lower Heating Value. To Convert to % Thermal Efficiency, Divide 2547 Btu/hp-hr by Heat Rate (Btu/hp-hr) and Multiply 100

RC = Regenerative Cycle SC = Simple Cycle

GT18463G

Figure 5. MS5002 Performance History - ISO Rating

back to a version of the NACA 65 series airfoil profile that was modified for increased ruggedness. The MS5001N, and consequently the MS5002B, was derived from the MS5001M compressor for increased airflow. The MS5001N and B's higher airflow was achieved by redesigning the first three compressor stages for increased outside diameter, adding a 'zero' compressor stage at the inlet, and replacing the fixed with variable inlet guide vanes to support start-up, part-load and regenerative cycle operation. A four bearing design philosophy is used for the compact and sturdy MS5002 turbines. This arrangement was based on design experience gained during the MS3002H/J and MS7002 development and has proven highly successful as witnessed by the many millions of trouble free operating hours logged by the MS5002 fleet.

In addition, the original development program of the MS5002 also employed the highly successful concept of scaling. Scaling is based on the principle that geometrical dimensions or rotational speed could be varied in such a way that the aero design would not change resulting in an aerodynamically and mechanically similar line of turbines. In particular, scaling techniques were employed to develop the turbine sections of the original MS5/2A and B models. The high pressure and low pressure turbine sections were scaled up from the highly successful MS3002 turbine, some units of which have accumulated over 300,000 hours of operating time.

The combustion system was derived from the highly successful MS5001. The combustion system for the MS5002A&B employs the standard combustion liner design that has been successfully used on all MS3000 & MS5000 machines. The number of combustion chambers was increased from 10 to 12 to match the airflow design criteria and transition piece to stage one nozzle fit up requirements of this lower pressure ratio machine. In addition, the 12 can arrangement was found to be the optimum layout as the arrangement does not have a casing entry point at the horizontal center line and results in a simple #2 bearing vent and drain piping system.

Additional improvements have been introduced on the MS5002 since its introduction, two of the more substantial are the following. In 1978 the original inlet guide vanes were changed to the improved '7C' profile, resulting in the modern MS5002B rating of 35,000 Hp.

Beginning in 1985 an uprate development program was undertaken to increase the MS5002B rating to 38,000 HP (ISO). This rating was applied to new unit production with a model letter change as a MS5002C in 1987. Similar to the MS5432D, the MS5002C advanced technology package can be applied to all existing MS5002 A & B units. Figure 6 is a list of com-

Sourcebook Code		MS5002A	MS5002B
FT2J	2 Vane Stage 1 Nozzle	X	X
FT2K	GTD111 Directionally Solidified Stage 1 Bucket	X	X
FR1G	TBC Coated Combustion Liners With Splash Plate Cooled Crossfire Tube Collars	X	X
FR1G	Swirl Cooled Crossfire Tubes With Hardfacing	X	X
-	LP Thrust Bearing Pad	X	X
FS1Y	Up-Drain #2 Bearing Liner	X	X
-	Turbine Shell Insulation Packs	X	X
-	HP & LP Turbine Rotor Bolt Tightening (Low Ambient Temp. Applications Only)	X	X
-	Stage 2 Bucket	X	-
FS1J	Stainless Steel Exhaust Diffuser (High Ambient Temp. Applications Only)	X	-

GT18464E

Figure 6. MS5002A Advanced Technology Uprate Package - Hardware Changes

ponents required to uprate previous MS5002A/B models to a MS5002C advanced technology package and rating. A complete description of the MS5002C's design improvements are included in the Component Technology Section to follow. This uprate package has been applied to over 67+ MS5002B units by Nuovo Pignone and General Electric, uprating their output to meet changing operational conditions. In addition, since the 5002C's introduction in 1987 as the standard for new unit production, GE/NP have shipped over 90 5002C units cumulatively logging hundreds of thousands of hours operating time. See Figure 7 for an experience list.

# Units Uprated	Application	Model
16	International Platform	MS5002B
42	International Process	MS5002B
6	International Water Injection	MS5002B
3	Domestic Process	MS5002B
Total 67 Units		

GT21320D

Figure 7. MS5002 Advanced Technology Uprate Experience List

MS5002D TURBINE DESIGN DESCRIPTION

Design Description

The new MS5432D is available as both a new unit and an uprate. The MS5002D evolved directly from the MS5002C. For the new MS5002D the most significant changes are summarized below:

	MS5002C	MS5002D Phase 1	MS5002D Phase 2
Sales Availability		Uprate Only	New Unit & Uprate
Compressor Stages	16	17	17
Nozzle area [in^2]	194.7	194.7	183.2 (-6%)
Pressure Ratio	8.8	10.13	10.75
Firing Temperature [°F]	1770	1787 (+17)	1807 (+37)

The new MS5002D compressor is derived from the 17 stage MS6001B compressor. The MS6001B design was modified for this application based on a complete engineering analysis and fully instrumented, full load testing performed at Nuovo Pignone. See figure 8 for picture of instrumented prototype unit in the NP factory during unit assembly. With this modification, the MS5002 airflow and pressure ratio are increased, see Figure 5 for a breakdown of increases by original turbine model.

The new MS5002D first stage nozzle is derived from the existing model C stage one nozzle. The main changes include a 6% reduction in nozzle orifice area over the MS5002C area as outlined above, and a new core plug for improved cooling of the internal nozzle vane segments.

Advanced sealing technology was introduced on the MS5002D at the high pressure packing, number 2 bearing, and the second stage shrouds.

The above design changes and design philosophy are described in full in the following sections and applies for both the new unit and uprate, except where noted. See Figure 9 for a complete list of material required to uprate an existing 52B/NT or 52C unit to 52D. The following sections describe the changes and improvements included in the model change or Uprate to MS5342D. Refer to MS5002A/B/C Turbine Design later in this paper for detailed descriptions of those systems not affected by MS5002C to D Uprate.

MS5002D Compressor Design

The result of the MS5002D compressor design is increased airflow compared to the previous MS5002 compressors. The decision to change to a slightly modified version of the 17 stage MS6001B compressor and the history of MS5000 and MS6000 compressor development is apparent in Figure 10. The MS6000 compressor is a direct descendant of the MS5000N/B compressor. The MS6000 compressor speed has been maintained at MS5000 levels. In addition, the design of the MS6001B called for a turbine with the same footprint as a MS5000. Plus the engineering study, as outlined, proved the advantages of the MS5002D compressor design.

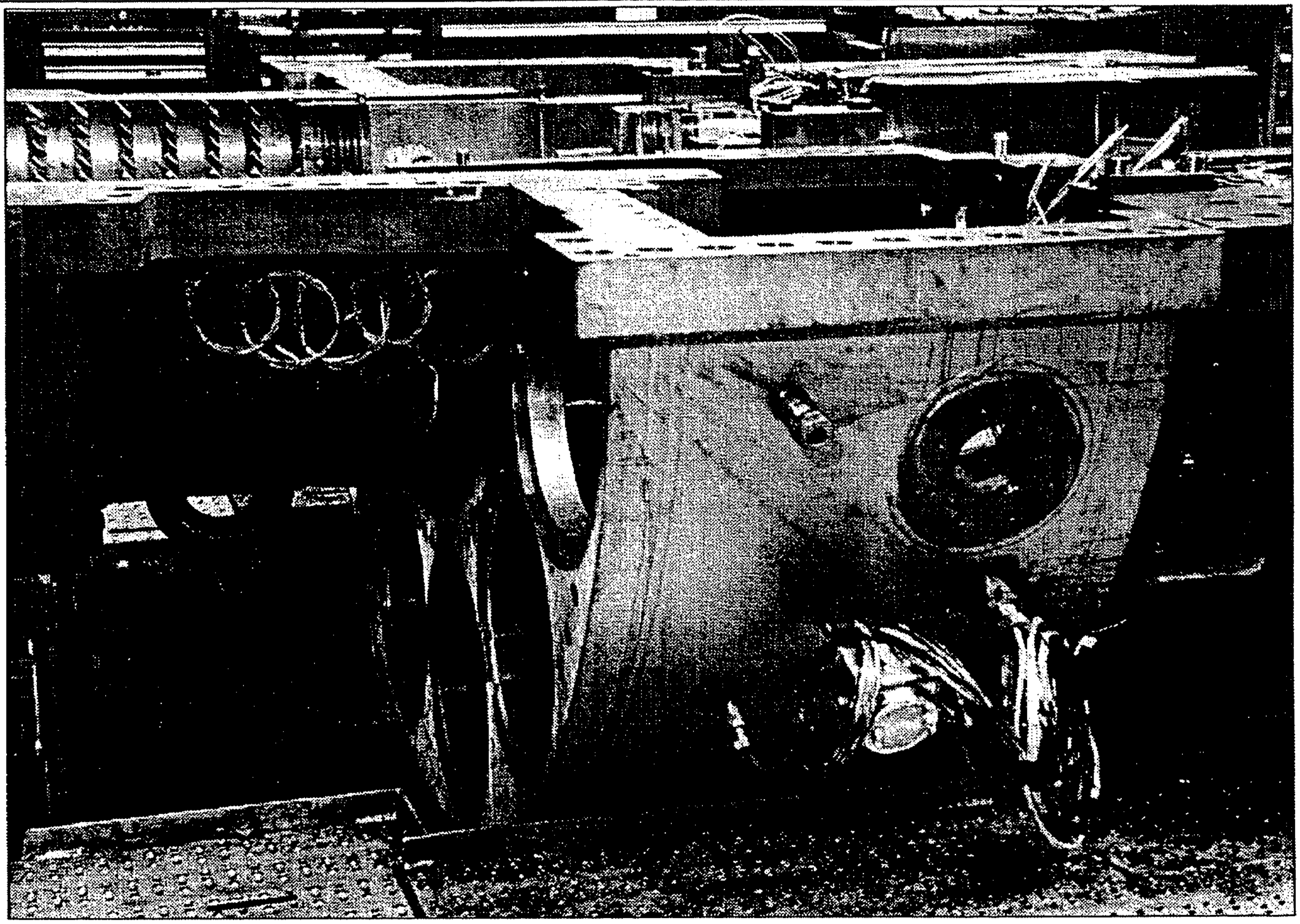

Figure 8. Photo of Instrumental Full Load 5/2 D Test Prototype

- Inlet Bell Mouth and #1 Bearing
- Stage-1 Nozzle, Optimized
- Complete Compressor Rotor Assembly Including Compressor Blades and Distance Piece
- MS5002D GTD-450 Inlet Guide Vanes
- Axial Compressor Forward Casing
- Compressor Discharge Casing
- Combustion Chamber Wrapper
- Axial Compressor Stator Blades
- Sealing and Air Piping
- Bearing Oil Piping
- Antisurge Valves
- Bearing No. 2
- H.P. & L.P. Thrust Bearing
- In Addition, Several Items Will Be Modified, Including:
  - Turbine Base Plate
  - Gas Fuel Piping
  - Inlet Ducting

Firing Temperature Increase to 1807°F

GT25860

Figure 9. MS5002D Uprate Package Components

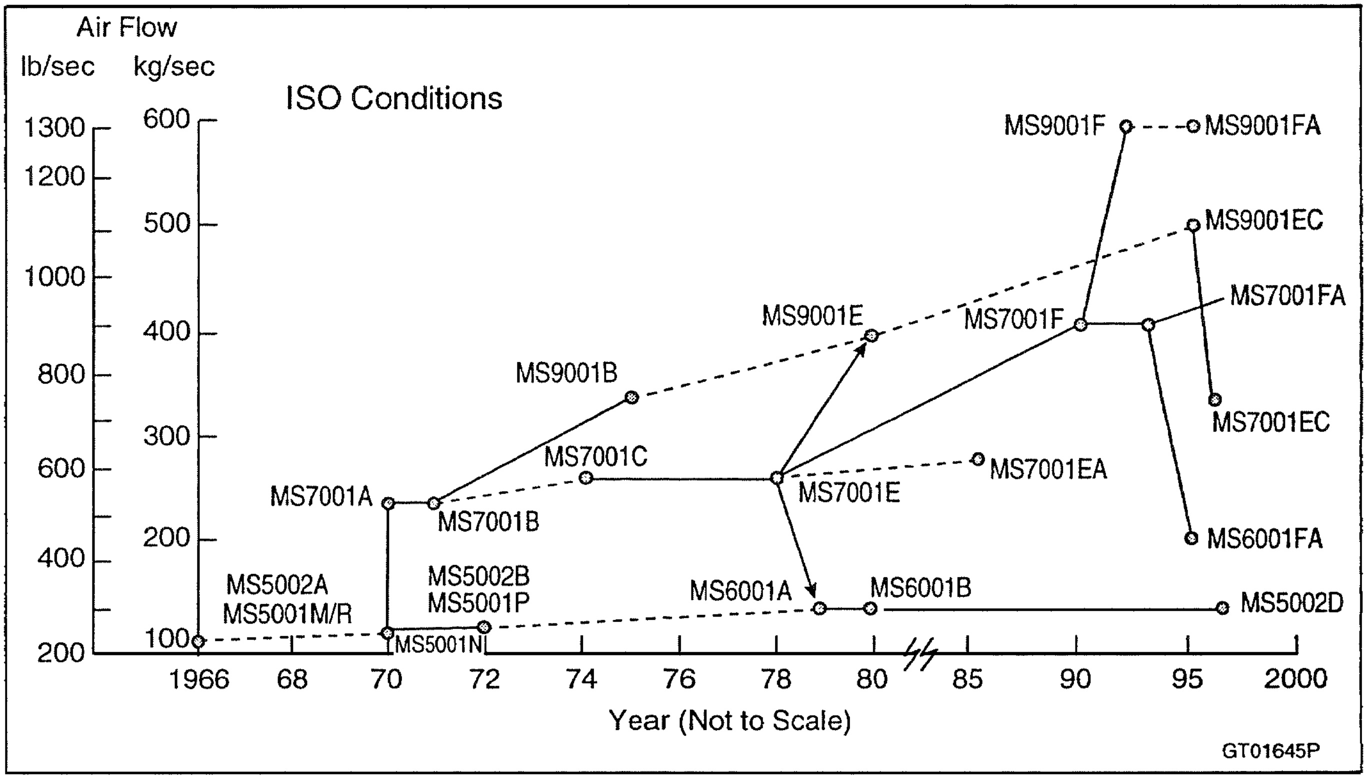

Figure 10. Growth in Compressor Air Flow

The MS6001B compressor was applied to a MS5002C turbine design and flow mapping of the resultant compressor was performed, first through computer modeling, and second through extensive factory testing. The testing drew heavily on Nuovo Pignone's long history of compressor development and full string full load testing. (Reference Figure 11 for a photo of the instrumented unit in final assembly prior to being assembled and moved onto the test stand). The result is the MS5002D compressor, the compressor rotor of which is the same as the MS6001B, except for the 3rd stage compressor rotor blades and the 16th stage bore extraction for bucket cooling flows. The third stage compressor blade is modified by clipping the blade tip trailing edge for increased low speed operational flexibility over the MS6001B. In addition, the MS6001's 16th stage bore extraction is eliminated because the MS5002 has solid non-air cooled stage one buckets. Reference Figure 12 for a photo of the new MS52D third stage compressor blade.Due to their common heritage, the weights of the two rotors (5C/D) are similar, thus the #1 to # 2 bearing span has been maintained the same for 52C and 52D. Detailed lateral analyses have been done for HP rotor in parallel by GE and NP supported with experimental testing and full proto-type testing Independently both the analyses found no major differences in critical speeds between 52C and 52D or any new critical in the operating range.

To maintain the same flange to flange length with the longer 17 stage MS5002D compressor, the distance piece was modified (shortened) to accommodate the final compressor stage. This design results in the fewest changes for future field retrofit applications and places the accessory flange and downstream interfaces at the same functional location. This design minimizes changes to the compressor bellmouth, and consequently inlet plenum arrangement. Again, this is due to design similarities between the two compressor designs. Reference Figure 13 for a photo of the 52D high pressure rotor.

MS5002D Compressor Casings and Bearing Design

The main step of the uprate to a MS5002D turbine is the upgrade of the compressor design. Both the compressor rotor and compressor casing were derived from the MS6001B design. The uprate includes compressor casings and complete compressor stator vane arrangement, including the inlet bell mouth, forward, and compressor discharge casings, all of which have been derived from the MS6001B design for application on the MS5002D.

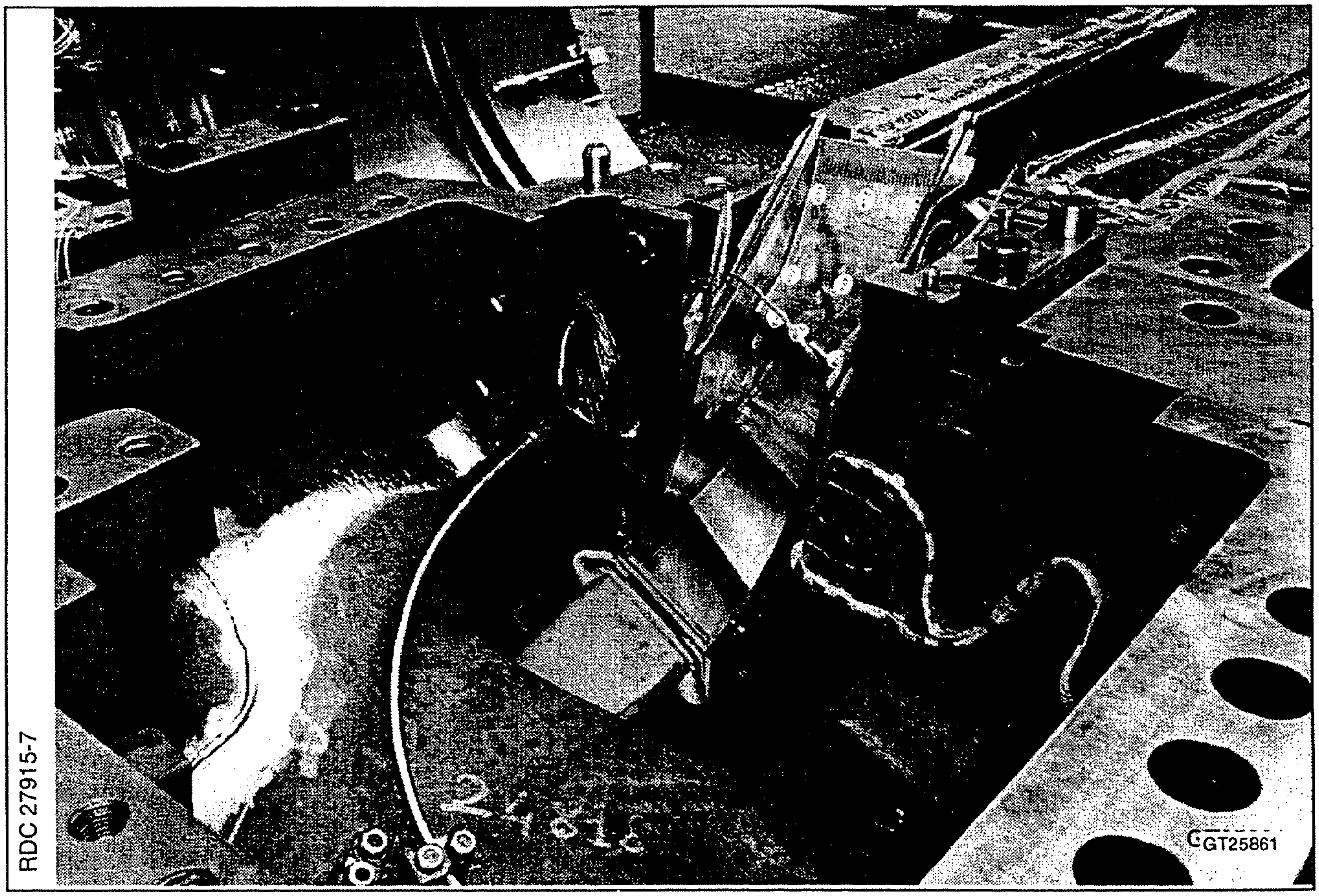

Figure 11. 5/2D Instrumented Stage 1 Nozzle From Prototype Prior to Full Load Testing

Figure 12. Modified 3rd Stage Compressor Blade

The MS5002D inlet bellmouth assembly was designed to minimize the changes to the inlet plenum arrangement and to the bellmouth compared to a MS5002B/C. This philosophy minimizes the changes needed for field retrofit applications. The changes from the MS5002B/C design consisted of slightly modifying the bellmouth's vertical centerline relative to the inlet plenum's vertical center line. (See Figure 14 for a comparison of the cross sections for the 52C and 52D.) The new bellmouth includes the Fr6 number one journal bearing. While the inactive thrust bearing doesn't change from the MS6001/MS5001P design, the high pressure active thrust bearing is improved to a copper backed design. The forward flex plate attachment point to the compressor, in order to match the existing base to simplify uprates, has been moved from the inlet to the forward compressor case. Thus, for uprates the base doesn't require modification in the field for flex plate relocation, saving down time and field work.

The forward compressor casing is also derived from MS6001B design. The main changes from the MS5002B/C casing design is the new larger MS5002D casing which has a slightly

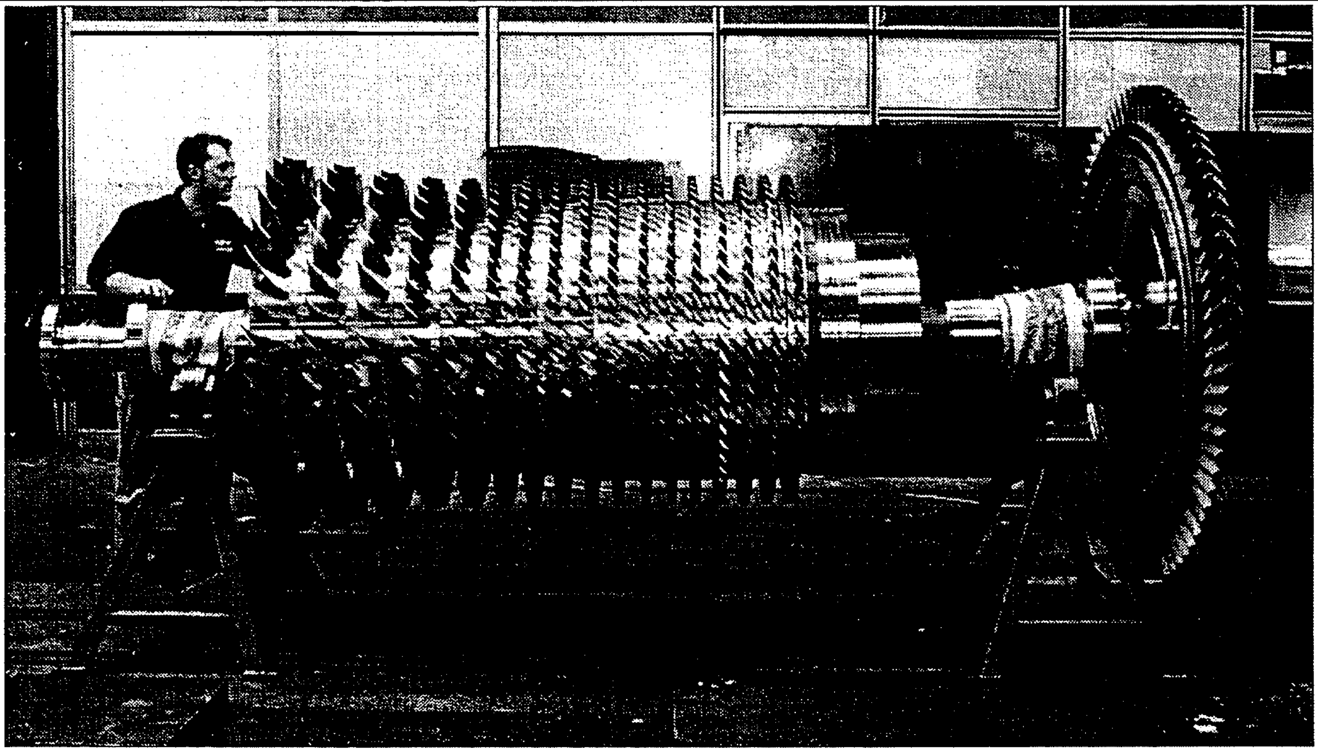

Figure 13. MS5002D High Pressure Rotor in NP Factory Prior to Assembly in Unit

modified version of the manifold for 4th stage air extraction.

The MS5002D compressor discharge casing was again derived from the MS6001B design. Similar to the distance piece discussion, the compressor discharge casing needed to be modified to adapt the MS5002D compressor to the MS5002 turbine shell. Thus, the compressor discharge casing legs were shortened, in parallel with the distance piece, to mate with the MS5002 turbine shell. The MS5002 number two bearing was slightly modified. The up drain bearing design incorporated with the MS5002B to B/NT or C uprate was retained, but lube oil flow was increased to increase bearing cooling in the hotter environment of the MS5002D's higher compressor discharge temperature. In addition, insulation packs were added to the outside of the bearing housing to augment the increased effectiveness of the cooling and the spray hole pattern has been optimized to avoid metal hot spots in the bearing housing. The extensive computerized thermal analysis has been verified with experimental data from full load testing performed at Nuovo Pignone. And, starting in late 1997 the mature version will include brush seals in the #2 bearing for improved performance. Reference the following section for a complete description of brush seals. Figure 16 shows a photo of the lower half compressor casings and new design number 2 bearing showing the insulation packs.

The MS5002D package includes new higher capacity low pressure thrust bearings to handle the increased thrust loads associated with the increased airflow and output. The existing LP rotor thrust bearing in No.4 bearing is changed to a direct lube oil copper backed design. The change to being direct lubricated requires machining on the bearing casing to *decrease* lube oil flow to this location, as the direct lubricated bearing requires less oil than the existing flooded design. And the HP thrust bearing is supplied as part of the new inlet bellmouth and number one bearing arrangement. To handle the increased turbine output the load coupling, if not already, must be replaced with one of a higher load capacity flexible design.

MS5002D Combustion System Design

The hot gas path portion of the combustion system is identical to the MS5002C, except for changes to the combustion wrapper. The combustion wrapper material was upgraded from ASTM- 516 Gr.55 to Gr. 70, and the wrapper barrel and horizontal flange thickness was increased with the increased compressor discharge pressure and temperature. The

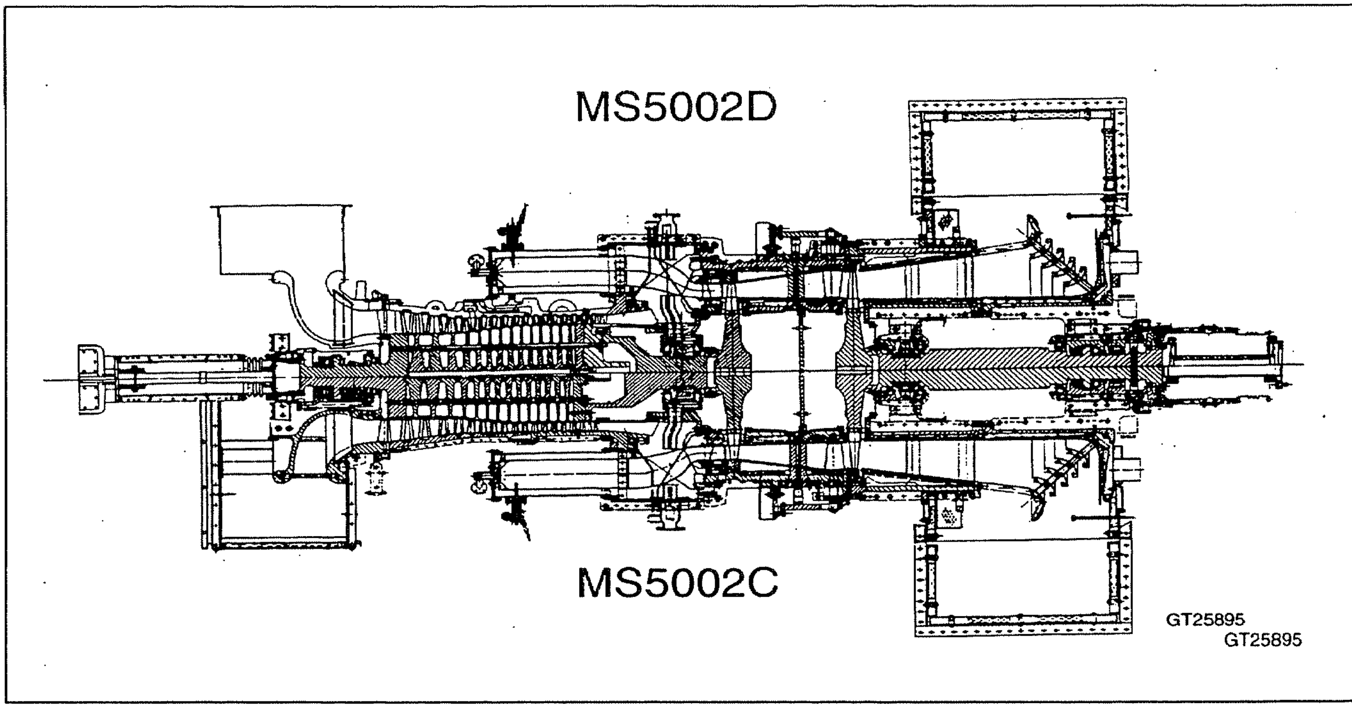

Figure 14. Cross-Section Comparison of MS5002C and D

bolting pitch on horizontal flange has been changed for minimizing the possibility of leakage.

For a description of the MS5002C combustion

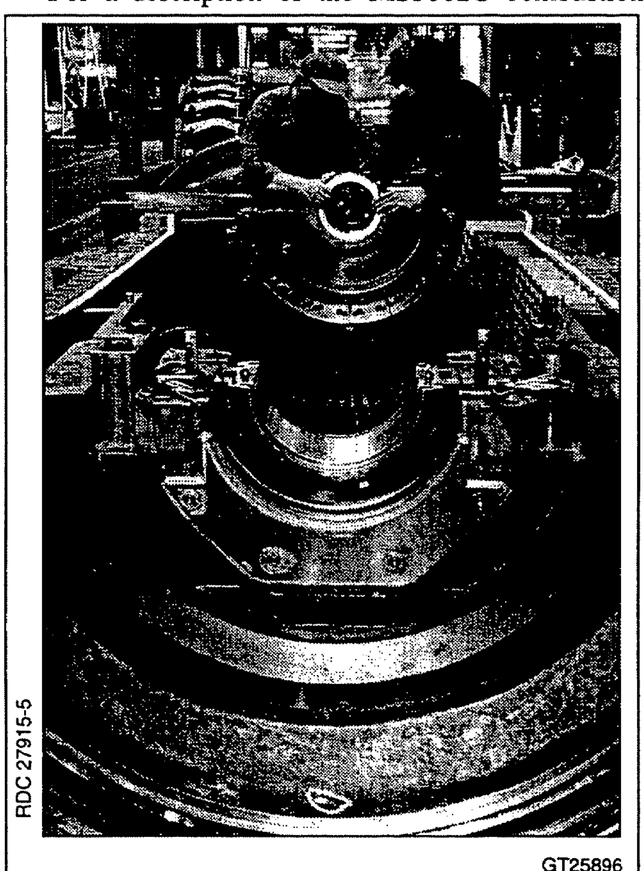

Figure 15. MS5002D Axial Compressor Casings

system development refer to the MS5002A/B/C production technology section later in this GER.

MS5002D Turbine Design

The MS5002D uprate program includes two phases. In phase 1, the uprate is performed without replacing the Model C, or B/NT advanced technology nozzle on those units that are equipped with them, while phase 2 replaces the model C advanced technology nozzle with the model D advanced technology nozzle for increased output. Phase 1 is for those customers who have Model B/NT's or C's and want to reduce spare requirements or reduce installation time.

Phase One - Stage One Nozzle

In Phase 1 of the MS5002D gas turbine uprate design the MS5002C Advanced Technology Stage 1 Nozzle is retained and the firing temperature is increased by 17 degrees fahrenheit for the MS5002D simple cycle machine. The uprate to the MS5002D compressor results in a significant increase in airflow and compressor discharge pressure. Thus the cycle pressure ratio, i.e. the ratio between turbine inlet pressure and compressor discharge pressure, increases with no change in the stage one nozzle area (the turbine flow path's controlling orifice). This pressure ratio improves results in increased turbine efficiency, thus the firing temperature is increased by 17 degrees fahrenheit to 1787 degrees fahrenheit to take advantage of the increase in pressure ratio while at the same time maintaining the stage one bucket temperatures at the pre-uprate configuration. This has been defined as Phase 1 of the MS5002D uprate. This option is only available as an uprate.

Phase Two - Stage One Nozzle

In Phase 2 of the MS5002D gas turbine uprate the stage one nozzle area was redesigned to optimize the new MS5002D compressor pressure ratio. The design change decreases the nozzle throat area by 6% through turning the nozzle vanes slightly to decrease the stage one nozzle orifice area resulting in a higher pressure ratio compared to Phase 1. This change allows the firing temperature to be increased by 37 degrees fahrenheit over the MS5002C design to 1807 degrees fahrenheit, again without increasing the total relative temperature of 1st stage buckets. This is available as an uprate and all new units will ship with this nozzle design.

In addition, the internal nozzle cooling of the new MS5002D nozzle was improved through a revised core plug design which better distributes the cooling air flow to the nozzle vane walls. The new design reduces the temperature gradients on the airfoil; thereby improving resistance to thermal metal fatigue cracks through an optimization of internal cooling flows with a new core plug machining.

Stage One Wheel

The stage one wheel material was upgraded to high strength, low porosity M152 high purity because of the increased operating temperatures the wheel experiences. The operating temperature of the stage one wheel increases because the cooling and sealing air used to cool the stage one forward wheel space is hotter with the increased compressor discharge temperature. The temperature levels and distribution have been successfully assessed throughout the entire operating range of the turbine, matching calculations with field temperature data from the wide MS5002C fleet and 52D prototype testing. Those customers currently operating with A286 wheels will not need to replace them when uprating.

The bolted connection between the distance piece and stage one wheel has been reinforced with four body bound bolts in order to withstand the increased torque passing through the flange itself (see also Controls Modifications paragraphs).

The Advanced Technology GTD-111 Direction-

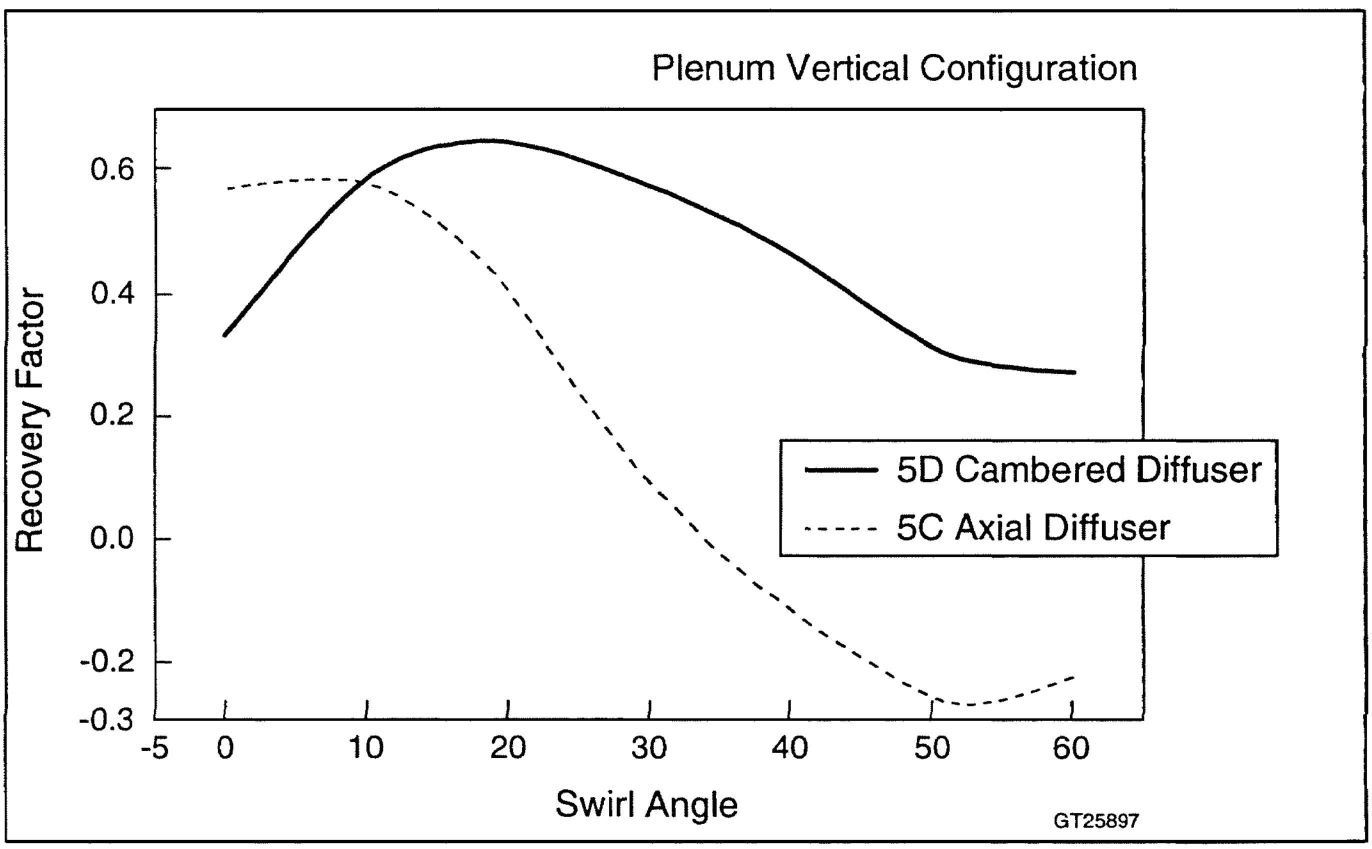

Figure 16. MS5002D Exhaust Diffuser Test Comparison

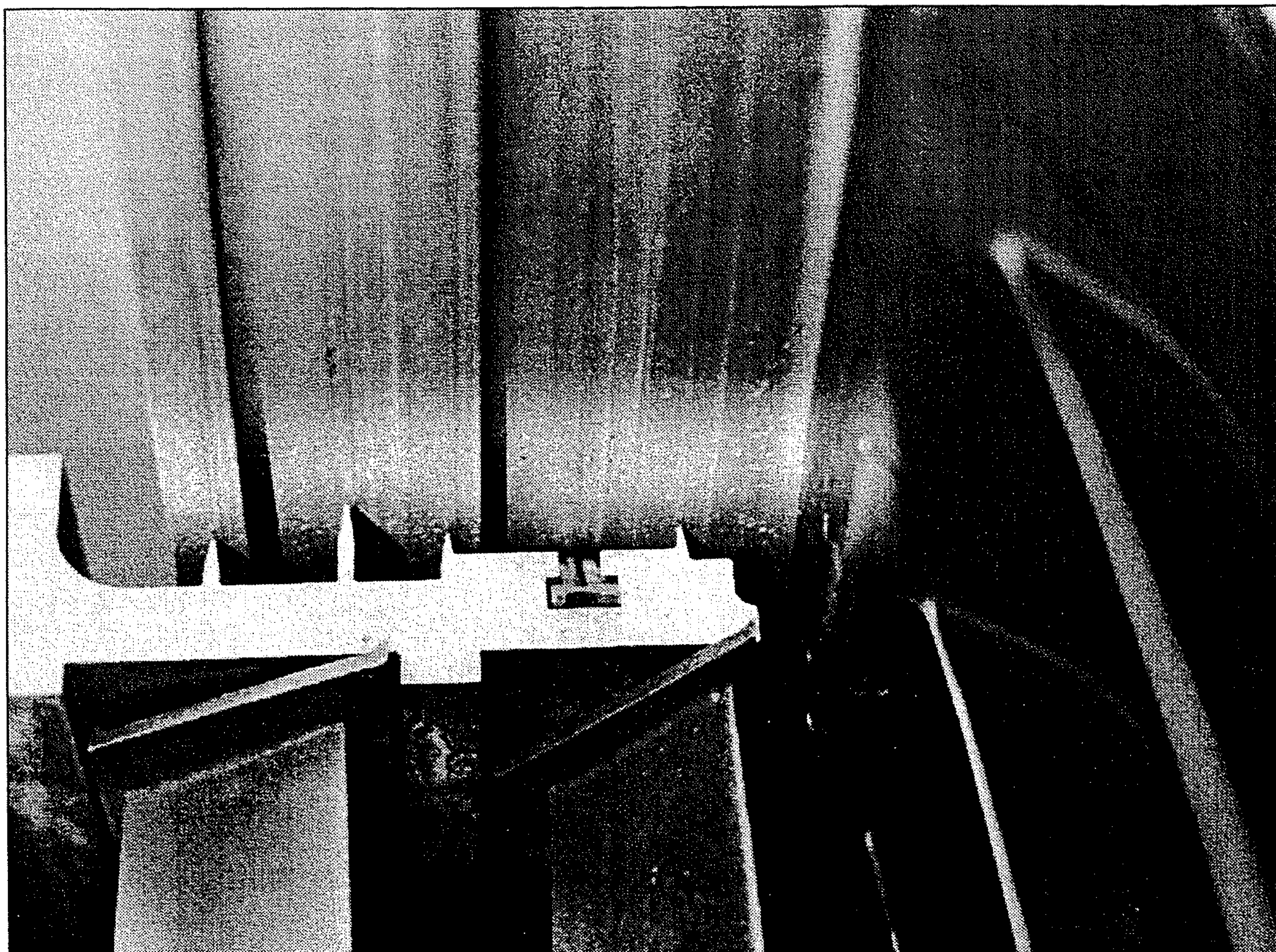

Figure 17. Photo of High Pressure Backing

ally Solidified MS5002 C stage one bucket design was not changed.

MS5002D Exhaust System Design

The support struts of the MS5002D exhaust frame were optimized to improve the recovery factor of the exhaust system with the higher airflow of the MS5002D, the struts were rotated and a cambered profile was added. Several rig tests have been conducted by NP for shape design of the strut and to map strut performance across the range of operating conditions. This enhancement improves output on new unit applications. This design is standard on new units, but is not included standard with the uprate. See figure 16 for a graph showing the improved pressure recovery characteristics of the rotated, or cambered, strut design versus the axial.

For uprating, diffusers with axial struts are acceptable. The advantage of reusing the diffuser is a much shorter installation time. The mechanical behavior of the old diffuser with the increased airflow of 52D has been tested successfully with a full load string test to guarantee operation stability across the load and airflow range. In addition, based on NP/GE's long history of turbine axial compressor uprates, a modification to stiffen the exhaust diffuser turning vanes is included as part of any uprate package to provide an added operating margin. Note, the airflow impact is mitigated by the new controls philosophy as described below, and is at a maximum delta versus the 52C at an ambient temperature of 25 degrees fahrenheit.

MS5002D Advance Sealing Design

Advanced sealing techniques were incorporated into the design of the MS5002D to achieve three important improvements: better performance, increased efficiency, and improved performance degradation. The result is better overall performance for a longer time. Starting in late 1997 the mature version of the 52D will include brush seals at the high pressure packing and the number 2 bearing air seals for improved performance. The following is a more complete description of the brush seals.

High Pressure Packing Sealing

The seal between the compressor discharge casing inner barrel and the compressor aft stub shaft is commonly referred to as the High Pressure Packing (HPP). The HPP is designed to regulate, at a steady state, a constant flow of compressor discharge air between the stationary inner barrel and the compressor rotor into the first forward wheel space. The clearance between the seals on the compressor discharge casing/inner barrel and the compressor rotor aft stub shaft controls the flow though this area, some of this bypass airflow is required for first forward wheel-space cooling. Controlling this bypass airflow to the minimum required for cooling increases the amount of air available to perform work in the cycle.

The compressor discharge air that does flow past the high pressure packing can take one of two routes. Some of the air leaks through the # 2 bearing seals and exits the cycle into the atmosphere (a loss in performance) through the bearing vent line. The other part of the airflow that leaks past the HPP seal passes through the first forward wheel-space to reenter the turbine cycle between the first stage nozzle and first stage bucket. Excess airflow though the HPP seal will distort the hot gas path temperature profile for the stage 1 bucket.

Use of brush seals controls this flow past the HPP and into the No. 2 bearing exactly to the desired constant steady state values of airflow needed past the HPP for the No. 2 bearing air-seals and forward wheelspace. In retrofit applications, the performance improvements that can be realized by installing brush seals at both locations can be greater than the sum of the performance gains that would be realized by installing brush seals at only one location.

HPP with brush seals - With the conventional labyrinth tooth/land seal packings on the inner barrel, the minimum clearance that can be tolerated is dictated by the expected rotor displacements during transient conditions and by turbine wheelspace cooling requirements. When a rub occurs, the labyrinth teeth can be damaged and cause excessive leakage through the packing. On a MS5002, a 20 mil increase in this clearance translates into a loss in performance (approximately 1.0% output and 0.5% heat rate). Rubs greater than 20 mils are not un-

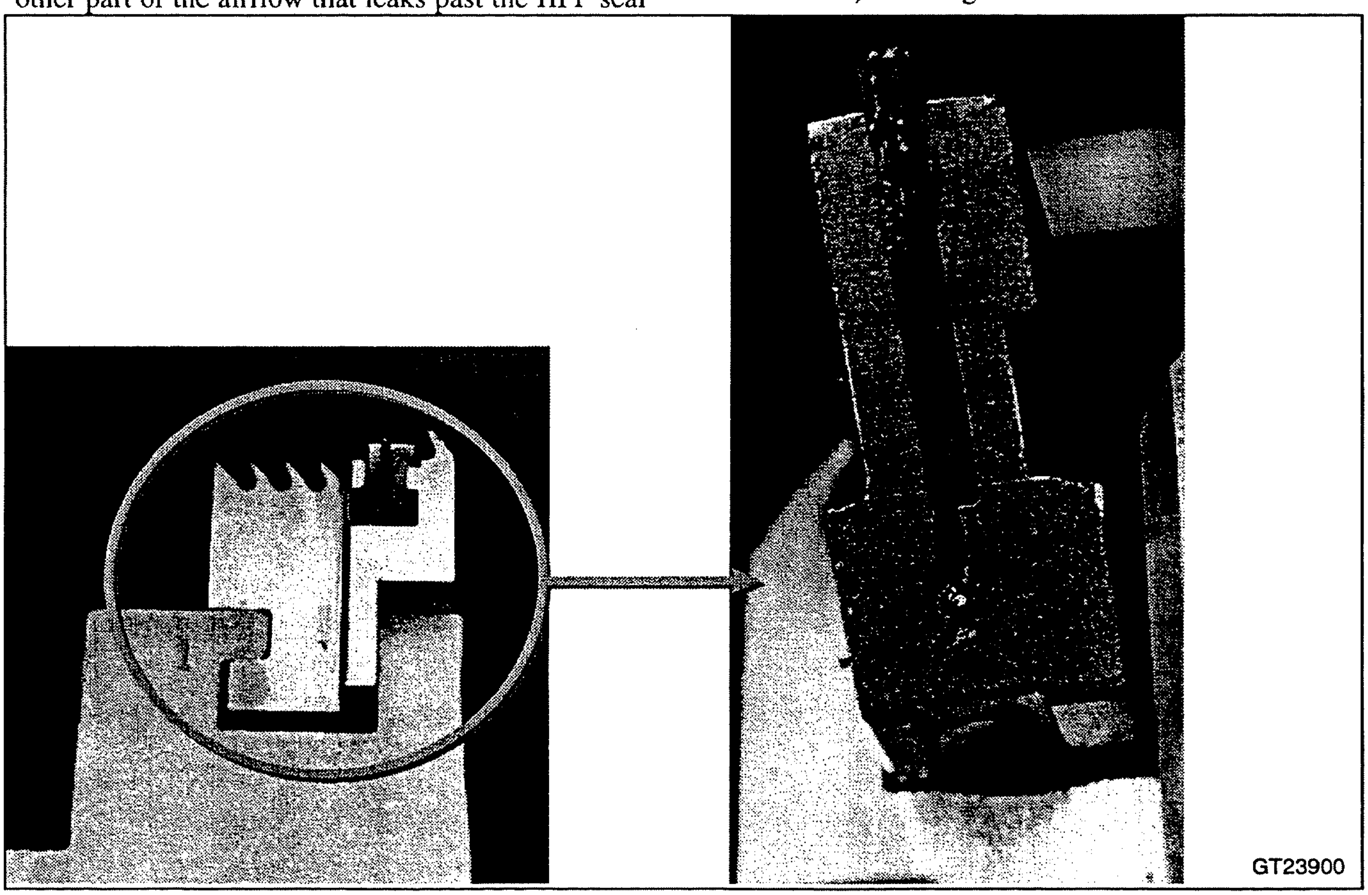

Figure 18. Typical No. 2 Bearing Brush Seal

common. See Figure 17 for a photo of a high pressure packing brush seal.

Rub-tolerant brush seals are designed to withstand rubs and maintain clearances in the critical compressor discharge (and # 2 bearing) area. Metallic brush material is used in place of one of the labyrinth teeth (the second tooth of five) on the inner barrel. Since the clearance between the brush seal and the rotor is reduced relative to the design clearance used with labyrinth tooth packings, there will be an increase in performance relative to a new labyrinth tooth seal. In addition, with brush seals at the high pressure packing, the unit will be able to sustain these initial performance levels over an extended period of time because a rub will not increase the clearance. Laboratory testing of brush seal material and field results have provided confidence that these seals will operate reliably over extended periods.

Initial maintenance recommendations will include seal replacement at 48,000 hours. A prototype brush seal has been operating successfully on a Frame 7E since October 1995 and several other units have already had these seals installed, in addition to years of experience on aero-derivative turbines.

No. 2 bearing brush seals - the MS5002 is a four bearing machine that includes two air seals in the No. 2 bearing housing - one on either side of the bearing. Since any air that leaks past these seals beyond the minimal functional requirement into the bearing housing to prevent lube oil leakage does not perform any additional work in the turbine, any reduction in this flow will result in an increase in performance.

The No. 2 bearing air seals have been redesigned to include brush seals similar to the brush seals used on the inner barrel. Prototype seals were recently

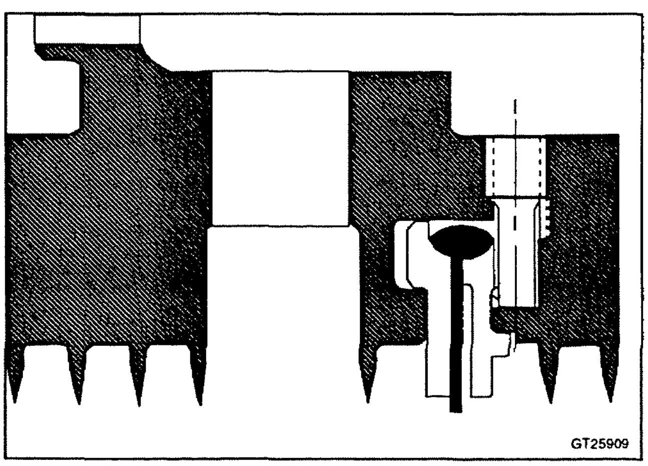

Figure 19. #2 Bearing Air Seal With Brush Seal

installed on two units (one 7E and one 9E). (See Figure 19 for a typical cross-section of a #2 bearing air seal equipped with brush seals.)

Stage 2 Shroud Blocks with Honeycomb Seals (FS2T)

Honeycomb seals are designed to reduce leakage associated with hot gases that flow around the tips of the buckets thereby improving both heat rate and output. In the past, cold clearances between the bucket shroud tips and the casing shrouds have been set based on expected reduced clearances during transient conditions. The clearance had to be large enough to allow these transients to occur without permitting contact between the bucket tip and the shroud. As a result, the steady state running clearance is typically larger than it needs to be from an efficiency standpoint. Honeycomb seals will allow contact between the bucket tip and the casing shrouds and will provide relatively tight clearances during steady state operation. Aircraft engines and Nuovo Pignone PGT design Heavy Duty Gas Turbines have been using this concept for a number of years.

Strips of honeycomb material made of a high-temperature, oxidation resistant alloy are brazed between the teeth on the casing shrouds. "Cutter teeth" on the shrouded second bucket tip rails will "cut" the honeycomb material away when contact occurs during transients. A groove is provided in the material for initial start-up. This produces steady-state running clearances which are, on an absolute basis, no larger than the difference between the steady state and the transient clearances. The effective clearance is actually tighter than the absolute clearance since the resulting groove in the honeycomb provides a tighter labyrinth seal than could be obtained with solid materials. See Figure 20 for a typical outline drawing of the second stage honeycomb shroud.

Stage 2 Honeycomb shrouds installed on a Frame 7E units were recently inspected after 8000 hours of service were found to be in excellent condition. In addition, the PGT10 has utilized honeycomb seals since their introduction for much longer than 8000 hours with successful inspections.

Installation of honeycomb shrouds requires installation of second stage buckets with "cutter teeth" on the bucket shroud rails. The cutter teeth on the bucket shroud rails are designed to cut a path through the honeycomb seal material on the shroud block.

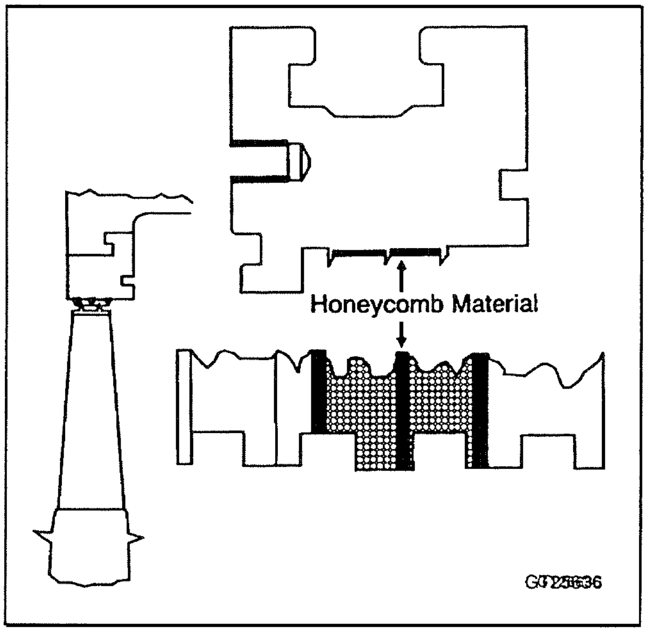

Figure 20. Honeycomb Seals for No. 2 Shroud Blocks

Cutter teeth will be included on all new second stage MS5002D buckets. For uprate applications a process to weld cutter teeth to existing buckets has been developed. The process will require that buckets be removed from the rotor for modification. The full row of buckets does not need to be modified. As a minimum, 50% of the buckets in a given row will need cutter teeth to ensure proper performance of the honeycomb material. The modification may take up to 3 weeks to complete (actual cycle time will depend on service shop loading). Modifying spare buckets in advance of an outage will reduce outage downtime.

Note: In short cycle outage situations, the stage 2 bucket and shroud modifications may be eliminated from the MS5002D Uprate to reduce the downtime associated with the disassembly and removal of the shrouds and buckets. This will slightly reduce the performance increase associated with this uprate.

MS5002D Plant and Auxiliary System Design

The MS5002D retains the proven MS5002B/C turbine and accessory base plant packaging. However some changes were made with the MS5002D in comparison to previous designs. The changes are as follows:

With the more powerful MS5002D the starting torque requirements are increased over previous models with the addition of the larger airflow compressor. Thus for retrofit applications this may require that the starting means be upgraded. For units equipped with expansion or steam turbine starting, means, the upgrade may only require an increase in flow or replacement of starting turbine internals. For units equipped with electric motor or diesel starting means this upgrade may require replacing the existing starting motor with a new more powerful motor. The starting means ability must be reviewed prior to uprating.

Similar to the above discussion, with the increase in compressor discharge pressure, the minimum gas fuel supply pressure requirements are higher than those required for earlier model MS5002's due to

Supply Pressures - PSIG (kg/cm^2)					
	Required Minimum				
Model Series	Std. @59°F (15°C)	Std. @0°F (-17.8°C)	DLN 1 @59°F (15°C)	DLN 1 @0°F (-17.8°C)	Maximum Allowable
3002 J	115 (8.1)	130 (9.1)	-	-	205 (14.4)
5001 P	200 (14.1)	235 (16.5)	-	-	275 (19.3)
5001 R	145 (10.2)	160 (11.3)	-	-	225 (15.8)
5002 A	175 (12.3)	175 (12.3)	-	-	225 (15.8)
5002 B	225 (15.8)	225 (15.8)	-	-	275 (19.3)
5002 D	280 (19.7)	280 (19.7)	-	-	320 (22.5)
6001 B	240 (16.9)	270 (19.0)	285 (20.0)	300 (21.1)	350 (24.6)
7001 EA	260 (18.3)	305 (21.4)	290 (20.4)	310 (21.8)	350 (24.6)

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Figure 21. Minimum and Maximum Standard Fuel Gas Supply Requirements

the increased pressure ratio. Reference Figure 21 for a history of the standard required gas fuel supply pressures. For more information on gas fuel system requirements reference GER-3648C, *Design Considerations for Gas Turbine Fuel Systems*, and GEI-41040. In addition for uprates, due to gas flow and minimum supply pressure increases, the customer should review any scrubbers, knock-out drums, filters, etc. installed upstream of the turbine purchasers connection.

MS5002D Control Modifications

The control philosophy of the 5/2D will be the same as that of the 5/2B/C, the only exception being the low ambient temperature HP speed control. When the ambient temperature decreases below 25°F, the corrected speed of the high pressure rotor will be slowly lowered with ambient, and consequently airflow will be lowered to achieve a reduction in power. This change is due to the fact that the maximum mechanical torque carrying limit of all MS5002's of the LP rotor is 50000 hp and load must be limited to not exceed this level either by lowering firing temperature or reducing airflow. (Note, some earlier, pre-1985 5/2's may have lower maximum torque carrying limits. Contact CM&U Engineering for more information for those pre-1985 units considering uprating.)

The advantage of controlling the turbine load by reducing high pressure shaft speed, versus reducing firing temperature, below the 25°F ambient is three-fold. (25°F is where the average machine would normally exceed the torque limit if unprotected.) First the thrust on LP bearing is minimized because airflow is reduced from 100% high pressure speed levels. For the same reason, the reduction in airflow compared to 100% HP set speed levels, the inlet and exhaust system see less mass flow at low ambients. Thirdly, the compressor, or gas generator, stays closer to its design point producing higher efficiencies.

Thus, starting at 25°F down to -40°F the HP rotor speed will be derated consistently with ambient temperature. Starting from 25°F conditions you have to correct the HP rotor speed for ambient temperature as follows:

RPM(T ambient)=SQRT(T ambient /(25+459))*RPM(25°F)

where temperatures are absolute Rankine ones and RPM(25°F) is your 100% HP speed set point.

- Inlet Plenum Assy
- Inlet Plenum Splitter Arrmt
- Inlet and #1 Bearing Assy Hsg
- Compressor Forward Casing
- Compressor Aft Casing
- Mach Inlet and #1 Brg Casing
- Fuel Nozzle Tips
- Gas Valve Plug
- Variable Inlet Guide Vane Assy - Incl Rack & Ring
- VIGV Actuator Assembly
- GTD-450 Reduced Camber IGV
- Stage Zero Wheel and Blade Assy
- Stage 1 Wheel and Blade Assy
- Stage 2 Wheel and Blade Assy
- Stage 3 Wheel and Blade Assy
- Stage 10 Wheel and Blade Assy
- Rotor Through Bolts
- Stator Through 9 Rotor Blade Assy (4 Stages)
- Stage 11 Through 16 Rotor Blade Assy (6 Stages)
- Stage 0-16 Stator Blade and Ring Assy (17 Stages)
- Load Coupling Assy
- Accessory Coupling Assy
- HP Thrust Bearing
- Forward Turbine Flex Support Plate Assy
- Lube Oil Piping Modification
- Cooling & Sealing Air Piping Modification
- Controls Modification
- IGV Controls - Contempro
- IGV LVDTs and Servovalve
- High Pressure Hydraulic Skid
- Bolting and Doweling Arrangement
- Requisition Management

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Figure 22. MS5002A-B Compressor Uprate Package Components

	MS3002 H to J (FT1B)	MS5001 LA to R (FT3H)	MS5001 16 to 17 Stage Compressor (FT3F)	MS5002 A–B	Total
1984	4	1	-	-	5
1985	5	-	-	-	5
1986	-	3	-	-	3
1989	-	2	1	-	3
1990	-	1	13	-	14
1991	4	1	1	-	6
1992	-	1	-	-	1
1993	3	3	-	-	6
1994	-	-	-	-	0
1995	-	-	-	-	0
1996	-	-	-	1	1
	16	12	15	1	44

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Figure 23. Gas Turbine Uprates With Conventional Technology Parts

Upgrades and Uprates

GE turbines are always designed looking to the future. As GE equipment engineers develop new technology for advanced machine designs, they also continually apply those improvements across the operating fleet of mature units.

The resulting uprate and upgrade programs enable power producers to retain competitive performance levels through gains in power output, efficiency, and reliability - along with substantial reduction of emissions, longer inspections intervals, and lower maintenance costs - with a minimal investment and installation expense.

MS5002A/B/C TURBINE DESIGN DESCRIPTION

Compressor Upgrades - MS5002A (FT2E)

In 1970, the basic MS5001 compressor was uprated by adding a zero stage to increase airflow by approximately 28% and output by 36%. Previous 15 stage 5002 model A compressors can all be uprated either to the 16 stage 5002C compressor design, or to the larger MS5002D design depending on economics and power requirements.

The uprate of a MS5002A to the 16 stage MS5002B/C compressor design can be accomplished by changing the compressor bellmouth forward and aft compressor casings and stages 1, 2, 3 and 10 compressor wheels and blades, adding a zero stage and adding variable inlet guide vanes. See history section for a description of compressor development.

The remaining stages of compressor blading are also recommended to be changed because of the age of blades and the increased loading on them, that results from the increased airflow and pressure ratio associated with the 52A to B/C compressor uprate. For 5002A model this modification would have to be done in conjunction with a hot-gas-path uprate to an Advanced Technology Configuration to accommodate the increased airflow. See Figure 22 for a list of parts required for the compressor uprate and hot gas path uprate.

Eighteen compressor uprates have been shipped to date. See Figure 23 for an experience list.

High Flow Inlet Guide Vanes

Improvements in inlet guide vane (IGV) material and airfoil design have also increased airflow on more recent units. The new inlet guide vanes are directly interchangeable with original IGV's in complete sets. However, in many cases new control curves and/or new IGV angle settings are required to achieve optimal performance improvement.

In 1986, a "reduced camber" high-flow IGV design was introduced as a byproduct of the MS7001F and MS6000 development program. Due to the significant performance improvement from this thinner IGV airfoil, the new design was quickly applied across the entire GE heavy-duty product line for both new unit production and field unit performance improvements. The new reduced camber IGV's are made of GTD-450 stainless steel. This is a special alloy that optimizes corrosion resistance and increases strength to provide a significant improvement in crack resistance over the original 403-SS stainless steel material. As part of the modification kit for GTD-450 IGVs, a set of tight clearance, self lubricating IGV bushings are supplied. In addition, with the new MS5002D the IGV bushing is longer to better distribute load and improve wear resistance. Figure 24 details design and performance improvements with GTD-450 high flow IGV designs.

The new high-flow fixed IGVs for MS5002A will continue to be made from AISI 316-SS materials.

Thermal Barrier Coated Combustion Liners (FR1G)

The new technology combustion liners of an MS5002C/D are improved through three major changes over previous designs. These changes are TBC coating, hardfacing on the collars and crossfire

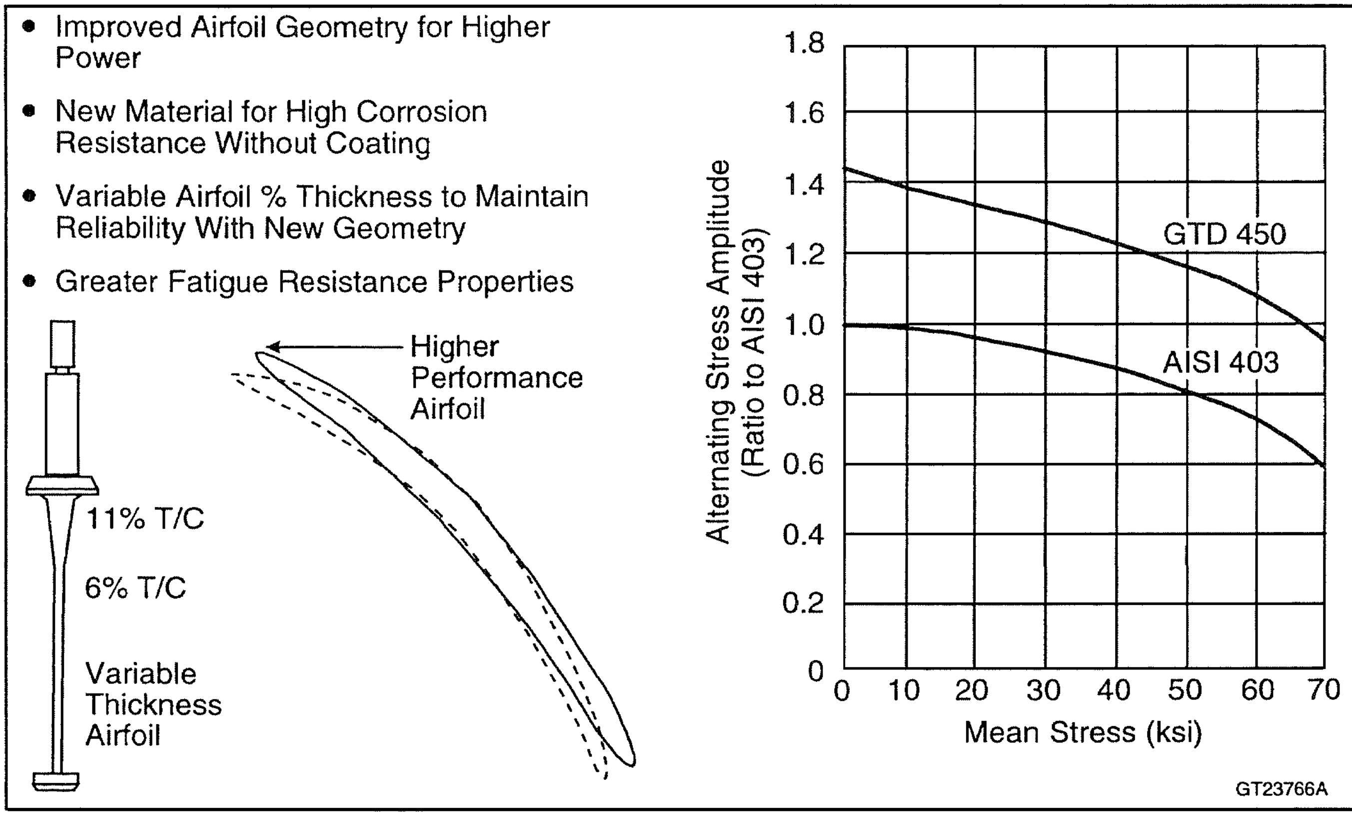

Figure 24. Design Improvements With GTD-450 High-Flow IGV Designs

tubes, and splash plate cooling around the crossfire tube collar. The TBC consists of two materials applied to the hot side of the component, a bond coat applied to the surface of the part and an insulating oxide applied over the bond coat. This .015 inch thick coating provides an insulating layer that reduces the underlying base material temperature and mitigates the effects of hot streaking or uneven gas temperature distributions.

The liners also use splash plate cooling around the crossfire tube collar. Impingement cooling on the splash plate increases the effectiveness at the collar location. This configuration reduces stress concentrations and cracking at the louvers experienced in the earlier design.

New technology MS5002 units will receive liners with hardfacing on the collars and crossfire tubes. The hard facing on crossfire tubes consists of a flame-sprayed chrome-carbide wear coating being applied to the mating surfaces of the crossfire tubes. The hard faced crossfire tubes are then matched with hard faced crossfire tube collars on the combustion liner to complete the package. The hard facing on the crossfire tubes and collars helps to resist wear in the collar region, resulting in a longer part life.

Transition Pieces

The transition pieces for a standard combustion system have not been changed from the 52B/NT or 52C floating seal design.

Advance Technology 2 Vane Stage One Nozzle (FT2J) (Or Phase 1 Stage One Nozzle)

In 1987, the first stage nozzle was improved by reducing the number of vanes per segment down from the original MS5/2A&B's design's three to the advance technology design's two. The reduction in the number of vanes per segment for the nozzle has a significant impact on cycles to crack initiation with improvements of almost 3 to 1 possible for the stage 1 nozzle. The material of the original nozzle, FSX-414, continues to be utilized. The MS5002B Advanced Technology 2-vane stage 1 nozzle provides better maintenance characteristics and a longer part life. This is the nozzle mentioned in the Phase 1 discussion.

Advance Technology GTD-111 Directionally Solidified Stage One Bucket (FT2K)

The directionally solidified (D/S) GTD-111 1st stage bucket is a relatively recent advancement in material developed by GE. This new material possesses improved rupture strength, low cycle fatigue strength, and improved corrosion resistance.

For the directionally solidified GTD-111, the high temperatures advantages are the result of the elimination of transverse grain boundaries from the bucket, compared to equiaxed superalloys. This allows for a substantial increase in creep life, thermal fatigue and impact strength when compared to the equiaxed. These buckets are coated with PLASMAGUARD GT-29 PLUS coating (or GT-33 depending on customer criteria, reference GER-3569F, *Advanced Gas Turbine Material and Coatings* for more information on coatings.) - a vacuum plasma spray coating with aluminum that greatly increases both the corrosion and oxidation resistance of the bucket. Also, new coverplates will be required when replacing pre-1978 thin wall stage 1 buckets. In other cases the new coverplates are not necessary but can be purchased if the current coverplates are worn.

The installation of GTD111 directionally solidified buckets provides a substantial increase in creep life, thermal fatigue, rupture strength, corrosion resistance and impact strength resulting in the ability to raise firing temperatures.

GTD-222 Turbine Shell Support Pins (FS1V)

Some MS5002 units have experienced cracking in the existing turbine shell support pins. These cracks are weld repairable at GE service shops but the cost of this repair may be prohibitive. New support pins are now available which use GTD-222 material to replace the FSX-414 material. GTD-222 is a GE patented nickel based super alloy that has a significant improvement in creep strength compared to FSX-414 and is weld repairable. GTD-222 has increased low temperature hot corrosion resistance.

GTD222 turbine shell support pins provide a replacement part with superior creep strength and weld reparability which lead to longer parts life. In addition, compared to older versions, the attack angle of the support pin is optimized to match 52C and D flow swirl angle.

Although not required for an uprate on those units that shipped after 1978 with modern rotated, or high flow support pins, installation of new pins is recommended after 72,000 operating hours to eliminate any high operating hour support pin creep or cracking potential problems preventing the user from achieving their nominal major inspection interval without opening the turbine case.

MS5002 (B/NT or C) Advanced Technology Package - Models A and B (FT2C)

The MS5002B gas turbine was introduced in 1970. Various minor design changes have been made to reach the 35,000 HP ISO rating as explained in the history section above. Also, as explained above because of interest expressed by many customers, a development program was undertaken in 1986 to increase the MS5002B rating to 38,000 HP (ISO). This rating was applied to current production units as an MS5002C in 1987. This advanced technology package can be applied to all existing MS5002 A & B units. Figure 6 shows a comparison of MS5002 ratings for both original and uprated configurations. Figure 7 is a listing of the MS5002 advanced technology package. This uprating package has been sold for over 67+ MS5002B units, uprating their output to meet changing operational conditions, in addition to the 60+ units that have shipped from Nuovo Pignone and GE factories as Model C turbines. See Figure 8 for an uprate experience list. This advanced technology package also results in considerable maintenance savings due to fewer inspections, per Figure 25.

The MS5002 advanced technology uprate pro-

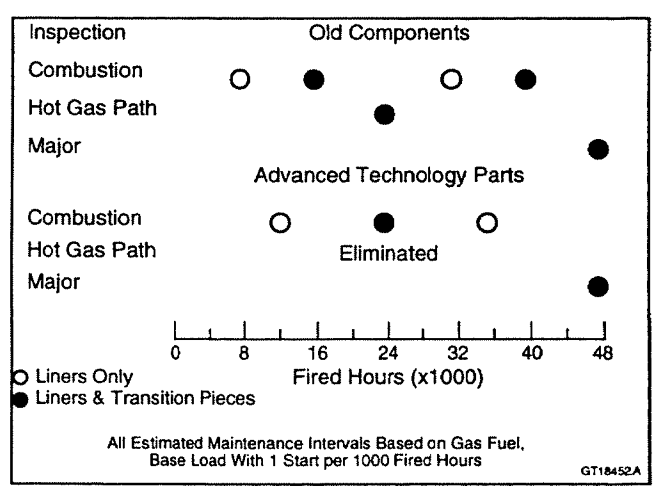

Figure 25. MS3002/MS5001/MS5002 Advanced Technology Packages Maintenance Interval Extensions

*Mechanical Drive***

Advanced Technology Uprate Model	Firing Temp °F/°C	Output HP/kW	Heat Rate Btu/HP-hr/ kJ/kWh	Exhaust Flow 10^3 lbs/hr/ 10^3 kg/hr	Exhaust Temp °F/°C	Comments
MS3002F - N/T	1643/895	11,590/8,643	11,140/15,761	410.5/186	980/527	Simple Cycle
MS3002F - N/T	1628/887	10,620/7,919	8,160/11,545	410.5/186	605/318	Regen Cycle
MS3002A-F	1575/857	9,700*/7,233	-	379*/172	-	Simple Cycle
MS3002A-F	1625/885	9,400*/7,010	8,450*/11,955	379*/172	-	Regen Cycle
MS3002J - N/T	1770/966	15,140/11,290	9,500/13,441	415/188	1008/542	Simple Cycle
MS5002A - N/T	1745/952	27,130/20,231	9,940/14,063	776.1/352	1016/547	Simple Cycle
MS5002B - N/T	1770/966	36,000/26,845	9,150/12,945	974.4/442	967/519	Simple Cycle
MS5002D - Ph. 1	1787/975	41,600/31,045	8,910/12,563	1,124/510	960/516	Simple Cycle
MS5002D - Ph. 2	1807/986	42,600/31,791	8,730/12,309	1,122/509	955/513	Simple Cycle

* MS3002A-F uprates are based on NEMA conditions, all other #s are at ISO conditions
** All uprates are based on using reduced camber High Flow IGVs

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Figure 26. Absolute Performance Guarantees for Advanced Technology

gram can also be applied to earlier MS5002A units for MS5/2 A advance technology package. Due to the increase in firing temperature, it is necessary to also change the MS5002A stage 2 buckets to the MS5002B standard design, per Figure 7. To maximize output at higher ambients, it is also desirable to change to a better grade of stainless steel for the exhaust diffuser to accommodate the higher exhaust temperatures of the less efficient MS5002A.

ABSOLUTE PERFORMANCE GUARANTEES

All performance uprates listed in this paper are based on airflow or firing temperature increases that are directly correlated to performance increases, usually expressed as "percentage increases" or "delta increases." The absolute performance achievable after an uprate can vary due to many variables usually present on older units – casing out-of-roundness, surface finish of non-uprated parts, clearances, etc.

Recognizing that many customers prefer absolute performance guarantees, Figures 26 was prepared to show common performance guarantee points for typical MS5002 advanced technology uprates. All performances listed are based on ISO conditions (59 F/15 C, sea level, 0"/0" inlet/exhaust pressure drops, 60% relative humidity), natural gas fuel and base load, and assumes the axial flow compressor is not rebladed. Similar performance guarantees can be easily provided for variations on these conditions.

Non-Recoverable Performance Degradation

Since uprate performance increases are based on real airflow and/or firing temperature increases, the performance increases provide real and lasting performance improvements. Figure 27 was plotted to show the approximate performance increase for a typical MS5002B advanced technology uprate at approximately 48,000 fired hours. The expected typical non-recoverable performance degradation is plotted for the original configuration as well as for the uprate. This figure shows that the performance increase still returns an expected incremental performance increase after 100,000 fired hours. With the addition of advanced sealing technology, this return will be even greater. By comparison, uprates that are based on component refurbishment and/or blade coatings will usually disappear completely in 10,000 to 15,000 fired hours.

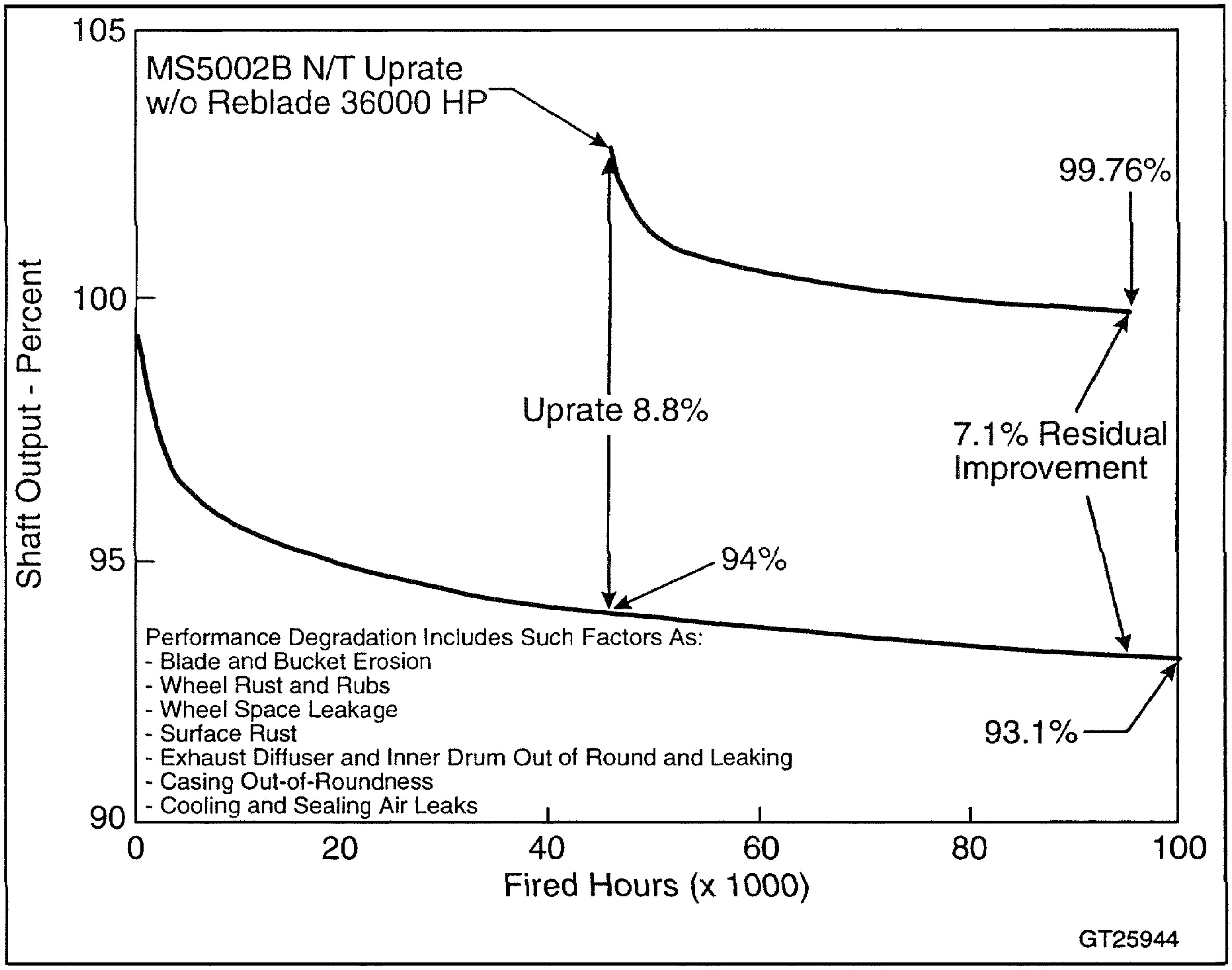

Figure 27. Estimated Non-Recoverable Performance Degrading Effects MS5002B Gas Turbine Uprate

EMISSION LEVELS

When considering an uprate to an existing gas turbine, the impact on emission levels must be considered. Figure 28 lists typical NOx emission levels before and after uprates for the uprate programs described in this paper. Also listed are reduced emission levels with the various options available for emission control (water injection, steam injection and dry low NOx). Detailed review of site and specific emission levels are provided with each uprate study.

There are two sources of NOx emissions in the exhaust of the gas turbine. Thermal NOx is generated by the fixation of atmospheric nitrogen in the flame. Conversion of fuel bound nitrogen (FBN) also generates NOx. The methods described below control thermal NOx emissions and are not effective in controlling the conversion of FBN. FBN is usually found in lower quality distillates and coal gasses, but no matter the source FBN must be taken into account when emissions calculations are made. The options to reduce thermal NOx production are as follows:

Low NOx Louvered Combustion Liners (FR1B)

A "lean head end" louvered design combustion liner is available for all MS5000 units. The louvered slot pattern and dilution hole pattern have been changed compared to the standard high technology liner to provide more dilution air flow at the head end of the liner resulting in a much "leaner" combustion system than the standard louvered liner. This shifting of dilution air flow quenches the products of combustion faster in the combustion zone, thereby reducing the time available for NOx production with a guaranteed 30% reduction in NOx as compared to the standard louvered liner. Figure 29 compares the original louvered liner design ("N" liner) to the lean head end liner ("P" liner).

Two Shaft Units** Model	Firing Temp. °F/°C	Dry S.C.	Dry R.C.*	H_2O/Steam Inj. S.C.	H_2O/Steam Inj. R.C.	Dry Low NO_x S.C.	Dry Low NO_x R.C.
MS3002F	1575/1625/857/885	115	201	42	50	-	42
MS3002J	1730/943	128	217	42	50	42	42
MS3002J-N/T	1770/966	140	236	42	50	42	75
MS5002	1700/927	125	220	42	50	42	-
MS5002B-N/T	1770/966	137	255	42	50	42	-
MS5002D-Ph. I	1787/975	144	-	42	-	42	-
MS5002D-Ph. II	1807/986	150	-	42	-	42	-

* S.C. = Simple Cycle and R.C. = Regenerative Cycle

** Two-Shaft NO_x Levels Are All on Gas Fuel

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Figure 28. Nox Emission Levels at 15% O2 (ppmvd)

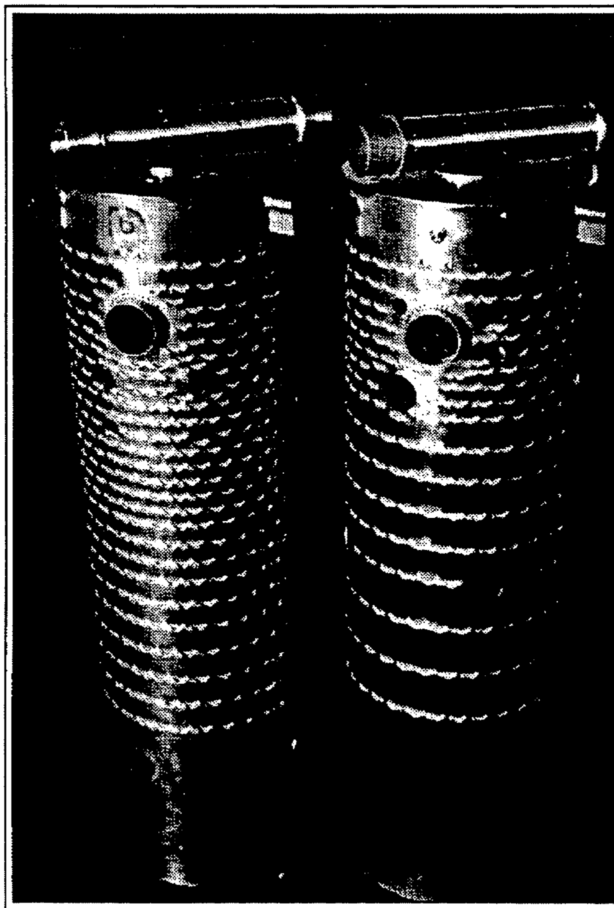

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Figure 29. Louvered Low Nox Lean Head End Combustion Liners

When the MS5002B to C advanced technology uprate is applied in conjunction with an upgrade to the lean head end louvered P liner, the result is an uprate that results in lower NOx levels. Figure 30 plots NOx emissions for an advanced technology level uprate with and without the P lean head end liner. Dozens of advanced technology uprates have been sold with the lean head end liner without the need to add emissions control equipment.

Dry Low NOx Combustion System (FG2B)

The dry low NOx-I combustion system reduces NOx emission, without steam or water injection on gas fuel units, through lean-premixed burning in a multi-zone combustion liner, and by new fuel control equipment which directs fuel to the different liner zones depending upon the mode of operation. Included in the dry low NOx option are new combustion casings, combustion liners, combustion covers and primary and secondary stage fuel nozzles. Per Figure 30, the NOx emissions level for a MS5002C or MS5002D unit are 25 PPmvd @15% O2 at base load on natural gas fuel with DLN.

For retrofit application of DLN systems several valves and piping arrangements will need to be modified or replaced. In addition, the turbine control system needs to be upgraded to MARK V to support the control hardware. An alternative for MARK I, MARK II, or Mark IV systems is to add a micro-

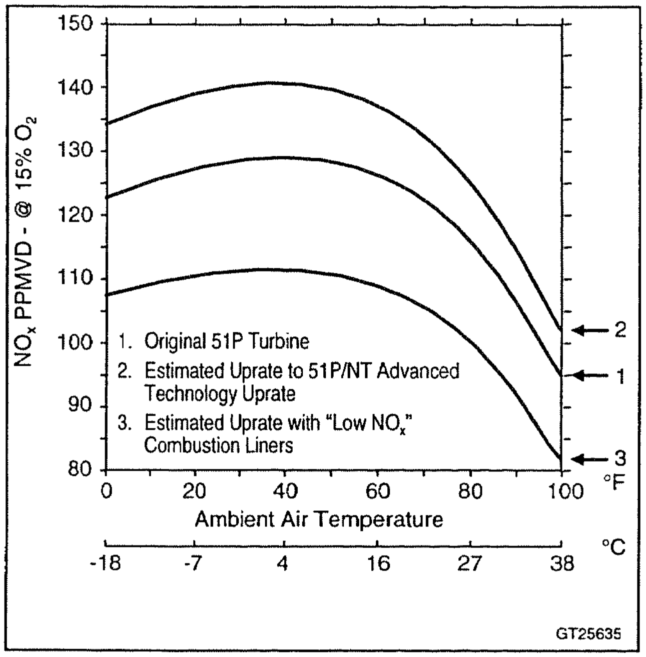

Figure 30. PG 5341 Gas Turbine Lean Head End - Low Nox Louvered Liners

processor based controller NOx box to the existing control system.

In dry low NOx operation, fuel flow is administered to each combustion zone through the primary and secondary fuel nozzles. Total fuel flow is controlled by conventional methods using the speed ratio/gas control valves on gas fuel systems. The combustion system is made up of two major components: fuel nozzle system & liners with venturi, and cap/centerbody. The combustion system is arranged to form two stages for combustion. Turbine operation, from start-up to full load, involves four different modes of combustion in the multizone combustion liner. The distribution of the fuel and flame to the different combustion zones is matched to turbine speed and load conditions to obtain the best performance and emissions. Reference Figure 31 for an outline of a typical MS5002 DLN combustion system..

The most effective emissions controlling mode, dry low NOx-I premix operation, is possible from approximately 70% to 100% load when the ambient temperature is above 50 degrees F. DLN premix operation is also possible from 90% to 100% load down to 0 degrees F.

Refer to GER-3568D, *Dry Low NOx Combustion Systems for GE Heavy Duty Gas Turbines* for additional information on the dry low NOx-I combustion system.

CONTROL SYSTEM UPGRADES

A great variety of control system enhancements and upgrades is available for all vintages of gas turbine control. For older systems where complete control panel replacement is not desired, many functional enhancements are available to add on to the existing control panel. When a complete control panel replacement is required, we can replace the existing control with a complete GE SPEEDTRONIC™ Mark V panel (triple redundant processors or simplex). The latest MKV panel can also take over complete load compressor control, further

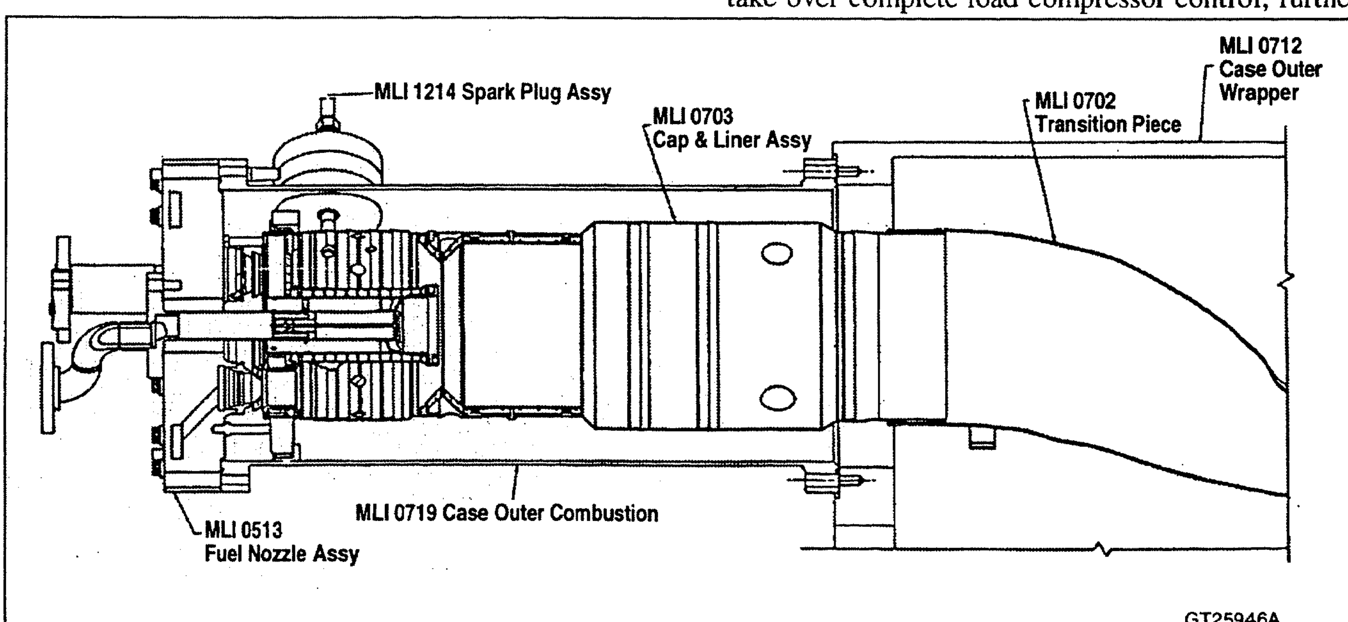

Figure 31. MS5002 DLN System

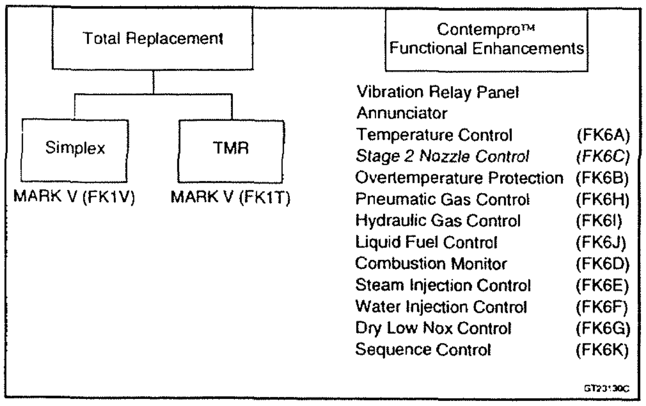

Figure 32. Categories of Control Panel Retrofits and Upgrades

increasing reliability and simplifying plant lay out. Figure 32 shows control options available. (Complete details of available control and instrumentation upgrades are available in the GE publication, "Control System Upgrades for Existing Gas Turbines in the 1990s," GER-3659.)

LOAD COMPRESSOR UPGRADES

Nuovo Pignone offers a wide range of uprates to load compressors to meet the changing operational needs of the driven equipment when combined with an uprate. A combined turbine and compressor uprate may result in higher production with higher efficiency, and therefore lower fuel costs, with extended maintenance intervals resulting in lower operating costs and improved availability. In addition, Nuovo Pignone offers upgrade to dry gas seals for almost its complete line of compressor offerings. For more information contact CM&U Engineering.

SUMMARY

The MS5342D is the latest addition to the world leading GE and Nuovo Pignone fleet created to better serve the needs of the mechanical drive market. In addition, the Model D creates a more powerful class of uprate opportunity for all 550 GE Frame 5002 design heavy-duty gas turbines. These new unit and advanced technology uprate packages provide significant savings to our customers due to reduced maintenance, improved efficiency and increased output. The more powerful MS5342D provides improved operational flexibility by meeting peak demand without decreasing production. In many cases the MS5342D allows increased production from existing sites without significant changes in processes or balance of plantAdvances in emission control technology allow lower than ever levels of emissions to be achieved to meet changing regulatory requirements and corporate environmental concerns. A turbine uprate combined control system upgrading and an upgrade to dry gas seals achieves the best overall improvement in turbine and plant reliability and brings the unit to the state of the art in technology.

REFERENCES

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3) Rowen, W.I., "Design Considerations for Gas Turbine Fuel Systems," GER-3648C, GE Industrial & Power Systems, August 1994.
4) Beltran, A.M., Pepe, J.J., Schilke, P.W., "Advanced Gas Turbine Materials and Coatings," GER-3569E, GE Industrial & Power Systems, August 1994.
5) Carlstrom, L.A., Wilhelm, C.F., "General Electric Heavy-Duty Gas Turbine Design Philosphy," GE Industrial and Power Systems, August 1978.

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