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GE Power Systems

Performance and Reliability Improvements for Heavy-Duty Gas Turbines

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Abstract

Many significant advances in technology have been applied to new unit production. These advanced technology improvements can be applied to field units to achieve increased performance, useful life and reliability. Additionally, many development programs have been specifically developed for application to existing operating units.

Several types of improvements are now available for compressors, combustion systems and hot-gas-path turbine parts. This paper provides a summary of uprate programs available for all models of GE heavy-duty gas turbines with special emphasis on new programs for MS6001, MS7001 and MS9001 (both E and F class models). Complete tabulations of performance improvement, material changes and maintenance interval extensions are included. All uprates that involve changes in firing temperature and/or airflow will have some impact on emissions. Tabulations of original gas turbine emission levels and uprated turbine emission levels are included for reference. Advanced technology uprate packages are available to upgrade almost all of the 6,000 GE-design heavy-duty gas turbines.

Introduction

Turbine uprate packages have been introduced because of continued strong user interest in extending intervals between maintenance, improving efficiency and increasing output. *Figure 1* lists the main items the customer and GE must consider when evaluating a unit for one of the advanced technology uprate options.

This paper covers new uprates that have been successfully developed specifically for field unit application and new uprates that are available as a result of using engineered components that were developed for current new-unit production. *Figure 2* lists uprates covered in this paper. *Figure 3* shows the growth in scope and numbers of advanced technology uprates supplied per year. To date there are over 400 firing temperature uprates for field units involving every

- 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

Sourcebook Code	Frame Size	Model	Type Uprate
FT1A	MS3002	A thru G	Advanced Technology Uprate
FT1U	MS3002	A thru G	MS3002 “A” to “F” Uprate
FT1D	MS3002	H & J	MS3002J Advanced Technology Uprate
FT1W	MS3002	H & J	Uprate to Model “K”
FT2C	MS5002	A & B	MS5002C Advanced Technology Uprate
FT2R/FT2S	MS5002	A, B & C	Uprate to MS5002D
FT3L/FT3M	MS5001	A thru P	Advanced Technology Uprate
FT3F	MS5001	A thru M and R	16 to 17 Stage Compressor Uprate
FT4L	MS6001	A & B	Uprate to MS6571B
FT5X	MS7001	A & B	Uprate With 7001EA Turbine Parts
FT5Y	MS7001E	C, E & EA	Uprate to 2035F /1112C
FT5Q	MS7001E	C, E & EA	Uprate to 2055F / 1123C
FT5L	MS7001F	F, FA	Uprate to MS7241FA
Numerous	MS7001F	F, FA	Uprate with MS7241 Component Kits
--	All Models	All	High Flow Inlet Guide Vanes
FT6X	MS9001	B	Uprate With MS9001E Turbine Parts
FT6C	MS9001E	E (MS9141 & 9151)	Uprate to 2020F/1104C
FT6Y	MS9001E	E	Uprate to 2055 F/1124C
FT6Z	MS9001F	F, FA	Uprate to MS9531FA
Numerous	MS9001F	F, FA	Uprate with MS9351 Components
--	All models	All	Firing Temperature Increase to Full Rating

GT18447 “I”

Figure 2. Gas turbine uprates

Year	3/2 (A thru G) Adv Tech (FT1A)	3/2J Adv Tech (FT1D)	5/1R Adv Tech (FT3L)	5/1P Adv Tech (FT3M)	5/2 Adv Tech (FT2C)	6/1B 2055F/ 1123C (FT4L)	7/1 B to E (FT5X)	7/1E 2020F/ 1104C (FT5C)	7/1E 2035F/ 1112C (FT5Y)	7/1E 2055F/ 1123C (FT5Q)	9/1 B to E (FT6X)	9/1E 2055F/ 1124C (FT6Y)	Total # Uprates Shipped
1984	-	-	4	2	-	-	-	-	-	-	-	-	6
85	-	-	5	5	-	-	-	-	-	-	-	-	10
86	6	-	-	4	-	-	-	2	-	-	-	-	12
87	3	-	3	12	1	-	-	-	-	-	-	-	19
88	5	-	4	9	4	-	1	-	-	-	-	-	23
89	3	-	2	5	2	-	-	-	-	-	-	-	12
90	4	-	5	24	27	-	1	-	-	-	-	-	61
91	2	-	6	12	12	-	1	3	-	-	1	-	37
92	3	8	1	19	1	-	2	-	-	-	1	-	35
93	2	-	-	13	4	-	2	4	-	-	1	1	27
94	1	1	-	7	-	-	3	4	5	-	1	-	22
95	-	2	-	4	-	-	4	2	8	-	-	1	21
96	4	-	1	8	2	1	-	-	15	-	1	-	28
97	4	3	1	2	10	4	1	-	11	1	-	1	37
98	-	2	-	2	2	-	1	1	5	1	-	-	21
99	1	2	1	11	2	2	5	-	15	2	-	1	40
Total	38	18	33	139	67	7	21	16	59	4	5	4	411

GT19815L

Figure 3. Gas turbine advanced technology uprate shipments through 1999

frame size. The most common time to consider an uprate is during the first or second major overhaul when the unit has been in operation 10 years or more.

Every owner of GE heavy-duty gas turbines should evaluate the overall economics of the various uprate programs. In most cases, the economic evaluation will justify one of the available uprate packages at the next major overhaul.

Information on specific uprate packages or components is available in the Gas Turbine Sourcebook. Reference codes (such as 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 for quick reference on all uprate options listed in the GER and for all other package options available for heavy-duty gas turbines. Soon all of the uprate options as well as those for emissions, fuels, reliability improvement and controls upgrades will be accessible directly by customers on the GE/WEB Optimizer program.

GE engineers and/or customers have written many papers that document the evaluation and implementation process for the more significant uprates. *Figure 4* lists the most recent ASME papers that document results of these successful uprate projects.

GE design heavy duty gas turbines. *Figure 5* summarizes these development programs with a matrix that shows which program applies to each frame size. We leverage each new program across the entire product line to make each of these programs available to all customers.

Approximately 20% of the inlet air to the axial flow compressor gets lost to the thermal cycle due to losses associated with cooling hot gas path parts or losses due to large clearances. Most uprates on gas turbines typically are achieved by higher airflow or higher firing temperatures. Recently a significant effort has been applied to reducing airflow losses from cooling air and improved seals. The majority of development in the past few years has been directed to reducing these airflow losses. Most of the recent development programs are focused in this area.

- 86-GT-40 New Technology Uprating of Process Compressor and Generator Drive Gas Turbines (MS5001LA)
- 87-GT-24 Performance and Reliability Improvements for Heavy Duty Gas Turbines
- 87-GT-123 5001N Gas Turbine Advanced Technology Uprate
- 88-GT-143 The Modernization of a 1965 MS5001 Gas Turbine: New Life for an Old Unit (MS5001K)
- 89-GT-8 Life Extension and Performance Enhancement of an Industrial Gas Turbine Through Upgrading (MS3002F)
- 90-GT-284 Modification of a GE 7001B Gas Turbine for Increased Reliability by Using 7001E Parts
- 90-GT-350 MS3002 Advanced Technology Uprate Application and Operating Experience (MS3002C)
- 91-GT-48 Field Performance Testing of an Uprated Gas Reinjection Compressor-Turbine Train (MS5001R)
- 91-GT-49 Turbine-Compressor Train Uprated for 30% Increase in Gas Flow (MS5001R)
- 91-GT-318 Conversion of Two MS5001 Gas Turbines to Meet Emission Requirements in the Netherlands
- 92-GT-335 MS5002B Gas Turbine Advanced Technology Uprate for LNG Application
- 90-GT-13 GE MS7001E Gas Turbine Advanced Technology Uprate
- 97-GT-450 Results of the GT Prime Program Improvements at the T. H. Wharton HL&P Site
- 98-GT-359 Combustion Aspects of Application of Hydrogen and Natural Gas Fuel Mixtures to MS9001E DLN Gas Turbines at the ELSTA Plant in Terneuzen, Netherlands

Figure 4. Reference ASME papers on heavy-duty gas turbine uprates

New Uprate Development Programs Designed for New Units

Most existing uprate programs were based on leveraging new unit technology. Over the past three years we have invested heavily in additional uprate programs specifically designed to serve the needs of the existing installed fleet of

High-Pressure Packing Brush Seals (FS2V)

Figure 6 shows the original labyrinth seal design between the compressor discharge casing

	3/2H & J	5/1N & P	5/2 B & C	6/1B	7/1 B&E	9/1 B & E
HPP Brush Seal (FS2V)	X	X	X	X	X	X
#2 Bearing Brush Seal (FS2X)	-	-	X	-	X	X
Stage 2&3 Honeycomb Shroud Seals (FS2T/FS2V)	X	X	X	X	X	X
Stage 1 Shroud Cloth Seals (FS2Y)	X	X	X	X	X	X
Stage 1 Shroud Abraidable Seals (FS2O)	X	X	X	X	X	X
Inner Stage Brush Seal (FS2Z)	-	X	-	X	X	X
One Piece Stage 1 Shroud (FS2Y)	-	-	-	-	-	X
86° IGV with GTD 450	-	X	X	X	X	X
GTD 222 Stage 2 Nozzles (FS1P)	-	-	-	X	X	X
Lean Head End Liners (FR1B)	X	X	X	X	-	-
Load Gear Speed Increase (FT3X/FP4D)	-	X	-	X	-	-
MS5002D Uprate (FT2S)	-	-	X	-	-	-
MS5002D S1N in MS5002C (FT2T)	-	-	X	-	-	-
Tilted Control Curves with Adv Tech Uprate (FT7I)	X	X	X	X	X	X
2055F Uprate (FT4L/FT5Q/FT6Y)	-	-	-	X	X	X
Extender Combustion Upgrade (FR1V)	-	X	X	X	X	X
9% Steam Augmentation	-	-	-	-	X	X
MS 3162K Uprate (FT1W)	X	-	-	-	-	-

X = Available Now

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Figure 5. Development programs for each frame size

"inner barrel" and compressor aft stub shaft. This seal restricts compressor discharge air from leaking into the forward wheel space area. This seal is designed with a nominal clearance of 40 mils to allow for thermal growth differentials and rotor movement during high vibration events.

In practice, most operating units have clearances significantly higher (20 to 60 mils) than nominal. This increased labyrinth seal clearance results in considerable unit performance loss. For a MS7001E unit, a rub of 20 mils on the labyrinth seal teeth equates to at least 1.0% loss in unit performance.

To increase unit performance and to reduce the rate of performance degradation due to wear on labyrinth seal teeth, a new wire brush seal design has been developed. *Figure 6* details the wire brush seal. Since the wire brush seal is flexible and will bend (not wear) on contact

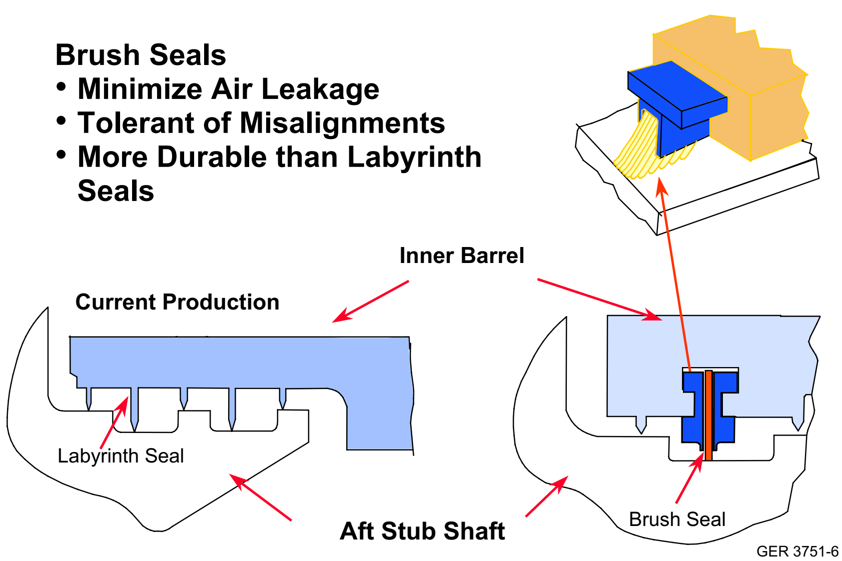

Figure 6. Typical brush seal element

with the compressor aft shaft, a closer clearance can be allowed for the initial installation. This provides an increase in output.

Also, since the wire brush seal will “bounce back” to its original configuration after a “rub,” there will be substantially less performance degradation over time than for the original labyrinth seal. Performance improvement is typically about 1% output and 0.5% heat rate. *Figure 6* shows a typical HPP brush seal.

#2 Bearing Brush Seals (FS2X)

The airflow that passes through the High Pressure Packing (HPP) pressurizes the inner wheel space of the turbine. For units with a middle bearing, a significant amount of this air will leak through the #2 bearing outer seals and vent to atmosphere. This represents a significant performance loss. As a follow-on to the successful HPP brush seal program, a brush seal was designed for both the forward and aft outer bearing casing seals. This seal has been successfully applied for MS7001E, MS9001E and MS5002 units. Performance improvement is typically 0.3% output and 0.2% heat rate. An example of a #2 bearing brush seal arrangement is shown in *Figure 7.*

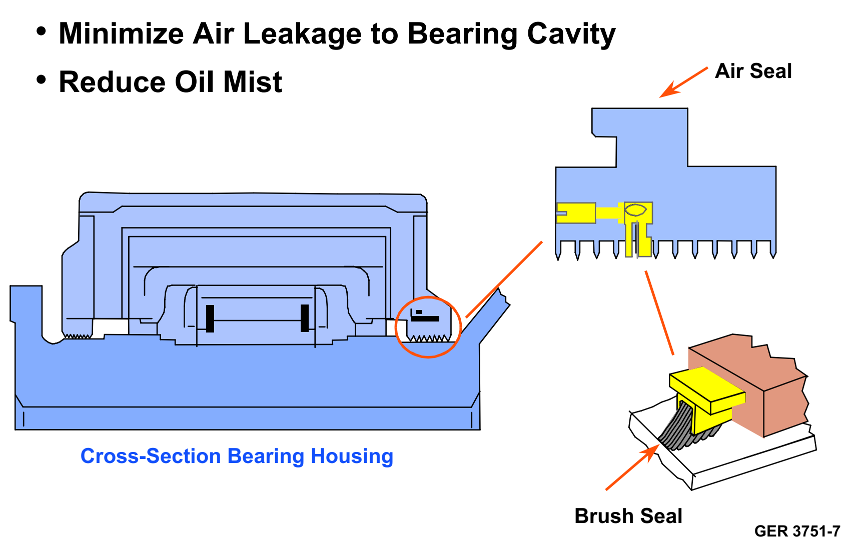

Figure 7. #2 bearing brush seal

Stage 2 Nozzle Inner Diaphragm Brush Seal

There is a large gap between the stage 2 nozzle inner diaphragm and the stage 1-2 wheel spacer to prevent any contact due to rotor vibration, thermal transients or nozzle deflection. Unfortunately this gap is a substantial leak path. As a continuation of the successful HPP and #2 bearing brush seal programs, a brush seal has also been designed to improve the inner stage packing seal. This seal is now available for all single shaft designs and provides a performance improvement of approximately 1% output and 0.5% heat rate. A cross-section of a stage 2 nozzle with a brush seal is shown in *Figure 8.*

Stage 2 and 3 Shroud Honeycomb Seal (FS2T/FS2U)

To avoid bucket tip rub, the clearances between the bucket tip and the stationary shroud blocks have always been about 100 mils. This large clearance allows a significant amount of hot gas

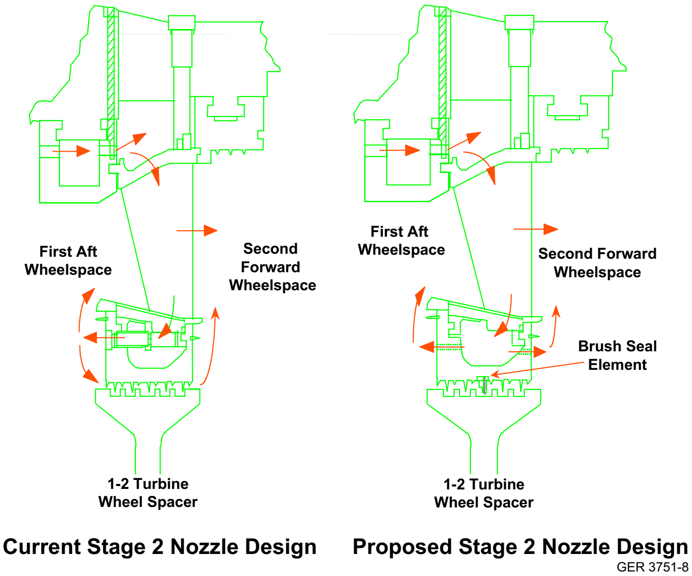

Figure 8. Stage 2 nozzle with a brush seal

to flow over the bucket tip, resulting in significant performance loss. To address this issue, a honeycomb seal insert (*see Figure 9*) was designed to be inserted between the labyrinth seal teeth in the stage 2 and 3 shroud blocks.

The honeycomb material is softer than the shroud and bucket material, which makes it sacrificial in nature for this application. The bucket tip shroud labyrinth seals are designed to cut a groove into the honeycomb material. The tight clearance between the bucket tip and the honeycomb shroud seals provide a performance improvement up to 0.6% in both output and heat rate. To make sure we effectively cut a groove into the honeycomb material we also design a "cutter tooth" on the leading edge of the bucket shroud tip labyrinth seals (*see Figure 10*).

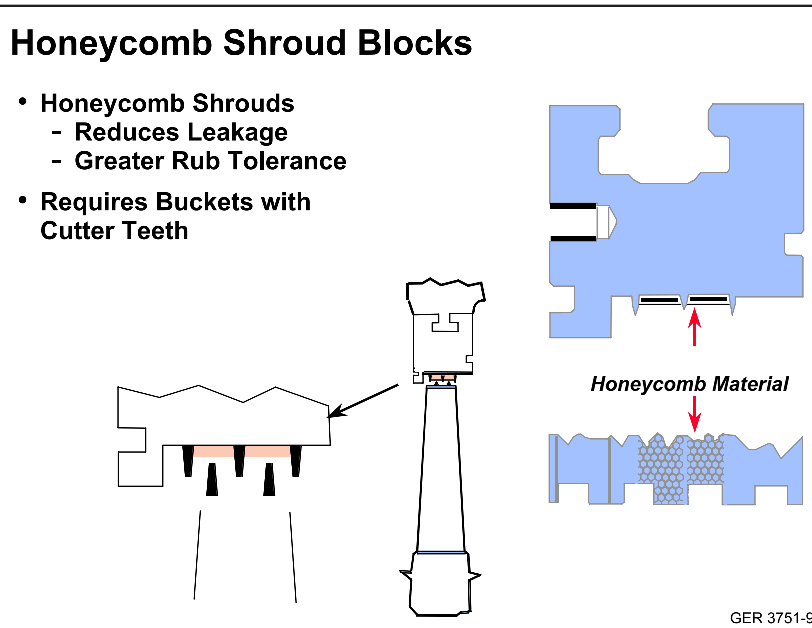

Figure 9. Honeycomb seal insert

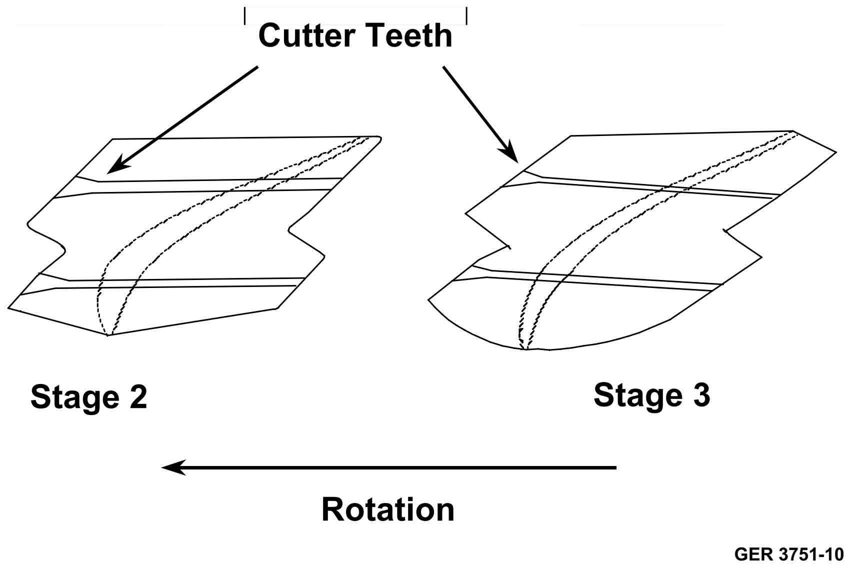

Figure 10. Bucket shroud cutter teeth

Stage #1 Shroud Cloth Seals (FS2Y)

Leakage of compressor discharge air past the shroud block segments is one of the most critical areas for performance loss. The original pumpkin-tooth style design with an interlocking spline seal is a good seal, but is fairly inefficient. The new design has a flat-face shroud block with a cloth seal that inserts into grooves in both adjacent shroud blocks. *Figure 11* compares the improved design versus the original pumpkin-tooth design. *Figure 12* compares the original bar type spline seal versus the upgraded cloth seal.

The cloth-seal design seals both radial and axial flow and provides a flexible seal to allow for individual shroud block misalignment. This improved seal design restricts the higher pressure, compressor discharge air from leaking into the hot gas path. As a result, it provides a performance improvement of up to 0.7% in output and 0.5% in heat rate.

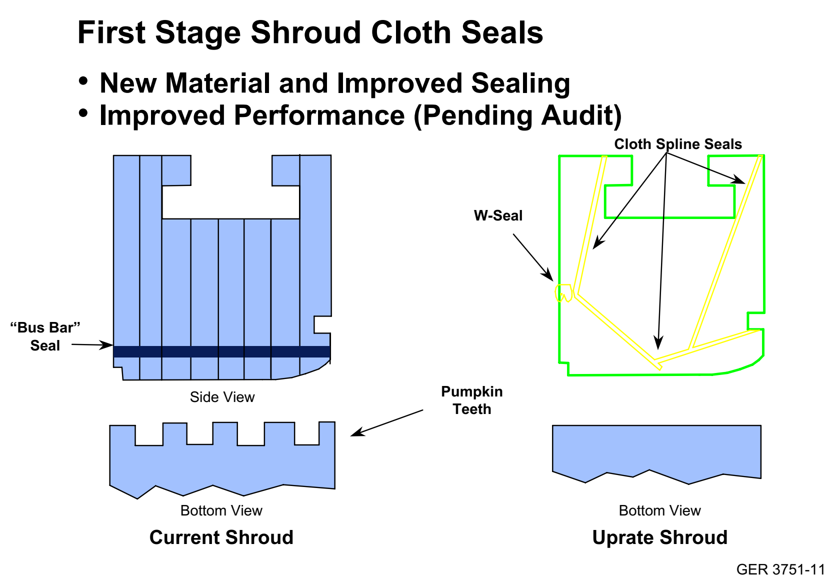

Figure 11. "Pumpkin-tooth" design vs. new shroud seal design

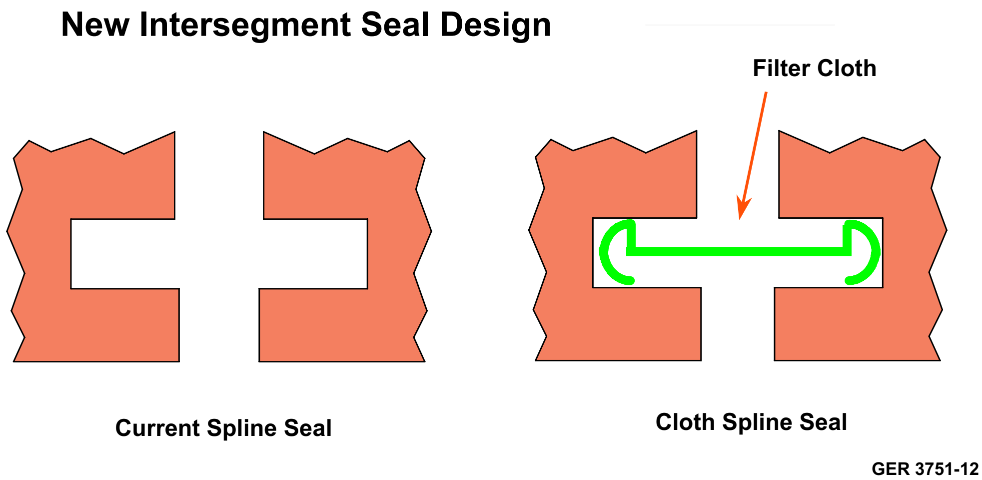

Figure 12. Bar type spline vs. cloth-seal design

Stage 1 Shroud Abraidable Coating (ES20)

Clearance between the stage 1 bucket and the stage 1 shroud block is a critical factor because it allows combustion air to leak over the tip of the stage 1 bucket, which causes significant performance loss.

A large clearance typically is required to account for conditions that can result in significant bucket rub:

- Casing out-of-roundness
- Misalignment of the rotor
- Shroud block misalignment

The abraidable coating is intended to account for all of these items and to provide an absolute reduction in hot running clearances. The abraidable seal is a 40-mil thick coating in the inner diameter of the stage 1 shroud blocks. The intention is to have the bucket tips rub into the abraidable coating during the first few start-ups to mold a round gas path, regardless of casing roundness, shroud misalignment, rotor misalignment or bucket tip rubs (on used buckets). The expectation on an installed turbine is a minimum performance improvement of 0.4.0% output and 0.3% heat rate. *Figure 13* depicts a typical abraidable coating on a Stage 1 shroud.

This combination of cloth-seal replacement shroud blocks and abraidable coating should provide impressive performance improvements in excess of 1.1% output and 0.8% in heat rate.

MS9171E Single-Piece Stage 1 Shroud

The initial design for the MS9171E (2055F) design incorporated a two-piece, Stage 1 shroud. This was necessary to achieve acceptable parts life with the original A&SI 310 stainless steel material. The more recent HR120 material is a more crack resistant alloy and is better able to withstand the higher firing temperature. Thus we can now provide a single-piece stage 1 shroud block. The cooling and sealing air changes associated with the 2-piece shroud design resulted in a performance loss of 0.9% to output and 0.4% heat rate. Thus for all MS9171E (2055F) units we can provide the new HR120 single-piece shroud to recover this performance loss (*see Figure 14*).

Reduced Camber, High Flow Inlet Guide Vanes

Improvements in Inlet Guide Vane (IGV) material and airfoil design have also increased airflow. *Figure 15* details performance increases available by applying the latest IGV designs to

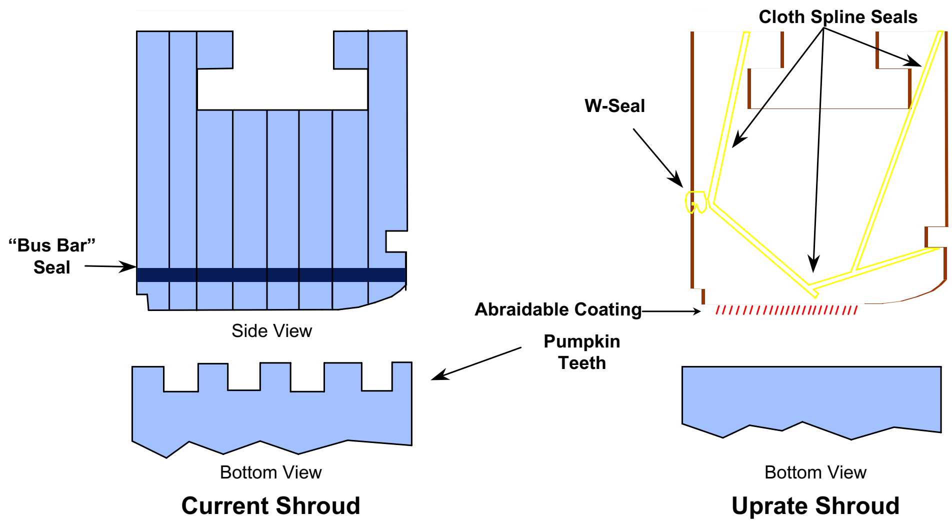

Figure 13. Abraidable sealing coating on a stage 1 shroud

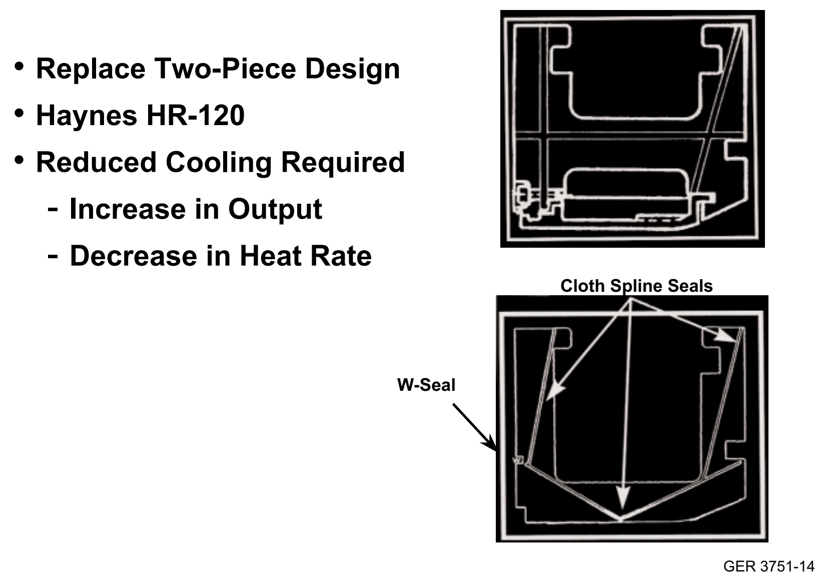

Figure 14. MS9171E one-piece stage one shroud block

older units. The new IGVs are directly interchangeable with the original IGVs in complete sets. However, in many cases new control curves and/or inlet guide vane settings are required to achieve optimal performance. Additionally, the new reduced camber IGVs are made from GTD 450, a stronger and more corrosion-resistant stainless steel.

As part of the modification kit for GTD 450 IGVs, a set of tight clearance, self-lubricating IGV bushings are also supplied.

GTD222 Stage 2 Nozzle Material (FS1P)

The new GTD222 high-nickel based alloy was developed in response to the need for an improved creep-resistant alloy for stages 2 and 3 for the MS6/7/9 higher firing temperature designs. The improvement in creep resistance was so great that we were able to reduce the cooling air for the stage 2 nozzle. *Figure 16*

Sourcebook Codes			Incremental Changes Output	Heat Rate	Temperature Change T_{EX} (F/C)
Variable IGV-Design Turbines — Reduced Camber High Flow GTD-450 IGV					
FT3C	MS5001N/P	Pre-1978	3.9%	-0.2%	-11/-6
FT3C	MS5001P	1978 Thru 1987	1.9%	-0.5%	-4/-2
FT2B	MS5002B	Pre-1978	3.8%	-0.1%	-10/-6
FT2B	MS5002B	1978 Thru 1987	1.8%	-0.3%	-4/-2
FT4C	MS6001B	Pre-1988	1.9%	-0.2%	-2/-1
FT5B	MS7001B		4.8%	-0.7%	-12/-7
FT5B	MS7001C		4.5%	+0.1%	-11/-6
FT5B	MS7001E	Pre-1988	1.9%	-0.1%	-3/-2
FT5B	MS7001EA	Pre-1988	1.4%	-0.3%	-2/-1
FT6B	MS9001B		4.8%	-0.7%	-12/-7
FT6B	MS9001E	Pre-1988	1.9%	-0.2%	-2/-1
Fixed IGV-Design Turbines (316-SS IGV)					
FT1F	MS3002 A Thru J	Pre-1978	2.2%	-0.5%	-6/-3
FT3I	MS5001 A Thru M and R		1.0%	-0.3%	-2/-1
FT2M	MS5002A		1.1%	-0.4%	-2/-1

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Figure 15. GTD 450 IGV performance increase

- **Improved Creep Resistance**
- **Improved Nozzle Vane Cooling**
  - **Redesigned Core Plug**
- **Improved Performance**
  - **Reduced Cooling Air Flow**

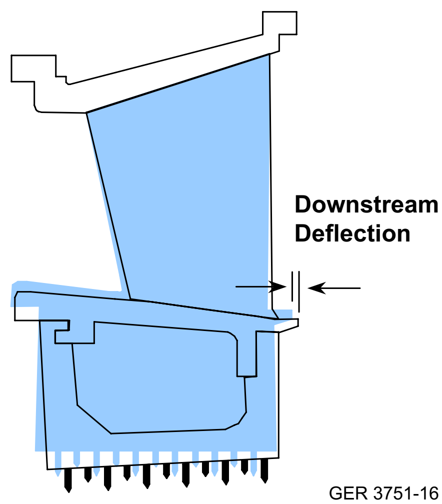

Figure 16. GTD 222 stage 2 nozzle creep

shows typical creep deflection between Hot Gas Path inspections. *Figure 17* shows a comparison of creep deflection between the original FSX414 material and the new GTD222 material. *Figure 18* shows the performance improvements for MS 6/7/9 units.

Lean Head End (LHE) Combustion Liners (FR1B)

The original design of louvered combustion liners for MS3/5 units had relatively high NO_X levels. More recent developments in combustion liner technology enable the use of leaner head end/lower NO_X designs. NO_X reductions of up to 30% can be achieved by applying the newer LHE technology. *Figure 19* shows a comparison of the original liner versus the LHE liner. In areas where emission regulations allow it, all uprates to an advance technology uprate package can be done when applying the LHE liner to actually get an uprate with lower emissions. *Figure 20* shows an overall 20% reduction in

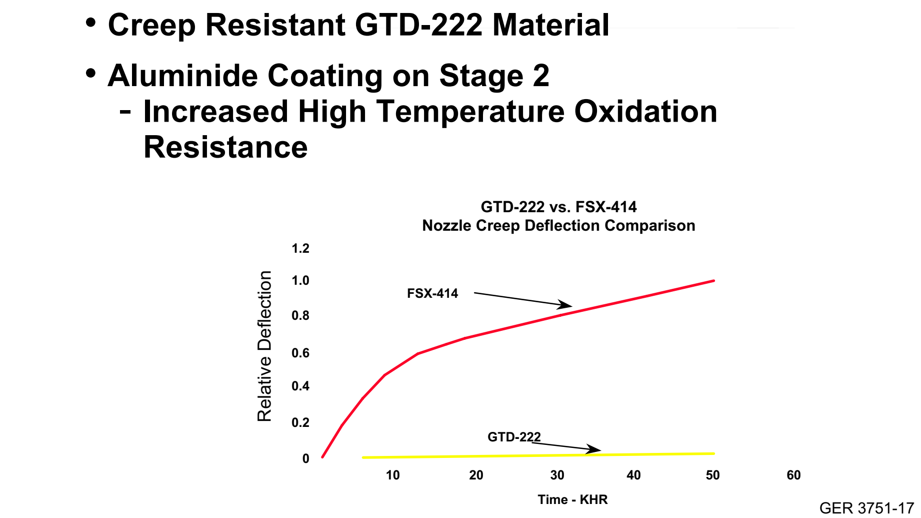

Figure 17. Stage 2 and 3 nozzle creep deflection

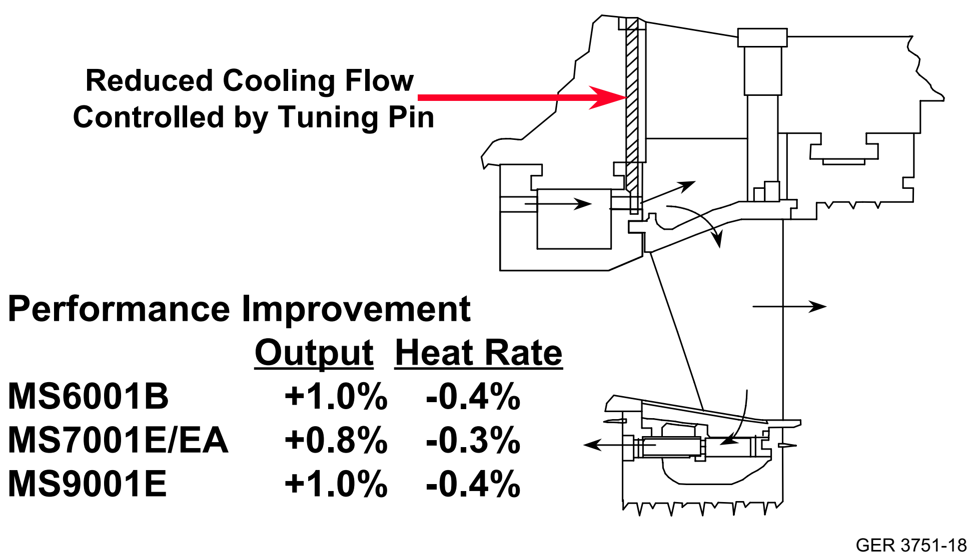

Figure 18. GTD stage 2 nozzle performance improvement

NO_X emissions when applying an advance technology uprate for a MS5001P unit.

MS5432D Advance Technology Uprate (FT2T)

Due to the strong customer interest in uprates for the MS5382C, the MS5432D was introduced. For the MS5002D we combined the highly successful MS5002C hot gas path with the MS6001B axial flow compressor as shown in *Figure 21*. This new design has been successfully applied for both uprates of field units as well as for new unit production to provide approximately a 13% power increase.

MS3162K Advance Technology Uprate (FT1W)

Due to strong customer interest in uprates for the MS3152J, MS3216K is being introduced. This design improvement applies modern advanced airfoil design technology to the MS3002 axial flow compressor. This uprate

Figure 19. Louvered low NO_X lean head end combustion liners

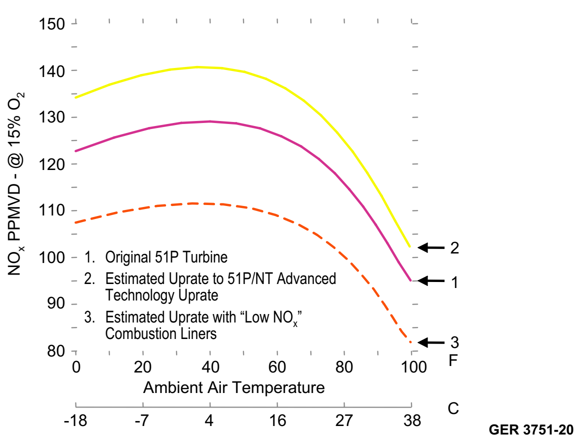

Figure 20. Lean head end – low NO_X louvered liners

requires new compressor wheels and blades but retains the original compressor casings. The increase in output is 8.0% and the improvement in heat rate is 7.0%. *Figure 22* shows a cross section of a MS3002 unit to highlight the parts that are affected by this advanced technology uprate.

MS7001F/FA PG 9001F/FA Uprate Packages

There have been numerous uprates/upgrades involved in the 7F/9F product line over the past several years. In most cases the latest upgraded buckets, nozzles and shrouds can be applied to all of the older production F/FA units. Additionally, if these design improvements are applied in selected packages. significant performance improvements will result. *Figure 23* shows specific performance improvements that can be achieved by applying selected component kits to the older production 7/9 F/FA models.

Massive Steam Injection for MS 7001E

GE has offered steam injection for power augmentation for 40 years on all of our production machines. *Figure 71* shows the relative output/efficiency improvements with up to 5.0% steam injection (as a percentage of airflow). Considerable design effort was applied in 1999 to develop a 9% steam injection option for the MS7001E &EA models. It was determined that by applying the current production advance technology hot gas path parts we can achieve 29.0% in output without any loss in parts life. *Figure 24* lists various parameters involved in applying the 9.0% steam injection option.

Conventional Uprates Applying New Unit Advance Technology

MS3002 Advanced Technology Uprate Package - Models A through G (FT1A)

The MS3002 gas turbine was introduced in 1950. Various design changes in combustion and turbine hot-gas-path design were developed over the years, as the unit was uprated from the MS3002A through the MS3002F and G models. *Figure 25* lists the performance characteristics for the various models. This unit has been used for many pipeline, process and generator-drive applications. An advanced technology uprate package was developed because of continued strong customer interest in reduced mainte-

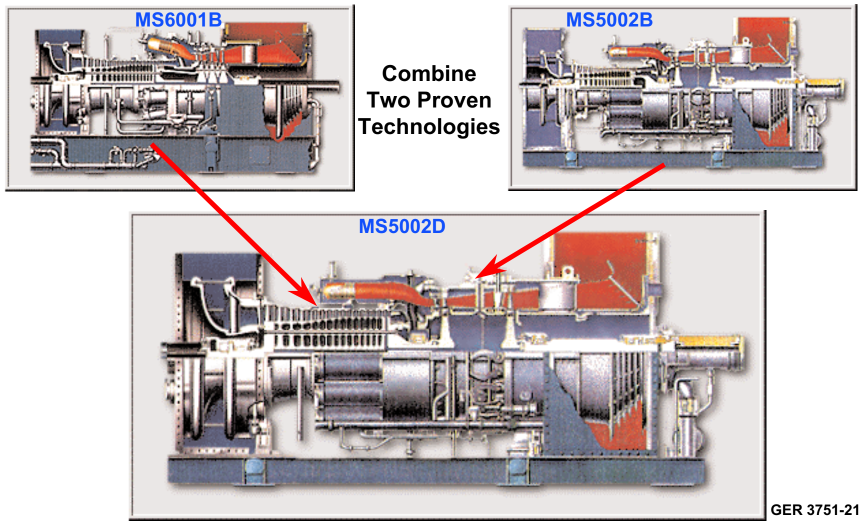

Figure 21. MS5002D advanced technology uprate

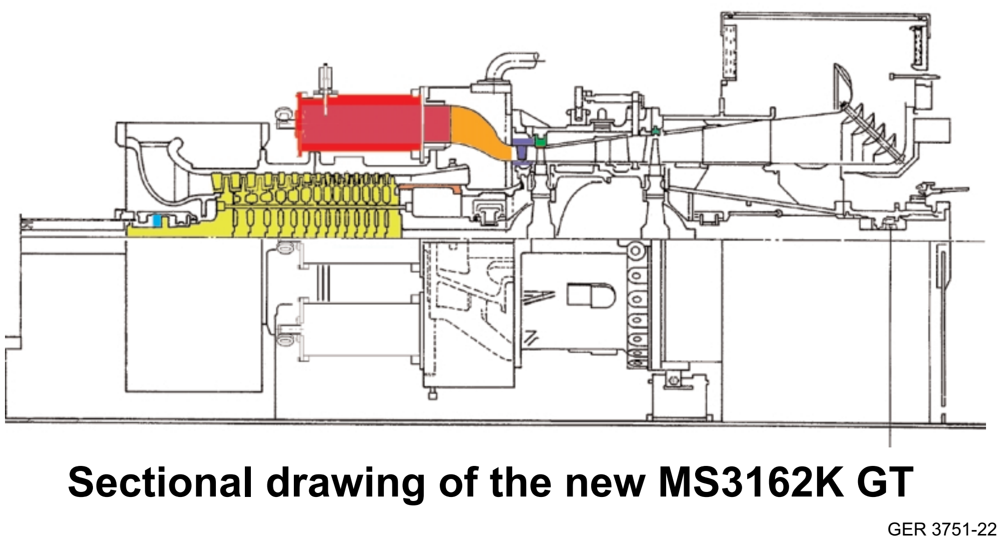

Figure 22. MS3162K advanced technology uprate

nance cycles, improved efficiency and increased output. *Figure 26* details the MS3002 advanced technology package. *Figure 27* details predicted improvements in thermal efficiency and output for the advanced technology parts package for regenerative cycle units.

Considerable fuel savings are realized with improvements in thermal efficiency to 33.0% for the regenerative cycle. Regenerative cycle units can be uprated to over 10,620 HP at ISO conditions with greater than 33.0% thermal efficiency, regardless of original unit configuration. Most simple-cycle units can be uprated to 11,590 HP at ISO conditions. *Figure 28* details expected reductions in maintenance intervals.

As maintenance inspections for hot-gas path are extended to 48,000 hours, considerable reductions in planned outages and associated main-

HGP UPRATE PACKAGES FOR PG7001 AND PG9001 UNIT

No.	SB CODE	PACKAGE DESCRIPTION	PG7211F % KW	PG7211F % HR	PG7221FA % KW	PG7221FA % HR	PG7231FA+ % KW	PG7231FA+ % HR	SB CODE	PG9281F % KW	PG9281F % HR	PG9311FA % KW	PG9311FA % HR
1	FV1N	S1N, S1B, S1S			2.08	-0.95	0.64	-0.51	FV4N			1.69	-0.78
2	FV1O	S1N, S1B			0.97	-0.48	0.13	-0.37	FV4O			0.79	-0.38
3	FV1P	S1B, S1S	1.18	-0.66	1.64	-0.97	0.31	0.00	FV4P	0.72	-0.46	1.10	-0.72
4	FV1Q	S1N, S1S			1.50	-0.43	0.70	-0.55	FV4Q			1.40	-0.45
5	FV1T	S2N, S2B, S2S, S3N, S3B, S3S, HPP Brush Seal, CDC Bore Plugs, and 88 IGV	2.83	-1.05	1.86	-0.89	0.60	-0.20	FV4T	1.96	-0.66	0.99	-0.52
6	FV1U	S2B, S2S, S3B, S3S, HPP Brush Seal, CDC Bore Plugs, and 88 IGV	2.77	-0.98	1.79	-0.80	0.09	0.00	FV4U	2.77	-0.98	1.51	-0.61
7	FV1V	S2B, S2S, HPP Brush Seal, CDC Bore Plugs, and 88 IGV	2.49	-0.75	1.49	-0.55	0.08	0.00	FV4V	2.49	-0.71	1.37	-0.48
8	FV1W	S3B, S3S, HPP Brush Seal, CDC Bore Plugs, and 88 IGV	2.68	-0.83	1.55	-0.51	0.00	0.00	FV4W	2.64	-0.72	1.41	-0.37
		Firing Temperature	5.94	-0.45	2.10	-0.02	0.00	0.00		5.89	-0.41	2.08	0.00
9		TOTAL AVAILABLE	9.95	-2.16	6.04	-1.86	1.24	-0.71		8.57	-1.53	4.76	-1.30

Note

(1) All KITS consist of FA+E components, and assume no firing temperature increase (except KIT 9).
(2) Control modifications are required
(3) Brush seal, CDC bore plugs and 88 IGV are NOT included for 7FA+
(4) Under review

Figure 23. PG7001F and PG9001F uprate packages

- **Standard and MNQC Combustor Only**
- **9% of Compressor Air Flow is 55.45 pps Steam Flow in Wrapper**
- **Expected Output Improvement of 29.6% (77.8 MW to 100.8 MW)**
- **Expected Heat Rate Improvement of 8.1% (10664 to 9800 Btu/kw-hr)**
- **Parts Life Impact on Maintenance Schedules Has Been Established**
- **Total Plant Solution/Package**

GER 3751-24

Figure 24. MS7001EA 9% steam injection

tenance costs are realized. *Figure 29* is a cross-section detailing existing components that are replaced with advanced technology components. Performance tests on all units completed to date show actual performance improvements in excess of those shown in *Figure 27.*

MS3002 Uprate to 3/2F Configuration (FT1U)

Earlier MS3002 Models A through E and G can be uprated with MS3002F combustion and hot-gas-path parts for significant improvements in output, heat rate and expected parts life.

Uprating with 3/2F combustion and hot-gas-path parts will provide 9,400 HP NEMA rating in regenerative cycle and 9,700 HP NEMA rating in simple-cycle operation. For example, an MS3002A unit rated at 5,000 HP could be uprated to 9,400 HP in regenerative cycle configuration by upgrading with MS3002F hot gas path components. For performance changes for

Model	Ship Dates	hp (kW) Range*	Heat Rate** (Btu/hp-hr/ kJ/kWh	Firing Temp. (F/C) RC	SC	Air Flow* (10^3 lbs/hr/ 10^3 kg/hr)
3502A,B	1951-56	5,000-6,700 (3,729-4,996)	10,100/14,289	1,450/788	1,450/788	355/161
3762C	1955-59	To 7,600 (5,667)	9,280/13,129	1,500/816	1,500/816	355/161
3802D	1961-63	To 8,000 (5,966)	9,070/12,832	1,550/843	-	360/163
3852E,G	1963-66	To 8,500 (6,338)	8,900/12,592	1,575/857	1,525/829	371/168
3932F	1966-73	To 9,300 (6,935)	8,490/12/012	1,625/885	1,575/857	371/168
3142H, J	1969-1992	To 14,600 (10,887)	7,410/10,484	1,750/954	1,730/943	415/188
3152J	1992-1999	15,140 (11,290)	9,500 (S.C.)/13,441	-	1,770/966	415/188
3162K	2000-	16,600 (12,450)	8,690 (S.C.)/12,245	-	1,779/970	415/188

*Ratings for models A thru G are based on NEMA (1000 ft/300m altitude and 80 F/27 C) conditions and models H & J are based on ISO (sea level and 50 F/16 C) conditions. To convert from NEMA to ISO ratings for approximate comparison, multiply NEMA rating by 1.12. Includes 0/0 inches H_2O inlet/exhaust pressure drops. Ratings are based on gas fuel.

**Heat rates given are for regenerative cycle and are lower heating value. To convert to % thermal efficiency, divide 2547 Btu/hp-hr by heat rate (Btu/hp-hr) and multiply by 100.

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Figure 25. MS3002 performance history

	3002A/B	3002C THRU G
• 2 Vane Stage 1 Nozzle	X	X
• GTD 111 Stage 1 Bucket	X	X
• High-Pressure Turbine Rotor Assembly	X	X
• Stage 2 Nozzle	X	X
• GTD 111 Stage 2 Bucket	X	X
• Low-Pressure Turbine Rotor Assembly	X	X
• Floating Seal Transition Piece	X	X
• Turbine Shell	X	X
• Combustion Liners	X	X
• Splash Plate Crossfire Tube Collars	X	X
• Exhaust Diffuser	X	X
• Round-The-Corner Combustion	X	-

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Figure 26. MS3002 A through G uprate parts

other models, refer to *Figure 25*. Both ratings also include the high flow 81° IGVs. The MS3002F components are much more readily available than earlier production parts, which makes it possible to achieve considerable benefits in parts availability and parts standardization. In upgrading the combustion system for older vintage MS3002 units, the MS3002F or MS3002J combustion systems could be used. The MS3002J combustion system has the added advantage of being easily converted to a Dry Low NO_X (DLN) combustion system if also required.

This uprate requires converting to the MS3002F Stage 1 and 2 shrouds, nozzles, wheels and buckets, and either the MS3002F or MS3002J combustion system. All MS3002F hot-gas-path components can be retrofitted into the existing

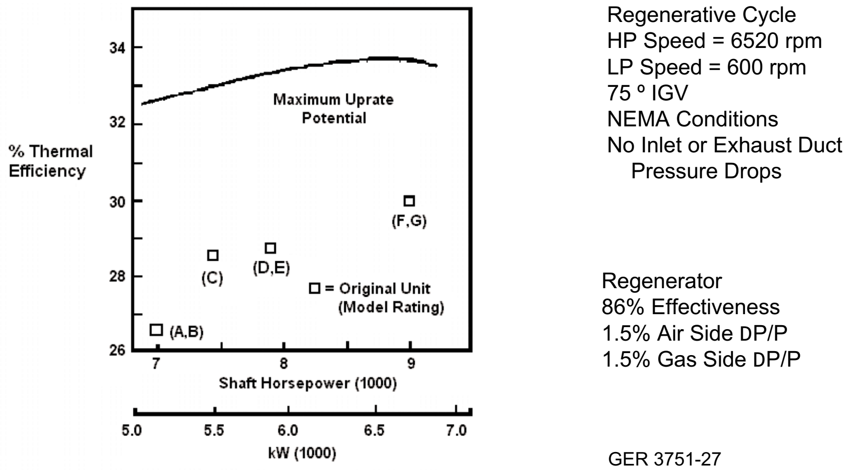

Figure 27. MS3002 regenerative cycle thermal efficiency improvements

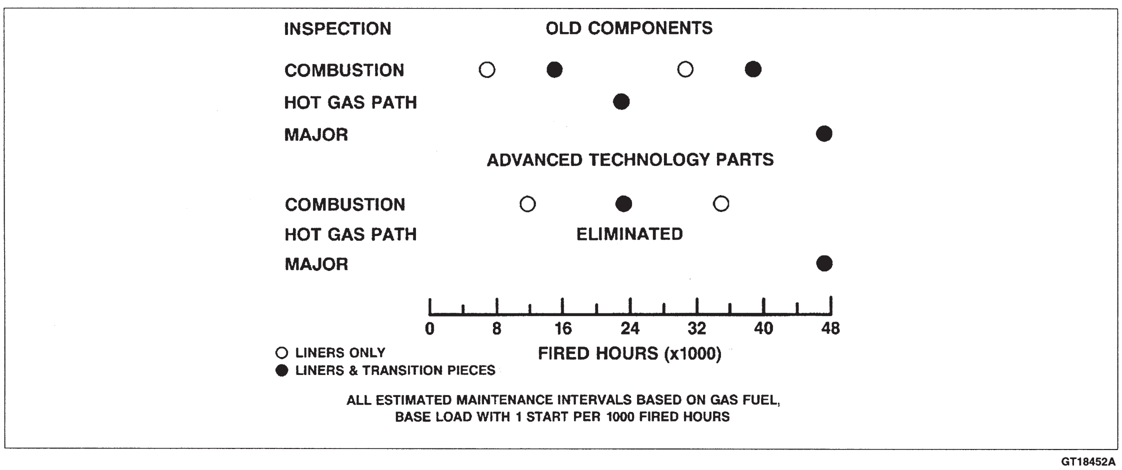

Figure 28. MS3002/MS5001/MS5002 advanced technoloy packages maintenance interval extensions

turbine shell with some modifications. *Figure 30* details individual component upgrades for use in applications where a complete “A” to “F” uprate may not be required.

MS3002 H and J Advanced Technology Uprate Package (FTID)

A modernization and uprate program developed for the MS3002 H and J units based on similar design improvements has been introduced on other units in the GE heavy-duty product line. This program involves uprating the turbine to 1,700 F/966 C from the present 1,730 F/943 C firing temperature. *Figure 25* lists the original performance for these units. *Figure 31* details the design improvements for the MS3002 H and J advanced technology uprate program. The key ingredient required for the MS3002J advanced technology uprate is the directionally solidified GTF 111 Stage 1 bucket. All of the components in this package are necessary to enable the uprate and will provide improvements in output of 3.7% and heat rate of 0.3%.

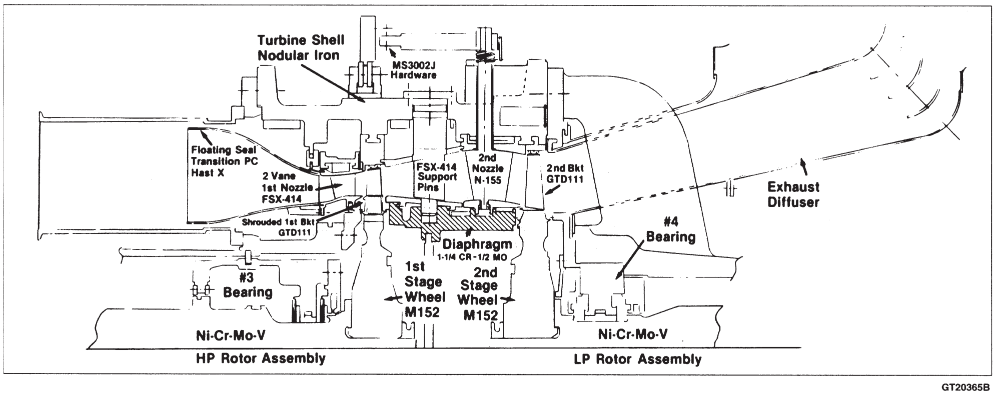

Figure 29. MS3002 modernization and uprate program

Sourcebook Code	Component	Design Improvements
FS2L	Stage 1 Nozzle	- FSX414 Investment Casting vs Previous Fabricated Design
FS1J	Stage 1 Wheel/Bucket	- Solid One Piece 3/2F Forged A286 Wheel Replaces Composite Wheel. Stage 1 3/2F Bucket Is Made from U500 Material And Has an Integrated Coverplate
FT1T	Stage 2 Wheel/Bucket	- Solid One Piece 3/2F Forged A286 Wheel Replaces Composite Wheel. 3/2F Wheel Can Run at 6000 RPM vs. 5000 RPM for Composite Wheels. Stage 2 Bucket Will Be 3/2F Bucket Made of U500 Material.
FT1V	Combustion System	- MS3002 J Liner, Casing, Header Elbow and Transition Pieces to Replace Original MS3002A Design
FS2M	Exhaust Diffuser	- Longer More Efficient Advanced Technology Design Provides 1% Increase in Output and Efficiency

GT23767

Figure 30. MS3002F component design improvements

Sourcebook Code	
FT1S	- 2 Vane FSX414 Stage 1 Nozzle
FT1R	- GTD111 Directionally Solidified Stage 1 Buckets
FR1G	- Thermal Barrier Coated Combustion Liner with Splash Plate Cooled Cross Fire Tube Collars
FR1J	- Swirl Cooled Cross Fire Tubes
FR1N	- Hard Facing on Cross Fire Tube Ends
FR1C	- Thick Wall Transition Pieces with Floating Seals
	- Performance Improvements
	• 3.7% Increase in Output • 0.3% Decrease in Heat Rate
	- HP & LP Turbine Rotor Bolting Tightening (Low Ambient Temp. Applications Only)
	- LP Thrust Bearing Pad
FS1U	- Stainless Steel Exhaust Diffuser (High Ambient Temp. Applications Only)

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Figure 31. MS3002H and J advanced technology uprate

In addition to the performance improvement, considerable extension of recommended inspection intervals can be realized. *Figure 28* compares recommended maintenance intervals for the original design components and the advanced technology components when used in complete uprate packages. The significant differences are an extension of combustion inspection intervals from 8,000 hours to 12,000 hours and elimination of the recommended hot-gas-path inspection, which was at 24,000 hours.

As maintenance intervals for hot-gas-path parts are extended to 48,000 hours, considerable reductions of planned outages and associated maintenance costs are realized. Nine sets of MS3002J advanced technology uprate parts have been installed. MS3002J units shipped prior to 1978 would get an additional 2.2% output increase by using the latest design inlet guide vanes (*see Figure 15*). High ambient temperature MS3002J units will also need to change the exhaust diffuser material to a high temperature stainless steel design. *Figure 43* shows the relative performance improvement for an MS5002A unit by increasing the exhaust temperature limit to 1050 F/566 C. Similar performance improvements will be achieved for MS3002J units by using the higher temperature stainless steel exhaust diffuser material (*see figure 39*).

MS3162K Advance Technology Uprate (FT1W)

To address strong customer interest in improved thermal efficiency and increased output, the new MS3162K was recently introduced. The primary design change is in the axial flow compressor with an improved aerodynamic blading design. The overall increase in per-

- Complete Aerodynamic Redesign of Compressor Blades
- Parallel Combustion System
- Combustion Liner and Transition Piece Redesign
- Reduced Area Stage One Nozzle
- Stage One Shroud Seals
- Increased Capacity Thrust Bearing
- High Pressure Packing Brush Seal
- #2 Bearing Brush Seal
- Combustion Wrapper Redesign
- Compressor Anti-Surge Valve

GER 3751-32

Figure 32. MS3162K advanced technology uprate definition

	Output	Heat Rate
High Flow IGV's (Pre 1978) (FT1F)	+2.20%	-0.50%
MS3152J Adv Tech Uprate (FT1D)	+3.70%	-0.30%
Stage 2 Shroud Honeycomb Seal (FS2T)	+0.40%	-0.40%
HPP Brush Seal (FS2V)	+0.70%	-0.50%
Stage 1 Shroud Cloth Seal (FS2Y)	+0.50%	-0.50%
MS3162K Adv Tech Uprate (FT1W)	+8.20%	-7.15%
Total	+15.7%	-9.35%

GER 3751-33

Figure 33. MS3002J uprate summary

formance is +8.2% output and –7.15% heat rate. The complete redesigned compressor blading will still fit within the existing 3/2 J compressor casings. *Figure 22* is a cross-section of the new MS3162K. A detailed listing of all design changes is shown in *Figure 32*. A significant visual difference is the change to a parallel reverse flow combustion system.

Figure 33 is a summary of all performance improvements for MS3142J units

MS5001 Advanced Technology Uprate Package - Models A through P (FT3L and FT3M)

The MS5001 unit was first introduced in 1957. Various design changes in combustion and turbine hot-gas-path design have been made over the years, as the unit was uprated from the MS5001A to the current MS5001P model. *Figure 34* lists the original performance characteristics of the various models. This unit has been used for both mechanical- and generator-drive applications.

The initial advanced technology uprate package was designed to apply to models L through P only. This uprate package is intended to improve efficiency and output and to extend maintenance intervals. *Figure 35* details the MS5001 parts package for models A through P. *Figure 28* details expected extensions in maintenance intervals. As maintenance inspections for hot-gas-path are extended to 48,000 hours, considerable reductions of planned outages and associated maintenance costs are realized. Estimated output and heat rate improvements for MS5001 advanced technology uprates are shown in *Figure 36* for models MS5001 L through P.

Incremental output and heat rate improvements can be as high as 31.1% and 9.1%, respectively. Load equipment capability must be carefully reviewed for each application to determine if it is adequate for the uprate or if a similar uprate is required. Several units with advanced technology parts have had more than 50,000 operating hours since the uprate. To determine the best possible uprate program for each customer, it is usually necessary to do a thorough review of all available uprates and to review the capabilities of all associated load equipment.

Further review of the advanced technology uprate package resulted in a design to apply the uprate to older vintage MS5001A through

Model	Ship Dates	kW (NEMA) [(1)]	Firing Temp (F/C)	Air Flow (10^3 lbs/hr/ 10^3 kg/hr)	Exhaust Temp (F/C)	Heat Rate (LHV) Btu/ kW-hr	Efficiency % Btu/hr (LHV)
A	1957-61	10,750	1500/816	662/300	840/449	15,810	21.6
C	1961-64	10,750	1500/816	662/300	835/446	15,810	21.6
D	1961-63	10,750	1500/816	662/300	835/446	15,810	21.6
E	1963	11,500	1500/816	695/315	830/443	15,780	21.6
G	1963-64	12,000	1500/816	695/315	830/443	15,120	22.5
H,J	1964	12,500	1500/816	695/315	820/438	14,430	23.6
K	1965	12,500	1500/816	695/315	820/438	14,430	23.6
L	1966-67	14,000	1600/871	702/318	895/479	14,440	23.6
LA	1968-70	15,250	1650/899	709/322	930/499	14,190	24.1
M	1969-70	16,100	1700/927	716/325	965/518	14,050	24.3
		kW (IS0) [(1)]					
R	1970-87	19,400	1720/938	767/348	955/513	13,260	25.8
R-N/T	1987-	20,500	1755/957	767/348	970/521	12,780	26.8
N	1970-72	24,600	1730/943	928/421	898/481	12,190	28.0
P	1972-78	24,600	1730/943	938/425	904/484	12,140	28.1
P	1978-86	23,350	1730/943	968/439	901/483	12,020	28.4
P-N/T	1987-	26,820	1765/963	981/445	905/485	11,860	28.7

[(1)] In early 1970s, Rating Standards Were Changed From NEMA (1000 ft/300m Altitude and 80F/27C) to ISO (Sea Level and 59F/16C) Conditions. To Convert From NEMA to ISO Rating for Approximate Comparison, Multiply NEMA Rating by 1.12. Includes 0/0 Inches H_2O Inlet/Exhaust Pressure Drops. All Ratings Based on Natural Gas Fuel.

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Figure 34. MS5001 performance history

Sourcebook Code			5001 A-K	5001L/LA/M	5001N/P/R
FR1L	-	Floating Seal Transition Pieces	X	X	X
FR1G	-	TBC Coated Combustion Liners with Splash Plate Crossfire Tube Collars	X	X	X
FT3O	-	2 Vane Stage 1 Nozzle	X	X	X
FT3R	-	GTD111 Stage 1 Bucket	X	X	X
FT3T	-	4 Vane Cast Segment Stage 2 Nozzle	X	X	X
FT3E	-	Shrouded Tip Stage 2 Bucket and New Stage 2 Turbine Wheel	X	X	-
	-	Turbine Shell	X	-	-
	-	Distance Piece	X	-	-
	-	Stage 1 Turbine Wheel	X	-	-
	-	Outer Combustion Casings	X	-	-
	-	Exhaust Frame	X	-	-
FS1U	-	Stainless Steel Exhaust Diffuser (High Ambient Temperature Only)	X	X	-

GT18456C

Figure 35. MS5001 models A through P advanced technology uprate package hardware changes

	Drive	Incremental % Gains Output	Incremental % Gains Heat Rate	Exhaust Temp. Increase ºF/ ºC
5001L	Generator	31.1	9.1	86/48
5001L	Mechanical	25.9	7.2	77/43
5001LA	Generator	20.3	7.5	51/28
5001LA	Mechanical	17.7	7.2	52/29
5001M	Generator	14.0	6.5	16/9
5001M	Mechanical	12.3	7.1	19/11
5001R	Generator	6.0	2.9	16/9
5001R	Mechanical	5.7	2.7	15/8
5001N	Generator	6.0	3.3	10/6
5001P	Generator	6.0	3.3	10/6

GT18457D

Figure 36. MS5001 models L through P advanced technology uprate package

MS5001 K models. This basically involved a new turbine casing in addition to the advanced technology package. *Figure 34* shows original performance for models A through K. The maximum uprating by applying the advanced technology package is the MS5001 R advanced technology rating, also shown in *Figure 34*. Actual percentage improvement for this performance uprate can vary depending on original unit configurations.

Compressor Upgrades - MS5001 Models A through M and R (FT3F) and 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 5001 models A through M and the more recent 5001R models can all be uprated to the 5001 N/P compressor design by adding a zero stage. This 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.

It is also recommended to change the remaining stages of compressor blading because of the age of blades and the increased loading on them, resulting from increased airflow and pressure ratio. For 5001 models A through M, this modification would have to be done in conjunction with a hot-gas-path uprate to a 5001R model configuration to accommodate the increased airflow. MS5001R units can be uprated without combustion or flange-to-flange changes.

Sixteen compressor uprates have been shipped to date. The typical MS5001 shaft speed range for mechanical-drive application is 80% to 105% of 4,860 rpm for the lower airflow 16-stage compressor MS5001 A through M and R units. The higher airflow 17-stage MS5001N/P compressor has a more limited speed range of 90% to 105% of 5,100 rpm. Thus, with this modification, some speed range flexibility loss comes with the airflow/output increase. *Figure 34* shows airflows for all 5001 models.

An uprate of 36% is possible at site rating conditions of 40 F/4 C at 5,100 rpm with only a compressor uprate. An uprate of 42% is possible with compressor and advanced technology turbine uprate. *Figure 37* shows an MS5001 16-stage compressor and an MS5001 17-stage compressor to demonstrate the differences in length and configuration between 16- and 17-stage compressor MS5001 units. Similarly, the MS5002A compressor can be uprated to the MS5002B configuration by adding a zero compressor stage to provide full MS5002B performance, as is shown in *Figure 41*.

MS5001 Speed Increase to 5,355 RPM (FP4E)

Most mechanical-drive MS5001 units were rated at 4,860 rpm at the 100% speed point. This allowed for the 5% over-speed requirement most mechanical-drive customers require for operational process variations.

To take advantage of the various advanced technology uprate programs available for these units, it is frequently necessary to drive the load compressor at a higher speed. Considerable mechanical and dynamic analysis was done on the MS5001 rotor design (both 16-stage MS5001R and 17-stage MS5001P) that resulted in a decision to operate MS5001 units as high as 5,355 rpm (105% of 5,100 rpm). To date, 16 MS5001 mechanical-drive units have been uprated to operate as high as 5,355 rpm.

There is a fairly minor rotor bending critical speed at about 5,400 rpm, so operation at 5,355 rpm does not conform to the API requirement

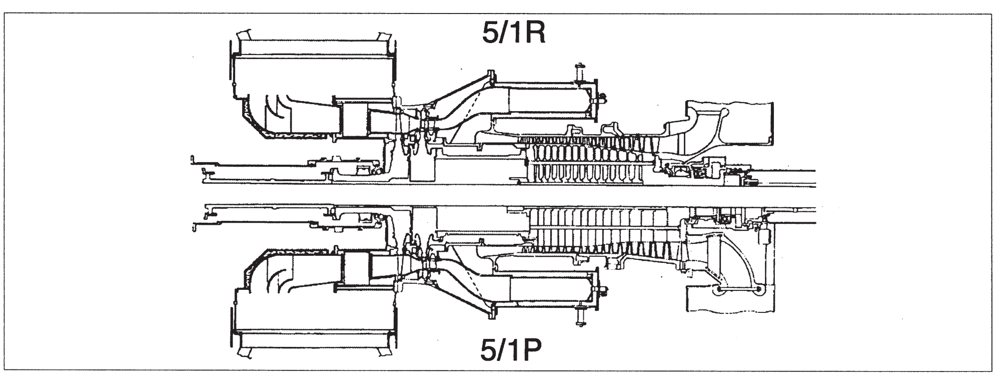

Figure 37. Comparing MS5001R and P

for a 5% speed margin from all critical speeds. However, no vibrational problems have resulted on the units that have the speed increase.

This successful experience led to allowing generator-drive units to operate at 5,355 rpm. As all MS5001 generator-drive units have load gears, this uprate would require changing out the load gear or replacing all the rotating internal parts. As the turbine will operate at the same torque at the higher speed, the output will increase up to 3% at higher ambient temperature conditions. *Figure 38* plots output versus ambient temperature for an MS5001P unit comparing 5,100 rpm versus 5,355 rpm speed.

The airflow is already so high at lower ambients that the compressor/turbine efficiency is near optimum. The higher airflow associated with the speed increase results in efficiency that offsets the output increase due to speed. Thus, there is no performance advantage at lower ambients, as shown in *Figure 38*.

Exhaust Frame and Diffuser Upgrade (FS1W)

Many older upgrade MS5001 and MS5002 units are already near their exhaust temperature control limit due to materials in the exhaust diffuser. By re-skinning the exhaust frame and diffuser with higher temperature material, we can go to a much higher limit at 1050 F. This is necessary in many cases to realize the Advance Technology Uprate that is shown later in *Figure 43*.

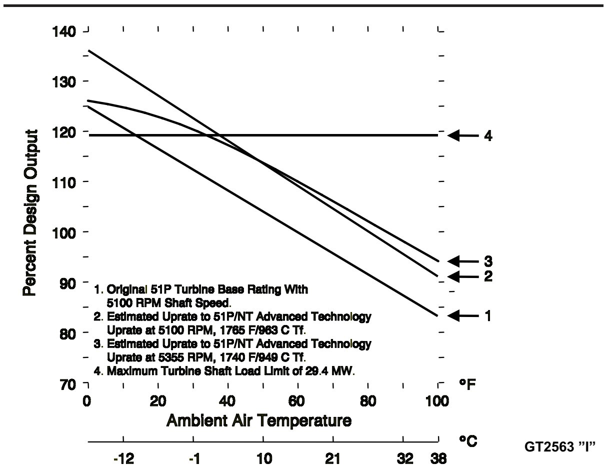

Figure 38. MS5001P performance at 5,355 rpm

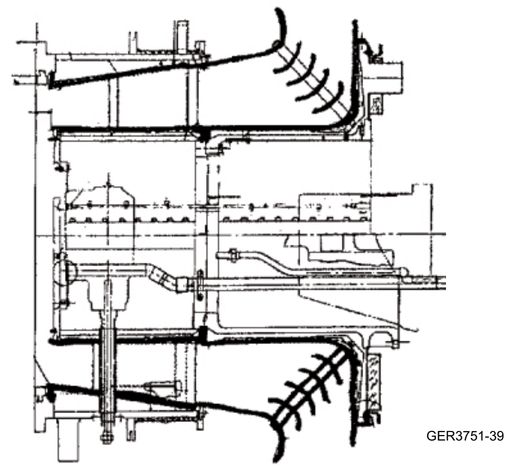

Figure 39. MS3000 and MS5000 exhaust diffuser upgrade

Figure 39 is an outline of the areas that need to be upgraded. It is necessary to remove the exhaust frame and diffuser assembly to get access for the rebuild operation.

MS5001P Uprate Summary

Figure 40 is a summary of all applicable uprates for the MS5001 model for reference.

MS5002 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. Because of the interest expressed by many customers, a development program was undertaken to increase the MS5002B rating to 38,000 HP (ISO). This rating has been applied to current production units as an MS5002C. This advanced technology package can be applied to all existing MS5002 A and B units. *Figure 41* shows a comparison of MS5002 ratings for both

	Output	Heat Rate
Advanced Tech Update (FT3M)	+6.0%	-1.0%
GTD 450 IGV's (Pre 1978/post 1978) (FT3B/FT3C)	+3.9%/1.9%	-0.2/0.5%
86º IGV's	+0.2%	+0.1%
High Pressure Pkg Brush Seals (FS2V)	+0.6%	-0.4%
Stage 2 Shroud Honeycomb Seals (FS2T)	+0.4%	-0.4%
5355 RPM Turbine Speed (FT3X)	+3.0% (at High Ambients)	
Stage 1 Shroud Cloth Seals (FS2Y)	+0.5%	-0.5%
Inner Stage Brush Seal (FS2Z)	+1.0%	-0.5%
S1S Abraidable Coating Seals (FS2O)	+0.4%	-0.3%
Total	+16.0/14.0%	-3.2/-3.5%

GER3751-40

Figure 40. MS5001P uprate summary

ISO Rating

	Ship Dates	Output hp (kW)		Heat Rate** Btu/hp-hr (kJ/kWh)		Firing Temp F/C		Air Flow (10^3lbs/hr) (10^3 kg/hr)		Exhaust Temp (F/C)	
		RC	SC	RC	SC	RC	SC	RC	SC	RC*	SC
MS5262A	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
MS5322B	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
MS5332B	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
MS53352B	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
MS53382C	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
MS5432D	July 1997	-	42,600/ 31,770	-	8,700/ 12,309	-	1,807/ 986	-	1,113/ 504	-	950/ 510

Includes 0/0 Inches H_20 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 41. MS5002 performance history

original and uprated configurations. *Figure 42* is a listing of the MS5002 advanced technology package. This uprating package has been sold for over 70 MS5002B units, uprating their output to meet changing operational conditions. This advanced technology package also results in considerable maintenance savings due to fewer inspections, as shown in *Figure 28*. The MS5002 Advanced Technology Uprate Program can also be applied to earlier MS5002A units.

Due to the increase in firing temperature, it is also necessary to change the MS5002A stage 2 buckets to the MS5002B standard design, as shown in *Figure 42*. To maximize output at higher ambients, it will usually also be desirable to change to a higher temperature stainless steel for the exhaust diffuser. *Figure 43* shows the difference in output for an MS5002A

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	-
FS1U	Stainless Steel Exhaust Diffuser (High Ambient Temperature Applications Only)	X	-

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Figure 42. MS5002A and B advanced technology uprate package hardware changes

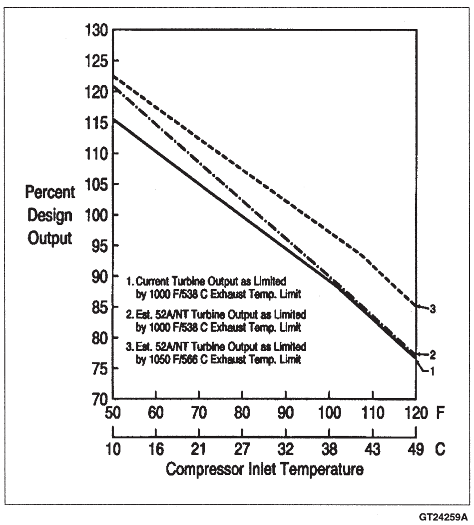


Figure 43. MS5002A exhaust temperature limit impact on advanced technology uprate

advance technology uprate with the standard 1000 F/538 C exhaust temperature limit versus the additional output possible at higher ambient temperatures with a 1050 F/566 C exhaust temperature limit. The latter exhaust temperature limit is possible due to the new high-temperature stainless steel material.

MS5002 "D" Advanced Technology Uprate (FT2R and FT2S)

Due to continued strong customer interest in additional uprate capability for the MS5002 unit, an MS5002 uprate to the MS5002D model was developed. This involves replacing the 17-stage MS5002 axial compressor with a 17-stage MS6001 axial flow compressor. *Figure 21* depicts the combination of MS6001 and MS5002 technology to produce the MS5002D.

The MS5002D field retrofit program can be offered in two phases: MS6001 compressor upgrade only for about 10% uprate (FS2R) or MS6001 compressor with optimized hot gas path for about 12% uprate (FS2S). The primary design change for the optimized hot gas path is a new Stage 1 nozzle with reduced throat area to provide a higher compressor pressure ratio.

Figure 44 is a tabulation of all of the available uprate programs for a typical MS5002B unit.

Figure 45 is an uprate study for a typical MS5002B unit with options to uprate to an MS5002C or an MS5002D configuration. Also shown is a comparison of standard uprate performance vs. performance with a control curve "tilted" to optimize high ambient temperature output.

MS6001B Uprates

Figure 46 provides a history of ratings for all vintages of MS6001 models. Several uprate options are available (*see Figure 47*) by applying the lat-

	Output	Heat Rate
GTD 450 IGV's (Pre 1978/post 1978) (FT2A/FT2B)	+3.8/+1.690%	-0.1/-0.3%
86º IGV Setting	+0.20%	--
MS5002 "B" to "C" Adv Tech Uprate (FT2C)	+7.0%	--
MS5002 "C" to "D" Adv Tech Uprate (FT2S)	+13.0%	-1.0%
Stage 2 Shroud Honeycomb Seal (FS2T)	+0.40%	-0.40%
HPP Brush Seal (FS2V)	+0.50%	-0.40%
#2 Bearing Brush Seal (FS2X)	+0.20%	-0.10%
Stage 1 Shroud Cloth Seals (FS2Y)	+0.50%	-0.50%
5/2D S1N in 5/2C (FT2T) (Included in "C" to "D" Uprate)	+2.40%	-1.0%
Total "B" to "C"	+12.6%	-2.5%
Total "C" to "D"	+16.4%	-2.5%
Total "B" to "D"	+28.6%	-2.5%

GER3751-44

Figure 44. MS5002B uprate summary

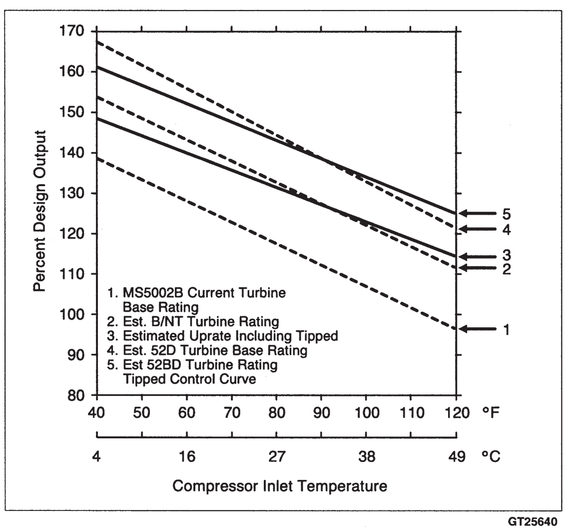


Figure 45. MS5002B uprate with "tilted" control curve

est new unit technology. The improved honeycomb shroud seals (FS2T and FS2U) provide improved sealing over the shroud tips on stage 2 and 3 buckets, thus improving output by 0.6% (*see Figure 9*). The load gear can be replaced to allow the turbine speed to increase to 5,133 rpm (FP4D), as shown in *Figure 48*. The higher turbine speed will provide approximately 1% higher output. The GTD stage 2 nozzle and inlet guide vane improvements are shown in *Figure 18*. The sum of these improvements will yield a 9.45% output increase for units built prior to 1987.

MS6571B Uprate to (FT4L)

All vintages of MS6001 units can be uprated by 35 F/19 C in firing temperature by applying the MS6001 advanced technology uprate package (*see Figure 47*). This uprate program began in late 1994 with field testing on a fully instrumented MS6001 unit to provide a detailed aerodynamic and performance map of the existing design. Based on this test data, an uprate program was developed to increase firing temperature by 35 F/19 C. *Figure 49* is a summary of all the uprate programs for a MS6001B unit.

Due to concern over bucket life for stages 1 and 2, the metallurgical, mechanical design and cooling circuits were extensively redesigned to provide considerable additional expected parts life and to be suitable for the firing temperature

Turbine Model	Ship Dates	Firing Temp (F/C)	Output* (kW)	Heat Rate* (Btu/kWhr/kJ/kWhr)	Exh Flow (10^3 lbs/hr)	Exhaust Temp (F/C)
MS6431A	1978	1850/1010	31,050	11,220/11,835	1,077	891/477
MS6441A	1979	1850/1010	31,800	11,250/11,867	1,112	901/483
MS6521B	1981	2020/1104	36,730	11,120/11,729	1,117	1017/547
PG6531B	1983	2020/1104	37,300	10,870/11,466	1,115	1005/541
PG6541B	1987	2020/1104	38,140	10,900/11,497	1,117	999/537
PG6551B	1995	2020/1104	39,120	10,740/11,329	1,137	1003/539
PG6581B	2000	2077/1136	41,090	10,740/11,329	1,161	1010/543
PG6101FA	1998	2350/1288	69,270	10,095/10,648	1,658	1095/591

*ISO conditions, unit operating at Base Load on Fuel and no inlet or exhaust losses.

GT25632A

Figure 46. MS6001B performance history

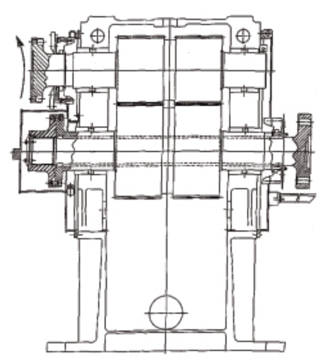
- **Stage 1 Bucket - GTD111 With Perimeter Cooling**
- **Stage 2 Bucket - Turbulated Cooling**
- **Stage 3 Bucket - IN738 With Advanced Aero**
- **Stage 1 Nozzles - Chordal Hinge for Improved Sealing & Side Wall Cooling**
- **Stage 2, 3 Nozzles - GTD222**
- **Stage 1 Shroud - Improved Intersegment Cloth Seals**
- **Nimonic Transition Piece**
- **TBC Coated Combustion Liners**
- **Extendor™ Combustion Upgrade**

GT24956D

Figure 47. MS6571B advanced technology uprate materials

- **Increase Turbine Speed**
- **Performance Improvements**

	60 Hz	50Hz
Output	**+0.82%**	**+0.60%**
Heat Rate	**- 0.11%**	**-0.07%**



Model 674

GER3751-48

Figure 48. MS6001B 5,133 rpm load gear

increase. The remaining hot gas path parts have been upgraded with the same design changes incorporated in the MS9001E when its firing temperature was increased to 2055 F/1124 C. The performance increase for the firing temperature increase is approximately 3.0%.

MS7001B Turbine Uprate (FT5X)

The MS7001B model was introduced in 1970. Design changes in compressor, combustion and

	Output	Heat Rate
Stage 2 Nozzle/GTD-222 (FS1P)	+1.00%	-0.40%
Stage 2 Shroud Honeycomb Seals (FS2T)	+0.35%	-0.35%
Stage 3 Shroud Honeycomb Seals (FS2U)	+0.25%	-0.25%
GTD-450 IGVs (Pre-1987) (FT4C)	+1.50%	-0.30%
86º IGV Setting (FT4M)	+0.40%	+0.20%
Turbine Speed Increase (FP4D)*	+0.82%	-0.11%
Improved Cool Stg 1 Nozzle (FS2J)	--	--
Stage 1 Shroud Cloth Seals (FS2Y)	+1.0%	-0.4%
Inner Stage Packing Brush Seal (FS2Z)	+1.0%	-0.50%
HP Packing Brush Seals (FS2V)	+0.75%	-0.50%
Firing Temp Uprate Package (FT4L)	+3.0%	-0.20%
S1S Abraidable Coating Seal (FS20)	+0.4%	-0.30%
Total	+9.45%	-3.10%

** 60 Hz GE-Supplied Load Gears*

GER3751-49

Figure 49. MS6001B uprate summary

Model	Ship Dates	Performance* kW (NEMA) (1)	Firing Temp (F/C)	Air Flow (10^3 lbs/hr/ 10^3 kg/hr)	Heat Rate (Btu/kW-hr/ kJ/kWh)	Exhaust Temp (F/C)
PG7651A	1970-71	47,260	1650/899	1.851/0.840	11,910/12.563	844/451
PG7711B	1971-72	51,800	1800/982	1.851/0.840	12,090/12,753	944/507
		kW (ISO)(1)				
PG7821B	1972-1978	60,000	1840/1004	1.905/0.864	10,960/11,560	947/508
PG7851B	1978-1979	61,750	1850/1010	1.967/0.892	10,920/11,518	944/507
PG7931C	1974-1977	68,500	1950/1065	2.129/0.966	10,970/11,571	986/530
PG7971E	1974-75	71,700	1985/1085	2.040/0.925	10,600/11,181	992/533
PG7981E	1976-78	73,200	1985/1085	2.125/0.964	10,530/11,107	974/523
PG7101E	1978-81	75,000	1985/1085	2.176/0.987	10,590/11,170	977/525
PG7111E	1981-84	76,900	2020/1104	2.210/1.002	10,590/11,170	1000/538
PG7111EA	1984-87	80,080	2020/1104	2.303/1.045	10,650/11,234	989/532
PG7111EA	1987-88	81,760	2020/1104	2.366/1.073	10,600/11,181	987/531
PG7111EA	1988-95	83,310	2020/1104	2.332/1.058	10,470/11,044	982/528
PG7121EA	1995-97	85,080	2020/1105	2.332/1.058	10,420/10,991	995/535
PG7121EA	1998-	86,580	2035/1113	2.382/1.079	10,340/10,907	994/534
PG7211F	1988-91	147,210	2300/1260	3.241/1.470	9,960/10,506	1,100/593
PG7221FA	1992-95	159,100	2350/1288	3.347/1.518	9,440/9,957	1,087/586
PG7231FA	1995-99	167,000	2400/1316	3.428/1.555	9,420/9,936	1,101/594
PG7241FA	1999-	171,700	2420/1327	3.581/1.622	9400/9915	1,131/601
PG7251FB	2001	181,400	2555/1402	3.600/1.631	9310/9820	1,149/621

*Base load distillate fuel, includes 0/0 inches H_2O iInlet/exhaust pressure drops

(1) In early 1970s, rating standards were changed from NEMA (1000 ft/300m altitude and 80F/27C) to ISO (sea level and 59F/15C) conditions. To convert from NEMA to ISO rating for approximate comparison, multiply NEMA rating by 1.12. Includes 0/0 inches H_2O inlet/exhaust pressure drops.

GT18468J

Figure 50. MS7001 performance history

hot-gas-path components were introduced over the years to achieve the present MS7001 EA model. *Figure 50* lists a performance uprate history for the MS7001 model. By applying standard current production MS7001EA parts to older MS7001B units, GE can increase output as detailed in the four possible uprate options listed in *Figure 51*. *Figure 52* details individual design improvements for each MS7001EA component involved in the B to E uprate.

The most significant design improvement for each MS7001B and E unit is the stage 1 turbine nozzle. As shown in *Figure 50*, the E unit has a higher airflow than the B unit, but it has a smaller "throat area" for the stage 1 nozzle. This design provides a significant increase in compressor pressure ratio. When the MS7001EA Stage 1 nozzle is applied to MS7001B units, there is a 6% increase in compressor pressure ratio. Extensive evaluation indicated the increase in pressure ratio was acceptable on MS7001B units. The first application of this uprate was to a utility unit in Alaska. Extensive field testing (completed in August 1988) proved this uprate was a success.

Option	IGV	Stage 1 Bucket	Stage 1 Nozzle	Stage 2 Bucket	Stage 2 Nozzle	Stage 3 Bucket	Stage 3 Nozzle	Stage 17 Stator *** Blades and EGVs	Combustion	Exhaust Frame & Diffuser
(1)	GTD-450	X	X	-	-	-	-	X	-	-
(2)*	GTD-450	X	X	X**	X	-	-	X	X	-
(3)*	GTD-450	X	X	X	X	X	X	X	X	-****
(4)*	GTD-450	X	X	X	X	X	X	X	X	X

* Generator and station electrical equipment uprate may be required.
** Non air-cooled bucket for MS9001B applications
***Blades must be replaced in the 17th EGV1 and EGV2 stator rows for low ambient applications, water or steam injection applications, or modulating inlet guide vane applications. A new stage 17 wheel is also recommended if replacement with a curved impeller has not been made for MS7001B applications.
***Exhaust diffuser may be required for option 3 for high ambient temperature applications.

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Figure 51. MS7001B and MS9001B material changes with current production E/EA hardware

Sourcebook Code	Component	Design Improvements
FS2J	Stage 1 Nozzle	- 2 Vane/Segment, 6% Higher Pressure Ratio, Chordal Hinge With Improved Sidewall Sealing, Improved Sidewall Cooling
FS2G	Stage 1 Bucket	- DS GTD111, GT33 +, Blunt Leading Edge Airfoil and Coating on Cooling Holes
FS1P	Stage 2 Nozzle	- Air Cooled, Long Chord, GTD222 for Increased Creep Resistance, Aluminide Coating, Reduced Cooling
FS1L	Stage 2 Bucket	- Air Cooled, IN738, Scalloped Tip Shroud (ten cooling holes)
FS1R	Stage 3 Nozzle	- Long Chord, GTD222 for Increased Creep Resistance
FS1M	Stage 3 Bucket	- Increased Firing Temperature Design, IN738 Scalloped Tip Shroud
-	Combustion	- Slot Cooled Liners (FR1H), Nimonic Thick Wall Transition Pieces (FR1D) and Thermal Barrier Coated Liners (FR1G)
FS2Y	Stage 1 Shrouds	- HR120 Material With Cloth Seals
FS2X	#2 Bearing	- Brush Seals in Outer Bearing Seals
FS2T, FS2U	Stage 2/3 Shrouds	- Honeycomb Seal Shroud Design
FS2V	HPP Brush Seal	- Brush Seal on Compressor Inner Barrel Replaces Labyrinth Seal Design

GT18466 "I"

Figure 52. MS7001EA component design improvements

Option 1 involves new reduced camber IGVs and MS7001EA Stage 1 buckets and nozzle. Due to increased efficiency, the actual exhaust temperature decreases for this option.

Option 2 is intended to increase firing temperature as much as possible to keep exhaust temperature at pre-uprate levels. This option would be applicable to heat recovery unit application, where exhaust temperature decreases would be detrimental to combined-cycle efficiency and exhaust temperature increases might not be compatible with the HRSG.

Option 3 is the maximum exhaust temperature with the existing MS7001B exhaust frame and diffuser assembly. This option would increase the MS7001B rating at ISO conditions to approximately 70 MW.

Option 4 involves increasing the firing temperature for an MS7001B unit to the full 2020 F/1104 C MS7001E/EA firing temperature by also changing to the MS7001EA exhaust frame and diffuser assembly. *See Figures 57 and 58* for these uprate options.

In addition to the output increases, a significant improvement in maintenance/inspection intervals is achieved by using the higher firing temperature MS7001E parts. *Figure 53* details expected extensions in maintenance intervals

Inspection Intervals - Hours

		7B/9B	7EA/9E	Extendor™
Combustion Liners		3,000	8,000	16,000
Transition Pieces	- Thin Wall	3,000	-	-
	- Thick Wall	8,000	8,000	-
	- Nimonic	-	12,000	16,000
Hot Gas Path		24,000	24,000	
Major		48,000	48,000	

Significant Savings in Maintenance Cost

GT24891D

Figure 53. Typical MS7001B vs. MS7001E maintenance

using 7EA hot-gas-path parts. Due to the cost of this uprate, it may be desirable to uprate MS7001B units a few components at a time to take advantage of the individual component design improvements. Each MS7001EA component in *Figure 52* can be applied to MS7001B units with only minor modification. A turbine/generator performance comparison will be required in each case to determine load equipment capability to accept the uprating. This may also result in generator and electrical auxiliary modifications.

MS7001C, E and EA Uprate to 2035 F/1112C Tf (FT5Y)

All vintages of MS7001C, E and EA units can be uprated to the latest 7EA firing temperature of 2035 F/1112 C. *Figure 54* details all required material changes for each model to uprate to 2035 F/1112 C. *Figures 57 and 58* list output and heat rate improvements for increasing firing temperature to 2035 F/1112 C, and for all other performance improvements applicable to MS7001 C, E and EA models.

- **Improved Stage 1 Nozzle With Chordal Hinge and Improved Sidewall Cooling and Sealing Design**
- **Directionally Solidified (DS) Stage 1 GTD111 Buckets**
- **New HR120 Stage 1 Shroud Blocks With Cloth Seals**
- **GTD222 Stage 2 Nozzle - Reduced Cooling Air Design**
- **7EA Stage 2 Scalloped Shroud Bucket - IN738**
- **GTD222 Stage 3 Nozzle**
- **7EA Stage 3 Scalloped Shroud Bucket - U500**
- **Extendor™ Combustion Wear System**
- **Thermal Barrier Coated Combustion Liners - Hastelloy-X**
- **Nimonic Thick Wall Transition Pieces**

Recommended

- **GTD450 Reduced Camber IGVs Set at 86°**
- **Stage 2/3 Honeycomb Shroud Blocks**
- **HPP & #2 Bearing Brush Seal**
- **1100 F/593 C Exhaust Isotherm Conversion (100 HP Blowers)**

GT24916B

Figure 54. MS7001E/EA uprate requirements for 2035 F/1112 C firing temperature

MS7001 C, E and EA uprates to 2055F/ 1123C Tf (FT5Q)

All vintages of MS7001C, E and EA units also can be uprated to the latest MS7001EA 7EA firing temperature of 2055 F/1123 C. This involves changing the stage 2 and 3 buckets, stage 1 nozzle and stage 1 shroud to the latest designs detailed in *Figure 52*. *Figure 55* is a diagram of all of the MS7001E 2055F uprate sections. Depending on the turbine vintage, the unit's existing firing temperature and other product improvements that may have already been incorporated, output may be improved from 5% to 19% (*see Figure 57*). Heat rate can also be improved by over 3% as shown in *Figure 58.*

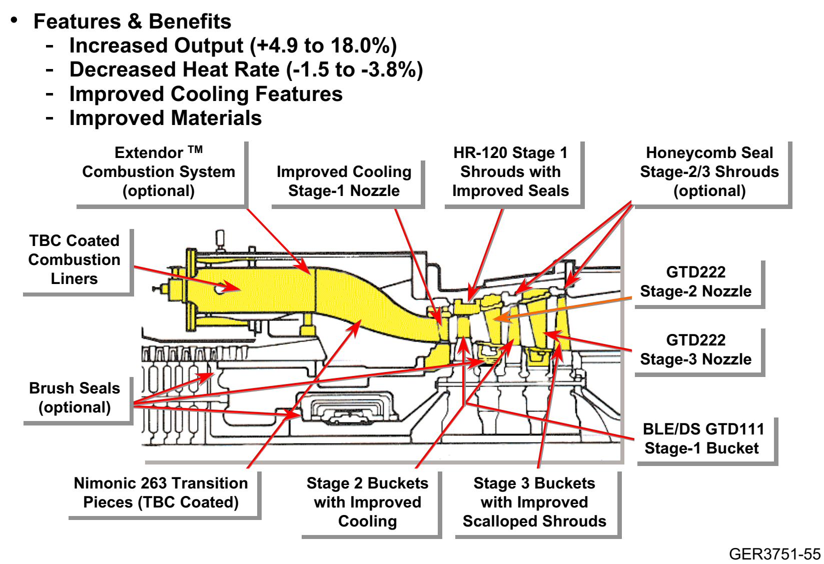

Figure 55. MS7001E 2055 F uprate

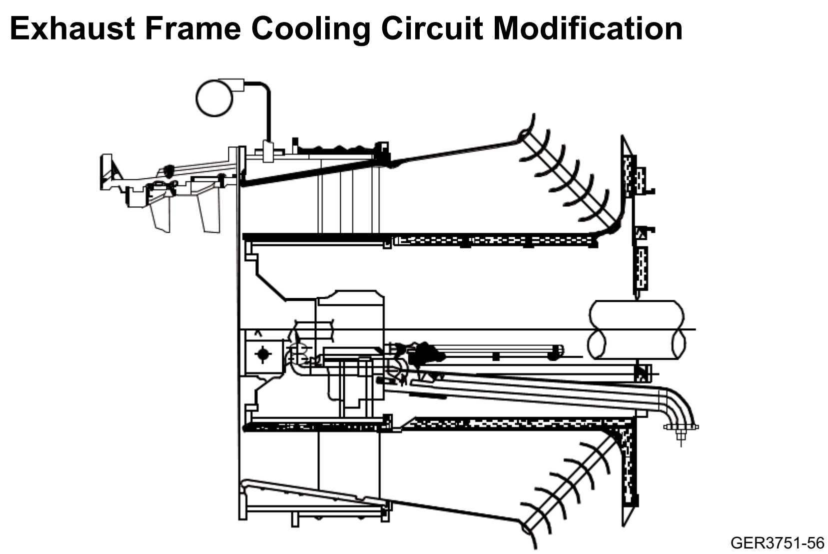

Figure 56. MS7E and MS9E exhaust frame diagram

	MS 7001B-E Uprate Options								
	I	II	III	IV	MS 7001C	MS 7001E	MS 7001E	MS 7001EA	MS 7001EA
Original Tf (°F/°C)	1840/ 1004	1840/ 1004	1840/ 1004	1840/ 1004	1950/ 1066	1985/ 1085	2020/ 1104	2020/ 1104	2035/ 1113
Maximum Uprated Tf (°F/°C)	1840/ 1004	1905/ 1041	1965/ 1074	2020/ 1104	2055/ 1124	2055/ 1124	2055/ 1124	2055/ 1124	2055/ 1124
	Increase in Output								
	%	%	%	%	%	%	%	%	%
Increase in Tf & Control Mods (FT5X)	-	6.7	12.8	18.2	-	-	-	-	-
2020F & Controls Mods (FT5C)	-	-	-	-	7.4	4.0	-	-	-
2035F & Control Mods (FT5Y)	-	-	-	-	8.7	5.4	2.3	1.8	-
2055F & Control Mods (FT5Q)	-	-	-	-	10.3	7.0	3.9	3.4	1.6
GTD450 IGVs (84°) (FT5B)	4.3	4.3	4.3	4.3	4.1	1.5	1.5	1.5	-
Additional 2° IGV (86°)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	-	-
GTD222 S2N (FS1P)	-	-1.0	-1.0	-1.0	0.8	0.8	0.8	0.8	-
Exh. Frm. Motor Blowers (FS2D)	-	-	-	0.2	-	-	-	-	-
Air-Cooled S2B	-	-1.65	-1.65	-1.65	-	-	-	-	-
HR120 S1S/Cloth Seals (FS2Y)	-	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Stage 2 Bucket Shrouds with Honeycomb Seals (FS2T)	-	0.35	0.35	0.35	0.35	0.35	0.35	0.35	-
Stage 3 Bucket Shrouds with Honeycomb Seals (FS2U)	-	-	0.15	0.15	0.15	0.15	0.15	0.15	-
HPP Brush Seals (FS2V)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Number 2 Bearing Brush Seals (FS2X)	-	-	-	-	0.30	0.30	0.30	0.30	0.30
Stage 2 Nozzle Diaphram Brush Seals (FS2Z)	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00
S1S Abraidable Coating Seal (FS2O)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
*Maximum Output Increase**	6.6	11.7	18.0	23.6	19.5	13.6	10.5	9.6	5.0

*Total effects are a compounding effect of all the performance improvements from above.
Sourcebook codes are provided in parentheses.
NOTE: All performance estimates apply at ISO conditions (59° F/15°C, 14.7 psia/1.013 bar)

GT25155D

Figure 57. MS7001 uprate options: effect on output

	MS 7001B-E Uprate Options								
	I	II	III	IV	MS 7001C	MS 7001E	MS 7001E	MS 7001EA	MS 7001EA
Original Tf (°F/°C)	1840/ 1004	1840/ 1004	1840/ 1004	1840/ 1004	1950/ 1066	1985/ 1085	2020/ 1104	2020/ 1104	2035/ 1113
Maximum Uprated Tf (°F/°C)	1840/ 1004	1905/ 1041	1965/ 1074	2020/ 1104	2055/ 1124	2055/ 1124	2055/ 1124	2055/ 1124	2055/ 1124
	Decrease in Heat Rate								
	%	%	%	%	%	%	%	%	%
Increase in Tf & Control Mods (FT5X)	-	-1.1	-2.0	-2.6	-	-	-	-	-
2020F & Controls Mods (FT5C)	-	-	-	-	0.6	-0.3	-	-	-
2035F & Control Mods (FT5Y)	-	-	-	-	-0.7	-0.4	-0.1	-0.1	-
2055F & Control Mods (FT5Q)	-	-	-	-	-0.7	-0.4	-0.1	-0.1	
S1N Chordal Hinge (FS2J)	-1.9	-1.9	-1.9	-1.9	-0.25	-0.25	-0.25	-0.25	-0.25
GTD450 IGV's (84°) (FT5B)	-0.7	-0.7	-0.7	-0.7	-0.1	-0.3	-0.3	-0.3	-0.3
Additional 2° IGV (86°)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	-	-
GTD222 S2N (FS1P)	-	0.4	0.4	0.4	-0.3	-0.3	-0.3	-0.3	-0.3
Exh. Frm. Motor Blowers (FS2D)	-	-	-	-0.1	-	-	-	-	-
Air-Cooled S2B	-	1.1	1.1	1.1	-	-	-	-	-
HR120 S1S/Cloth Seals (FS2Y)	-	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Stage 2 Bucket Shrouds with Honeycomb Seals (FS2T)	-	-0.35	-0.35	-0.35	-0.35	-0.35	-0.35	-0.35	-0.35
Stage 3 Bucket Shrouds with Honeycomb Seals (FS2U)	-	-	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15	-0.15
HPP Brush Seals (FS2V)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Number 2 Bearing Brush Seals (FS2X)	-	-	-	-	-0.2	-0.2	-0.2	-0.2	-0.20
Stage 2 Nozzle Diaphram Brush Seals (FS2Z)	-0.3	-0.3	-0.3	-0.3	-0.5	-0.5	-0.5	-0.5	-0.5
S1S Abraidable Coating Seal (FS2O)	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
Maximum Heat Rate Improvement	-3.5	-3.95	-5.0	-5.7	-3.65	-3.55	-3.25	-3.45	-3.35

*Total effects are a compounding effect of all the performance improvements frozm above.
Sourcebook codes are provided in parentheses.
NOTE: All performance estimates apply at ISO conditions (59° F/15°C, 14.7 psia/1.013 bar)

GT25156C

Figure 58. MS7001 uprate options: effect on heat rate

1100 F/593 C Maximum Exhaust Isotherm Limit (FT7G)

The higher firing temperatures currently used on MS6001/7001/9001 units frequently result in reduced operating flexibility and, sometimes, output on higher ambient days. Figure 59 plots exhaust temperature versus ambient temperature for a typical MS7001E unit for different IGV angles.

Many older units were shipped with a 1020 F/ 549 C or 1040 F/560 C maximum exhaust temperature limit (isotherm). In many cases, the following resulted:

- Reduction in output on hot days as firing temperature had to be reduced when maximum exhaust temperature was reached
- Inability to operate at lower IGV angles

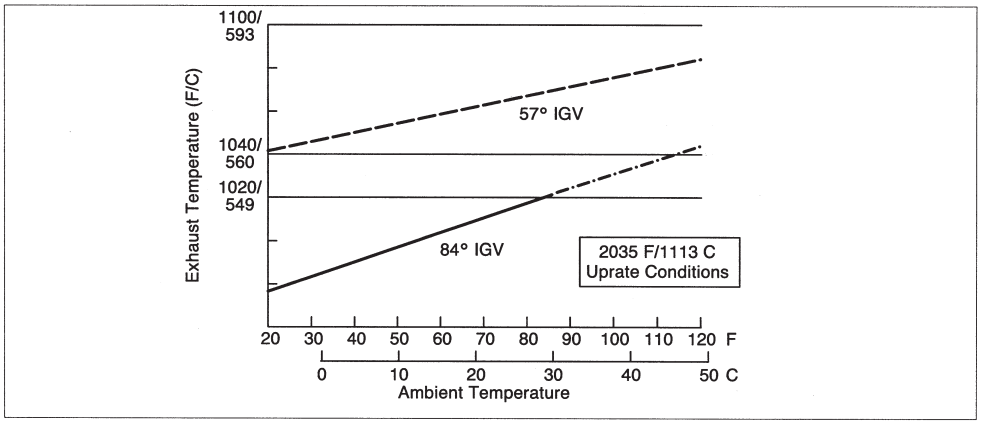

Figure 59. Improved operational flexibility and increased exhaust heat recovery when modulating IGVs with exhaust isotherm increase to 1100 F/593 C

on hot days to maximize part load heat rate at part load on heat recovery units

- Reduced turn down ratio on DLN units at all ambients

The increase in maximum exhaust temperature setting to 1100 F/593 C resolves these problems, as shown in *Figure 59*. *Figure 56* shows a cross section of the material changes required to go to 1100 F exhaust temperature limit. The change in maximum exhaust temperature setting generally will require changing the exhaust frame blower to 100 HP blowers. The ability to raise the maximum exhaust temperature setting

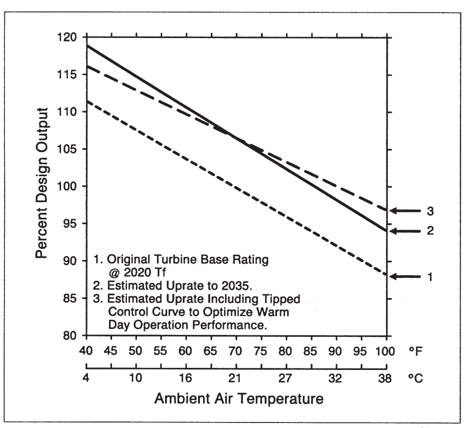

Figure 60. MS7001E uprate with "tilted" control curve

on existing units must be reviewed thoroughly due to possible impact on other exhaust system components.

Uprates with "Tilted" Control Curves (FT7I)

Normally turbine control curves are designed to keep a constant firing temperature across the ambient temperature range of each site. This results in a significant decrease in unit output at higher ambient temperatures. To attempt to partially compensate for this performance loss, we can "tilt" the control curve to "overfire" on hot days and "underfire" on cold days. The formula provides 1.55 additional output on hot days and loses about 20% on cold days. The parts life savings on cold days compensates for the slight parts life decrease on hot days by overfiring. This option is restricted to base load units and to units with the latest advance technology uprate components. See *Figure 60* for a typical example of a tilted control curve.

MS7001F and FA Uprate to the "MS7001FA Uprate" Configuration (FT5L)

The MS7001F was introduced in 1988 and has been uprated for new unit production to the current "MS7001FA uprate" configuration. Ratings for all vintages of MS7001F units are listed in *Figure 50*. Numerous design changes in metallurgy, cooling and coatings have been incorporated into the latest 7FA uprate designs. In each case, the original 7F/FA parts can be upgraded individually, on a spare part basis, to realize the parts reliability advantages of the latest PG7241FA uprate parts. Due to variations in 7F units, it is essential that an individual unit review be made to determine the scope of the uprate kit for each unit. *Figure 23* shows the performance gains for earlier 7F vintage units by applying selected kits of PG7241FA parts.

MS9001B Turbine Uprate (FT6X)

Many design changes have been incorporated into the MS9001 since its mid-1970s introduction. *Figure 61* lists a performance uprate history for the MS9001 model. Current production MS9001E buckets and nozzles (all three stages) can be retrofitted into all earlier production MS9001B units with minor modifications and into existing MS9001E units as direct replacement parts. Substantial improvements in expected parts life will be realized when uprating older MS9001B units with current production MS9001E hot-gas-path parts. Two customers have already purchased several MS9001E components to uprate their MS9001B units.

It is also possible to uprate MS9001B combustion systems to use MS9001E components by changing to the MS9001E type combustion system. This would provide significant improvements in recommended combustion inspection intervals (*see Figure 53*).

Model	Ship Dates	ISO Performance* kW	Firing Temp (F/C)	Air Flow (10^6 lbs/hr 10^6 kg/hr)	Heat Rate (Btu/kW-hr kJ/kWh)	Exhaust Temp. (F/C)
PG9111B	1975-81	85,200	1840/1004	2.736/1.241	10,990/11.592	945/507
PG9141E	1978-81	105,600	1955/1068	3.155/1.431	10,700/11,286	953/512
PG9157E	1981-83	109,300	1985/1085	3.183/1.444	10,700/11,286	968/520
PG9151E	1983-87	112,040	2000/1093	3.214/1.458	10,570/11,149	977/525
PG9167E	1988-92	116,930	2020/1104	3.222/1.461	10,290/10,854	980/527
PG9171E	1993	127,300	2055/1124	3.355/1.520	10,620/11,202	1003/539
PG9301F	1993-94	209,740	2300/1260	4.804/2.179	10,080/10,632	1,082/583
PG9311FA	1994	223,760	2350/1288	4.819/2.186	9,630/10,158	1,097/592
PG9351FA	1999	251,800	2420/1327	5.174/2.344	9,295/9,804	1123/623

*Base load distillate fuel, includes 0/0 inches H_2O inlet/exhaust pressure drops.

GT18469H

Figure 61. MS9001 performance history

Figure 51 details four options for increased performance for MS9001B units when using MS9001E hot-gas-path components similar to the MS7001B to E uprate.

Option 1 involves new reduced camber IGVs and MS9001E stage 1 buckets and nozzles. Due to increased efficiency, the actual exhaust temperature decreases for this option.

Option 2 is intended to increase firing temperature as much as possible to keep exhaust temperature at pre-uprate levels. This option would be applicable to heat recovery unit applications, where exhaust temperature decreases would be detrimental to combined-cycle efficiency and exhaust temperature increases might not be compatible with the HRSG.

Option 3 is the maximum exhaust temperature with the existing MS9001B exhaust frame and diffuser assembly. This option would increase the MS9001B rating at ISO conditions to approximately 93 MW.

Option 4 involves increasing the firing temperature for the MS9001B units to the full 2020 F/1104 C MS9001E firing temperature by also changing to the MS9001E exhaust frame and diffuser assembly. See *Figures 65 and 66* for performance improvements for these four uprate options.

- **Turbulated Cooled GTD111 Stage 1 Buckets***
- **GTD222 Stage 3 Nozzle****
- **Extendor™ Combustion Upgrade**
- **TBC Coated Slot-Cooled Liners**
- **Nimonic Transition Pieces**
- **9E Exhaust Frame and Blowers**

Recommended

- **GTD450 Reduced Camber Inlet Guide Vanes**
- **Stage 2 & 3 Honeycomb Shroud Seals**
- **High Pressure Packing Brush Seals**
- **1000 F/538 C Maximum Exhaust Temperature**

* Any vintage GTD111 Stage 1 Buckets Shipped After 1987 Can Be Used
**A Long Chord FSX414 Stage 3 Nozzle Can Be Used

GT24887C

Figure 62. MS9001E uprate requirements for 2020 F/ 1104 C firing temperature

MS9001 Uprate to 2020 F/1104 C (FT6C)

Earlier models of MS9001E turbines with firing temperatures of 1955 F/1068 C, 1985 F/1085 C or 2000 F/1093 C can be uprated to the MS9161E rating at 2020 F/1104 C. *Figure 62* details all required changes and *Figure 65* lists improvements in output. *Figure 66* lists improvements in heat rate for this uprate as well as for all other performance improvements applicable to earlier MS9001E models.

MS9001 Uprate to 2055 F/1124 C (FT6Y)

All models of MS9001E turbines can be upgraded to the MS9171E rating at 2055 F /1124 C. *Figure 63* details all required material changes and *Figure 65* lists output improvements. *Figure 66* lists heat rate improvements for this uprate as well as for all other performance improvements applicable to earlier MS9001E models.

- **Improved Stage 1 Nozzle With Chordal Hinge and Improved Sidewall Cooling and Sealing Design**
- **Turbulated Cooled GTD111 Stage 1 Buckets**
- **Two-Piece Stage 1 Shroud Blocks**
- **Reduced Cooling GTD222 Stage 2 Nozzle**
- **GTD111 Stage 2 Buckets**
- **GTD222 Stage 3 Nozzle**
- **IN738 Stage 3 Buckets**
- **Extendor™ Combustion Upgrade**
- **TBC Coated Slot-Cooled Liners**
- **Nimonic Transition Pieces**
- **9E Exhaust Frame and Blowers**

Recommended

- **GTD450 Reduced Camber Inlet Guide Vanes**
- **Stage 2 & 3 Honeycomb Shroud Blocks**
- **High Pressure Packing Brush Seals**
- **1100 F/593 C Exhaust Temperature**

GT24886C

Figure 63. MS9001E uprate requirements for 2055 F/ 1124 C firing temperature

All components involved in the MS9001 uprate programs are identical to the components used in new unit production. Due to the extensive scope of these uprate programs, it may be desirable to incorporate individual components on a spare/replacement part basis. *Figure 64* details all the design improvements on the flange-to-flange components. Performance improvements associated with individual components are included in *Figures 65 and 66*. GER-3928 has complete details on the MS9001 uprate programs.

MS9001F Uprate to the MS9001FA Configuration (FT6Z)

The MS9001F began production in 1993. Ratings for all vintages of MS9001F units are listed in *Figure 61*. Numerous design changes in metallurgy, cooling and coatings have been incorporated into the latest 9FA designs. In each case the original 9F parts can be upgraded individually, on a spare parts basis, to realize the parts reliability advantages of the latest 9FA parts. Due to variations in 9F units, it is essential that an individual unit review be made to deter-

Sourcebook Code	Component	Design Improvements
FS2J	Stage 1 Nozzle	- 2 Vane/Segment, Improved Sidewall Cooling
FS2H	Stage 1 Bucket	- GTD111, GT29 +, Blunt Leading Edge Airfoil and Turbulated Cooling Holes
FS2C	Stage 1 Shroud	- 2 Piece Shroud for 9E
FS1P	Stage 2 Nozzle	- Air Cooled, Long Chord, GTD222 for Increased Creep Resistance
FS2F	Stage 2 Bucket	- Air Cooled, GTD111, Scalloped Tip Shroud
FS1R	Stage 3 Nozzle	- Long Chord, GTD222 for Increased Creep Resistance
FS2K	Stage 3 Bucket	- Increased Firing Temperature IN738 Material
-	Combustion	- Slot Cooled Liners (FR1H), Nimonic Thick Wall Transition Pieces (FR1D) and Thermal Barrier Coated Liners (FR1G)
FS2T, FS2U	Stage 2 & 3 Shroud Blocks	- Honeycomb Seal Shroud Design
FS2V	Inner Barrel	- Brush Seal on Compressor Inner Barrel Replaces Labyrinth Seal Design

GT24257B

Figure 64. MS9001E component design improvements

	MS 9001B-E Uprates				9E-2020 F/1104C (FT6C)			9E-2055/F1124C (FT6Y)				
	I	II	III	IV								
Original Tf (°F/°C)	1840/ 1004	1840/ 1004	1840/ 1004	1840/ 1004	1955/ 1068	1985/ 1085	2000/ 1093	1955/ 1104	1985/ 1104	2000/ 1093	2020/ 1104	2055/ 1124
Maximum Uprated Tf (°F/°C)	1840/ 1004	1905/ 1041	1965/ 1074	2020/ 1104	2020/ 1104	2020/ 1104	2020/ 1104	2055 1124	2055/ 1124	2055/ 1124	2055/ 1124	2055/ 1124
	Increase in Output											
	%	%	%	%	%	%	%	%	%	%	%	%
Increase in Firing Temp. & Control Mods (FT5X)	-	6.7	12.8	18.2	6.5	4.0	2.7	9.5	7.0	5.7	3.5	-
Bore Plugs	0.33	0.33	0.33	0.33	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
C450 1GV (84°)	4.3	4.3	4.3	4.3	1.5	1.5	1.5	1.5	1.5	1.5	-	-
Additional 2° IGV (86°)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Rotated S3B	-	-	0.6	0.6	-	-	-	0.3	0.3	0.3	0.3	-
GTD222 S2N	-	-1.0	-1.0	-1.0	-	-	-	1.0	1.0	1.0	1.0	1.0
Exhaust Frame Blowers	-	-	-	0.2								
Air-Cooled S2B	-	-	-1.65	-1.65	-	-	-	-	-	-		-
Stage 2 Bucket Shrouds with Honeycomb Seals (FS2T)	-	0.35	0.35	0.35	-	-	-	0.35	0.35	0.35	0.35	0.35
Stage 3 Bucket Shrouds with Honeycomb Seals (FS2U)	-	-	0.15	0.15	-	-	-	0.15	0.15	0.15	0.15	0.15
HPP Brush Seals (FS2V)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Number 2 Big Brush Seals (FS2Y)	-	-	-	-	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Stage 2 Nozzle Diaphram Brush Seals (FS2Z)	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
HR120 One Piece S1S W Cloth Seals (FS2Y)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	1.3
S1S Abraidable Coating Seal (FS20)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
*Total Effect on Output **	7.3	13.4	18.6	24.20	11.9	9.4	8.1	16.7	14.2	12.9	9.2	6.3

*Total effects are a compounding effect of all the performance improvements above.
Sourcebook codes are provided in parentheses.
NOTE: All performance estimates apply at ISO conditions (59° F/15°C, 14.7 psia/1.013 bar)

GT24910D

Figure 65. Frame 9 uprate options: effect on output

mine the scope of the uprate kit for each unit. *Figure 23* shows the performance gains for earlier 9F and 9FA vintage units by applying selected kits of PG9351FA parts.

Model Letter Uprates

In addition to the advanced technology uprates for a given model gas turbine, it is possible to uprate from one model letter to another (i.e., MS5001L to MS5001R). A quick review of the performance history charts in this paper will show the significant differences in firing temperature, airflow and rating among the various models.

- MS3002 (*see Figure 25*)
- MS5001 (*see Figure 34*)
- MS5002 (*see Figure 41*)
- MS6001 (*see Figure 46*)
- MS7001 (*see Figure 50*)
- MS9001 (*see Figure 61*)

	MS 9001B-E Uprates				9E-2020 F/1104C (FT6C)			9E-2055/F1124C (FT6Y)				
	I	II	III	IV								
Original Tf (°F/°C)	1840/ 1004	1840/ 1004	1840/ 1004	1840/ 1004	1955/ 1068	1985/ 1085	2000/ 1093	1955/ 1068	1985/ 1085	2000/ 1093	2020/ 1104	2055/ 1124
Maximum Uprated Tf (°F/°C)	1840/ 1004	1905/ 1041	1965/ 1074	2020/ 1104	2020/ 1104	2020/ 1104	2020/ 1104	2055/ 1124	2055/ 1124	2055/ 1124	2055/ 1124	2055/ 1124
Decrease in Heat Rate												
	%	%	%	%	%	%	%	%	%	%	%	%
Increase in Firing Temp. & Control Modifications	-	-1.1	-2.0	-2.6	-0.5	-0.27	-0.15	-0.77	-0.54	-0.42	-0.27	-
S1N Chordal Hinge	-1.9	-1.9	-1.9	-1.9	-	-	-	-0.25	-0.25	-0.25	-0.25	-0.25
Bore Plugs	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
C450 1GV (84°)	-0.7	-0.7	-0.7	-0.7	-0.38	-0.38	-0.38	-0.38	-0.38	-0.38	-	-
Additional 2° IGV (86°)	-	0.4	0.4	0.4	-	-	-	0.4	0.4	0.4	0.4	0.4
Rotated S3B	-	-	0.6	0.6	-	-	-	-0.28	-0.28	-0.28	-0.28	-
GTD222 S2N	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2-Piece Shroud	-	-	-	-	-	-	-	0.4	0.4	0.4	0.4	
Exhaust Frame Blowers	-	-	-	-0.1								
Air-Cooled S2B	-	-	1.1	1.1	-	-	-	-	-	-		-
Stage 2 Bucket Shrouds with Honeycomb Seals (FS2T)	-	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Stage 3 Bucket Shrouds with Honeycomb Seals (FS2U)	-	-	-0.15	-0.15	-0.15	-0.15	-0.15	0.15	0.15	0.15	0.15	0.15
HPP Brush Seals (FS2V)	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Number 2 Big Brush Seals (FS2Y)	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
Stage 2 Nozzle Diaphram Brush Seals (FS2Z)	-0.3	-0.3	-0.3	-0.3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
HR120 One Piece S1S W Cloth Seals (FS2Y)	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.6
S1S Abraidable Coating Seal (FS20)	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
Total Effect on Heat Rate *	-4.2	-5.2	-5.8	-6.5	-3.2	-3.0	-2.8	-4.0	-3.8	-3.6	-3.1	-3.3

*Total effects are a compounding effect of all the performance improvements above.
Sourcebook codes are provided in parentheses.
NOTE: All performance estimates apply at ISO conditions (59° F/15°C, 14.7 psia/1.013 bar)

GT24911E

Figure 66. Frame 9 uprate options: effect on heat rate

In general, model letter uprates can be accomplished with relative ease where firing temperature changes are involved, and less easily accomplished where airflow changes are involved. However, every older unit can be uprated to a higher model letter.

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, such as casing out-of-round, surface finish of non-uprated parts, and clearances. Recognizing that many customers prefer absolute performance guarantees, *Figures 67*

Generator Drive**

Advanced Technology Uprate Model	Firing Temp °F/ °C	Output kW*	Heat Rate Btu/kW-hr*/ kJ/kWh	Exhaust Flow 10^3 #/hr/ 10^3 kg/hr	Exhaust Temp °F/ °C	Comments
MS5001R - N/T	1755/957	19,800	13,250/13,976	774.6/351	975/524	-
MS5001P - N/T	1765/963	25,240	12,430/13,111	952.1/432	924/496	Axial Strut (Pre 1978)
MS5001P - N/T	1765/963	25,720	12,110/12,774	949.1/431	919/493	Rotated Strut (Post 1978)
MS7001B/E (#1)	1840/1004	60,910	11,020/11,624	2040/925	911/488	Option #1
MS7001B/E (#2)	1905/1041	63,500	11,100/11,708	2041/926	954/512	Option #2
MS7001B/E (#3)	1965/1074	67,140	11,010/11,613	2042/926	990/532	Option #3
MS7001B/E (#4)	2020/1104	70,540	10,940/11,540	2043/927	1024/551	Option #4
MS7001E	2020/1104	77,840	10,830/11,423	2299/1043	1000/538	-
MS7001E	2035/1113	78,810	10,820/15,308	2299/1043	1010/543	-
MS7001EA	2035/1113	81,950	10,690/15,124	2365/1073	997/536	-
MS9001B/E (#1)	1840/1004	87,960	11,000/11,600	2938/1332	911/488	Option #1
MS9001B/E (#2)	1905/1041	93,270	10,940/11,540	2939/1333	954/512	Option #2
MS9001B/E (#3)	1965/1074	97,600	10,900/11,500	2940/1333	990/532	Option #3
MS9001B/E (#4)	2020/1104	102,580	10,830/11,420	2942/1334	1024/551	Option #4
MS9001E	2020/1104	114,610	10,520/11,100	3316/1504	982/528	-
MS9001E	2055/1124	119,380	10,400/11,000	3317/1504	1004/540	-

* All Uprates Are Based on Using Reduced Camber High Flow IGVs.
** All Uprate Performance is Based on ISO (59 º F/16ºC, Sea Level, 0"/0" Inlet/Exhaust Pressure Drops, 60% Relative Humidity) Natural Gas Fuel, Base Load and Assumes Axial Flow Compressor is Not Rebladed.

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Figure 67. Absolute performance guarantees for advanced technology generator drive

Mechanical Drive**

Advanced Technology Uprate Model	Firing Temp °F/ °C	Output HP/kW	Heat Rate Btu/kW-hr/ kJ/kWh	Exhaust Flow 10^3 #/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
MS3002 A-F	1575/857	9,700*/7,233	-	379*/172	-	Simple Cycle
MS3002 A-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
MS5001R - N/T	1755/957	26,080/19,448	9,700/13,724	735.2/333	987/531	Simple Cycle

* MS3002A-F Uprates Are Based On NEMA Conditions, All Other Numbers Are At ISO Conditions.
** All Uprates Are Based On Using Reduced Camber High Flow IGVs.

GT23566C

Figure 68. Absolute performance guarantees for advanced technology mechanical drive

and 68 were prepared to show common performance guarantee points for typical 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 assume the axial flow compressor is not rebladed. Similar performance 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 69* is plotted to show the approximate performance increase for a typical MS7001B uprate option III at approximately 48,000 fired hours.

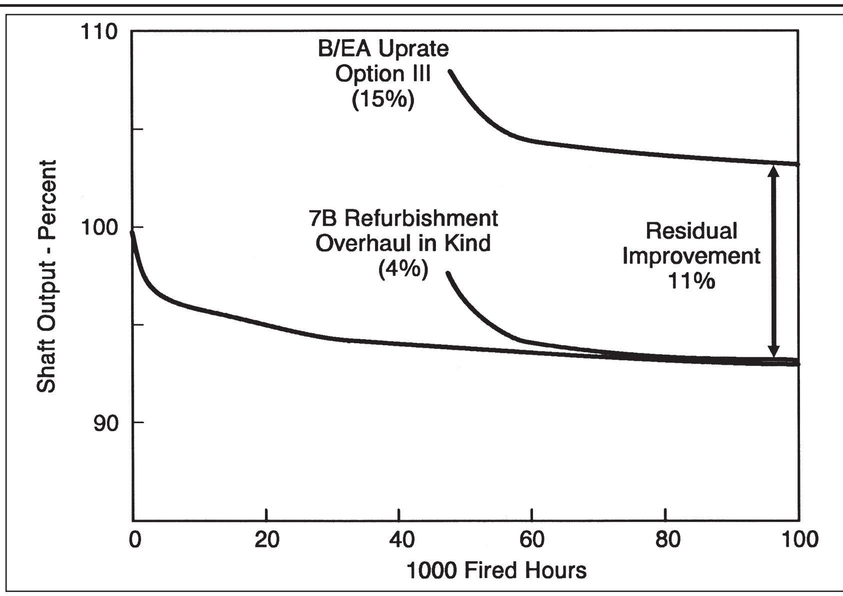

Figure 69. Estimated non-recoverable performance degradation effects

The expected typical non-recoverable performance degradation is plotted for the original configuration as well as for uprate option III. This shows that the performance increase of 15.05% at 48,000 fired hours still returns an expected incremental performance increase of 10.9% at 100,000 fired hours. 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.

Several sealing design improvements listed in this publication are intended to reduce performance degradation between major overhauls:

- Cloth seals for stage 1 shroud blocks
- High-pressure packing brush seals
- No. 2 bearing brush seals
- No. 2 and No. 3 bucket/shroud honeycomb seals
- Abraidable coating for stage 1 shroud blocks

Considerable research and development effort continues in order to develop improved gas path leakage sealing systems that improve output and reduce performance degradation rate on existing units.

Power Augmentation Uprates

For certain applications where power augmentation or supplemental power is needed for certain operating conditions, a variety of power augmentation options are available:

- Evaporative coolers for inlet air (FJ3F)
- Steam injection into compressor discharge (F3JB)
- Water or steam injection into combustor head end (FGIA/FGIB)
- Helper/starter expansion turbines (FJ3E)

Evaporative coolers can result in power increases of up to 14% in hot dry ambients. *Figure 70* shows typical power augmentation for adding an evaporative cooler.

Steam injection for power augmentation can result in power increases of 15% to 18% by injection of up to 5% mass flow (of compressor inlet air) of steam into the compression discharge. *Figure 71* shows typical power augmentation for adding steam injection. A development program is in progress to evaluate increasing the maximum allowable steam injection rate with a goal of 9% by mass flow of air (refer to Application Engineering for details).

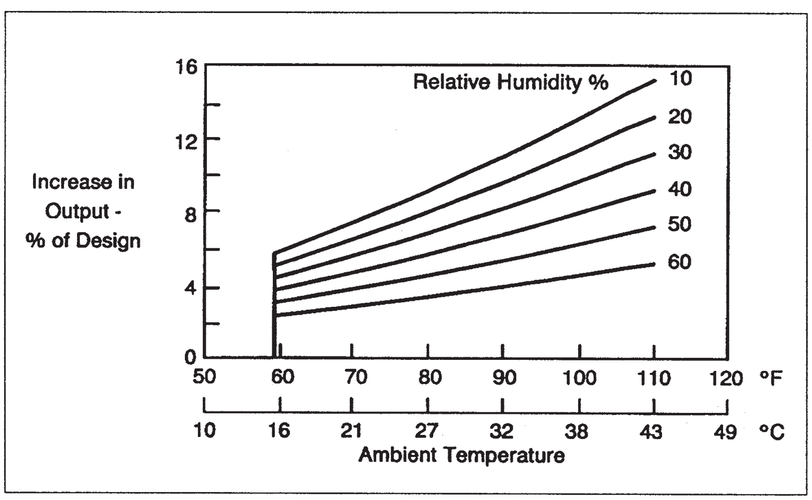

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Figure 70. Effect on output and heat rate of evaporative cooling over the ambient range

Model	Steam Injection (%)	Increase in Output Power (%)	Decrease in Heat Rate (%)
MS3002J	5	19.0	-9.0
MS5001R	5	15.2	-6.5
MS5001P	5	13.2	-4.6
MS5002B	5	16.0	-7.5
MS6001	5	15.0	-5.0
MS7001B	5	17.0	-6.0
MS7001E	5	15.0	-5.0
MS7001E	9	29.6	-8.1
MS9001B	5	17.0	-6.0
MS9001E	5	15.0	-5.0

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Figure 71. Turbine performance improvement with steam injection

Water or steam can be injected into the combustor head end using the standard NO_x water/steam injection systems. Approximately 2% mass flow is possible, which results in approximately 5% to 6% performance increase. Helper/starting turbines would have to be sized for specific applications.

Considerable application engineering support is required to maximize performance improvement for any of these power augmentation options. In addition, a thorough review of all gas turbine auxiliaries and all load equipment must be made to ensure that they are compatible with the supplemental power output.

Combustion System Upgrades

Each of the advanced technology upgrades detailed in this paper includes significant improvements to combustion system components. These combustion system upgrades can also be supplied as individual options for substantial improvements in component life and/or for extension in recommended combustion inspection intervals. *Figure 72* details the more significant combustion system design improvements incorporated into new unit production during the past several years. All these design improvements are available individually or as a package. The Sourcebook codes listed for each option provide an easy reference number for GE field offices to quickly provide detailed information on each option. *Figures 28 and 53* provide details on maintenance interval extensions.

Extendor™ Program for Increased Combustion Inspection Intervals (FR1V)

All heavy-duty gas turbines undergo periodic combustion inspections to check for material creep, thermal barrier coating erosion and wear. See *Figures 28 and 53* for standard recommended inspection intervals with conventional and advanced technology parts. *Figure 73* details the new combustion wear-resistant components now known as the Extendor™ system. With the Extendor system, combustion inspection intervals can be extended up to 24,000 hours for base load continuous dry units operating dry on natural

Sourcebook Codes	G.T. Models	3/2A-G	3/2H-J	5/1A-M	5/1R&P	5/2A&B	6/1A&B	7/1A&B	7/1E&EA	9/1B	9/1E
	Combustion Features										
FR1L	Floating Seal Transition Piece	-	X	X	X	X	-	-	-	-	-
FR1C	Heavy Wall Transition Piece	-	X	-	-	-	-	X	X	X	X
FR1D	Nimonic Tranisition Piece	-	-	-	-	-	-	X	-	X	-
FR1G	TBC Coated Liners	X	X	X	X	X	X	X	X	X	X
FT1V	3/2J Combustion for 3/2A-G	X	-	-	-	-	-	-	-	-	-
FR1H	7E Combustion for B Units	-	-	-	-	-	X	X	-	-	-
FR1V	9E Combustion for B Units	-	-	-	-	-	-	-	-	X	-
FR1J	Swirl Cooled Cross-Fire Tube	-	X	X	X	X	X	-	-	-	-
FR1N	Hard Facing	-	X	X	X	X	X	X	X	X	X
FR1P	New Tech Liners	X	X	X	X	X	-	-	-	-	-
FR1Q	New Tech T/P	X	-	X	X	-	-	-	-	-	-
FR1R	Hast X-inner Elbow	X	X	X	X	X	-	-	-	-	-
FR1B	Low NO_x Liners	X	X	X	X	X	X	-	-	-	-
FR1E	Multi-Nozzle Quiet Combustor	-	-	-	-	-	-	X	X	-	-
FR1T	Breech Load Fuel Nozzle	-	-	X	X	-	X	X	X	X	X
FR1V	Extendor™ Wear Kit	-	-	-	X	X	X	X	X	-	-

GT23768B

Figure 72. Combustion upgrade features

gas fuel (12,000 hours with water injection using breach load fuel nozzles).

The Extendor system is a combination of:

- Wear-resistant coatings and materials
- Enhanced clearances
- Mechanical design improvements

The Extendor combustion system improvements can be retrofitted into existing combustion hardware during routine maintenance or to new components using the same conversion package. The system is currently available for standard Frame 5, 6, 7 and 9 gas turbine models with slot-cooled combustion liners and Nimonic transition pieces. See *Figure 73* for additional details.

Emission Levels

In considering an uprate to an existing gas tur-

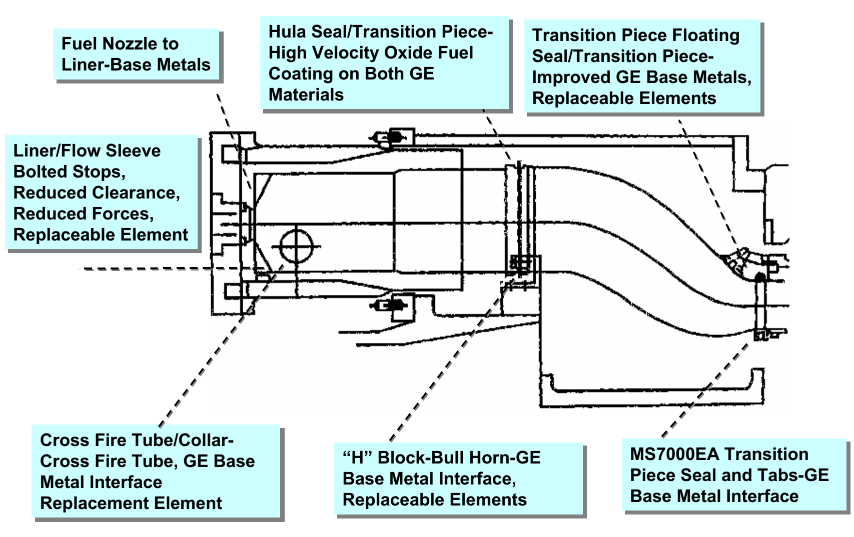

Figure 73. Extendor™ system design improvements

Single Shaft Units		Dry		H_2O/Steam Inj		Dry Low NO_x	
Model	Firing Temp. F/C	Gas	Dist.	Gas (FG1A/FG1B)	Dist (FG1C/FG1F)	Gas (FG2F)	Dist* (FG2F)
MS5001R	1720/938	126	193	42	65	33	42
MS5001P	1730/943	128	195	25	42	20	42
MS5001P-N/T	1765/963	142	211	25	42	20	42
MS6001B	2055/1124	148	267	42	65	9	42
MS7001B	1840/1004	109	165	25	42	-	-
MS7001B Option 3	1965/1074	124	191	25	42	15	42
MS7001B Option 4	2020/1104	132	205	25	42	15	42
MS7001EA	2020/1104	154	228	25	42	9	42
MS9001B	1940/1060	109	165	42	65	-	-
MS9001B Option 3	1965/1074	124	191	42	65	25	-
MS9001B Option 4	2020/1104	132	205	42	65	25	-
MS9001E	2020/1104	157	235	42	65	25	42
MS9001E	2055/1124	132	241	42	65	25	42
Two Shaft Units* **		**Dry**		**H_2O/Steam Inj**		**Dry Low No_x**	
Model	**Firing Temp. F/C**	**S.C.**	**R.C.****	**S.C.**	**R.C.**	**S.C.**	**R.C.**
MS3002F	1575/1625/857/885	115	201	42	50	-	42
MS3002J	1730/943	128	217	42	50	25	33
MS3002J-N/T	1770/966	140	236	42	50	25	33
MS5002B	1700/927	125	220	42	50	42	65
MS5002C&D	1770/966	137	255	42	50	42	65

* With Water Injection for Distillate Fuel
** S.C. = Simple Cycle and R. C. = Regenerative Cycle
***Two-Shaft NO_x Levels Are All On Gas Fuel

GT23289F

Figure 74. NO_x emission levels at 15% O_2 (ppmvd)

bine, the impact on emission levels must be considered. *Figure 74* lists typical NO_x emission levels before and after uprates for many of the uprate programs. Also listed are reduced emission levels with various options available for emission control (water injection, steam injection and Dry Low NO_x). Detailed review of site and specific emission levels are provided with each uprate study.

Low NO_x louvered combustion liners – MS5/1, 3/2, 5/2 (FR1B)

A lean "head end" louvered combustion liner is available for MS3002, MS5001 and MS5002 units. The louvered slot pattern and dilution hole pattern have been changed to provide a much "leaner" combustion system than the standard louvered liner. This results in an approximately 30% reduction in NO_x as compared to the standard louvered liner. *Figure 20* compares the original louvered liner design ("N" liner) to the lean head end liner ("P" liner). As shown in *Figure 74*, the NO_x emissions level for a standard MS5001P unit increases about 12% when uprating with advanced technology parts.

When the advanced technology uprate is applied in conjunction with the lean head end louvered P liner, the result is an uprate that results in significantly lower NO_x levels (i.e., a 12% increase due to uprate minus 30% for lean head end liner). *Figure 20* plots NO_x emissions for an advanced technology 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. Lean head end liner designs are available for almost all vintages of MS3002, MS5001 and MS5002 units for both regenerative and simple cycle applications for gas fuel only, or for distillate fuel units with atomizing air.

Summary

GE has an advanced technology uprate package available to uprate almost all of the 7,200 GE design heavy-duty gas turbines, as shown in *Figure 71*. These advanced technology uprate packages provide significant savings to our customers due to reduced maintenance, improved efficiency and increased output. Changes in emission levels associated with a gas turbine uprate may also make it necessary to add/change emission controls due to regulatory requirements. It is frequently desirable to also consider a control system upgrade or replacement in conjunction with a turbine uprate to achieve the best overall improvement in reliability.

GE Has an Advanced Technology Uprate Package Available to Uprate Most of the 7,200 GE Design Heavy-Duty Gas Turbines to Improve Performance and Reliability

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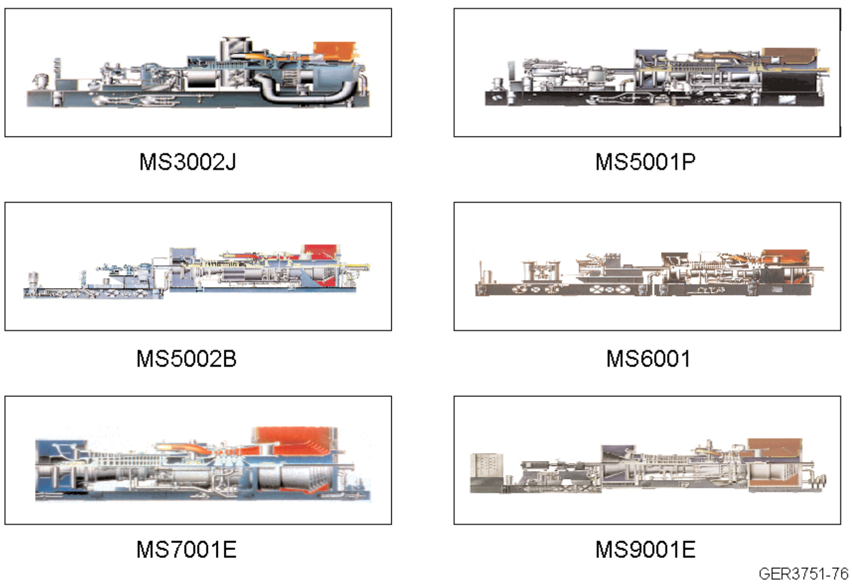
Figure 75. Uprate summary



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