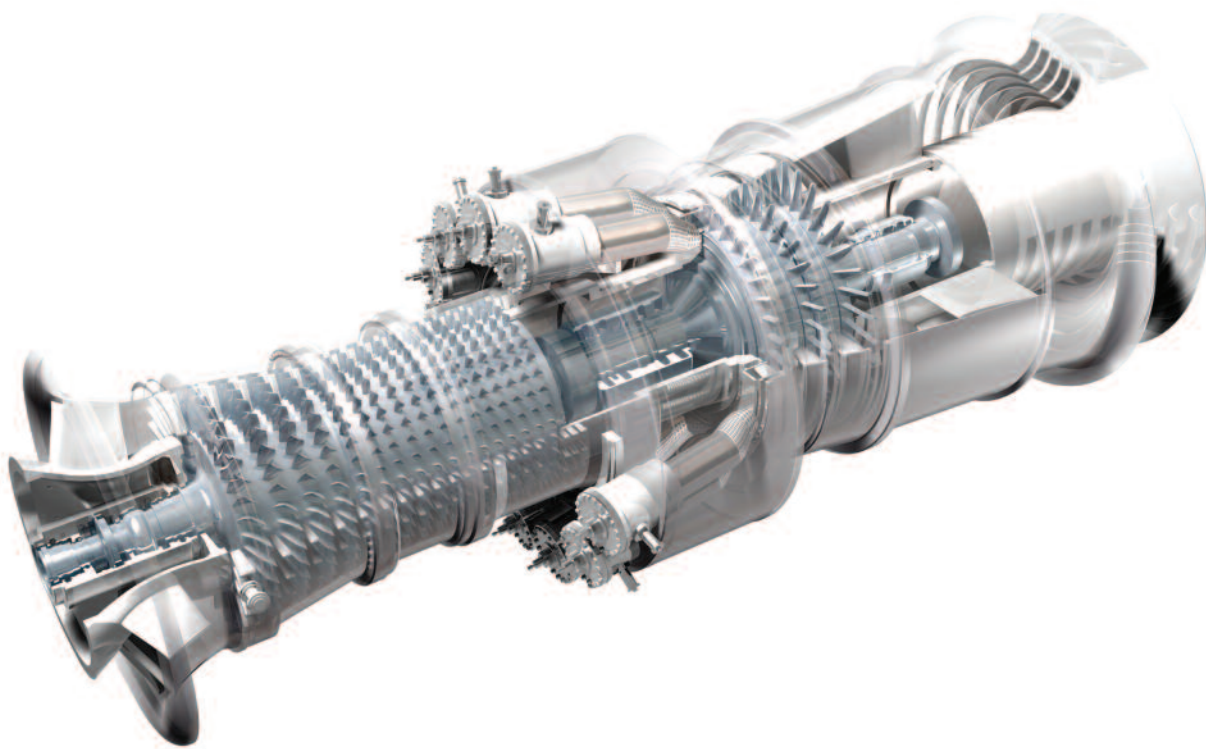


# Uprate Options for the MS9001 Heavy Duty Gas Turbine



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# Contents

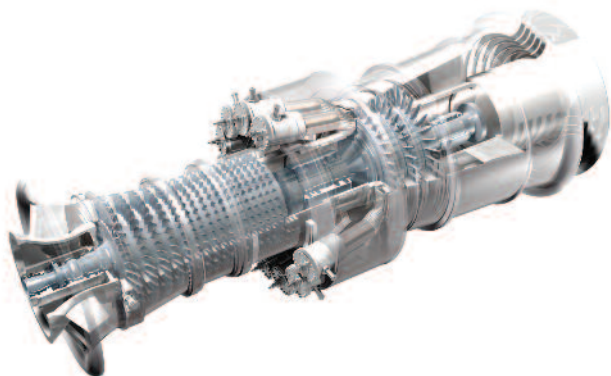
<b>Abstract .....</b>	<b>1</b>
<b>Introduction .....</b>	<b>1</b>
Packaged Turbine Upgrades .....	1
Individual Upgraded Parts .....	2
Life Extension .....	2
Emission Levels.....	2
Absolute Performance Guarantees and Turbine Degradation .....	2
Control System Upgrades .....	3
<b>MS9001 E-Class History.....</b>	<b>3</b>
<b>MS9001E Current Production Component Technology .....</b>	<b>3</b>
<b>Compressor Improvements .....</b>	<b>5</b>
GTD-450 Reduced Camber High Flow IGV Uprate (FT6B) .....	5
GTD-450 Compressor Stages 1 to 8 Uprate (FS1F) .....	6
High Pressure Packing Brush Seal Uprate (FS2V) .....	6
No. 2 Bearing Brush Seal Uprate (FS2X) .....	7
Shrouded S17 + EGV 1&2 and Counter Bore Covers Upgrades (FS2B).....	8
<b>Combustion System Improvements.....</b>	<b>8</b>
Uprate Combustion System from 9B to 9E (FR1H) .....	8
Add Water Injection to Gas or Dual Fuel Units (FG1A).....	10
Breech Loaded Fuel Nozzle Uprate (FR1T).....	11
Add Water Injection for Liquid Fuel Units (FG1C).....	11
Add Steam Injection for Power Augmentation (FJ3A/B) (A=manual, B=automatic).....	12
Add Steam Injection for NO <sub>x</sub> Control in Gas or Dual Fuel Units (FG1B/D) (B=manual, D=automatic).....	12
TBC Coated Combustion Liner Uprate (FR1G).....	13
Upgraded Nimonic 263™ Transition Piece with Improved Aft Bracket (FR1D).....	13
Extensor* Combustion System Uprate (FR1V and FR1W).....	15
Dry Low NO <sub>x</sub> Combustion System Uprate (FG2B) .....	18
Convert to Gas Fuel Only (FA1A) .....	19
Convert from Liquid to Dual Fuel (FA3D).....	20
<b>Hot Gas Path Improvements.....</b>	<b>20</b>
Upgraded Stage 1 Bucket (FT6J) .....	20
Upgraded TBC Coated Stage 1 Buckets (FS4G).....	22
Upgraded GTD-111* Stage 2 Bucket (FS2F).....	23
Non Air-Cooled GTD-111 Stage 2 Bucket Uprate (FS2I) .....	24
Upgraded Stage 3 Bucket IN-738™ (FS2K).....	24
Upgraded Stage 1 Nozzle with Chordal Hinge (FS2J) .....	25
Enhanced TBC Coating for Stage 1 Nozzle (FS6E).....	31
GTD-222+* Stage 2 Nozzle Uprate (FS1P).....	31
GTD-222+ Stage 3 Nozzle Uprate (FS1R) .....	32
Advanced Aero Stage 3 Nozzle (FS4K) and Advanced Aero Stage 3 Bucket Upgrades (FS4L).....	33
Upgraded HR-120™ Improved Stage 1 Shroud with Cloth Spline Seals (FS2Y).....	35
Stage 1 Shroud Abradable Coating Uprate (FS6A) .....	37

# Contents

Stage 2 and 3 Shroud Blocks Upgrades (FS2T and FS2U) .....	37
Interstage Brush Seal Upgrade (FS2Z).....	38
Discourager Seal Replacement (FW3E).....	39
Add Compressor and Turbine Water Wash (FC4A and FC4C).....	40
<b>Turbine Upgrade Packages .....</b>	<b>40</b>
Upgrade 9B Hot Gas Path and Combustion to 9E (FT6X).....	40
Increase MS9001E to 2020°F Firing Temperature (FT6C).....	44
Increase MS9001E to 2055°F Firing Temperature (FT6V).....	46
<b>Compartment and Exhaust Improvements.....</b>	<b>47</b>
Turbine Compartment Dual 100 HP Fan Upgrade (FF1E) .....	47
Upgrade to 100 HP Exhaust Frame Motor Bowers (FS2D).....	47
Replaceable Wheel Space Thermocouples Upgrade (FK5C) .....	48
Replaceable Exhaust Thermocouples Upgrade (FK5K) .....	48
Exhaust Frame Upgrade (FS1W) .....	48
Advanced Exhaust Plenum Upgrade (FD4K).....	49
<b>Summary .....</b>	<b>49</b>
<b>References .....</b>	<b>50</b>
<b>List of Figures .....</b>	<b>50</b>

# Uprate Options for the MS9001 Heavy Duty Gas Turbine

## Abstract



Advances in materials, cooling technology, and better design techniques have allowed E-class GE MS9001 turbines to be operated with higher firing temperatures and greater airflows, which result in higher turbine output and improved efficiency. Improvements in combustion technology have also made significantly lower emission levels a reality for operators.

The MS9001 heavy-duty gas turbine has undergone a series of uprates since its original introduction to the market in 1975. These uprates are made possible by the technology advances in the design of new machines based on information accumulated through millions of fired hours, new materials, and GE's on-going development programs.

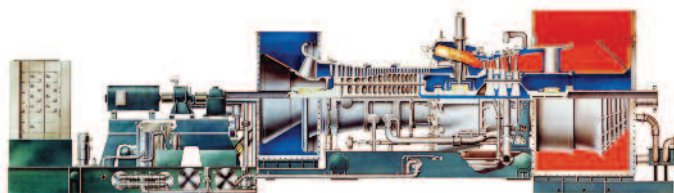
This document discusses design advances in critical components, and how the latest E-Class technology can be applied to enhance performance, extend life, and provide economic benefits through the increased reliability and maintainability of operating MS9001B and MS9001E turbines.

The MS9001B is a scaled version of the MS7001B, and MS9001E is a scaled version of the MS7001E; therefore, the confidence level of MS9001B/E uprates is very high based on a successful history in MS7001B/E uprate experience.

The first 2055°F uprate for MS9001E was successfully completed in 1990. Because this was the first uprate of its kind, extensive testing was completed to monitor compressor performance and start-up characteristics. Upon testing, the 2055°F uprate program was determined to be a success and since then many customers have increased their firing temperature—thereby significantly increasing wattage output. Numerous customers have purchased the individual uprate options described in this paper to realize performance and heat rate benefits.

## Introduction

Advanced design technology is usually introduced for new unit production and subsequently applied to customer-operated gas turbines by an uprate program. Many new uprate programs have been introduced for installed GE-designed heavy-duty gas turbines, including the MS9001E model illustrated in *Figure 1*. Each uprate program provides one or more of the following: increased output, improved heat rate and efficiency, improved reliability, reduced maintenance costs, longer inspection intervals, or longer parts lives. Uprates are based on current production components, parts that are not always specifically unique to older machines, and thus are readily available.



**Figure 1.** MS9001E Simple-cycle single-shaft heavy duty gas turbine.

## Packaged Turbine Uprates

Component improvements can be applied individually or as a complete uprate package, depending on schedule, budget, and machine condition. The design improvements and rationale are described for each possibility, including their effect on performance and maintenance.

GE Energy's turbine uprate packages have been introduced because of strong customer interest in extending the intervals between maintenance, improving efficiency, and increasing output. The E-Class technology uprate packages described in this paper include:

- MS9001 uprate from "B" to "E"
- MS9001E firing temperature increase to 2020°F, and to 2055°F
- MS9001 B and E emissions reduction
- Numerous performance and efficiency improvement uprates through airflow, material, and cooling technology advances

This publication covers uprates that have been successfully developed using components engineered for new unit production, or developed for units in operation. *Figure 2* lists the main benefits that should be evaluated for a unit under consideration for each advanced technology uprate option.

- Performance Improvements (Output/Heat Rate)
- Maintenance/Inspection Interval Extensions
- Availability/Reliability Improvements
- Emissions Reduction/Regulatory Agencies
- Life Extension

**Figure 2.** Benefits of uprates offered.

These uprates are possible due to GE's underlying design philosophy of maintaining the interchangeability of components for a given frame size—allowing these components to be installed in earlier vintage units with little or no modification. Installing the latest technology hardware and taking advantage of the highest, latest available firing temperatures allows operators to remain competitive in the power generation marketplace.

Gas turbine reference codes, such as FT6X for an MS9001 B to E advanced technology uprate, have been added to the text and to many of the figures for easier correlation to published documents by GE on specific uprate packages or components.

### Individual Upgraded Parts

Since the first MS9001B was shipped in 1975, virtually every key component in the MS9001 series has gone through design improvements. Buckets, nozzles, shrouds, and combustion components have undergone multiple evolutions based on new designs, improved manufacturing techniques, new materials, and acquired field experience.

Uprates can make good investments, with many exhibiting prompt payback for a specific operator. Each turbine application must be evaluated on its own merits, but in many cases, paybacks under two years have been registered. Uprates can be phased-in

according to the outage schedule, or installed in a single outage, with appropriate advance planning.

Each owner of a GE heavy-duty gas turbine should evaluate the economics of the various uprates for a specific application. In many cases, the economic evaluation justifies one of the available uprates at the next major overhaul and, in some cases, earlier. When more power generating capacity is required, uprating can provide a cost-effective alternative to purchasing and installing new units. At the same time, the improved parts provide extended life of the existing turbine.

### Life Extension

Operators can take advantage of technology improvements by using state-of-the-art components to replace older component designs during major and/or hot gas path inspections instead of replacing in-kind. These advanced technology components yield an increased service life when used in machines that fire at temperatures lower than that for which the advanced components are designed.

### Emission Levels

Emission levels can sometimes be affected when the gas turbine is uprated, and these levels must be accounted for during planning. Emission control options reduce the emission levels, and *Figure 3* compares typical nitrogen oxides (NO<sub>x</sub>) emission levels before and after uprates. Individual site requirements and specific emission levels can be provided in an uprate study supplied to GE customers through a GE Sales representative.

### Absolute Performance Guarantees and Turbine Degradation

Performance uprates discussed in this paper are based on airflow or firing temperature increases that are directly related to performance increases, expressed as a percentage (Delta) of increase. Quantifying turbine performance degradation can be difficult due to lack of

**NO<sub>x</sub> Emissions Levels at 15% O<sub>2</sub> (ppmvd)**

Single Shaft Units Model	Firing Temp. F/C	Dry		H <sub>2</sub> O/Steam Inj.		Dry Low NO <sub>x</sub>	
		Gas	Dist	Gas (FG1A/FG1B)	Dist (FG1C/FG1F)	Gas (FG2F)	Dist* (FG25)
MS9001B	1840/1004	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	162	241	42	65	25	42
MS9001E	2055/1124	162	241	42	65	15	42

**Figure 3.** NO<sub>x</sub> emissions levels at 15% O<sub>2</sub>.

consistent and valid field data. In addition, several variables exist, including site conditions and maintenance characteristics, operation modes, etc., that affect turbine performance and degradation trends. Delta upgrades, providing a performance change, are consistent with or without turbine degradation factors. Absolute guarantees must factor in degradation losses to calculate the final expected performance level. Therefore, the absolute performance guarantees offered usually appear slightly different than Delta percentage changes in order to account for turbine degradation.

## Control System Upgrades

The MS9001B and E turbines are controlled by the GE Mark I\* through Mark VI\* generation of controls. Several control system enhancements and upgrades are available, providing more reliable operation with today's superior control technology. Enhanced operating control can be realized in units that have older control systems.

## MS9001 E-Class History

The first MS9001 E-Class unit shipped in 1975 as a model MS9001B for the 50 Hz market, incorporating excellent design experience from the successful MS7001B. Operating with a design firing temperature of 1840°F (base load), the same firing temperature as the MS7001B, the MS9001B design represented an increase of 42% in output over the MS7001B. This introductory design incorporated the air-cooled stage 1 buckets, nozzles, and stage 2 bucket material improvements based on MS7001B design experience gained prior to 1975. As illustrated in *Figure 4*, the output of the MS9001 has increased by 45% based on technology improvements through 1994 (not including EC or F/FA product lines).

Introduced in 1978, the MS9001E incorporated the experience gained from MS7001E production and operation, as well as the design improvements that had evolved since the MS9001B was introduced. Introductory firing temperature for the MS9001E was 1955°F.

The MS9001E has seen many design improvements since it was initially introduced, with one obvious change being the increased firing temperature. Advances in materials, coatings, and cooling technology have supported a series of firing temperature increases. The current firing temperature for the latest MS9001E is 2055°F. All MS9001E gas turbines can be uprated to the 2055°F firing temperature.

## MS9001E Current Production Component Technology

Product technology derived from ongoing new product development, field service reports, and new materials and processes has resulted in improvements to compressor hardware, combustion liners, transition pieces, high flow inlet guide vanes, and all stages of buckets, nozzles, and shrouds.

Many of the design improvements for components involve a change in the materials used. *Figure 5* lists the composition of many of the gas turbine alloys discussed herein. For buckets, nozzles, and compressor blades, the most advanced materials of choice begin with the designation GTD which signifies a General Electric patented or proprietary alloy. Some of the materials listed for these parts are not used for current production, but are in the table for reference concerning machines operating vintage parts made of these older alloy compositions, such as X40. Many of the materials shown in the

Model	Ship Dates	ISO Performance* kW	Firing Temp °F/°C	Air Flow 10 <sup>6</sup> lbs/hr 10 <sup>6</sup> kg/hr	Heat Rate BTU/kWhr kJ/kWh	Exhaust Temp °F/°C
PG9113B	1975-81	86,200	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	877/525
PG9161E	1988-91	116,930	2020/1104	3.222/1.461	10,290/10,854	980/527
PG9171E	1991	123,450	2055/1124	3.231/1.466	10,080/10,632	998/537
	2003 – Current	126,100	2055/1124	3.231/1.466	10,100/10,650	1009/543
PG9231EC	1996	165,700	2200/1204	4.044/1.834	9,870/10,411	1,037/558
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	1,097/582

\*Base load distillate fuel, includes 3/10 inches H<sub>2</sub>O inlet/exhaust pressure drops

**Figure 4.** MS9001 E-Class performance history.

Component	Nominal Composition (%)												
	Cr	Ni	Co	Fe	W	Mo	Ti	Al	Cb	V	C	B	Ta
<b>Buckets</b>													
U500™	18.5	BAL	18.5	–	–	4	3	3	–	–	0.07	0.006	–
Rene 77™ (U700™)	15	BAL	17	–	–	5.3	3.35	4.25	–	–	0.07	0.02	–
IN-738™	16	BAL	8.3	0.2	2.6	1.75	3.4	3.4	0.9	–	0.1	0.001	1.75
GTD-111*	14	BAL	9.5	–	3.8	4.5	4.9	3	–	–	0.1	0.01	2.8
<b>Nozzles</b>													
X40™	25	10	BAL	1	8	–	–	–	–	–	0.5	0.01	–
X45™	25	10	BAL	1	8	–	–	–	–	–	0.25	0.01	–
FSX-414	29	10	BAL	1	7	3	–	–	–	–	0.25	0.01	–
N-155™	21	20	20	BAL	2.5	–	–	–	–	–	0.2	–	–
GTD-222*	22.5	BAL	19	–	2	–	2.3	1.2	0.8	–	0.1	0.008	1
<b>Combustors</b>													
SS309	23	13	–	BAL	–	–	–	–	–	–	0.1	–	–
Hastelloy-X™	22	BAL	1.5	1.9	0.7	9	–	–	–	–	0.07	0.005	–
Nimonic 263™	20	BAL	20	0.4	–	6	0.4	0.4	–	–	0.06	–	–
HA-188™	22	22	BAL	1.5	14	–	–	–	–	–	0.05	0.01	–
<b>Turbine Wheels</b>													
IN-706™	16	BAL	–	37	–	–	–	–	2.9	–	0.06	0.006	–
Cr-Mo-V	1	0.5	–	BAL	–	1.25	–	–	–	0.25	0.3	–	–
A286™	15	25	–	BAL	–	1.2	0.3	0.3	–	0.25	0.08	0.006	–
M152™	12	2.5	–	BAL	–	1.7	–	–	–	0.3	0.12	–	–
<b>Compressor Blades</b>													
AISI 403	12	–	–	BAL	–	–	–	–	–	–	0.11	–	–
AISI 403+Cb	12	–	–	BAL	–	–	–	–	0.2	–	0.15	–	–
GTD-450	15.5	6.3	–	BAL	–	0.8	–	–	–	–	0.03	–	–

Figure 5. Gas turbine alloys.

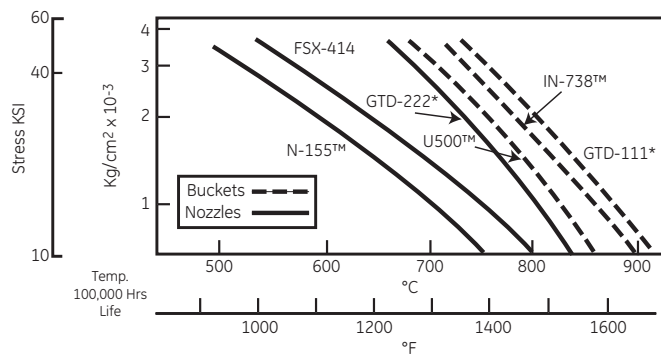


Figure 6. Creep stress rupture comparison of bucket and nozzle materials.

table for combustors and turbine wheels are still used today. The most used alloys for current production of combustors and wheels are Nimonic 263™, HA-188™, Hastelloy-X™, and IN706™, Cr-Mo-V, respectively. Figure 6 compares the rupture stress for the bucket and nozzle materials, illustrating the improvements associated with the new materials developed and offered in uprates.

Figure 7 lists the performance and/or heat rate uprate codes currently applicable for E-Class turbines.



Uprate	Description
FA1A	Convert To Gas Fuel Only
FA3D	Convert From Liquid To Dual Fuel
FA3L	Uprated Three-Way Valves to Replace Check Valves for DLN-1
FC4A	Add Compressor Water Wash Off Line
FC4C	Add Turbine Water Wash
FD4K	Advanced Exhaust Plenum Uprate
FF1E	Turbine Compartment Dual 100HP Fan Uprate
FG1A	Add Water Injection For Gas Or Dual Fuel Units
FG1B	Add Manual Steam Injection for NO <sub>x</sub> Control in Gas or Dual Fuel Units
FG1D	Add Automatic Steam Injection For NO <sub>x</sub> Control in Gas or Dual Fuel Units
FG1C	Add Water Injection For Liquid Fuel Units
FG2B	Dry Low NO <sub>x</sub> 1.0 Combustion System Uprate
FJ3A	Add Manual Steam Injection For Power Augmentation
FJ3B	Add Automatic Steam Injection For Power Augmentation
FK5C	Replaceable Wheel Space Thermocouple Uprate
FK5K	Replaceable Short Lead Design Exhaust Thermocouple Uprate
FK5P	Replaceable Connector Design Exhaust Thermocouple Uprate
FR1D	Uprated Nimonic Transition Pieces With Improved Aft Bracket
FR1G	TBC Coated Combustion Liners Uprate
FR1H	Uprate Combustion System From 9B To 9E
FR1T	Breech Loaded Fuel Nozzle Uprate
FR1V	Extendor* Combustion System Retrofit Uprate
FR1W	Extendor Combustion System New Uprate
FS1F	GTD-450 Compressor Stages 1 To 8 Uprate
FS1L	Air-Cooled Stage 2 Bucket Uprate
FS1P	GTD-222+* Stage 2 Nozzle Uprate
FS1R	GTD-222+ Stage 3 Nozzle Uprate
FS1W	Exhaust Frame Uprate
FS2B	Shrouded S17 + EGV1&2 And Counter Bore Covers Upgrades
FS2C	Uprated Stage 1 Shroud Blocks
FS2D	100HP Exhaust Frame Motor Blower Uprate
FS2F	Uprated GTD-111* Stage 2 Bucket
FS2I	Non Air-Cooled GTD-111 Stage 2 Buckets Uprate
FS2J	Uprated Stage 1 Nozzle With Chordal Hinge
FS2K	Uprated Stage 3 Bucket IN738
FS2T	Stage 2 Shroud Honeycomb Seal Uprate
FS2U	Stage 3 Shroud Honeycomb Seal Uprate
FS2V	High Pressure Packing Brush Seal Uprate
FS2X	Number 2 Bearing Brush Seal Uprate
FS2Y	Uprated HR-120™ Improved Stage 1 Shroud with Cloth Spline Seals
FS2Z	Interstage Brush Seal Uprate
FS4G	Uprated TBC Coated Stage 1 Buckets
FS4K	Advanced Aero Stage 3 Nozzle Uprate
FS4L	Advanced Aero Stage 3 Bucket Uprate
FS6A	Stage 1 Shroud Abradable Coating Uprate
FS6E	Enhanced TBC Coating for Stage 1 Nozzle
FT6B	GTD-450 Reduced Camber High Flow IGV Uprate
FT6C	Increase 9E To 2020°F Tf
FT6J	Stage 1 Bucket Uprate
FT6X	Uprate 9B Hot Gas Path And Combustion To 9E
FT6Y	Increase 9E To 2055°F Tf
FW3E	Discourager Seal Replacement

**Figure 7.** Upgrades available for 9B and 9E units.

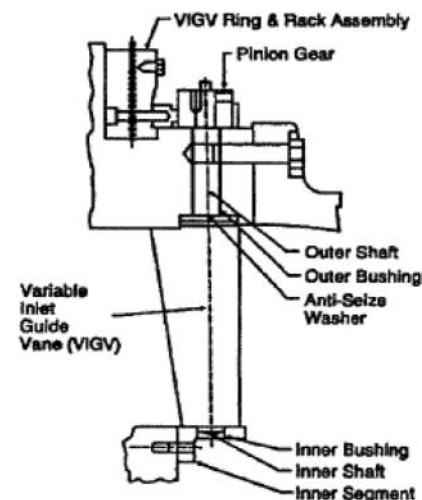
## Compressor Improvements

The first four stages of the MS9001B compressor were re-designed for the MS9001E model. Because new compressor casings and all new compressor rotor and stator blades would be required to upgrade the MS9001B compressor to later design compressors, this is usually not economically feasible and not typically quoted as part of a unit uprate.

Instead, the existing MS9001B compressor can be re-bladed with the original design/length blades, with special blade coatings for materials available for certain applications. Originally, a NiCad coating was applied to the first eight stages of the compressor blades that were AISI 403. (See *Figure 5*.) NiCad coating helps prevent corrosion pitting on the blades by combining a tough barrier of nickel with a sacrificial cadmium layer. NiCad coating was replaced by GECC-1\*, which provides the same protection as NiCad without the use of cadmium, which is considered an environmental hazard. Both GECC-1 and NiCad possess outstanding corrosion resistance in neutral and sea salt environments.

### GTD-450 Reduced Camber High Flow IGV Uprate (FT6B)

A widely used uprate product is the GTD-450 reduced camber, high-flow inlet guide vane illustrated in *Figure 8*. The new design, introduced in 1986, was quickly applied across the entire GE heavy-duty product line to enhance field unit performance, including MS9001E and B units. Note that previous design IGVs made of 403L stainless steel (SS) cannot be opened to 86 degrees, due to insufficient strength of the lower rated, 403L material with low carbon (L).



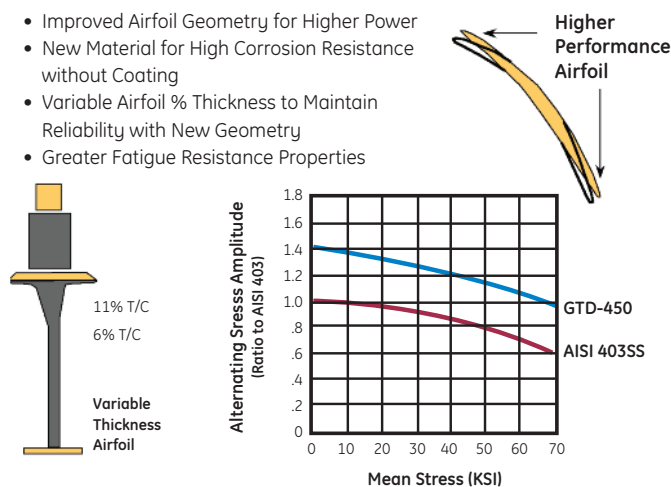
**Figure 8.** GTD-450 reduced camber high-flow variable IGV arrangement.

The benefits of this uprate are:

- Model 9B change in output: +4.4%, change in heat rate: -0.9%
- Model 9E (pre-1988) change in output: +1.5%, change in heat rate: -0.3%
- GTD-450 material provides excellent corrosion protection

The reduced camber, high-flow inlet guide vane is a flatter, thinner inlet guide vane designed to increase airflow while remaining dimensionally interchangeable with the original inlet guide vane. The reduced camber IGV, when open to 84 degrees, can increase power up to 4.4% and decrease heat rate by up to -0.9% while improving corrosion, crack, and fatigue resistances. Opening the IGVs to 86 degrees increases output an additional 0.4% at the expense of +0.2% heat rate.

The enhanced IGVs have higher reliability due to the use of a special precipitation hardened, martensitic stainless steel GTD-450, which is improved over the AISI 403 alloy previously used. (See Figure 9.) Material developments include increased tensile strength, higher high cycle fatigue strength, improved corrosion-fatigue strength, and superior corrosion resistance due to higher concentrations of chromium and molybdenum.



**Figure 9.** Design improvements with GTD-450 high flow IGVs.

The modification kit includes self-lubricating IGV bushings with tight clearance. A new rack and ring assembly, which controls guide vane positioning, can also be provided for improved reliability.

### GTD-450 Compressor Stages 1 to 8 Uprate (FS1F)

This modification for MS9001E units involves replacing the stage 1-8 compressor blades and stator vanes with GTD-450 material, uncoated. The GTD-450 stainless steel material provides high corrosion resistance even when uncoated, and significantly increases the strength of the blades and stator vanes.

The benefits of this uprate are:

- High tensile strength
- Corrosion resistance and crack resistance
- Significantly increased reliability and cycle life of the part

Replacing the existing stage 1 through 8 compressor blades and stator vanes with uncoated GTD-450 gives the blades and vanes a distinct material advantage. GTD-450 is a precipitation-hardened, martensitic stainless steel that provides increased tensile strength and superior corrosion resistance because of its higher concentration of chromium and molybdenum. GTD-450 uncoated blading with high corrosion resistance is supplied for the first 8 stages because during standard operation this region could be subjected to liquid water, therefore incurring an elevated risk of corrosion.

As illustrated in Figure 9, GTD-450 stainless steel compressor blades and stator vanes offer high tensile strength, high corrosion resistance, and high resistance to cracking that significantly increase the reliability and life cycle of these parts.

### High Pressure Packing Brush Seal Uprate (FS2V)

This uprate for MS9001B and E units provides +1.0% increase in output and improves heat rate by -0.5%. This option consists of modifying the existing labyrinth tooth and seal arrangement to add an effective brush seal element. With this option a new inner barrel with a new brush seal are installed. Note that FS2V is now a standard configuration on all new units since 2003 production year.

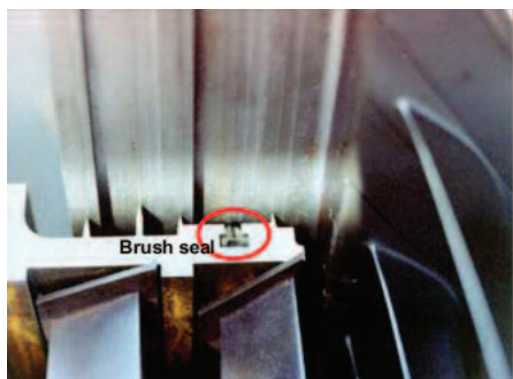
The benefits of this uprate are:

- Model 9B change in output: +1.0%, change in heat rate: -0.5%
- Model 9E change in output: +1.0%, change in heat rate: -0.5%

**Notes:** To obtain the above performance benefits on MS9001B units, operators should install HPP together with #2 bearing brush seals (FS2X).

A brush seal for 9E units with a honeycomb inner barrel configuration is now available.

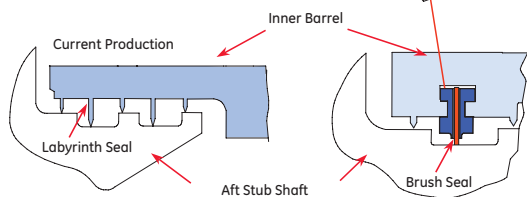
The seal between the compressor discharge casing inner barrel and the compressor aft stub shaft is called the high-pressure packing (HPP) seal. (See *Figure 10*.) The HPP seal is designed to regulate the flow of the compressor discharge air into the first forward wheel space. The HPP clearance determines the amount of flow to the wheel space. Ideally, this flow is limited to the amount required for first forward wheelspace cooling.



#### Typical Brush Seal Element

##### Brush Seals

Reduce air leakage  
Tolerant of misalignments  
More durable than labyrinth seals



**Figure 10.** HPP brush seal.

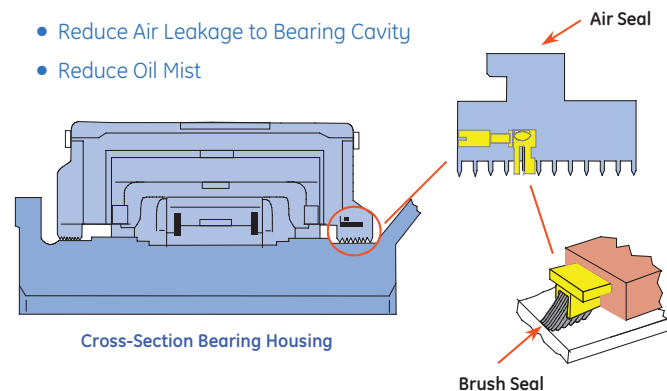
With the conventional labyrinth tooth/land seal packing on the inner barrel, the allowable clearance that can be tolerated is controlled by the expected rotor displacement during transient conditions, and by cooling wheelspace requirements. If a rub does occur, the labyrinth teeth can be seriously damaged and cause excessive leakage through the packing. A 20-mil rub is equivalent to a loss of approximately 1% in output. Rub-tolerant brush seals are designed to bend, thereby withstanding rotor excursions and maintaining clearances in this critical area with no increase in cooling airflow leakage. Metallic brush material is used in place of one of the labyrinth teeth on the inner barrel. With brush seals at the high-pressure packing, the unit is able to sustain initial performance levels over an extended time because the inevitable excursion does not increase the clearance.

Two different designs have been used to reduce leakage through the HPP. New units built since April 1994 shipped with a honeycomb seal on the inner barrel (similar to the design used for stage 2 and 3 shrouds). To retrofit a brush seal onto an operating unit having a honeycomb seal, the existing inner barrel must be removed and replaced with an inner barrel containing a brush seal. The inner barrel with brush seal is designed for use with the existing compressor aft stub shaft with high/low lands.

High-pressure packing brush seals, which are available for both the 9B and the 9E, provide 1% increase in output and -0.5% improved heat rate when replacing the labyrinth design. The high pressure packing brush seal provides 0.2% improvement in both output and heat rate relative to the honeycomb design.

#### No. 2 Bearing Brush Seal Uprate (FS2X)

The MS9001B and E units are three-bearing machines that include two air seals in the No. 2 bearing housing, one on either side of the bearing. The brushes provide a tighter seal than the original labyrinth seal. Since any air that leaks past these seals into the bearing housing does not perform any additional work, any reduction in this wasted flow results in an increase in performance. Brush seals for No. 2 bearing are illustrated in *Figure 11*. Note that FS2X is now a standard configuration on all new units manufactured in 2003 and shipped in 2003 or 2004.



**Figure 11.** Brush seals for #2 bearing.

The benefits of this uprate are:

- Model 9B change in output: +1.0%, change in heat rate: -0.5%
- Model 9E change in output: +0.3%, change in heat rate: -0.2%

**Note:** To obtain the above performance benefits on MS9001B units, operators should install HPP together with #2 bearing brush seals (FS2X).

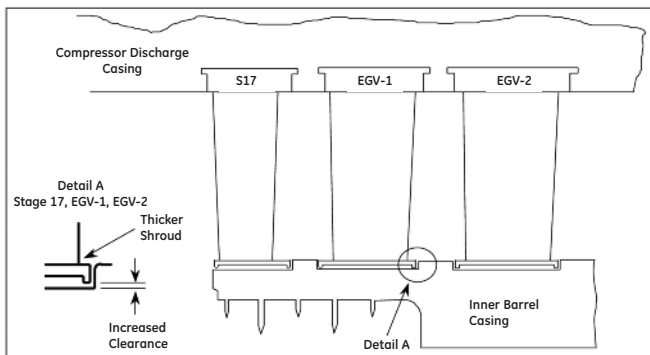
The FS2X bearing brush seals combined with high pressure packing brush seals installed together on the same unit have been tested in the field to yield 0.3% increase in output and -0.2% improvement in heat rate for MS9001E units, but yield a much better +1.0% increase in output and -0.5% improvement in heat rate for MS9001B units.

### Shrouded S17 + EGV 1&2 and Counter Bore Covers Upgrades (FS2B)

For MS9001E units, the need to implement the stage 17 stator correction is evaluated on an individual basis. Exit guide vane issues on some MS9001E units have been attributed to aerodynamic vane stall when running under certain operating conditions. To prevent this failure, the stage 17 stator vanes, and the two stages of exit guide vanes (EGVs) that follow the 17th stage, have been re-designed, (See Figure 12.) The vanes have all been shrouded and each stage of vanes goes into a broached ring that slides into a corresponding groove in the compressor casing. Setting the vanes in rings and shrouding them reduces the sensitivity of the structure and prevents blade failure.

#### Shrouded Stator 17 and EGV 1 & 2

- Stage 17 Stator and EGVs 1 & 2 have been shrouded to reduce the sensitivity of the structure and prevents blade failure
- Applicable to sites with low ambient conditions, steam or water injection, or modulating IGVs (i.e., for heat recovery applications)



**Figure 12.** Side view of the three stages of shrouded compressor blades.

The benefits of this uprate are:

- Enables stator blades to withstand the stall conditions
- Shrouded compressor stator blade assemblies, counter bore covers, or IGV angle re-scheduling reduces the sensitivity of the structure and prevent blade failure

A CM/U analysis is conducted to determine if shrouded compressor exit hardware is required for any specific unit. The stator 17 modifications will be reviewed for low ambient temperature sites, or where frequent operation with modulating inlet guide vanes occurs. Note that higher percentages of performance uprate and colder ambient conditions both result in a greater need for installing shrouded design for a specific unit.

Figure 13 illustrates an example of a CM/U analysis for a unit configuration in ambient temperatures from 41°F to 85°F and maximum IGV angle of 84 degrees. The figure illustrates that shrouded hardware is needed for most ambient temperatures at the IGV angles used. Counter bore cover plugs in the horizontal split line bolt holes are recommended on most units operating at colder ambient temperatures.

Operators should note that shrouded stator S17 and EGV 1&2 are now part of standard new unit design.

## Combustion System Improvements

Advances in the combustion system are driven by customer desires for performance increases and for compliance with regulatory requirements to reduce exhaust emissions. Relatively simple parts in early gas turbines are now complex hardware pieces with advanced materials and processing requirements. Combustion system upgrades can be supplied as a package, or as individual options. Depending on the option chosen and other machine conditions, upgraded combustion system components produce substantial improvements in component life and/or for extensions in recommended combustion inspection intervals.

### Uprate Combustion System From 9B to 9E (FR1H)

The combustion system for the MS9001B can be upgraded to the MS9001E. The new combustion system provides increased reliability and longer maintenance intervals and supports firing temperature increase.

The benefits of this uprate are:

- Increased reliability and longer maintenance intervals
- Supports a firing temperature increase

TBC coated slot-cooled liners and Nimonic 263™ transition pieces are available for the MS9001B. Retrofitting B-combustion systems with E-combustion systems increases inspection intervals and allows for higher firing temperatures. On the MS9001B, if the

Plot of Relative CM&U vs. IGV at Different Ambient Temperature

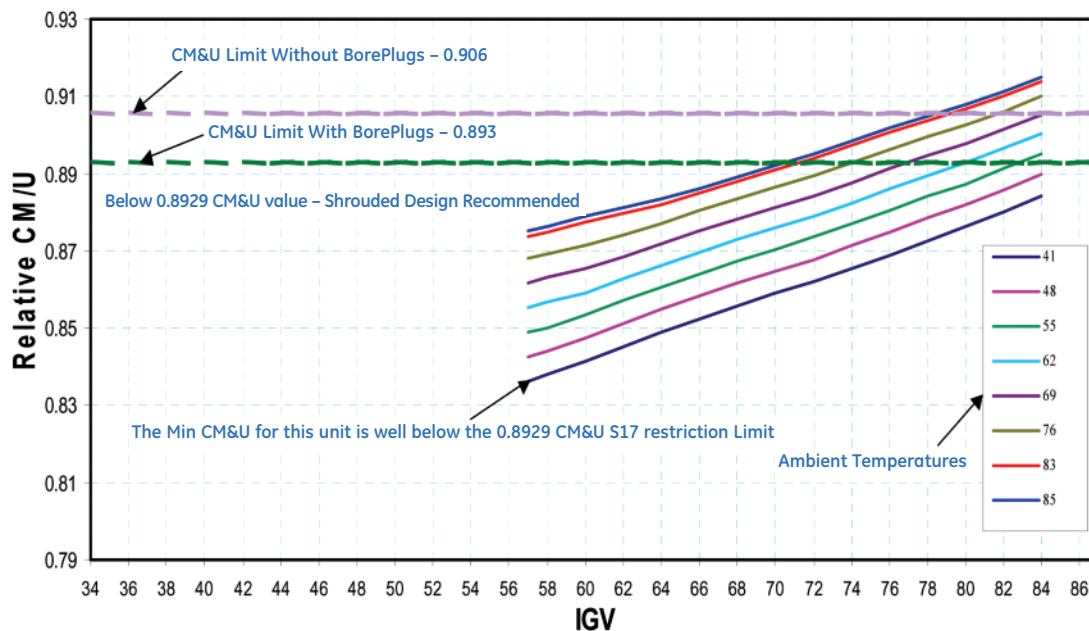


Figure 13. CM/U analysis for a specific unit showing need for shrouded design.

customer chooses to stay with the louvered liners, a new, advanced designed louvered liner has been designed.

The original MS9001B combustion system had parallel combustors. With the introduction of the MS9001E, the design evolved into a canted arrangement. Up until recently, in order to retrofit a 9B turbine with a 9E combustion system, a new compressor discharge casing was required to accommodate the canted arrangement. A new 9B/E combustion system has been developed which incorporates the design improvements seen in the MS9001E combustion system into a parallel arrangement. This design significantly reduces the cost and the installation time of this conversion, making it more attractive to the customer.

**Combustion Liner.** The original combustion liners were louvered. To improve the cooling effectiveness of the liner, a slot-cooled design was introduced. (See Figure 14.) The slot-cooled liner is significantly shorter than the louvered design, which further improves cooling. The inspection intervals for the slot-cooled liners increase to 6,500 hours for water diluent (or 8,000 hours for steam diluent) from the 3,000 hours for the louvered liner. The material is still Hastelloy-X™, but the liners are now given a thermal barrier coating (TBC). The TBC consists of two different materials applied to the hot side of the component, a bond coat applied to the inner surface of the liner, and

an insulating oxide applied over the bond coat. This 0.015-inch thick coating provides an insulating layer that reduces the underlying base material temperature and mitigates the effects of hot streaking (uneven gas temperature distribution). The liners also use splash plate cooling around the crossfire tube collar. Impingement cooling on the splash plate increases the cooling effectiveness at the collar location. This configuration reduces the stress concentrations thereby increasing life of the liner.

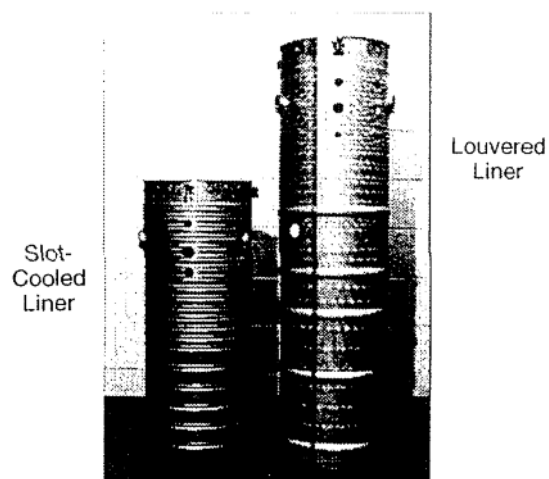


Figure 14. Improved slot-cooled liner versus original louvered liner.



The E-style slot-cooled liner is shorter than the old louvered liner (39 in. vs. 56 in.). This necessitates new combustor outer casings and crossfire tubes. On the MS9001B, a new, advanced design louvered liner is available as an option. This option applies if the customer wants to upgrade the current liners only, and keep the current combustion arrangement. Current louvered liners have a louver design that covers 270 degrees of liner circumference. In operation, especially when fired at peak firing temperature, this can cause buckling along the 90 degree arc where the louvers are absent. New liners, with full circumferential louvers, have not exhibited this buckling. Combustion inspection intervals with the advanced louvered liners can be increased to 6,000 hours.

**Transition Piece.** The new transition pieces are made of Nimonic 263™, which is a precipitation-strengthened, nickel-based alloy with a higher strength capability than Hastelloy-X™. This material has been used for over 30 years in aircraft engines, and has shown to have less creep deflection than Hastelloy-X™ transition pieces. The aft bracket has also been re-designed. The new design helps reduce the cracking at the bracket weld area by being able to pivot about the pin when a force is applied. Like the combustion liners, the transition pieces are coated with a TBC. The transition piece for the MS9001B uprate differs from the new production 9E transition piece in that its geometry accommodates the parallel combustion chamber arrangement.

On the MS9001B, the customer may choose to apply the new Nimonic 263™ transition piece only (Option A), or the new advanced louvered liner with the Nimonic 263™ transition piece (Option A + Option B), or go full conversion to an E-type combustion system. *(Note: The bracket for the Nimonic 263™ transition piece has a different bolt hole pattern than the previous designs, and as a result the stage 1 nozzle retaining ring needs to be modified with the new bolt hole pattern.)*

**Fuel Nozzles.** The newer designed fuel nozzle bodies include the lock plate feature and the weld-neck flanges on the gas and/or atomizing air flanges. The lock plate replaces the lock wire to give increased reliability and reduced risk of fuel gas leaks. The weld-neck flanges also reduce fuel nozzles leaks as well as cracking. Dual fuel or gas only systems are upgraded with hard faced, flow matched gas swirl tips that reduce wear against the combustion liner fuel nozzle collar. Dual fuel and oil-only systems are improved with stainless steel and Stellite™ internal body parts to reduce erosion rates and improve

flow uniformity. (Reference FR1T.) For the 9B, the breech loaded fuel nozzle design (current new unit configuration) can be an approved option. (Please contact GE for information on applicability.)

**Combustion Casing.** The B-style combustion casings must be replaced with a shorter version in order to accommodate the shorter E-style slot-cooled liner. The casings should not be cut down in order to modify them to a shortened version. Shorter casings require that the gas fuel and atomizing air manifolds be moved. The liquid fuel lines are re-laid with longer tubing. The new combustion casing covers are equipped with hinges to allow for ease of maintenance. The new casing arrangement contains flanges for a quantity of 4 flame detectors. GE recommends taking this opportunity to upgrade to GE's Reuter-Stokes flame detection system. (Reference FK5J).

**Spark Plug Leads.** Units with spark plug leads 311A5802 or 354A1513 (all part numbers) and all pre-1995 units should inspect them to ensure conformance to the minimum bend radius requirements identified in TIL-1234-2. Exceeding this limit results in noncompliance with requirements for Factory Mutual certification for use in hazardous areas (Class 1, Division 1, Groups B, C and D).

**Spark Plugs.** The E-Class combustion system requires longer spark plugs to ensure reliable ignition. The extended reach spark plugs were introduced for this purpose. Extended reach spark plugs manufactured prior to 178C6648G001 (with serial number 2122) should be replaced in accordance with TIL-487C.

**Manifolds.** The gas fuel and atomizing air manifolds are replaced.

**Liquid Fuel Piping.** The liquid fuel piping are re-run due to the shorter casings. New check valves are provided for improved reliability.

**Purge System (FW1U).** The purge system is modified to accommodate the shorter casings. New check valves are provided for improved reliability. This opportunity should be taken to ensure that TIL-551-B has been addressed, since it addresses gas fuel purge system safety concerns.

### Add Water Injection to Gas or Dual Fuel Units (FG1A)

This kit for MS9001B and E units includes the material necessary to add water injection to a unit. The modification kit includes replacement fuel nozzles containing water injection passages and connections, water

injection skid, instrumentation, manifolding, on-base piping, fuel flow measurement system, and control changes to operate the NO<sub>x</sub> system.

The benefits of this uprate are:

- Reduced NO<sub>x</sub> emissions level to meet locally required levels
- Significant increase in power and heat rate

This modification is not applicable to dual fuel units without atomized air. (Reference FA6B.)

The water injection system provides water to the combustion system of the gas turbine to limit the amount of nitrogen oxides (NO<sub>x</sub>) emitted in the turbine exhaust. This limit is site-specific and is dictated by the local regulating governmental agency. Applicable local regulations dictate not only the allowable emission levels, but may also require recording of the minute and hour averages of water flow, fuel flow, actual ratio of water-to-fuel, required water-to-fuel ratio, humidity, and megawatt load. Typically the required water-to-fuel ratio is established through field compliance testing of the individual unit per a specific standard. Based on these tests, a final control schedule is programmed into the control system that regulates the water injection system.

#### **Breach-Loaded Fuel Nozzle Uprate (FR1T)**

This modification for MS9001B and E units provides the turbine and on-base components for converting a water injection system from a standard, combustion casing end cover located water injection system to a breach-loaded system in which the water is injected through the fuel nozzle (current new unit configuration). This modification applies to either gas/liquid or liquid only. If the unit is not currently equipped with water injection, see Uprate FG1A.

The benefits of this uprate are:

- Reduced or eliminated combustion-liner cap cracking
- Extended inspection intervals
- Reduced outage time

With the latest design breach-loaded fuel nozzles, the water is injected through the center of the fuel nozzle, directing the water at the combustor flame. As a result, the water injection spray does not impinge on the fuel nozzle swirler or combustion cowl assembly. Thus, the breach loaded fuel nozzles reduce or eliminate any associated combustion liner cap cracking. This new design nozzle

extends combustion system inspection intervals, reduces downtime as well as decreases repair costs.

The primary benefit of breach-loaded fuel nozzles is to put the injected water at the same relative position as the fuel entry to the combustion system. This in turn allows for proper mixing and, based on this, reduced hot gas path wear and increased inspection intervals.

Water injection has a detrimental effect on the lives of the combustion system components. The combustion inspection intervals are shorter with water injection and are unit and fuel specific. In order to reduce thermal cracking of the fuel nozzles and liner cap/cowl assembly, a special breach loaded fuel nozzle was designed. (Reference FR1T.) In this design, the water is injected through an annulus in the center of the nozzle directly into the flame zone. This prevents water from impinging on the fuel nozzle or liner cap/cowl assembly. This typically eliminates the cracking of these components observed in the older designs and has allowed increased combustion inspection intervals. The breach-loaded nozzle also allows easy maintenance of the oil side of the nozzle. On units with oil operation, the application of the breach-loaded fuel nozzle requires increasing the pressure ratio of the boost atomizing-air compressor (by increasing speed) and/or controls changes for proper ignition.

#### **Add Water Injection for Liquid Fuel Units (FG1C)**

This uprate includes the components needed to add water injection to MS9001B units operating on liquid fuel only. The modification kit includes replacement fuel nozzles containing water injection passages and connections, a water injection skid instrumentation, manifold, on-base piping, fuel flow measurement system, and control changes to operate the NO<sub>x</sub> system. The water injection system provides water to the combustion system of the gas turbine to limit the amount of NO<sub>x</sub> in the turbine exhaust. In addition to this benefit, an increase in power is experienced.

The benefits of this uprate are:

- Reduced NO<sub>x</sub> emissions level to meet locally required levels
- Significant increase in power and heat rate

The water injection system consists of on-base components, controls, and an off-base water forwarding skid. This skid is an enclosed package, which receives water from a treatment facility and delivers

filtered water at the proper pressure and variable flow rates for operation of the gas turbine. (The water must be extremely clean.) The filtered water is introduced to the turbine combustion system through manifolding on the gas turbine, feeding the water injection nozzles. The water is injected as a water mist through water spray orifices that are installed in each of the turbine fuel nozzle assemblies. The water is injected into the combustion zones of each combustion chamber.

Typical NO<sub>x</sub> with water injection is about 42 ppmvd at 15% O<sub>2</sub> with natural gas fuel, or 65 ppmvd with liquid fuel. Output power increases and heat rate decreases.

### Add Steam Injection for Power Augmentation (FJ3A/B) (A=manual, B=automatic)

Steam injection for power augmentation in MS9001E units includes a signal that activates or shuts off the steam injection system due to gas turbine and/or load limitations. The maximum steam injection for power augmentation typically is 5% of compressor airflow for E-Class gas turbines. The power augmentation steam is injected into the compressor discharge airflow. As an additional benefit, a portion of the steam reacts in the combustion zone of the combustor thereby reducing NO<sub>x</sub> levels. The modification kit includes on-base steam injection manifold and piping, off-base steam injection equipment containing the control valve, stop valve, drain valves, steam flow measurement equipment, and control panel changes. Note that steam injection for power augmentation is not yet available for DLN combustion systems. The quantified benefits are:

- Model 9E change in output: +13%, change in heat rate: -5%

**Note:** *Estimated simple cycle turbine performance improvement at ISO conditions and 5.0% increase in mass flow.*

Superheated steam is injected into the compressor discharge stream upstream of combustion chambers increasing the mass flow through the turbine section, resulting in increased output power. The added mass flow is obtained without an appreciable change in compressor power. Since turbine output decreases with increasing ambient temperature, output can be maintained constant at higher temperatures, or be elevated above the non-steam injection cycle unit performance if power augmentation is desired. In addition, a beneficial reduction in heat rate is experienced.

### Add Steam Injection for NO<sub>x</sub> Control in Gas or Dual Fuel Units (FG1B/D) [B=manual, D=automatic]

Provided a New Products Development program is completed and approved, uprate FJ3A/B might be offered after an in-depth initial study is concluded. Contact Applications Engineering for further information.

When utilizing for NO<sub>x</sub> control in MS9001 B and E units, steam is injected through a set of injectors located in the end cover. The steam injection provides NO<sub>x</sub> emission control by modulating the steam injection rate proportional to fuel consumption. The steam injection system consists of steam flow control and regulating valves and control plus monitoring devices located off base in the operator's steam piping. The steam from this off-base source is supplied in a controlled flow to the turbine's steam injection manifold. The steam is then injected directly into the combustion can through the combustion cover, serving to lower combustion temperatures and thereby reducing NO<sub>x</sub> production.

The benefits of this uprate are:

- Model 9B NO<sub>x</sub> (gas): typically 42 ppmvd; NO<sub>x</sub> (distillate oil): typically 65 ppmvd
- Model 9E NO<sub>x</sub> (gas): typically 42 ppmvd; NO<sub>x</sub> (distillate oil): typically 65 ppmvd

**Note:** *Standard combustor with nozzle turbulated design combustion system.*

For 9B and 9E units, standard combustion NO<sub>x</sub> is reduced to 42 ppmvd for natural gas and 65 ppmvd for oil. The modification kit includes combustion can covers, on-base steam injection manifold and piping, off-base steam injection components containing the control and stop valves, steam flow measurement equipment, gas fuel flow meter, inlet humidity sensor, and control modifications. This modification is not applicable for liquid fuel units without atomized air. (Reference FA6B.)

The addition of steam injection for the NO<sub>x</sub> control system should be accompanied by increased protective functions. To allow for these additional control functions, a Mark V or later generation of GE control system is required. The standard control system changes provide for improved data logging functions that meet most regulatory agency requirements. The data to be logged is outlined above.



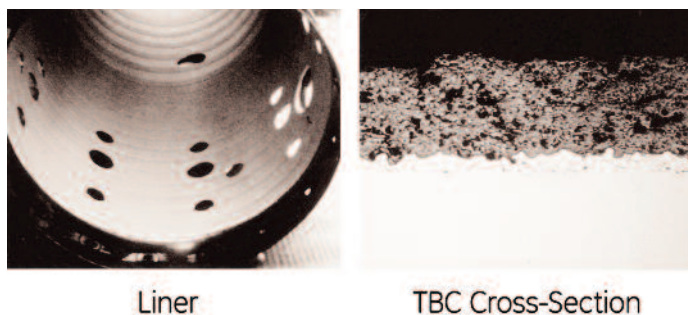
### TBC Coated Combustion Liner Uprate (FR1G)

This uprate applies a thermal barrier coating (TBC) to combustion liners for the MS9001E. (See *Figure 15*.) TBC-coated liners are equipped with an insulating layer that reduces the underlying base metal temperature, allows higher firing temperatures, reduces thermal stress, and reduces liner cracking.

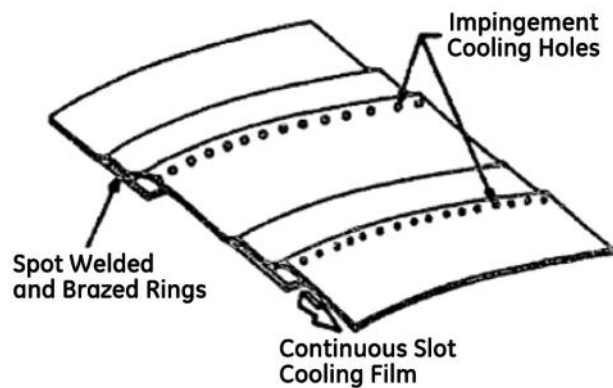
The louvered liner was replaced with a slot-cooled liner during the introduction of the first MS9001E. The slot-cooled liner provides a more uniform distribution of cooling air for better overall cooling. Air enters the cooling holes, impinges on the brazed ring and discharges from the internal slot as a continuous film of cooling air. A cutaway view of a slot-cooler liner section is illustrated in *Figure 16*. The slot construction provides a much more uniform circumferential distribution of cooling airflow. Air enters the cooling holes, impinges on the brazed ring and discharges from the internal slot as a continuous cooling film.

The liner body is Hastelloy-X™, a nickel base alloy that has not changed since the introduction of the MS9001B in 1975. Today, however, a TBC is applied to the liners. The TBC consists of two materials applied to the hot side of a component: a bond coat applied to the surface of the part and an insulating oxide applied over the bond coat. (See *Figure 15*.) This TBC provides about a 0.015-inch insulating layer that reduces the temperature of the underlying base material by approximately 100°F. The addition of TBC also mitigates the effects of uneven temperature distribution across the metal.

With the MS9001E firing temperature increase to 2055°F, the thickness of the liner was also increased by approximately 10 mils to accommodate the higher temperatures.



**Figure 15.** Thermal barrier coating.



**Figure 16.** Slot-cooled combustion liner; cutaway view.

### Upated Nimonic 263™ Transition Piece with Improved Aft Bracket (FR1D)

For MS9001B units, this modification allows for an increase in firing temperature when purchased as part of a combustion uprate. It also contributes to increased reliability and lengthening of maintenance intervals.

The original 9B combustion system was a parallel system with the combustion liner parallel to the centerline of the rotor. When the first 9E was developed, the combustion system was re-designed. The re-designed system was a canted system consisting of a shorter transition piece and the slot-cooled liner. Shortening the length of the transition section of the transition piece increased its stiffness. The canted design reduced the angle through which the combustion gases had to flow, thus providing a more direct flow path. The canted design made it possible to shorten the overall length of the transition piece.

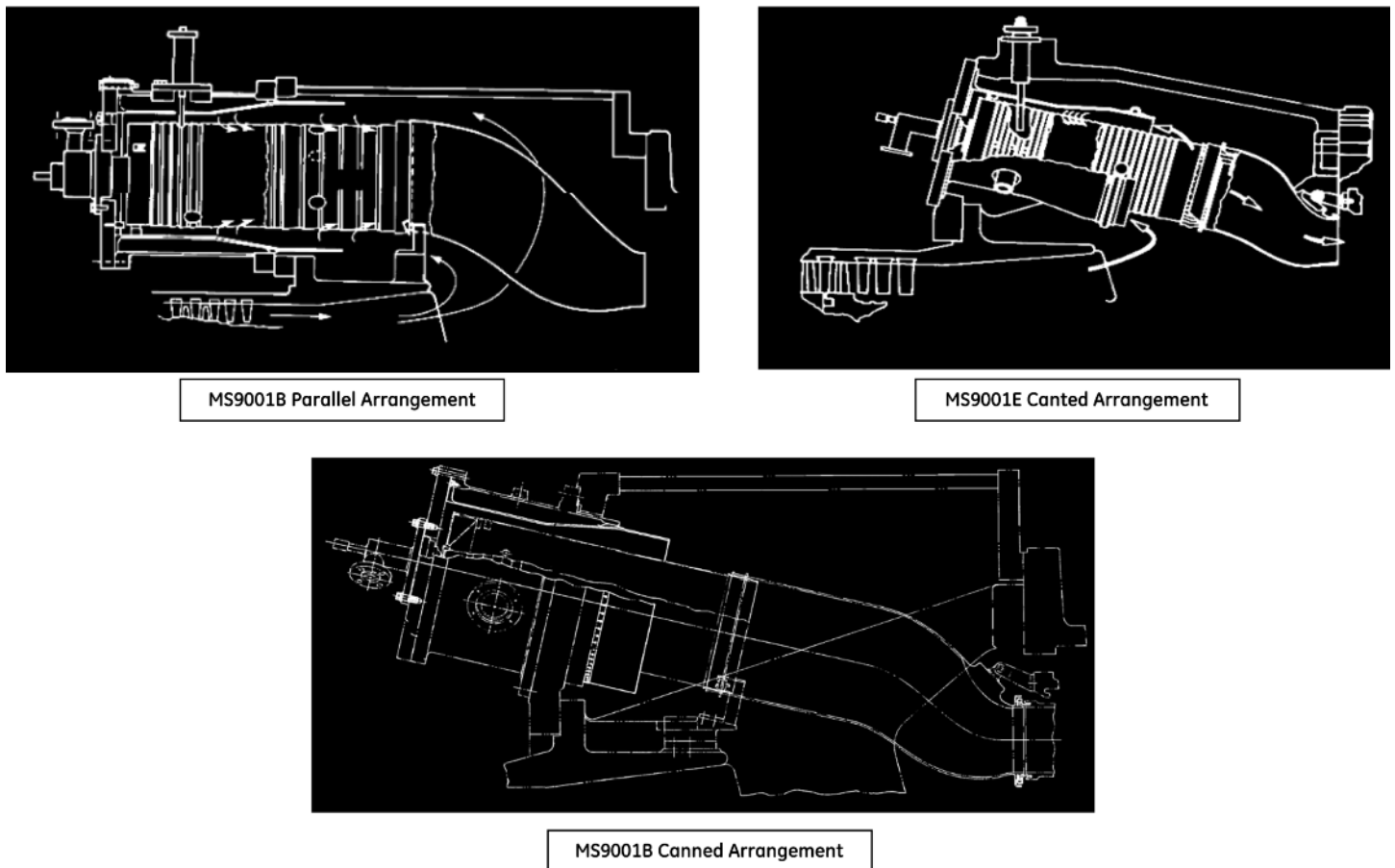
When the firing temperature was increased to 2055°F, the canted arrangement was upgraded to the canned arrangement. The canned arrangement consists of a longer transition piece with a thicker slot-cooled liner, as previously mentioned. The longer transition piece essentially pushes the liner out of the wrapper. Outer combustion casings are illustrated in *Figure 17*. The transition piece was lengthened by adding a 15-inch long cylinder to the forward end. While the transition piece length was increased, the curved section remained the same, thereby retaining its stiffness. The transition piece was lengthened to relocate the transition piece to liner interface, to provide a mount that would minimize wear induced by the compressor discharge flow. *Figure 17* illustrates the differences between the current 9E production canned arrangement, the canted arrangement, and the 9B parallel combustor designs.

Early 9B units utilized a thin-walled transition piece constructed of Hastelloy-X™ material. The original 9E transition piece was a thick-walled Hastelloy-X™. In the mid 1980s, the transition piece material was changed to Nimonic 263™, which is a nickel base superalloy with better creep and strength characteristics than Hastelloy-X™, increasing the creep life to 12,000-hours. The Nimonic 263™ transition pieces are coated with TBC material, thereby reducing metal temperatures and increasing component life. It has a positive curvature body and the aft bracket allows the transition piece to pivot about a pin during thermal excursion cycles. A comparison of the original and the re-designed aft bracket design is shown in *Figure 18*.

The uprate potential of MS9001B machines is affected by the inability of the transition piece to withstand higher firing temperature. The improved Nimonic 263™ transition piece enables MS9001B units to

be uprated beyond their current rated firing temperature. Additionally, this improved transition piece is required for these units to realize the full benefits of the Extendor\* combustion system.

The new cylinder mount bracket has dual bolting to provide torsional restraint to the body, which reduces wear. A comparison of the older and the re-designed bracket is illustrated in *Figure 19* and *Figure 20*. The aft bracket is now a forged cylindrical mount welded to the body, which eliminates cracking the body-to-mount weld region. Cooling air is admitted to the cylinder mount via cooling holes and an impingement plate to film cool the mount area. This film cooling, in conjunction with the thermal barrier coating illustrated in *Figure 20*, significantly reduces the transition piece metal temperatures. The Nimonic 263™ transition piece maintains the benefits of inner and outer floating seal arrangements used with the stage 1 nozzle interface.



**Figure 17.** MS9001E combustion system comparison.

### Extensor Combustion System Uprate (FR1V & FR1W)

The applicable frame to retrofit Extensor onto existing components (FR1V), and purchase new Extensor components (FR1W), is the MS9001E. Refer to *Figure 21* for illustration of the areas of the combustion system that receive Extensor treatments.

For new 9E units built since the year 2000, Extensor is an option re-named as CL-Extensor. CL-Extensor is a unification of two products offered by GE in the past – Extensor and CLE. GE has taken the best parts of each product to produce CL-Extensor. It is available for units with standard diffusion combustion systems and DLN combustion systems. For units operating in the field, GE offers either Extensor or CL-Extensor based on the customer's request. Please contact Applications Engineering for more information.

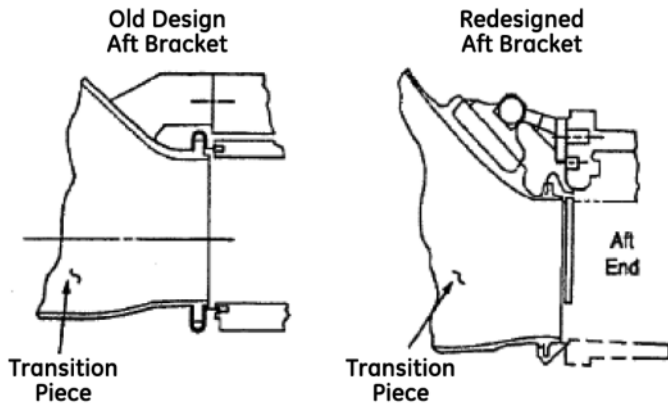
The Extensor combustion system was developed to reduce the effects of wear at the following interfaces:

- Liner and flow sleeve stops
- Fuel nozzle tip to combustion liner fuel nozzle collar
- Crossfire tube to combustion liner tube collar
- Combustion liner hula seal to transition piece forward sleeve
- Transition piece forward supports and bracket
- Transition piece aft picture frame seal

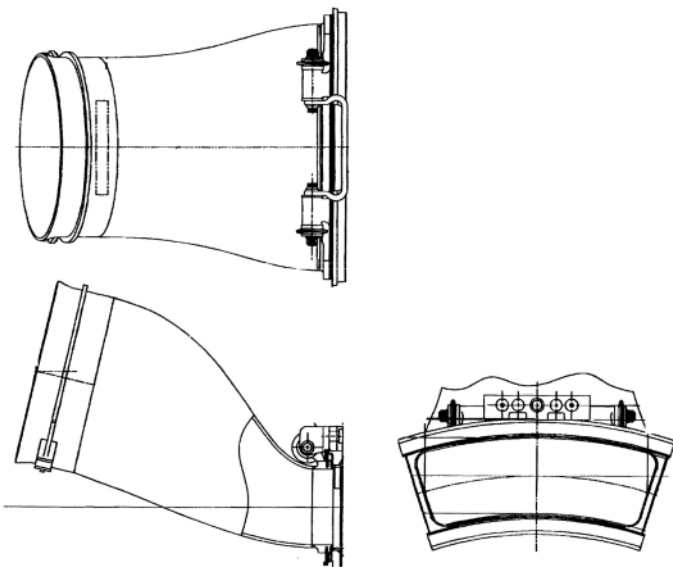
GE heavy-duty gas turbines require periodic combustion inspections due to wear, creep, and TBC coating erosion. GE has developed the Extensor product to increase combustion inspection intervals. The Extensor combustion system shown in *Figures 21 and 23* decreases combustion component wear, and increases combustion intervals by reducing the relative movement and associated wear of parts in the combustion system. Application of the Extensor wear system to 9E units extends combustion strength and inspection intervals by up to 24,000 hours. *Figure 22 and Figure 23* detail the improved combustion wear inspection intervals.

The benefits of this uprate are:

- Extended combustion inspection intervals (by reducing wear on combustion system components)
- Eliminating labor costs associated with combustion inspections
- Reduced component repair costs and increased unit availability



**Figure 18.** Comparison of old and new transition piece aft brackets.



**Figure 19.** Nimonic 263™ transition piece for Frame 9E.



**Figure 20.** Nimonic 263™ transition piece for Frame 9B showing downstream aft end coated inside only with TBC.

## Extensor Sub-Systems for MS9171 Model

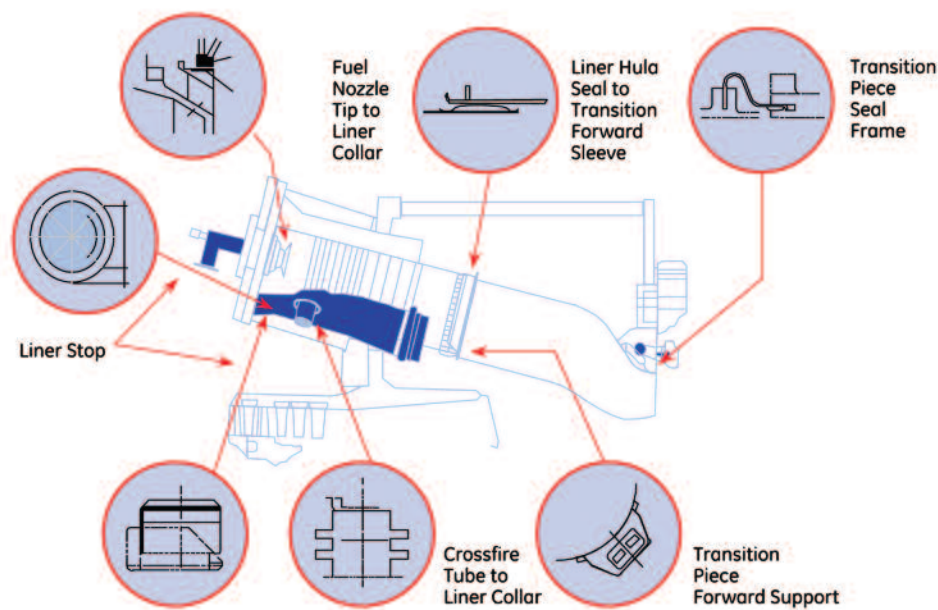


Figure 21. Areas of combustion system that are Extensorized.

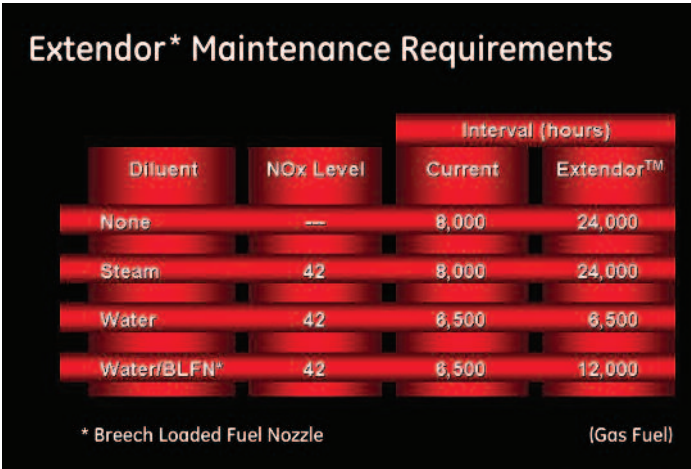


Figure 22. Extensor technology lengthens maintenance intervals.

The Extensor system is a combination of wear-resistant coatings, wear-resistant materials, enhanced clearances, and several mechanical design improvements that reduce combustion component wear by:

- Reducing the relative movement between combustion components
- Reducing forces and vibrations at wear interfaces

- Providing for critical clearance control at wear interfaces
- Using proven wear-resistant material couples developed by GE

The actual extension of combustion inspection intervals that Extensor provides depends on the type of combustion system installed and unit operation. Continuous duty units operating dry or with steam injection can double or triple combustion inspection intervals from 8,000 hours or 12,000 hours up to as many as 24,000 hours. Continuous duty units with breech-loaded style water injection fuel nozzles operating with water injection can extend combustion intervals from 6,500 or 8,000 hours to 12,000 hours. *Figure 22 and Figure 24* provide overviews of possible maintenance intervals when Extensor is applied.

**MS9001E Standard Extensor.** The system design is similar to the MS9001E standard Extensor. There are two minor differences in 9E transition pieces: (a) the MS9001E does not utilize “rat ears” on the end frame to position the floating seals; and (b) for PG9161 and earlier units, the transition piece forward support uses a “lug” arrangement rather than the “bullhorn” arrangement used on current production 9E units.

**MS9001E DLN Extensor.** The MS9001E DLN Extensor System has accumulated over 300,000 hours with great success, reliability,

and life extension. This system is now available commercially for extended life of combustion components.

**MS9001E Transition Piece Extendor.** This Extendor package is a subset of the MS9001E standard Extendor combustion system described above. Application of this Extendor system allows users to conduct “mini-combustion inspections” by removing the liners and leaving the transition pieces in the unit. (Refer to the combustion

inspection Intervals section later in this document.) This results in shorter outages and lower repair costs by eliminating the need to remove and repair transition pieces.

Since 9E dry low NO<sub>x</sub> (DLN) systems use the same transition piece as standard systems, this MS9001E transition piece Extendor can be applied on DLN system transition pieces.

MS9001E Extendor Component Modifications	Standard Comb	DLN	Trans Piece
<b>Combustion Liners</b>			
Three (3) “Lug” Type Liner Stops	X	X	
Increased Clearance – Fuel Nozzle/Liner Collar	X		
Hardened Fuel Nozzle Collar & Anti-Rotation Stop		X	
Wear Coating on Hula Seal	X	X	X
<b>Flow Sleeves</b>			
Boss for Wire-Type Crossfire Tube Retainer	X	X	
Three (3) Flow-Sleeve Stops	X	X	
Crossfire Tubes & Retainers			
Two-piece Crossfire Tubes & Wire-Type Retainers	X	X	
<b>Fuel Nozzles</b>			
Reduced Gas Tip Diameter	X		
Wear Coating on Gas Tip		X	
Transition Piece Forward Supports (“Bullhorns”)			
Sacrificial Wear Covers	X	X	X
<b>Transition Pieces</b>			
Wear Coating on Forward Sleeve (Interior)	X	X	X
Hardened Guide Blocks (“H-Blocks”) (9171)	X	X	X
Sacrificial Cover on TP Forward Support Lug (9161)			
Sacrificial Wear Strips in End-Frame Slots	X	X	X
New Side and Inner & Outer Floating Seals	X	X	X

**Figure 23.** Modifications for 9E Extendor.

Combustion Inspection Intervals Fired Hours Limit — Gas Fuel	Dry	Steam (42 NO <sub>x</sub> ppm)	Water <sup>1</sup> (42 NO <sub>x</sub> ppm)
9001E Standard without Extendor System (see GER3620K)	8,000	8,000	6,500
9001E Standard with Extendor System	12,000	12,000	12,000
9001E DLN System without Extendor System (see GER3620K)	12,000	–	–
9001E DLN with Extendor System	16,000 <sup>2</sup>	–	–
9001E Transition Piece with Extendor System	24,000 <sup>2</sup>	24,000 <sup>2</sup>	12,000 <sup>2</sup>

#### Notes

1. Assumes breech loaded fuel nozzle (BLFN). Many water-injected machines with standard fuel nozzles have experienced cracking of the combustion liner cap due to thermal fatigue because of water splashing on the cap. The BLFN eliminates this problem and is required for the full benefits of Extendor to be realized.
2. Mini-combustion inspections are recommended at the original inspection intervals. Remove and repair (as required) combustion liners, crossfire tubes, fuel nozzles, etc. Transition pieces may be left in the unit but should be inspected visually and/or with borescope. It is recommended that one or more transition pieces be removed for detailed inspection (until experience indicates that this is not necessary).

**Figure 24.** Increased inspection intervals for 9E Extendor.



**Note:** The MS9001E transition piece Extendor package cannot provide the same extension of combustion inspection intervals that the full Extendor package can. Although transition pieces may be left in the machines, borescope and/or visual inspection of the transition pieces and removal of some of the transition pieces for a more detailed inspection are recommended.

**MS9001E Extendor Combustion System Modifications.** Figure 23 provides a summary of the combustion component modifications included in the MS9001E Extendor combustion systems described. Figure 24 shows the increased inspection intervals after installing an Extendor DLN combustion system.

#### Notes:

1. Assumes breech-loaded fuel nozzle (BLFN). Many water-injected machines with standard fuel nozzles have experienced cracking of the combustion liner cap due to thermal fatigue because of water splashing on the cap. The BLFN eliminates this problem and is required for the full benefits of Extendor to be realized.
2. Mini-combustion inspections are recommended at the original inspection intervals. Remove and repair (as required) combustion liners, crossfire tubes, fuel nozzles, etc. Transition pieces may be left in the unit but should be inspected visually and/or with borescope. It is recommended that one or more transition pieces be removed for detailed inspection (until experience indicates that this is not necessary).

### Dry Low NO<sub>x</sub> Combustion System Upgrade (FG2B)

Customers operating MS9001E units that burn gas fuel without diluent supplies for injection purposes can achieve NO<sub>x</sub> emission requirements using dry low NO<sub>x</sub> combustors. The DLN combustion system for the MS9001E is illustrated in Figure 25. DLN combustion reduces NO<sub>x</sub> emissions without steam or water injection on gas fuel units. This is done by fuel staging, with lean fuel-to-air ratios dependant upon premixing fuel with hot compressor discharge air to yield lower temperature rises across the combustor. NO<sub>x</sub> control for gas fuel is via the dry low NO<sub>x</sub> system, while NO<sub>x</sub> control for distillate fuel oil is by lean combustion augmented with a water injection system.

The benefits of DLN are provided in Figure 3.

DLN combustors without diluent offer emission levels of about 15 ppmvd at 15% O<sub>2</sub> on natural gas fuel without impacting parts lives

caused by water or steam injection. For DLN dual fuel units, emission levels of about 42 ppmvd at 15% O<sub>2</sub> on liquid fuel with water injection are achieved.

The DLN combustor has six individual fuel nozzles in the primary combustion zone, and a single fuel nozzle in the secondary combustion zone. (See Figure 26 and Figure 27.) The DLN combustion system offers lower NO<sub>x</sub> emissions levels on gas fuel fired units without parts life reduction associated with water or steam injection NO<sub>x</sub> reduction systems. Emission levels of 15 ppmvd at 15% O<sub>2</sub> or less can be reached by using the DLN system on a 9E unit. The DLN-1 combustion system lowers the NO<sub>x</sub> emission levels on gas fuel fired units without the significant parts life reductions associated with steam or water injection.

The dry low NO<sub>x</sub> two-staged premixed combustor is designed for operation on natural gas and distillate liquid. The combustor operates by premixing the gas fuel with the air in the first stage,

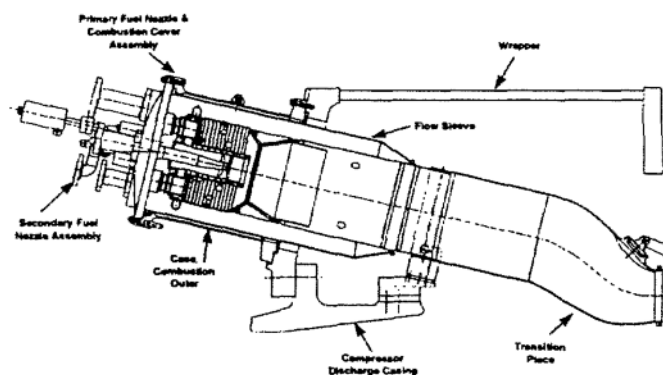


Figure 25. MS9001 E-Class dry low NO<sub>x</sub> combustion system.

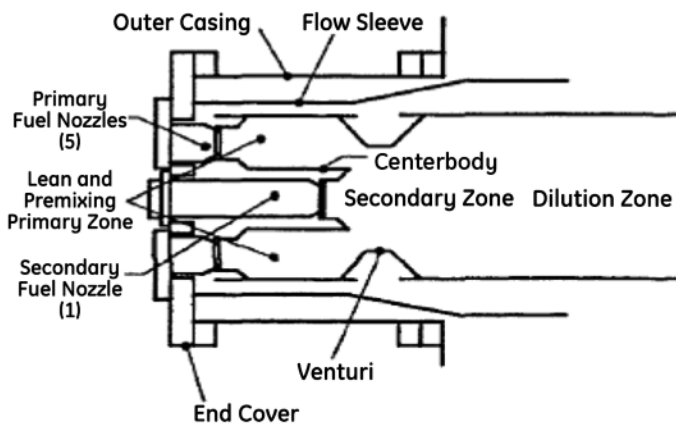


Figure 26. Dry Low NO<sub>x</sub> combustor.

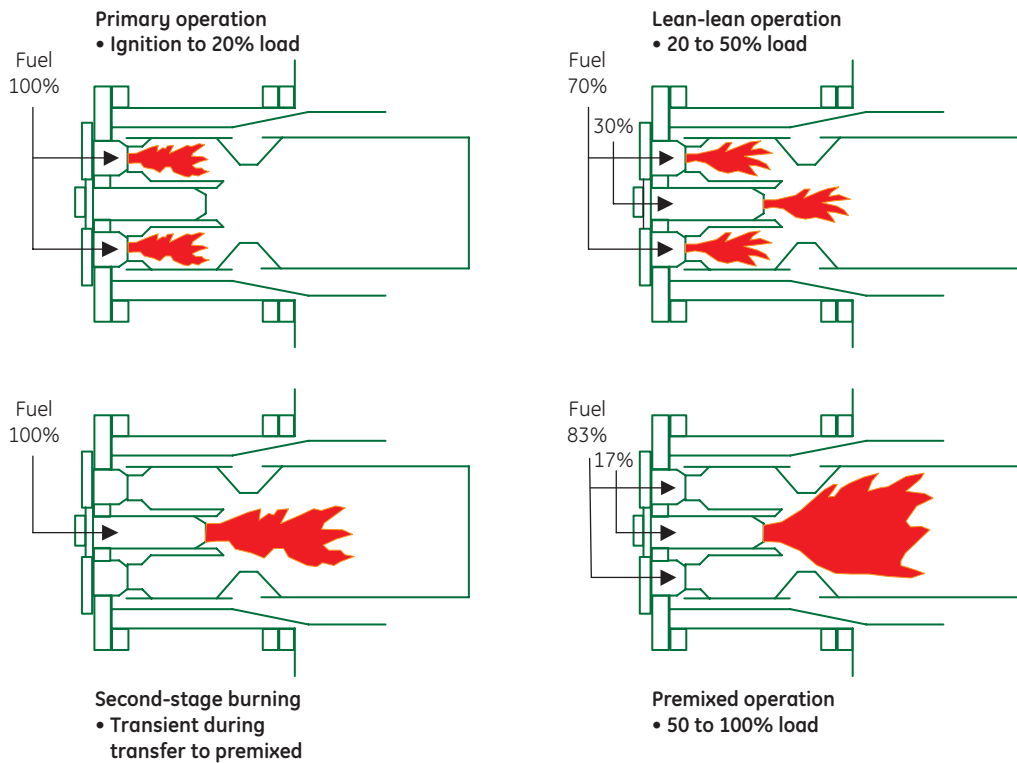


Figure 27. DLN operating modes.

and then combusting the mixture in the second stage. The fuel/air mixture flame has more mass than a standard diffusion fuel flame, and so burns colder with less  $\text{NO}_x$  produced. The DLN combustor also operates on #2 distillate liquid fuel, but not with premixing the fuel with air. While operating on liquid fuel, water injection is used for  $\text{NO}_x$  control. DLN operates at a constant flame temperature, and so has limited turndown in the premix operation mode. A product called “inlet bleed heat” mixes compressor discharge air with inlet air to extend turndown with DLN premix combustion.

A typical DLN combustor for the MS9001E is illustrated in Figure 28 and fuel delivery in Figure 29.

### Convert to Gas Fuel Only (FA1A)

For MS9001E units that are equipped with dual fuel DLN-1, the conversion to a gas only fuel system from a dual fuel liquid/gas system is designed to take advantage of the availability of gas fuel and to simplify the operation and maintenance of the gas turbine. This upgrade addresses the conversion of MS9001E DLN-1 units to gas-only from a gas and distillate dual fuel configuration.

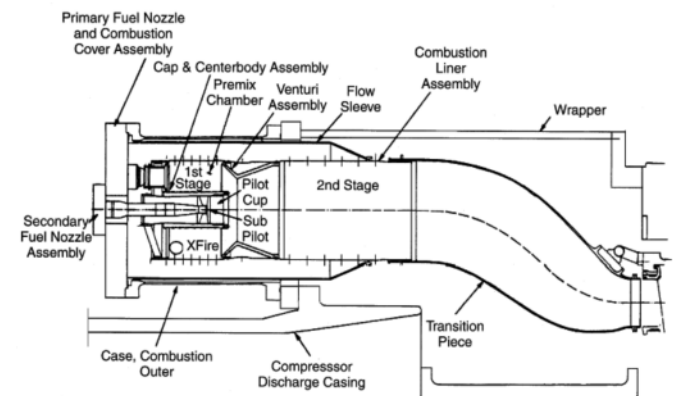


Figure 28. MS9001EA Dry Low  $\text{NO}_x$  combustion system.

## Dry Low $\text{NO}_x$ Gas Fuel System

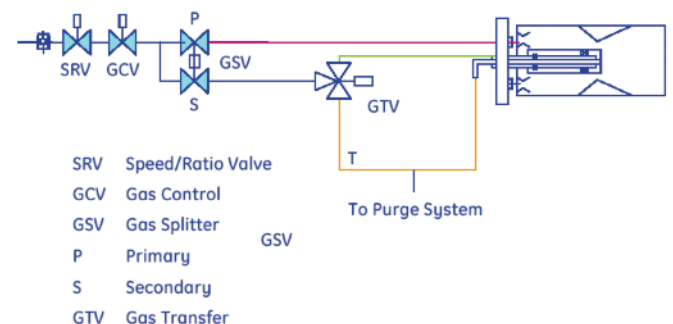


Figure 29. DLN fuel system.

The benefits of this conversion are:

- Ease of maintenance; and some units may utilize an available, possibly less costly fuel
- More easily handled fuel with simplified emission controls

This modification is for units that are equipped with a dual fuel, liquid and gas, DLN-1 system that are to be operated in the future on gas only. The conversion calls for a replacement of the primary and secondary fuel nozzle assemblies, elimination of the liquid fuel and atomizing air system, and a controls modification to disable liquid fuel operation. The primary benefits from converting to a gas only system is that it eases maintenance (removes atomizing air compressor), and could utilize available less costly fuel. Gas fuel is a more easily handled fuel and has simplified emission controls.

The conversion that is outlined here calls for:

- Modification (not replacement) of the primary and secondary fuel nozzle assemblies
- Elimination of all distillate fuel and water injection devices, manifolding and plumbing
- Removal of the atomizing air compressor
- Modification of the controls to disable the liquid fuel function

The advantages of this conversion are:

- Modification of the fuel nozzle assemblies is far less costly than full replacement
- Simplified operation and maintenance inherent in a gas-fuel-only configuration are achieved

### Convert from Liquid to Dual Fuel (FA3D)

Many existing gas turbines in the MS9001B & E family only have liquid fuel capabilities since (in the past) liquid fuel was felt to be a more viable fuel than gas fuel. However, gas fuel has become more available with liquid being primarily used as a backup.

The benefits of this conversion are:

- Significant operational flexibility
- Potential fuel cost savings from some units with the added fuel gas capability

There is no performance difference expected by adding gas fuel; however, natural gas emissions are lower than liquid fuel emissions.

Depending on site-specific conditions, NO<sub>x</sub> levels of 42 ppm can be achieved while operating on gas fuel and using water or steam for diluent injection.

## Hot Gas Path Improvements

### Upgraded Stage 1 Bucket (FT6J)

The MS9001B and E stage 1 bucket was re-designed with two changes: turbulated cooling and a blunt leading edge (BLE) design airfoil. The new design is directly interchangeable in complete sets with all existing buckets including the sharp leading edge (SLE) design found on 9B units. The modification kit includes the BLE buckets and associated installation hardware.

The benefits of this upgrade are:

- Increased bucket cooling, allowing more cooling air to reach the leading edge
  - Significantly reduces thermal gradients and cracks along the leading edge
- Improved materials extend the life of the buckets
- 9B units will experience a slight output increase; however, output is not affected in 9E units

The advantages of the latest stage 1 bucket come from both the re-design and the use of different materials. The turbulated cooled stage 1 buckets have air-cooling holes that are ribbed to create turbulent cooling, thereby increasing heat transfer capabilities. In addition, compared to 9B units, the first stage bucket has been improved with the blunt leading edge airfoil. The blunt leading edge improves low cycle fatigue (LCF) resistance, and the airfoil re-design increases the efficiency and performance of the airfoil.

The improvement of materials includes the use of the equiaxed GTD-111\* material for the stage 1 bucket. GTD-111 provides improved rupture strength and is more resistant to low cycle fatigue. (See *Figure 30*.)

These buckets are coated with GT-33 IN Plus\* coating, which is an advanced MCrAlY vacuum-plasma spray coating applied to the bucket exterior, and a diffused aluminide coating applied to the internal cooling passages. This coating provides hot corrosion protection and high temperature oxidation resistance. *Figure 31* shows a comparison of the older PtAl and GT-29\* coatings with the current GT-33 IN Plus coating. For further information on



## Turbine Section- Stage 1 GTD-111 Buckets

### Features

- GTD-111 Equiaxed Material for Improved Rupture Strength & to Minimize High Cycle Fatigue
- GT-29 INPLUS / GT-33 Incoat Coating
- Turbulated Cooling Circuit for Improved Cooling

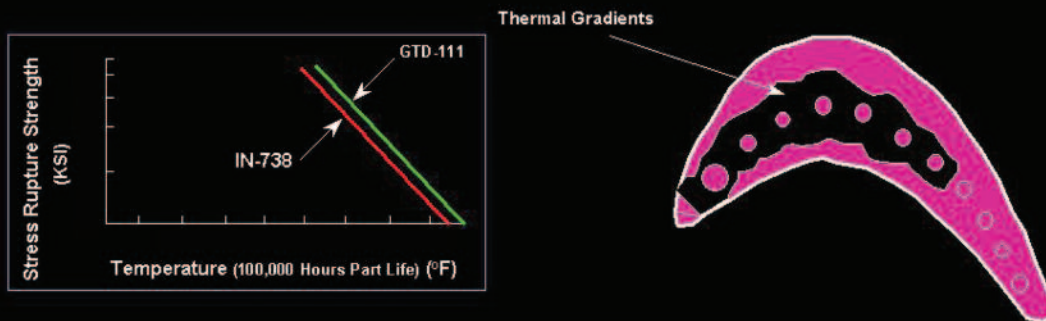


Figure 30. New stage 1 buckets have material and design improvements.

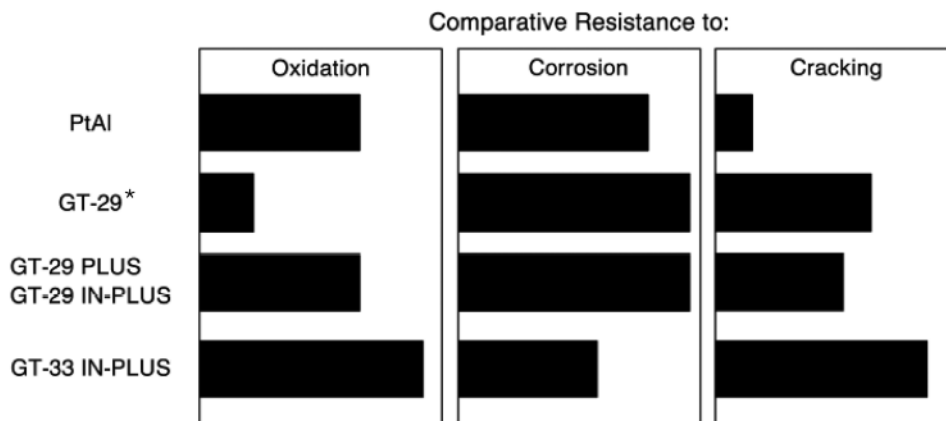


Figure 31. Types of bucket coatings.

bucket materials and coatings, see GER-3569, "Advanced Gas Turbine Materials and Coatings".

The BLE stage 1 bucket design allows more cooling air to reach the leading edge of the bucket. This increased cooling significantly reduces thermal gradients and associated cracks along the leading edge. The improved materials extend the life of the buckets. There

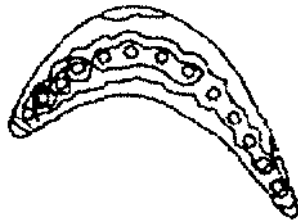
is a slight output performance increase in 9B units; however, output is not affected in 9E units.

There have been four major improvements now available to GE customers interested in stage 1 buckets:

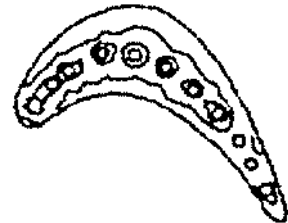
**Design Improvements.** The original design sharp leading edge has been blunted to allow more cooling air to flow over the leading

edge, which reduces thermal gradients and therefore reduces cracking. The blunt leading edge (BLE) design was initially used as the first MS9001E stage 1 bucket. (See Figure 32.)

Original Design and Thermal Gradients



Blunt Nose Bucket with Improved Thermal Gradients



**Figure 32.** Sharp and blunt leading edge bucket designs.

**Materials Improvements.** The original MS9001 E-Class stage 1 bucket was IN-738™, a precipitation-hardened, nickel base superalloy. In 1987, the material was changed to an equiaxed (E/A) material developed by GE as GTD-111, also a precipitation-hardened, nickel base superalloy that has a 35°F higher creep rupture strength and a greater low cycle fatigue strength than IN-738™. GTD-111 also has improved corrosion resistance compared to other superalloys.

**Coating Improvements.** The original MS9001 E-Class stage 1 bucket coating, platinum-aluminide (PtAl), was applied to stage 1 buckets to prevent oxidation and corrosion. In 1991, with the addition of turbulated cooling holes, the bucket coating was changed to GT-29 IN Plus\*. The GT-29\* coating is vacuum plasma spray applied, and then an aluminide coating is applied on the bucket exterior and on the internal cooling hole passages. In 1997, the coating was changed to GT-33 IN\*. GT-33 is a vacuum plasma applied coating that offers an increased resistance to cracking. “IN” again refers to an aluminide coating on the cooling hole passages (no exterior aluminide coating). GT-33 IN is GE’s new standard coating for stage 1 buckets, however GT-29 IN Plus is still available and sometimes recommended when combusting very highly corrosive fuels.

**Cooling Improvements.** The latest MS9001 E-Class stage 1 bucket is referred to as “turbulated” cooled. This design change was brought about by the latest firing temperature increase to 2055°F. This increase in firing temperature required an increase in cooling for the stage 1 bucket to maintain an acceptable temperature level. By creating air-holes that are “ribbed,” the cooling airflow becomes turbulent, resulting in improved cooling effectiveness without the need for additional cooling air.

#### Upated TBC Coated Stage 1 Buckets (FS4G)

For MS9001E units, thermal barrier coating can be applied to new and in-service stage 1 turbine buckets to extend bucket life and increase maintenance intervals.

The benefits of this uprate are:

- Potential of increased bucket life from from 72,000 hours to 96,000 hours for any particular operator, according to design predictions and field experience

- There is no emissions impact from this upgrade

Dense vertically cracked (DVC) TBC patented by GE provides a superior coating application due to the following:

- GE’s bonding coat, GT-33, which is superior to thinner, smoother, and less adhesive third-party coatings
- GE’s DVC TBC is more than twice the thickness of third-party TBC, and resists spallation to provide a more robust thermal gradient barrier
- Extensive GE lab data, GE Global Research studies, and design engineering modeling have been used to insure the optimum application, thickness, composition, and product performance of DVC TBC applied by GE

Coating first stage buckets with TBC increases hot gas path parts life and maintenance intervals at a very small debit to performance. Based on fleet leader data and extensive testing, it has been determined that 32,000 hour inspection intervals may be obtained. However, gains in inspection intervals are impacted by other factors such as firing temperature, base load vs. peaker duty, fuel and fuel quality, ambient temperatures, and number of hard starts and this will need to be considered on a unit-by-unit basis. (See GER-3620, “Heavy Duty Gas Turbine Operating and Maintenance Considerations.”)

### Upated GTD-111 Stage 2 Bucket (FS2F)

The latest stage 2 bucket for MS9001B and E units is the same design as the stage 2 E-Type Bucket (FS1L) but is made out of GTD-111 material with GT-33 coating instead of uncoated IN-738™. GTD-111 material possesses a 35°F improvement in rupture strength in the equiaxed form compared to IN-738™. It has a corrosion resistance comparable to IN-738™, the acknowledged corrosion standard for the energy industry, and is superior to IN-738™ in low cycle fatigue strength.

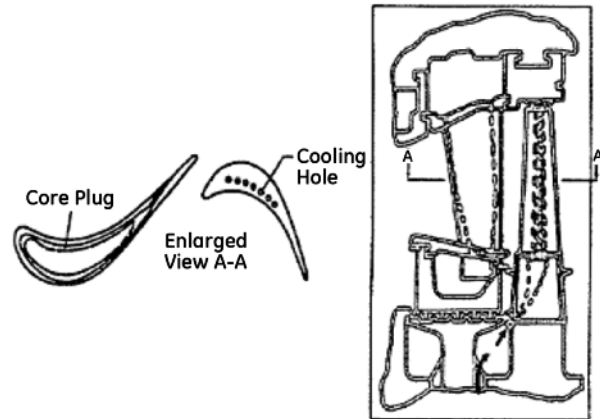
The benefits of this uprate are:

- Higher firing temperatures can be achieved with the air-cooling
- Improved elevated temperature strength and hot corrosion resistance with new GTD-111 bucket material
- Creep life increased by 80% over the original design due to reduced stress with new tip shroud design

Since these buckets are air-cooled, 9B units require replacing the spacers between the first and second stage wheel to allow air to flow to the second stage bucket. 9E units have air-cooled buckets and therefore have the proper spacers. The spacers have to be ordered well enough in advance to get proper hole size. A GE Service Shop is required to unstack and restack the rotor as well as rebalance it.

The new stage 2 bucket design also includes cutter teeth on the bucket tip shroud rails. These are designed to cut a slot in the honeycomb seal material on the stage 2 shroud block with no metal transfer to the bucket. This allows new shroud blocks with honeycomb seals to be installed. (Reference FS2T.) Cutter teeth have been included on all stage 2 MS9001B and E buckets produced since 1996.

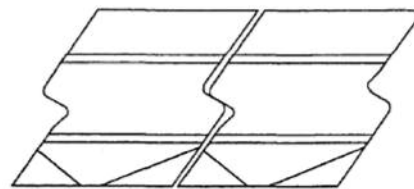
**Cooling Improvements.** The original MS9001B stage 2 bucket did not have internal air-cooling. The MS9001E design contains air-cooled stage 2 buckets, as illustrated in *Figure 33*. The addition of air-cooling allows for higher firing temperatures. To replace non air-cooled stage 2 buckets with the new air-cooled buckets, the 1-to-2 wheel spacer must be replaced with the new design that allows air to flow to the stage 2 bucket. The new stage 2 bucket can be supplied without internal cooling air passages as a direct part replacement for the MS9001B. With this option, the 1-to-2 wheel spacer would not have to be replaced. While lower in cost,



**Figure 33.** MS9001E stage 2 air-cooled bucket.

the non air-cooled version of this bucket would not be able to withstand an increase in firing temperature above 1905°F.

**Tip Shroud Improvements.** The shroud tip was scalloped and thickened between the seal teeth, and the underside of the shroud was tapered. (See *Figure 34 and 35*.) Scalloping the leading edge decreased the tip shroud stress. The final design resulted in a 25% reduction in stress levels and an 80% increase in creep life over the original design. The latest design change added cutter teeth to the bucket tip rails. These cutter teeth were designed for use with the new honeycomb stage 2 shrouds. During transients when the bucket tip clearance is the smallest, the cutter teeth cut a path through the honeycomb material in the shroud, thus minimizing the steady state clearance. Stage 2 buckets with cutter teeth are required for use with honeycomb shrouds, but can also be used with the traditional design shrouds.



**Figure 34.** Scalloping of bucket shroud.



**Figure 35.** Final configuration of bucket shroud.

**Materials Improvements.** For early MS9001E production, the material was changed to IN 738™ (a precipitation-hardened, nickel-based superalloy), which provided an increase in elevated temperature strength and hot corrosion resistance. In 1992, the material was changed to GTD-111, also a precipitation-hardened, nickel based superalloy, to improve creep rupture strength. In addition to higher creep rupture strength, GTD-111 has higher strength in low cycle fatigue. Originally, 9B turbines had stage 2 buckets made of U-500™, a precipitation-hardened, nickel based alloy. IN-738™ is a better choice as it is specifically designed for land-based gas turbines. Combining elevated temperature strength and hot corrosion resistance, IN-738™ has lasted longer and, in tests comparing it to U-500™, is in better condition even after four times testing duration. (See *Figure 36*.)

	Previous Stage 2 Bucket	Improved Stage 2 Bucket
<b>Material</b>	U500™	IN-738™
<b>Shrouded Design</b>	Not Scalloped	Scalloped
<b>Cutter Teeth*</b>	Not Present	Present
<b>Firing Temp</b>	Up to 1840°F	Up to 1840°F

\*Refer to GER3571 for information about cutter teeth applications.

#### Benefits

- Elevated temperature strength and hot corrosion resistance compared to U500™ bucket material
- Improved tip shroud design increases creep life by 80% over original design
- Designed life expectancy of three hot gas path inspections (72,000 hours for gas only, dry, base loaded operation)
- Permits operation at higher firing temperatures – up to 1840°F

**Figure 36.** Improved stage 2 bucket.

**Coating Improvements.** With the change in material to GTD-111, GT-29 IN Plus coating was added. IN Plus coating refers to an aluminide coating on the internal cooling passages (IN) and an over-aluminide coating on the exterior of the bucket (Plus). Like the stage 1 bucket, the standard coating was changed to GT-33 IN during early 1997. GT-33 IN consists of GT-33, a vacuum plasma spray coating, on the exterior of the bucket and an aluminide coating on the interior of the cooling hole passages. GT-33 IN provides superior crack resistance relative to GT-29 IN Plus. GT-29 IN Plus is still available and is recommended for use in very highly corrosive fuel applications.

#### Non Air-Cooled GTD-111 Stage 2 Bucket Uprate (FS2I)

This modification replaces the existing non air-cooled stage 2 buckets on MS9001B units with GTD-111 material, non air-cooled stage 2 buckets (S2B). This non air-cooled S2B cannot withstand an increase of firing temperature above 1905°F. Above this firing temperature, an air-cooled S2B is required. Performance is not affected, as cooling holes are plugged before the buckets are installed.

The benefits of this uprate are:

- A non air-cooled stage 2 bucket with overall increased strength
- Performance will not be affected, as cooling holes will be plugged

The latest stage 2 bucket is made out of GTD-111 material (equiaxed) with GT-33 IN coating instead of uncoated IN-738™ material. (See *Figure 37*.) GTD-111 material possesses about a 35°F improvement in rupture strength in the equiaxed form, compared to IN-738™. (See *Figure 37*.) It has a corrosion resistance comparable to IN-738™, the acknowledged corrosion standard for the industry, and is superior to IN-738™ in low cycle fatigue strength.

For 9B applications where no S2B cooling is needed, the air-cooled E-type GTD-111 material stage 2 buckets are sent to a GE service shop to have the six holes plugged on the bucket tip shroud, making them directly interchangeable with existing buckets on 9B units, and a new wheel spacer is not needed.

#### Uprated Stage 3 Bucket IN-738™ (FS2K)

The MS9001 E-Class stage 3 bucket has undergone improvements in design, manufacturing, materials, and processes. These advanced buckets can be installed on MS9001B and E units. *Figure 38* outlines the improvements.

The benefits of this uprate are:

- Improved third stage buckets parts lives for higher-firing uprated temperatures
- Efficiency will improve slightly on 91E units

**Design Improvements.** With the introduction of the 9E, the airfoil was redesigned to take advantage of the additional airflow. The airfoil was again re-designed in 1991 as part of the uprate program. The trailing edge was thickened, and the chord length increased. Like the stage 2 buckets previously described, the shroud leading edge was scalloped, the shroud tip was thickened between the seal teeth, and the underside for the shroud was tapered. These design

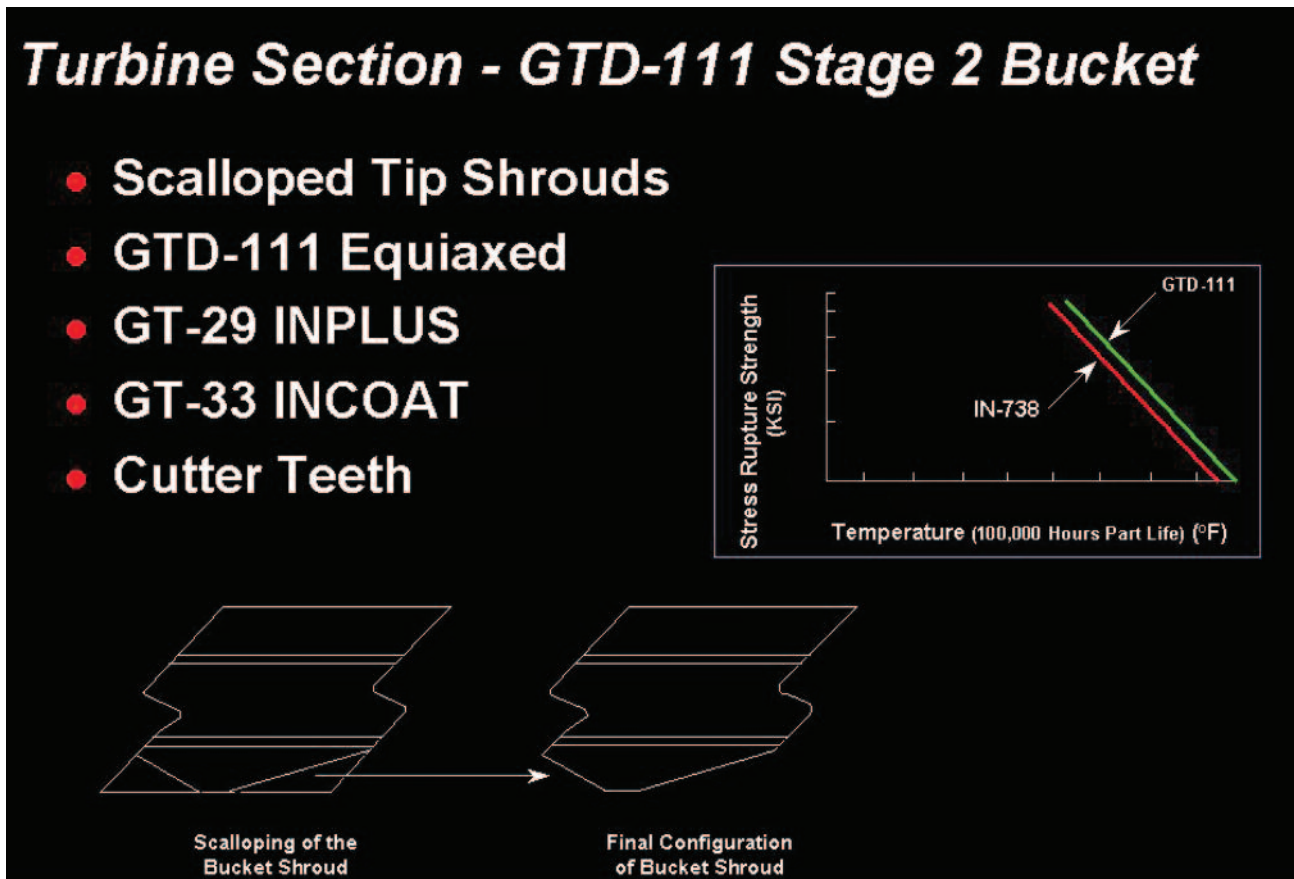
changes resulted in an increase in creep life of the bucket. Like the stage two buckets, cutter teeth were added to the bucket tip rails. These cutter teeth are required to use with the stage 3 honeycomb shrouds. Current production stage 3 buckets include cutter teeth. To use the 9E bucket on a 9B machine, the stage 3 shrouds must be replaced or modified. *Figure 39* illustrates the machining points on the shroud that are required for the modification. Additionally, due to interference with the angel wing, owners/operators may elect to machine the exhaust frame to facilitate rotor removal, however it is not required.

**Process Improvements.** The original MS9001B stage 1, 2, and 3 buckets were cold-straightened after being cast, thereby inducing plastic strain in the material. The combination of the induced and creep strains resulted in potential creep-rupture cracks initiating and propagating by high cycle fatigue. GE developed a new manufacturing process for the MS9001E bucket, which eliminated the need for the cold straightening step; thus, eliminating the process-induced strain and potential creep rupture cracking.

**Materials Improvements.** The bucket material has been improved. The stage 3 bucket was originally made of U-500™, a precipitation-hardened nickel based alloy. To improve elevated temperature strength and hot corrosion resistance, the bucket material was changed in 1992 to IN-738™, a precipitation-hardened nickel based superalloy having improved creep properties.

#### Upated Stage 1 Nozzle With Chordal Hinge (FS2J)

The MS9001B and E stage 1 nozzle has evolved through four generations, each improving on its predecessor, starting with the MS9001B 4-vane per segment nozzle. The second generation, designed for the MS9001E, was used primarily for cleaner fuel applications. The third generation—the universal nozzle—was significant because it is applicable for gas, distillate, and ash bearing fuels. The fourth generation, known as the chordal hinge nozzle, incorporated GE aircraft engine technology as well as improved cooling and sealing technology. A comparison of each generation is shown in *Figure 40*.



**Figure 37.** Non air-cooled GTD-111 buckets have better creep properties.



# Turbine Section-Stage 3 Rotated Buckets

## IN-738 Stage 3 Bucket

### Features

- New Bucket Material
- Rotated Bucket Profile
- New Shroud Tip Design
- Cutter Teeth

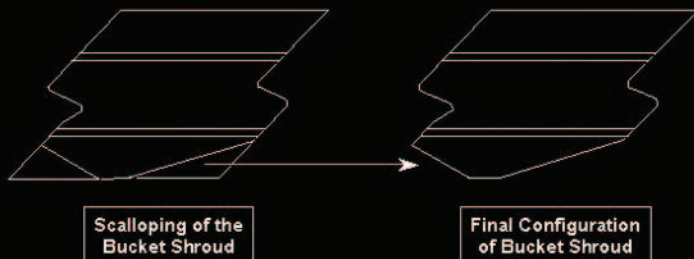
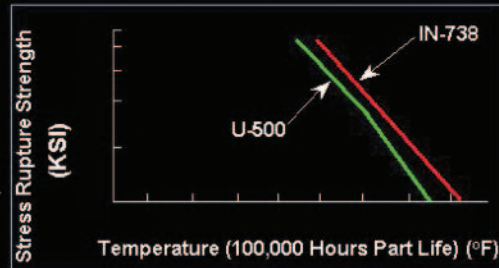
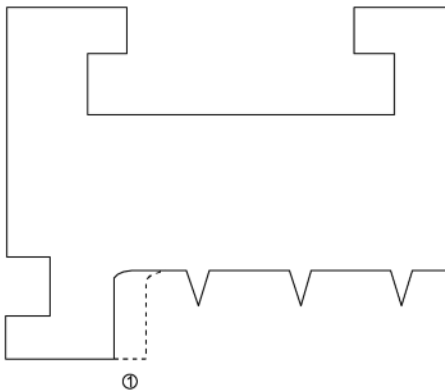


Figure 38. Improved stage 3 buckets.



① Modify Existing Third Stage Shrouds as Shown Above.

Figure 39. Machining required on stage 3 shroud.

The benefits of the new stage 1 nozzle include a long operating life up to 72,000 hours, reduced heat rate of operating units, and operation at higher firing temperatures to 2084°F.

The benefits of this uprate are:

- Model 9B change in output: 0.0%, change in heat rate: -1.90%
- Model 9E change in output: 0.0%, change in heat rate: -0.25%

**Note:** For 9E firing at 2055°F, no benefit at 2020°F.

Several design modifications were made to the original MS9001B stage 1 nozzle to develop the MS9001E cleaner fuel stage 1 nozzle. One of the most dramatic changes was made in response to the vane fillet cracking problem—caused by high thermal stress induced by the high thermal gradient across the sidewall/vane interface. (See Figure 41.) By decreasing the number of vanes per segment, structural redundancy and thermal stresses were reduced, thus minimizing the vane fillet cracking. The original 9B stage 1 nozzle had four vanes per segment and required 12 segments. The cleaner fuel nozzle has only two vanes per segment, for a total of 18 segments. As illustrated in Figure 40, the interface between the support ring and nozzle was moved downstream.

At the same time that the number of vanes per segment was reduced, the shape of the airfoil was optimized and the vanes were rotated to

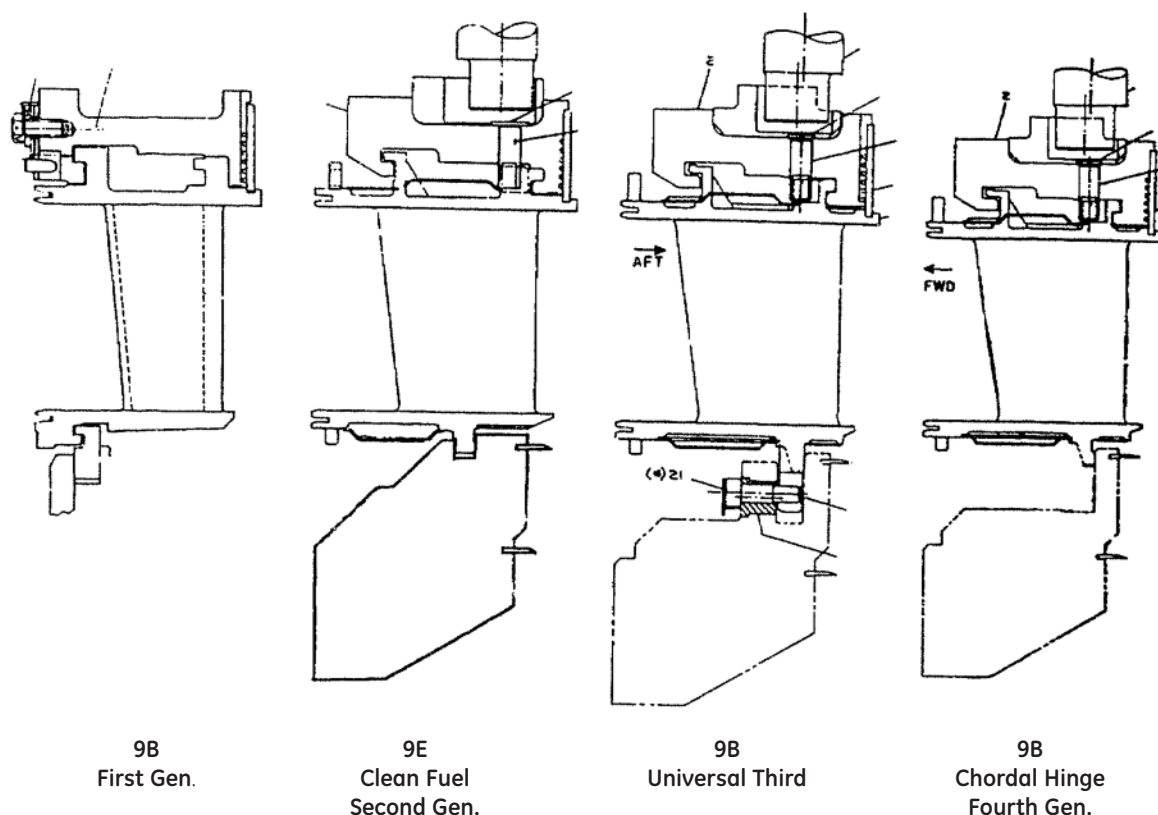


Figure 40. Comparison of 9B and 9E stage 1 nozzles.

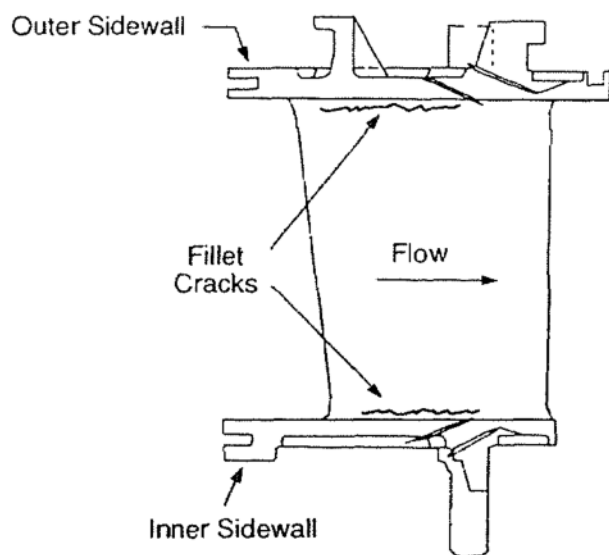


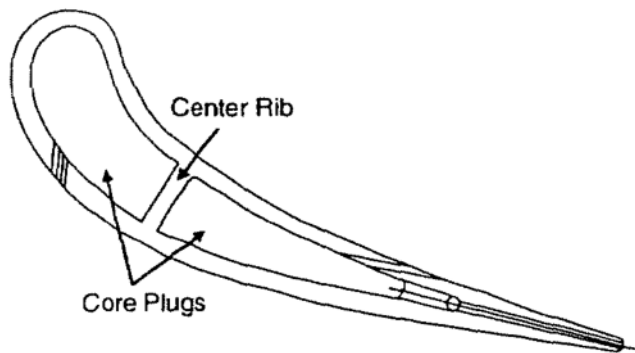
Figure 41. Cracked stage 1 nozzle.

reduce the throat area. The new airfoil shape and reduction in throat area increased the pressure ratio. Installing this design into an MS9001B can increase the pressure ratio by as much as 6%.

The suction sidewall thickness of the nozzle airfoil at the pitch section was increased by 13%, which effectively reduced the aerodynamically-induced stress and thereby increased the creep life of the part. The stress level was further reduced by the addition of an internal center rib seen in Figure 42.

The universal fuel nozzle was developed from the cleaner fuel nozzle in response to the need to burn residual fuels, as well as cleaner fuels. The airfoil shape was rounded (making it more blunt) and the entire cooling system was re-designed. The pressure side cooling holes were replaced with slots and placed closer together to provide more uniform cooling. (See Figure 43.) Trailing edge cooling was also added as illustrated in Figure 43. This improved cooling design decreased surface metal temperature by as much as 5%, thus reducing cracking, airfoil ballooning, and trailing edge bowing.

In the Generation 2 (GEN 2) arrangement the nozzle support ring interface was moved further downstream, in line axially with the



**Figure 42.** Stage 1 nozzle airfoil pressure-side-film cooling modification.

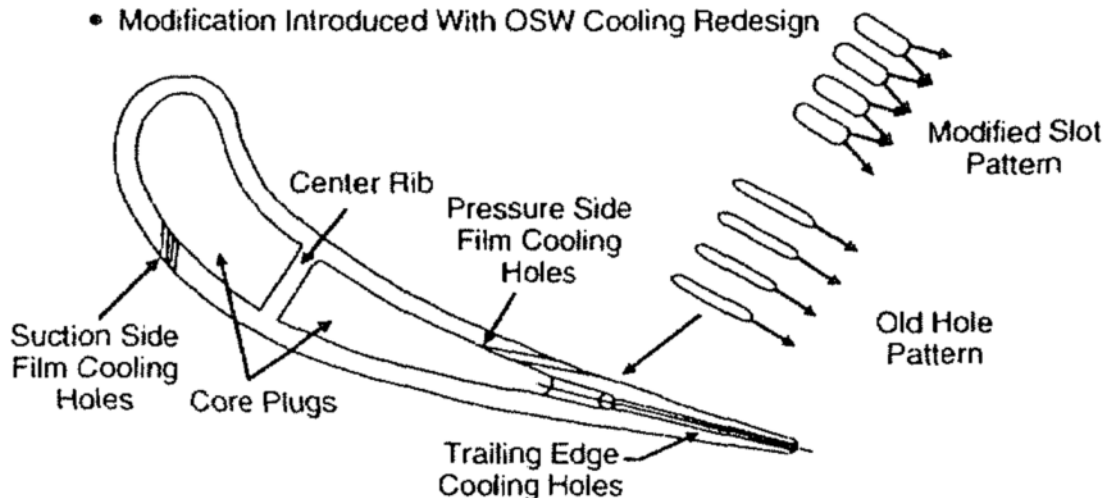
nozzle retaining-ring interface. This change was implemented to minimize torsional forces exerted on the sidewall near the nozzle retaining-ring interface.

In 1992, the GEN 3 nozzle added a tangential support lug consisting of an integrally cast and milled radial slot side-support lug onto the stage 1 nozzle inner sidewall. A support pin and bushing were also added to secure the nozzle segment. A lock plate and a single retainer bolt were used to keep the support pin in place. This arrangement was intended to provide additional tangential support for the nozzle.

The fourth and current generation of stage 1 nozzle is the chordal hinge nozzle introduced in 1994. This nozzle is the result of two major design changes maintaining the philosophy of burning both cleaner and heavy fuels. The first design change was made to reduce the leakage between nozzle segments and between the nozzle and support ring. The chordal hinge, which incorporates the latest in GE Aircraft Engine sealing technology, was added. The chordal hinge refers to a straight-line seal on the aft face of the inner sidewall rail, which ensures that the seal is maintained even if the nozzle rocks slightly. The chordal hinge and the new sidewall seal design are illustrated in *Figure 44*. The chordal hinge reduces leakage between the nozzle and the support ring. The leakage between the nozzle segments was decreased by improving the sidewall spline seals.

The second major change was to improve the sidewall cooling. As the firing temperatures increased over the development of the MS9001E, the nozzle metal temperatures increased, causing oxidation and erosion to occur on the sidewalls. To reduce oxidation and erosion, the cooling effectiveness was increased. The overall cooling effectiveness was improved by relocating some of the sidewall cooling holes and re-shaping some of the vane cooling holes into slots, as illustrated in *Figure 45*.

- **Pressure Side Film Holes Replaced With Slots to Provide Better Coverage**
  - Closer Spacing
  - Better Exit Condition
- **Modification Introduced With OSW Cooling Redesign**

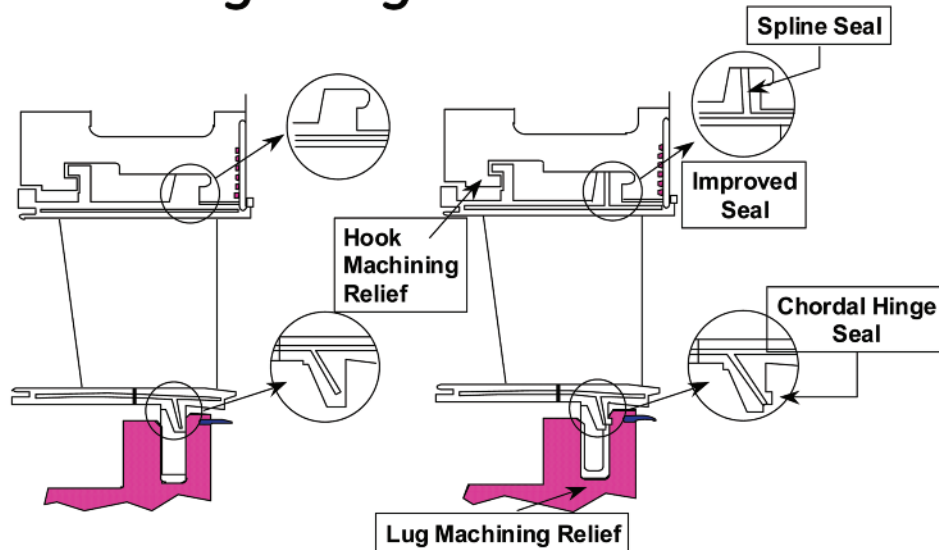


**Figure 43.** Stage 1 nozzle airfoil pressure-side film cooling.



## Turbine Section

### Chordal Hinge Stage 1 Nozzle



## Improved Sidewall Cooling Reduces Erosion and Oxidation

Figure 44. Stage 1 nozzle improved sidewall sealing with chordal hinge.

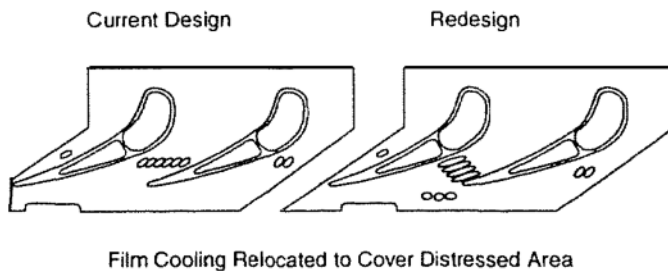


Figure 45. Stage 1 nozzle improved cooling outer sidewall film cooling.

When the chordal hinge nozzle was first introduced, the tangential pin hardware was replaced with a single piece bushing/tangential pin to secure the nozzle. A flat lock plate with two retainer bolts was used to keep the bushing /tangential pin in place. (See Figure 46.) More recently, the tangential pin hardware has been eliminated because field inspections have indicated that the hardware does not provide additional tangential support. In addition to eliminating the

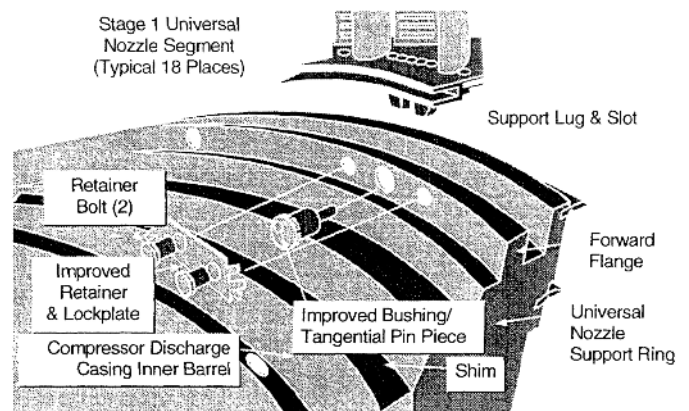


Figure 46. First stage nozzle improved inner sidewall tangential support.

hardware, the forward flange on the support ring has been eliminated. (See Figure 47.) These design modifications make the universal nozzle and the chordal hinge nozzle interchangeable with no support ring modifications required.

As illustrated in *Figure 40*, the 9B stage 1 nozzle and the 9E cleaner fuel nozzle support ring interface are located further upstream than either the universal or chordal hinge nozzle. Therefore, to install the chordal hinge nozzle in a unit that currently has the 9B nozzle or the cleaner fuel nozzle, a new support ring must also be provided to site. As previously mentioned—when installing the chordal hinge stage 1 nozzle in a machine that currently has the universal stage 1 nozzle—a new support ring is not required (assuming the installed ring is not damaged) because the location of the support ring interface is the same for both designs.

During development of the MS9001 E-Class stage 1 nozzle, the nozzle material FSX-414, was not changed. FSX-414 is a cobalt base superalloy that provides excellent oxidation, hot corrosion, thermal fatigue resistance, weldability, and castability. *Figure 48* illustrates the improvements existing on the upgraded stage 1 nozzle offered. These benefits result in -1.90% and -0.25% improvements in heat rates for 9B and 9E units, respectively.

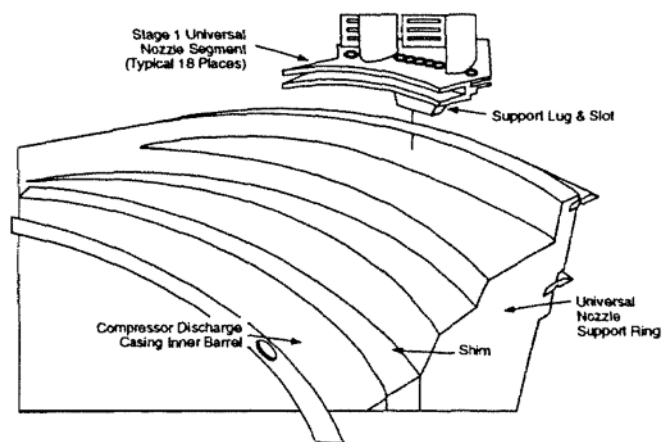
GE Energy's newly designed improved cooling stage 1 nozzle in *Figure 48* offers advanced sidewall cooling and a new sidewall sealing design that allows operation at higher firing temperatures—while maintaining component reliability and life cycle. The new design incorporates the following GE-proprietary features:

- Spline seal improvements
- FSX-414 alloy
- Enhanced thermal barrier coating (ETBC\*)

The improved cooling stage 1 nozzle is a universal nozzle that can be used to replace nozzles based on the older universal nozzle design, as well as pre-universal nozzles operating on either conventional or heavy fuel.

**Improved Sidewall Sealing and Cooling.** A GE-proprietary design on improvements to the spline seal, along with diffused cooling holes, provides improved cooling performance, allowing increased firing temperatures up to 2084°F.

**Increased High Temperature Capability.** The GE-proprietary FSX-414 cobalt-based superalloy possesses superior properties (compared to other nickel-based superalloys) at very high temperatures—allowing increased firing temperatures up to 2084°F. FSX-414 offers enhanced weldability and excellent oxidation/corrosion resistance with high strength at highest firing temperatures.



**Figure 47.** First stage nozzle and support ring with no tangential hardware.

### Improved Cooling FSX-414 Stage 1 Nozzle

- Made from FSX-414, a GE-proprietary, cobalt-based alloy
- Available uncoated, with standard or enhanced thermal barrier coating

Offers:

- advanced sidewall cooling
- a new sidewall sealing design, increased efficiency
- operation at higher firing temperatures while maintaining component reliability and life cycle

**Figure 48.** Improvements in upgraded stage 1 nozzle for 9B and 9E units.

**Coating Options.** Based on operating needs, this nozzle is available with three coating options:

- No thermal barrier coating (No TBC): Unless requested otherwise, no coating is applied to the nozzle. The nozzle should be uncoated for heavy fuel applications.
- Thermal barrier coating (TBC): This coating offers increased resistance to thermal fatigue that can result in life extension and improved maintenance intervals.
- Enhanced thermal barrier coating (ETBC): With a slick, highly erosion-resistant coating, this TBC provides a smooth surface finish to the stage 1 nozzle. With GE's proprietary smooth finish, ETBC improves the benefits of thermal barrier coatings, and can result in higher sustained performance over time. (See uprate FS6E.)

### Enhanced TBC Coating for Stage 1 Nozzle (FS6E)

For MS9001E units, the stage 1 nozzles can be coated with an enhanced thermal barrier coating (ETBC) that can be applied to the leading edge, pressure side, and outer wall of the stage 1 nozzle. (See Figure 49.) ETBC provides a smoother surface finish to the stage 1 nozzle, which incorporates a slick, highly erosion-resistant coating over the TBC. The ETBC coating on E-Class stage 1 nozzles helps protect the TBC from erosion and provides a smooth surface, which contaminants cannot adhere upon.

### Enhanced Thermal Barrier Coating

eTBC, an advanced three layer coating system consisting of:

- a bond coat
- a porous class TBC
- a top layer of smooth coat

The coating system can be applied to internal surface of the liner or pressure face of S1N.

It reduces friction and erosion which yields performance.

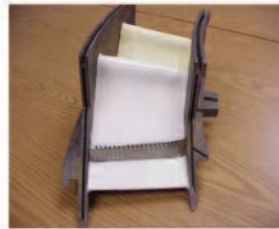
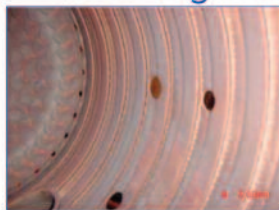


Figure 49. Stage 1 nozzle with enhanced TBC.

The benefits of this uprate are:

- Enhanced erosion resistance 3X greater than porous, standard TBC
- 5X smoother surface finish compared to standard TBC
- Reduced susceptibility to surface fouling
- Sustained smooth surface finish and unit operating performance
- Predicted heat rate improvement over TBC alone
- Reduced metal temperatures provide prolonged component life, increased durability, and increased maintenance intervals

The performance improvements are possible due to the sustained surface finish of the smooth coat over time. Improved surface finish reduces heat transfer, thus increasing part durability, improving erosion resistance (3X greater in laboratory testing), and reducing surface fouling. ETBC should not be used by customers operating with heavy fuel, or an IGCC application due to possible

build-up of combustion products on the ETBC, which could negate its benefits if such build-up might occur.

### GTD-222+\* Stage 2 Nozzle Uprate (FS1P)

To minimize the tangential deflection due to creep, a series of design changes were implemented for the stage 2 nozzle in MS9001E, as illustrated in Figure 50.

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

Reduced Cooling Flow Controlled by Tuning Pin

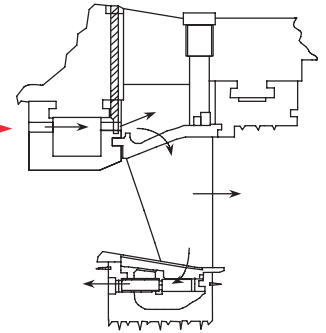


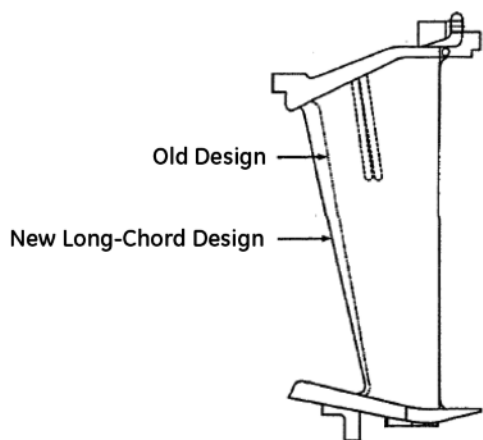
Figure 50. Design changes and reduced airflow in non-pressurized stage 2 nozzle.

The benefits of this uprate are:

- Model 9B (non air-cooled) change in output: -1.0%), change in heat rate: +0.2%
- Model 9E (air-cooled) change in output: +1.0%), change in heat rate: -0.4%

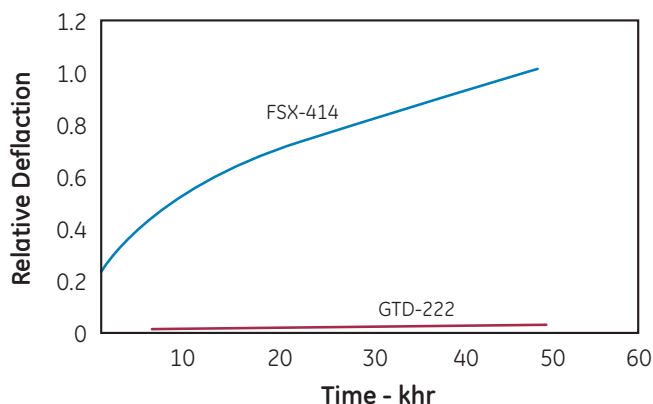
**Note:** The GTD-222+ second stage nozzle significantly reduces nozzle downstream stream creep deflection.

For the MS9001E only, the first major change was to increase the chordal length, which reduced stress levels in the vanes and improved creep resistance. Note that the MS9001E always had long chord length and short sidewall. (See Figure 51.) In late 1991, the original nozzle material FSX-414 was replaced with GTD-222+, a nickel based alloy, because of its superior creep strength and therefore reduced deflection downstream. Figure 52 shows a comparison of the nozzle creep deflection of GTD-222+ and FSX-414. GTD-222+ has a 200°F creep strength and 40% tensile strength advantage over FSX-414 at operating temperatures. An aluminide coating was then added to protect against high temperature oxidation.



**Figure 51.** Long and short chord nozzle design comparison.

### GTD-222 vs. FSX-414 Nozzle Creep Deflection Comparison



**Figure 52.** Nozzle creep deflection comparison.

With the material change to GTD-222+, less cooling flow for the nozzle could be reduced, due to the material's superior high temperature creep properties. The cooling was decreased by inserting a longer tuning pin in the stage 1 shroud and decreasing the size of the cooling hole in the aft face of the shroud. For better distribution of cooling air, the nozzle core plug was re-designed and the size of the pressure side cooling holes was decreased. GE experience with MS9001E gas turbines has found that wheel space temperatures run significantly cooler than the design limit. Based on this experience, the stage 2 nozzle cooling flow that also surges and cools the wheelspaces can be reduced, providing additional output without affecting parts life.

Reducing the nozzle cooling flow yields an increase in output power. (See *Figure 53*.) The MS9001E will see an increase in output of approximately +1.0% with either the one- or two-piece stage 1 shroud with new tuning pins in conjunction with the GTD-222+ stage 2 nozzle. (The original one-piece shroud must have the aft cooling hole size reduced to realize the full performance benefit.) Because the existing MS9001B stage 2 nozzle is not air cooled, installing this air-cooled stage 2 nozzle results in an output loss of approximately -1.0% due to the air extracted from the system for cooling airflow.

GE has developed a brush seal for the stage 2 nozzle diaphragm based on the successes of the high-pressure packing and No. 2 bearing brush seal. (Reference FS2Z.) The brush seal design uses a brush seal in place of the middle long tooth on the diaphragm. This brush seal provides a performance improvement due to the reduction in cooling flow.

The seal between the diaphragm and the 1-to-2 spacer regulates the amount of cooling airflow between the first aft and second forward wheel spaces. The current seal is a labyrinth seal with a series of short and long teeth on the diaphragm and high and low lands with teeth on the spacer. The stage 2 nozzle cooling air comes in through the stage 1 shroud and enters the stage 2 nozzle core plug via the plenum formed between the outer sidewall of the nozzle and turbine shell. The air flows through the nozzle core plug; some of the air exits the nozzle via the trailing edge cooling holes and the remainder of the cooling air flows into the cavity between the diaphragm and the nozzle. The air flows to the first aft wheel space and through the diaphragm/spacer seal (inner stage packing) to the second forward wheel space.

This GTD-222+ nozzle includes an aluminide coating for increased high temperature oxidation resistance.

The benefits of the GTD-222+ nozzle are illustrated in *Figure 54*.

### GTD-222+ Stage 3 Nozzle Uprate (FS1R)

The original stage 3 nozzle, like the stage 2 nozzle, experienced tangential deflection. To minimize creep and so decrease tangential deflection, three design changes were made. (See *Figure 55*.) First, on the MS9001B only, the chord length was increased to reduce overall airfoil stress levels. The MS9001E always had the longer length. Secondly, an internal airfoil rib, similar to the one for stage 1 nozzle, was added to provide additional stability and

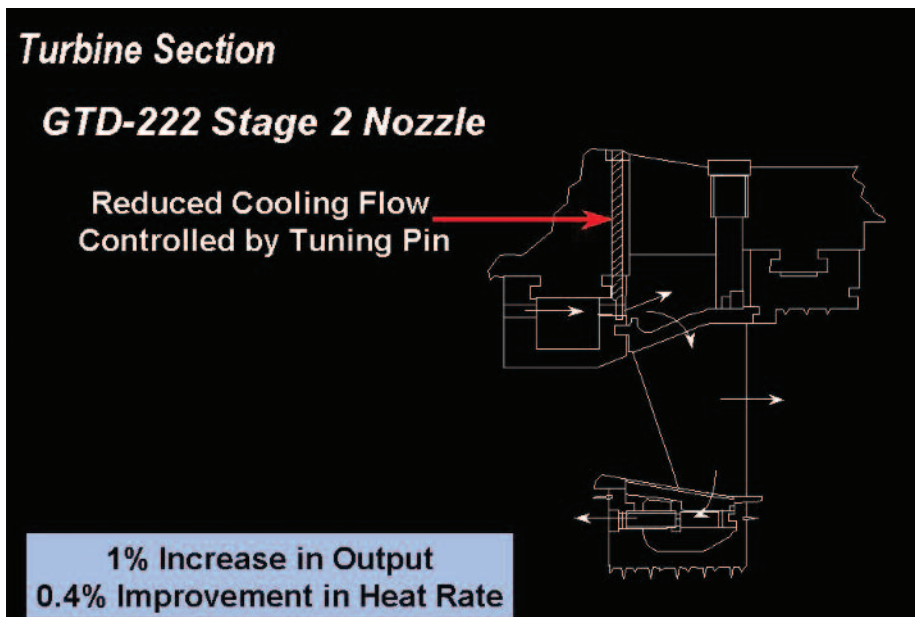


Figure 53. Reduced cooling flow gives increased output.

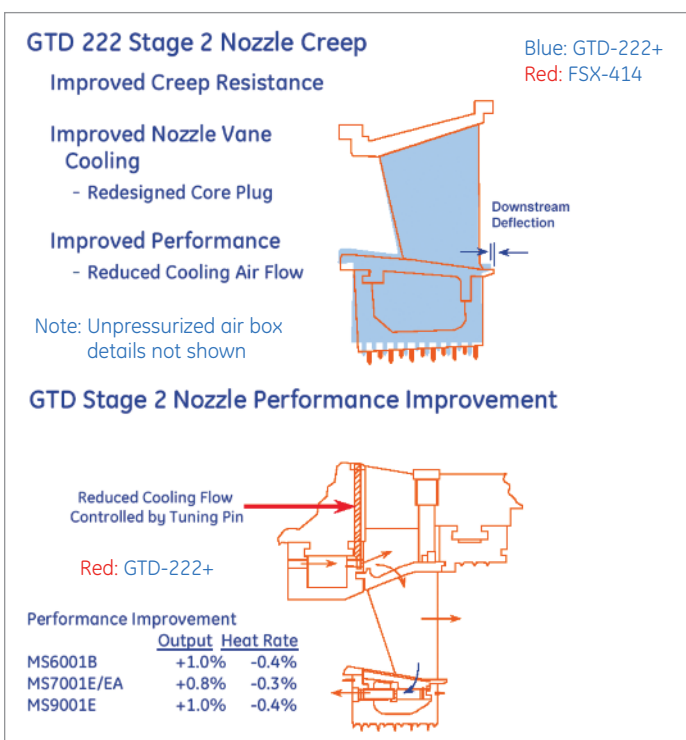


Figure 54. Benefits of GTD-222+ nozzles as compared to FSX-414 nozzles.

increase the component's buckling strength. Finally, in 1992, the material was changed from FSX-414 to GTD-222+. Unlike the stage 2 nozzle, an aluminide coating is not necessary due to lower metal temperatures seen in stage 3. Since this nozzle, which can be

installed in both MS9001B and E units, is not air-cooled there is no performance benefit like the stage 2 nozzle (and no performance detriment). Dimensionally, the GTD-222+ nozzle is interchangeable with the existing FSX-414 nozzle.

The benefits of this uprate are:

- Nozzle downstream creep deflection, a key life-limiting factor, is eliminated
- Re-design and change of material for the third stage nozzle reduces stress levels and increases creep life

GE field experience demonstrates that the GTD-222+ nozzle—after thousands of operating hours in GE's high firing turbines—has achieved a remarkable reliability record and customer satisfaction.

### Advanced Aero Stage 3 Nozzle (FS4K) and Advanced Aero Stage 3 Bucket Uprates (FS4L)

**FS4K Advanced Nozzle.** In order to improve output and decrease heat rate in MS9001B and E units, the advanced aero third stage nozzle is re-designed with improved airfoil aerodynamics. (See Figure 56.) This improved design gives additional performance benefits when used in combination with the advanced aero stage 3 bucket, FS4L, as illustrated in Figure 57. The uprate includes the third stage nozzle and diaphragm, plus required hardware.



# Turbine Section- Stage-3 GTD-222 Nozzle

## Features

Chord Length Increased  
Addition of an Internal Airfoil Rib  
GTD-222 Creep Resistant Material

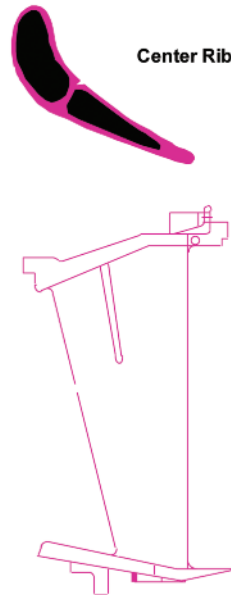
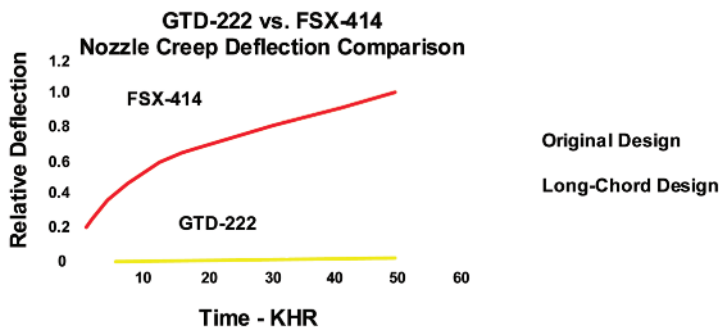
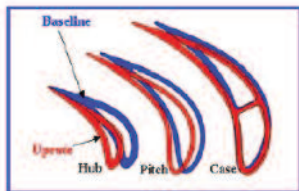


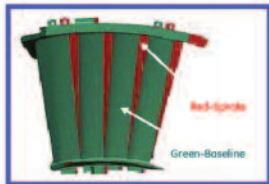
Figure 55. Improved stage 3 nozzle.

## New Stage 3 Nozzle Design Provides Significant Efficiency Improvement



**New Aerodynamic Nozzle Configuration**

- Improves Output and Heat Rate
- Significant Reduction in Hub Mach #
- Improved Angle of Attack Distribution Exiting Nozzle



**View Looking Upstream**

- New Slash Face Angles, Nozzle Seals, Core Pad Angles, and Thermocouple Tubing Accommodate New Design

Figure 56. Advanced Aero Stage 3 Nozzle.

The third stage nozzle was re-designed to improve aerodynamic performance. On the new airfoil, the inner and outer sidewalls are modified but the airfoil profile and wall thickness are the same. The flow path definition remains the same and the new nozzle design allows the use of the old machining fixtures in the hot gas path. There is no reduction in repair/replace intervals. Dimensionally, the advanced aero re-designed nozzle is interchangeable with the

## Stage 3 Bucket Changes Result From New, Higher-Efficiency, 3-D Aerodynamic Design



Figure 57. New stage 3 bucket design.

existing GTD-222+ nozzle. The latest stage 3 nozzle design is also made of GTD-222+.

On those 9B units that are not already equipped with the GTD-222+ or the advanced aero nozzle, the installation of the new design third stage nozzles provides an opportunity to install replaceable wheel space thermocouples, more information can be found in FK5C.

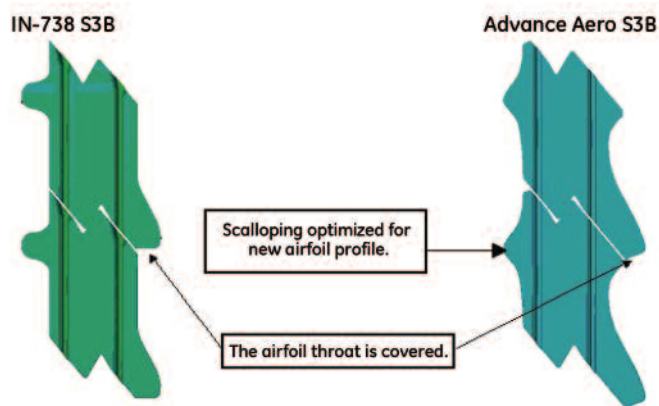
## Installation of Both Parts Provides the Greatest Benefit

### Significant Improvement in Output and Heat Rate

Part	S/C Output	S/C Heat Rate	Exhaust Energy	Exhaust Temp, delta
New S3B/New S3N, Hot Day, 100°F/38°C, Guarantee Pt	+0.7%	-0.7%	-0.8%	-6°F
New S3B/New S3N, ISO Day, 59°F/15°C, Reference Only	+1.0%	-1.0%	1.0%	-8°F
New S3B/New S3N, Cold Day, 0°F/-18°C, Reference Only	+1.2%	-1.2%	-1.1%	-9°F

Efficiency improvement results in exhaust temperature and exhaust energy decrease. Combined-cycle analysis can be provided to estimate over-all plant impact.

**Figure 58.** Performance benefit when Advanced Aero Stage 3 Bucket and Nozzle are combined on same unit.



**Figure 59.** Advanced Aero Stage 3 Bucket.

**FS4L Advanced Bucket.** This modification for MS9001B and E units replaces the existing stage 3 buckets with an advanced aerodynamic, re-designed stage 3 bucket with an improved airfoil. (See *Figure 56* and *Figure 57*.) This improved design allows for additional performance benefits when used in combination with the advanced aero stage 3 nozzle in FS4K. (See *Figure 58*.)

For 9E, the advanced aero bucket is dimensionally interchangeable with the existing bucket. The advanced aero stage 3 bucket is made of IN-738, offering excellent hot corrosion resistance and outstanding strength at highest firing temperatures.

The advanced aero stage 3 bucket new design includes “cutter teeth” on the bucket tip shroud rails. (See *Figure 59*.) The tip shrouds are re-scalloped for the new airfoil profile. The cutter teeth are designed to

cut a slot in the honeycomb seal material on the stage 3 shroud block, with no metal transfer to the bucket. This allows new shroud blocks with honeycomb seals to be installed. (Reference FS2U).

## Upated HR-120™ Improved Stage 1 Shroud with Cloth Spline Seals (FS2Y)

The new shroud design for MS9001E includes several improved sealing features that increase performance (output and efficiency) by reducing leakage between shroud segments and between the stage 1 shrouds and stage 1 nozzles. The improved stage 1 shrouds are made of a one-piece design from Haynes HR-120™ (see *Figure 60* and *Figure 61*), a solid solution-strengthened iron-nickel-chromium alloy that improves low cycle fatigue life, allows operation at higher 2055°F firing temperatures, increases performance and lowers heat rate.

The benefits of this uprate are:

- Model 9E (PG9171E) change in output: +1.3%), change in heat rate: -0.6%
- Model 9E change in output: +0.4%), change in heat rate: -0.2%

**Note:** The performance improvements listed above for PG9171E-rated 9/1E units include: a) conversion to one-piece shroud (+0.9% in output and -0.4% in heat rate); and b) upgrade to HR-120 design with cloth seals (+0.4% in output and -0.2% in heat rate). For units that currently have the older 310-SS, pumpkin tooth, one-piece stage 1 shroud, the performance improvement would only reflect the upgrade to HR-120™ one-piece design with cloth seals (+0.4% in output and -0.2% in heat rate). In the third quarter of 2003, the production 91E PG9171 new units started shipping with the one-piece HR-120™ improved stage 1 shrouds with inter-segment cloth seals.

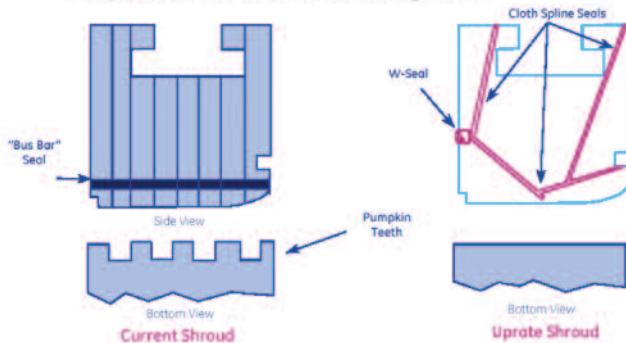
**Spline Seal Arrangement (GE Exclusive Design).** A new cloth seal arrangement, illustrated in *Figure 61* incorporates a flat side face and multiple cloth seals. This new design significantly reduces leakage between shroud segments, resulting in increased output and lowered heat rate.

**Haynes HR-120™.** This solid solution-strengthened iron-nickel-chromium alloy offers improved low cycle fatigue life and allows operation at higher firing temperatures up to 2055°F. The new stage 1 shroud material provides a 3X improvement in LCF life, in comparison to the current 310 stainless steel, and permits the use of a one-piece shroud at higher temperatures. The new material has both a higher inherent material strength, and more favorable time-at-temperature characteristics compared to 310 stainless steel.

## "Pumpkin-Tooth" Design vs. New Shroud

### First Stage Shroud Cloth Seals

- New Material and Improved Sealing
- Improved Performance (Pending Audit)



## Bar Type Spline vs. Cloth Seal Design

### New Intersegment Seal Design

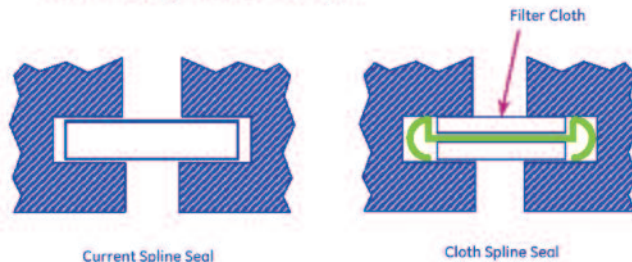


Figure 60. First stage shroud with cloth seals FS2Y.

### GE Proprietary Spline Seal Arrangement

A new GE proprietary design provides a spline seal arrangement incorporating a flat side face and multiple GE proprietary cloth seals. This new design significantly reduces leakage between shroud segments, resulting in improved output and increased efficiency.

### Haynes HR-120®

This solid solution, strengthened, iron-nickel-chromium alloy offers improved low cycle fatigue life and allows operation at higher firing temperatures, up to 2084° F.

### Feature Summary

	Previous Stage 1 Shroud	HR-120 Stage 1 Shroud
Sealing	Pumpkin tooth	Cloth spline seals
Material	Cast or Forged Stainless Steel	HR-120
Number of Pieces	One piece	One piece
Firing Temperature	Up to 2020° F	Up to 2084° F

### Advanced Shroud Seal Configuration

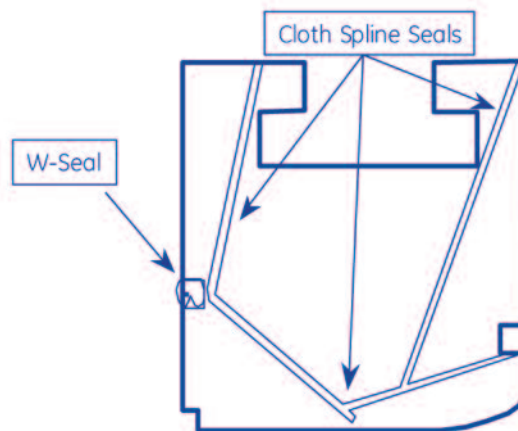


Figure 61. HR-120™ Improved Stage 1 Shroud.

For 9E units, the PG9171 two-piece stage 1 shroud was developed for the 2055°F uprate program. This is a costly design in terms of both dollars and performance. The two-piece design was film cooled using airflow from the compressor discharge. The body of the outer shroud was made of 310 stainless steel (310-SS) and the inner shroud was made of FSX-414. The increase in cooling flow required to cool this shroud resulted in a 0.9% decrease in output and an increase in heat rate of 0.4%.

In order to regain the lost performance associated with the two-piece design, GE has developed a new one-piece design made of Haynes HR-120™. The new stage 1 shroud material provides a 3X improvement in LCF life in comparison to the previous 310-SS, and permits the use of a one-piece shroud at higher temperatures. The new material has both a higher inherent material strength and more favorable time-at-temperature creep characteristics. The new shrouds provide an additional +0.4% performance increase and a -0.2% heat rate benefit.



### Stage 1 Shroud Abradable Coating Uprate (FS6A)

The stage 1 shroud blocks on MS9001E units can be coated with an abradable coating on the inner diameter surface. (See Figure 62.) The abradable coating on the stage 1 shroud allows for improved airflow control, and it allows tighter clearances between the bucket and shroud leading to performance improvements. The improved clearance and associated reduction in tip leakage of cooling airflow create a performance benefit. The abradable

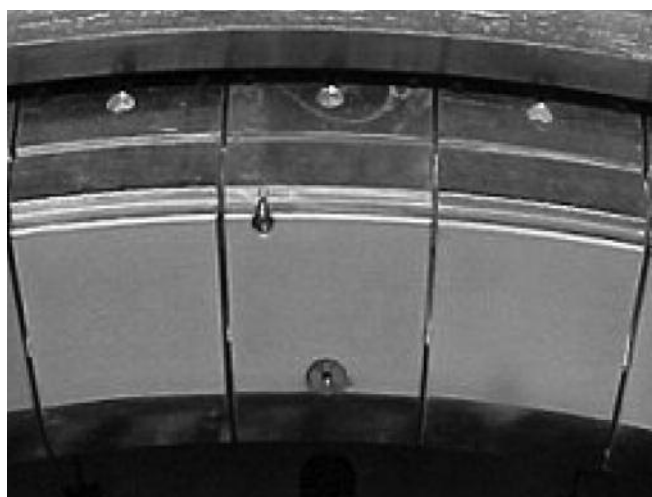


Figure 62. Stage 1 shrouds coated with abradable coating.

coating is designed to preferentially wear away in the event of a bucket tip rub, greatly avoiding wear of the bucket tips. It also allows tighter clearances between the bucket and shroud leading to performance improvements.

The benefits of this uprate are:

- Model 9E change in output: +0.4%, change in heat rate: -0.4%

The abradable coating on the Stage 1 shroud blocks gives +0.5% increased output power and an improved heat rate of -0.5%. Abradable coating addresses performance benefits by clearance reduction even under conditions of rotor misalignment and casing out of roundness. (See Figure 63.)

### Stage 2 and 3 Shroud Blocks Uprates (FS2T and FS2U)

Stage 2 and 3 honeycomb shroud blocks provide bucket tip sealing for MS9001B and E units. The original seals on these units were labyrinth. In an effort to provide better sealing in this area, honeycomb material was applied to both the stage 2 and 3 shrouds. (See Figure 64 and Figure 65.)

Honeycomb seals are designed to reduce bucket tip leakage, resulting in an improved heat rate and output. It is estimated that about 50% of the buckets in a given row will need cutter teeth to ensure proper performance of the honeycomb material and

## Stage 1 Shroud Abradable Coating

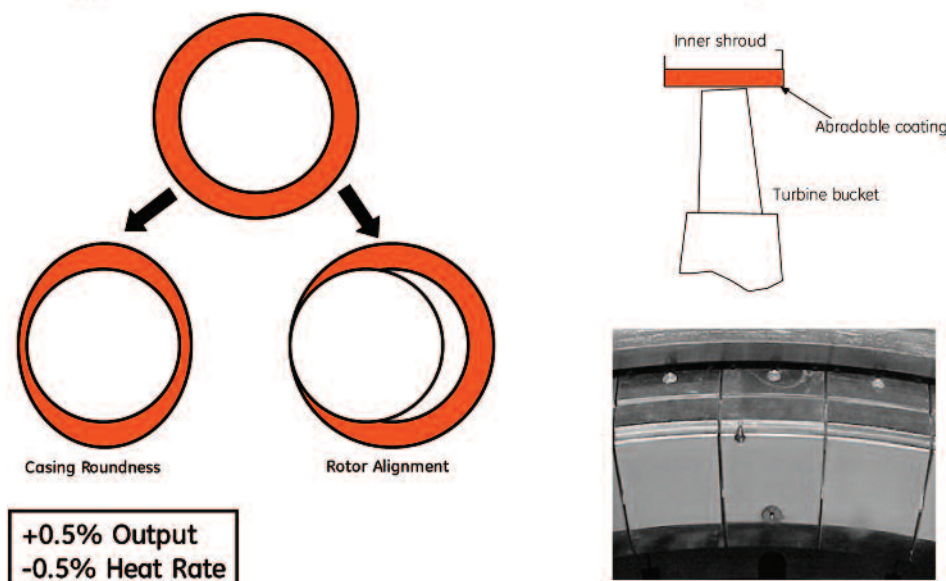
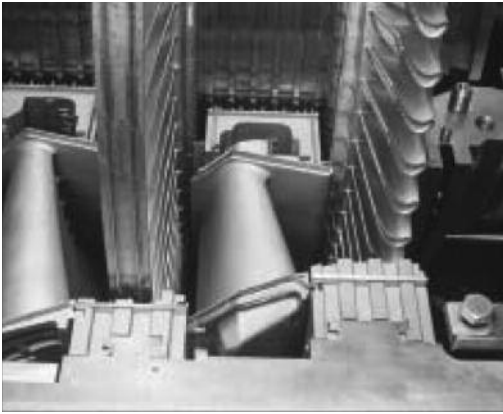


Figure 63. Abradable coating increases performance when rotor is not 100% aligned or casing is out of round.



**Figure 64.** Stage 2 shroud blocks with honeycomb and stage 2 buckets with cutter teeth.



**Figure 65.** Shroud block with honeycomb sealing.

achieve a +0.35% increase in output with a -0.35% decrease in heat rate for stage 2; and 0.15% increase in output, with a -0.15% decrease in heat rate for stage 3.

The benefits of this uprate are:

- Model 9B and E Stage 2 change in output: +0.35, change in heat rate: -0.35%
- Model 9B and E Stage 3 change in output: +0.15%, change in heat rate: -0.15%

Honeycomb allows contact between the bucket tip and casing shrouds during transient operation and provides relatively tight

clearances during steady state operation. (See *Figure 66.*) The cold clearances for the labyrinth seal are set based on avoiding contact between the bucket tips and shrouds that occur during transients, thus providing relatively more open clearances during steady state base load operation (compared to honeycomb shrouds).

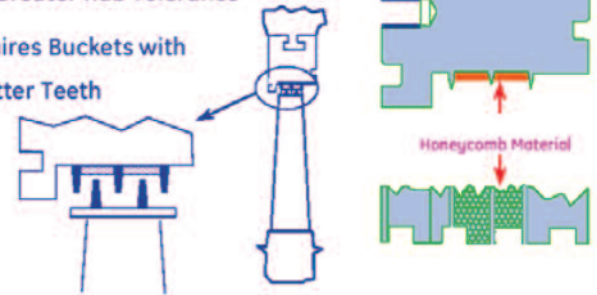
## Honeycomb Seal Insert

### Honeycomb Shroud Blocks

#### Honeycomb Shrouds

- Reduces Leakage
- Greater Rub Tolerance

#### Requires Buckets with Cutter Teeth



**Figure 66.** 7EA stage 2 honeycomb inner shroud design.

Honeycomb seals are made of a high temperature, oxidation-resistant alloy with 1/8-inch cell size and 5-mil foil thickness brazed between the teeth on the shrouds. "Cutter teeth" on the leading edge of the shrouded stage 2 and 3 bucket tip rails cut a groove in the honeycomb when contact occurs during transients. This produces a tighter seal and less lost airflow as compared to non-honeycomb shrouds.

Installation of honeycomb shrouds requires buckets with cutter teeth. As previously mentioned, current production stage 2 and 3 buckets have cutter teeth.

## Interstage Brush Seal Uprate (FS2Z)

For the MS9001E, this uprate delivers a +1.0% increase in output and a -0.5% heat rate benefit, and a +0.5% increase in output with a -0.3% heat rate benefit for the MS9001B.

The benefits of this uprate are:

- Model 9B change in output: +0.5%, change in heat rate: -0.3%
- Model 9E change in output: +1.0%, change in heat rate: -0.5%

The 2nd stage nozzle/diaphragm assembly contains a radial high-low labyrinth seal that reduces flow leakage between the diaphragm and the turbine rotor into the stage 2 forward wheel space area. (See *Figure 67.*) When added to a unit, the interstage

## Stage 2 Nozzle Brush Seal

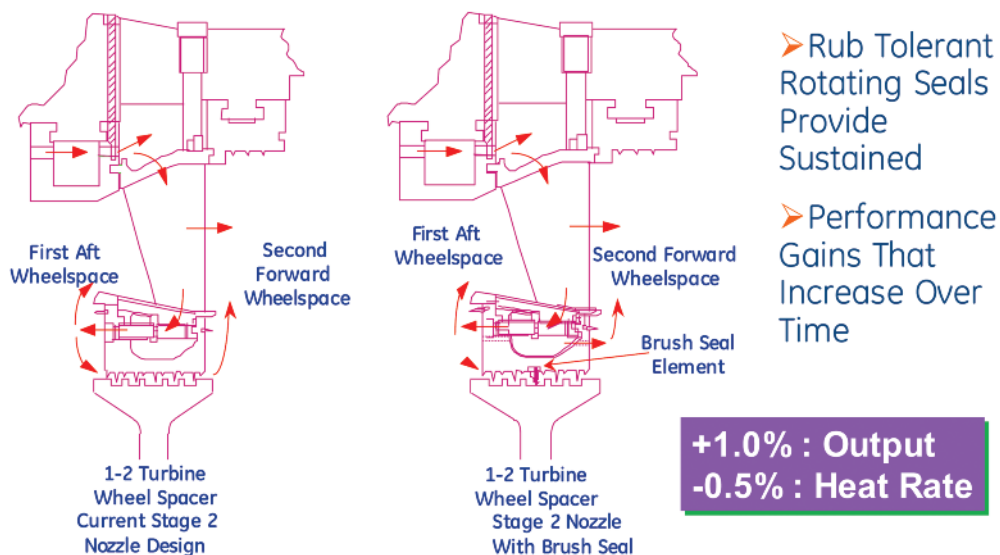


Figure 67. 7EA stage 2 brush seal inner diaphragm design.

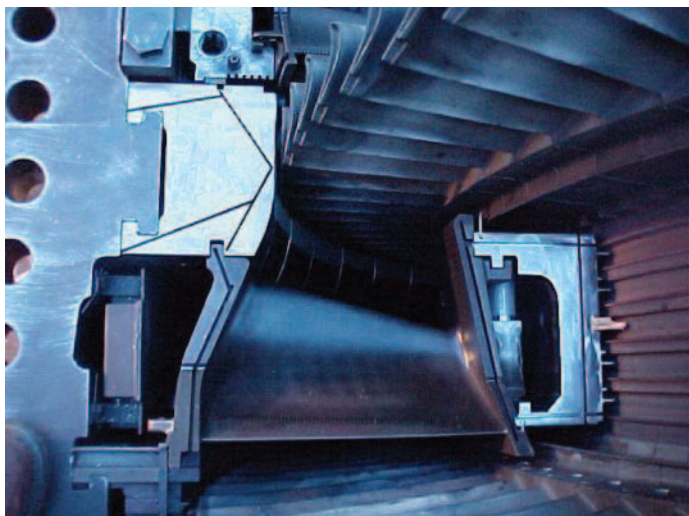


Figure 68. Installed interstage brush seal.

brush seal further reduces this leakage. (See Figure 68.) Since the hot gas in this leakage performs no useful work, any reduction in this leakage results in an increase in performance. Cooling airflow to the 2nd stage forward wheel space is reduced, but this flow is currently greater than required when the brush seal is not installed.

In testing, the sealing efficiency of a single brush is found to be up to 10 times that of a labyrinth seal under similar conditions. The

main advantage of the second stage brush seal is the reduction of flow leakage between the diaphragm and the turbine rotor into the stage 2 forward wheel space area.

For all vintage 9E units that install the stage 2 nozzle brush seal, counter bore covers are required to be installed on the inner barrels. Based on aerodynamic analysis, in some cases, compressor pressure ratio (CPR) control, IGV angle re-scheduling or stage 17 and EGV 1&2 shrouded vanes with slotted inner barrels may be required. (Reference FS2B).

### Discourager Seal Replacement (FW3E)

For MS9001E units, inspection and possible replacement of the deteriorating Al-Bronze seal material reduces the risk of excessive leakage from the seal.

The benefits of this uprate are:

- Increasing proper stage 2 bucket cooling with the installation of the new 410 stainless steel seal tooth material

The Al-Bronze material is known to be the cause of premature discourager seal failures in the field. It is advised that the discourager seal between the stage 1-to-2 spacer be inspected on all units shipped prior to 1996 for brittleness of the B50A422A Al-Bronze seal teeth material. (New units shipped in 1997 and after should have the

410-SS replacement material.) New seal material 410-SS stainless steel with much longer life is used as the replacement to reduce the risk of excessive leakage from the seal. This leakage has the potential of contributing to issues such as reduced cooling flow to the stage 2 buckets, which increases creep. This in turn can contribute to stage 2 bucket tip shroud creep deflection that results in loss of engagement of tip shroud interlock. Loss of engagement can result in bucket liberation and forced outage.

### Add Compressor and Turbine Water Wash (FC4A and FC4C)

For MS9001B and E units, turbine water wash (FC4C) is used to remove ash deposits from turbine sections left by the burning of low-grade liquid fuels. These deposits gradually reduce the thermal efficiency and output of the turbine. Water washing must take place while the turbine is off-line, while the wheel space temperatures are cool, and with the unit at crank speed. For machines burning high-grade liquid fuels or gas, turbine water wash is not needed.

Compressor water wash should be used in conjunction with turbine wash. The compressor water wash removes dirt and deposits from the compressor blading to increase unit performance.

The turbine and compressor water wash systems allow the customer to remove deposits from the compressor and turbine sections thereby recovering lost output and efficiency in machines.

## Turbine Uprate Packages

Each of the advanced technology uprates can be installed in MS9001B and E units with minor or no modifications.

Examples of design improvements are outlined in *Figure 70*.

While some of these components provide performance benefits individually, the most dramatic performance benefits are obtained by increases in firing temperature,  $T_f$ . Generally,  $T_f$  increases require a series of component changes based on the original configuration of the unit and the desired firing temperature. Therefore, several different packages have been designed for the MS9001B and E units to provide the maximum benefit for the customer. (See *Figure 71*.) There are four packages for the MS9001B and two packages for the MS9001E. Below, each of these packages is discussed.

### Uprate 9B Hot Gas Path and Combustion to 9E (FT6X)

The MS9001B turbine uprate is based on installing current production MS9001E components into the MS9001B. (See *Figure 72*.) This uprate package consists of four different options outlined in *Figure 73* and

### Root Cause of Cracking at Third Stage Hook

- Compressive yield and elevated temperatures at third stage hook fit cause fatigue cracking
  - Compressive yield exceeded on inner surface
  - Tensile residual stress on casing inner surface at shut down
  - Start and shut down cycles are low cycle fatigue LCF
  - LCF causes cracks
- Stress is below compressive yield for deep cracks
  - No tensile residual stress for deeper cracks
  - Cracks enter region of all compression, no tensile residual
  - No LCF, so cracks self arrest

**1st stage hook circumferential cracks might be of concern if deep.**

**Figure 69.** RCA of cracking at third stage hook fit.

*Figure 74*. The performance improvements associated with each of these options are given in *Figure 75* and *Figure 76*. The major design uprates included in this package are given in *Figure 71*. In addition to improving performance, the maintenance/inspection intervals can be increased.

**Option I** contains the advanced technology stage 1 buckets and nozzles and GTD-450 reduced camber inlet guide vanes. This option maintains the firing temperature at 1840°F while increasing the thermal efficiency, which decreases the exhaust temperature. This uprate option provides an increase in output of 6.4% at ISO conditions with the IGVs open to 86 degrees.

**Option II** raises the firing temperature to 1905°F, which is the maximum firing temperature that can be achieved while maintaining the original exhaust temperature. In addition to the components for Option I, this option includes new stage 2 buckets and nozzles, new stage 1 shroud, TBC coated slot-cooled liners, Nimonic 263™ transition pieces, and the Extensor combustion upgrade. The stage 2 buckets are GTD-111 buckets without air-cooling. Option 2 is feasible for combined cycle applications where a decrease in exhaust temperature would reduce the overall combined cycle efficiency and an increase in exhaust temperature might be limited by the Heat Recovery Steam Generator (HRSG). It should be emphasized that the performance benefits given in *Figure 75* and *Figure 76* are based on the IGVs opened to 86 degrees, and assume that all of the options have been installed.



Sourcebook Codes	Component	Design Improvements
FS2J	Stage 1 Nozzle	2 Vane/Segment, 6% higher pressure ratio, chordal hinge with improved sidewall sealing, improved sidewall cooling
FS2H	Stage 1 Bucket	GTD-111, T33 INCOAT, blunt leading edge airfoil and coating on cooling holes, turbulated cooling
FS1PJ	Stage 2 Nozzle	Air cooled, long chord, GTD-222 for increased creep resistance, aluminide coating, reduced cooling
FS2F	Stage 2 Bucket	Air cooled, GTD-111, GT33 INCOAT, scalloped tip shroud, cutter teeth
FS1R	Stage 3 Nozzle	Long chord, GTD-222 for increased creep resistance
FS2K	Stage 3 Bucket	Rotated airfoil, IN738, scalloped tip shroud, cutter teeth
–	Combustion	Slot cooled liners (FR1H), Nimonic™ thick wall transition pieces (FR1D) and thermal barrier coated liners (FR1G)

**Figure 70.** MS9001E component design improvement examples.

Component	MS9001 B/E Uprate Options				MS9001E to 2020°F	MS9001E to 2055°F
	Option 1	Option 2	Option 3	Option 4		
Firing Temperature	1840°F	1905°F	1965°F	2020°F	2020°F	2055°F
Increase in Output	6.4%	12.6°	18.2%	24.1%	6.4%-10.4%	5.1%-15.5%
S1B 9E GTD111 E/A BLE	X	X	X	X	X	X
S1N 9E 2 Vane Chordal Hinge	X	X	X	X		X
GTD450 Reduced Camber IGV (86 degrees)	X	X	X	X	X	X
S2N 9E GTD222 Reduced Cooling		X	X	X		X
S2B 9E GTD111 Air Cooled		X**	X	X		X
S3N IN738			X	X		X
Stg. 1 Shroud 1 Piece		X	X	X		X
Stg. 1 Shroud 2 Piece						X
Stg. 3 Shroud (for 9E Bucket Shroud)			X	X		
GE Exhaust Frame and Blowers				X	X	X
Slot-cooled Liners w/TBC		X	X	X		X
Extensor Combustion Upgrade		X	X	X	X	X
Stage 1/2 Wheel Spacer			X	X		X
Nimonic™ Transition Pieces		X	X	X	X	X
Inner Barrel Bore Plugs	X	X	X	X	X	X
Stage 2 Honeycomb Shrouds***		X	X	X		X
Stage 3 Honeycomb Shrouds***			X	X		X
High Pressure Packing Brush Seal***	X	X	X	X	X	X
#2 Bearing Brush Seal***	X	X	X	X	X	X

\* Need to have existing liners coated with TBC. This cost is not included in the package price.

\*\* Non air-cooled buckets

\*\*\* Optional – not required for Uprate

**Figure 71.** MS 9001 E-Class uprate options.

### MS9001B to E Advanced Tech Uprate

#### MS9001B Turbine Uprate (FT6X)

- Current production 91E buckets and nozzles can be retrofitted into earlier 91B units w/ minor modifications
- When uprating 91B units with 91E HGP parts, expect substantial improvements in parts life
- 91B combustion hardware can also be replaced with 91E components and significantly improve combustion inspection intervals

Figure 72. Uprating a 9B to a 9E.

**Option III** is designed to raise the exhaust temperature to the limit by increasing the firing temperature to 1965°F. In addition to the material provided for Options 1 and 2, stage 3 buckets, nozzles shrouds, and the turbine rotor 1-to-2 wheel spacer are also provided. Unlike Option 2, the stage 2 bucket is air-cooled. This uprate provides an 18.2% increase in output at an 86 degree IGV angle and ISO conditions.

**Option IV** raises the firing temperature to 2020°F. This option includes all of the components in Option 3, as well as a new exhaust frame and two 100 hp exhaust frame blowers to accommodate the increase in exhaust temperature. Increasing the firing temperature to this level can increase the output by 24.1% at an 86 degree IGV angle and ISO conditions.

Prior to the sale of any of these options, an engineering review of the turbine/generator performance is required to ensure that the load equipment can accommodate the increase in output. This review may indicate that the load equipment needs to be uprated. In many cases, the generator can operate at a higher power factor to produce more megawatts. A typical MS9001B performance study towards these ends is illustrated in *Figure 77*.

Each of these components in these package options can be purchased individually; however, all of the required components in a given option must be purchased and installed to receive the corresponding increase in firing temperature for that option. Each of the design improvements associated with the MS9001E components are outlined below.

- **Stage 1 Buckets.** This bucket is now made of GTD-111 with the IN Plus coating, has the blunt leading edge design, and is turbulated cooled. (Reference FT6J.)

### MS9001B to E Advanced Tech Uprate

#### MS9001B Turbine Urate (FT6X)

##### Option I

- Includes new GTD-450 High Flow Inlet Guide Vanes, first stage buckets and nozzles and inner barrel bore plugs. This option maintains the firing temperature at 1840°F/1004°C while increasing the thermal efficiency, thereby decreasing the exhaust temperature.

##### Option II

- Provides the material supplied in Option 1 as well as second stage non-Air-Cooled buckets and second stage nozzles, stage 1 shrouds, TBC coated slot cooled liner, Nimonic™ transition pieces and Extensor. The addition of these components supports a firing temperature increase to 1905°F/1040°C. This is the maximum firing temperature that can be achieved while maintaining the original exhaust temperature. This option is applicable to heat recovery unit applications, where exhaust temperature decreases can be detrimental to combined cycle efficiency and exhaust temperature increases might not be compatible with the Heat Recovery Steam Generator (HRSG).

Figure 73. Uprating a 9B to a 9E.

### MS9001B to E Advanced Tech Uprate

#### MS9001B Turbine Urate (FT6X)

##### Option III

- Includes all three stages of buckets and nozzles (including Air Cooled second stage buckets), inner barrel bore plugs, stage 1 two-piece shrouds, stage 3 shrouds, TBC-coated slot-cooled liners, Nimonic™ transition pieces and Extensor. This option allows for an increase in firing temperature to 1965°F/1074°C. This option is designed to raise the exhaust temperature to the limit.

##### Option IV

- Includes the same material as Option 3 as well as an exhaust frame and exhaust frame blowers, which are required to support the firing temperature increase to 2020°F/1104°C.

Each of these components in these package options can be purchased individually; however, all of the components in a given option must be purchased and installed to receive the corresponding increase in firing temperature.

Figure 74. Uprating a 9B to a 9E.



	MS9001B-E Uprates				MS9001E – 2020°F				MS9001E – 2055°F			
	I	II	III	IV								
Original TI, (°F)	1840	1840	1840	1840	1955	1985	2000	1955	1985	2000	2020	2055
Original TI, (°F)	1840	1905	1965	2020	2020	2020	2020	2055	2055	2055	2055	2055
	Increase in Output											
	%	%	%	%	%	%	%	%	%	%	%	%
Increase in Firing Temperature and Controls Modification	–	6.7	12.8	18.2	6.5	4.0	2.7	9.5	7.0	5.7	3.5	0.5
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 IGVs (84 degrees)	4.3	4.3	4.3	4.3	1.5	1.5	1.5	1.5	1.5	1.5	–	–
Additional 2° – IGv	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	–
GTD-222 S2N	–	-1.0	-1.0	-1.0	–	–	–	1.0	1.0	1.0	1.0	1.0
Haynes HR-120 One Piece Stage 1 Shroud	–	–	–	–	–	–	–	0.0	0.0	0.0	0.0	0.9
Exhaust Frame Blowers	–	–	–	0.2	–	–	–	–	–	–	–	–
Air Cooled S2B	–	–	1.65	1.65	–	–	–	–	–	–	–	–
S2B Shrouds with Honeycomb Seals	–	0.35	0.35	0.35	–	–	–	0.35	0.35	0.35	0.35	0.35
S3 Shrouds with Honeycomb Seals	–	–	0.15	0.15	–	–	–	0.15	0.15	0.15	0.15	0.15
HPP Brush Seals	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
No. 2 Bearing Brush Seals	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
<b>Total Effect on Output</b>	<b>6.4</b>	<b>12.8</b>	<b>18.2</b>	<b>24.1</b>	<b>10.4</b>	<b>7.8</b>	<b>6.4</b>	<b>15.5</b>	<b>12.9</b>	<b>11.5</b>	<b>7.6</b>	<b>5.1</b>

Figure 75. Frame 9 uprate options output increases.

	MS9001B-E Uprates				MS9001E – 2020°F				MS9001E – 2055°F			
	I	II	III	IV								
Original TF (°F)	1840	1840	1840	1840	1955	1985	2000	1955	1985	2000	2020	2055
Original TIF (°F)	1840	1905	1965	2020	2020	2020	2020	2055	2055	2055	2055	2055
	Decrease in Heat Rate											
	%	%	%	%	%	%	%	%	%	%	%	%
Increase in Firing Temperature and Controls Modification	–	-1.1	-2.0	-2.6	-0.6	-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
G450 IGVs (84 degrees)	-0.7	-0.7	-0.7	-0.7	-0.38	-0.38	-0.38	-0.38	-0.38	-0.38	–	–
Additional 2° - IGv	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Rotated S3B–	–	–	0.6	0.6	–	–	–	0.28	0.28	0.28	0.28	–
GTD-222 S2N	–	-0.4	-0.4	-0.4	–	–	–	-0.4	-0.4	-0.4	-0.4	-0.4
Haynes HR-120 One Piece Stage 1 Shroud	–	–	–	–	–	–	–	0.0	0.0	0.0	0.0	-0.4
Exhaust Frame Blowers	–	–	–	-0.1	–	–	–	–	–	–	–	–
Air Cooled S2B	–	–	1.1	1.1	–	–	–	–	–	–	–	–
S2B Shrouds with Honeycomb Seals	–	-0.35	-0.35	-0.35	–	–	–	-0.35	-0.35	-0.35	-0.35	-0.35
S3 Shrouds with Honeycomb Seals	–	–	-0.15	-0.15	–	–	–	-0.15	-0.15	-0.15	-0.15	-0.15
HPP Brush Seals	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	v	-0.5	-0.5	-0.5	-0.5
No. 2 Bearing Brush Seals	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
<b>Total Effect on Heat Rate</b>	<b>-3.3</b>	<b>-4.3</b>	<b>-4.8</b>	<b>-5.5</b>	<b>-1.6</b>	<b>-1.3</b>	<b>-1.2</b>	<b>-3.2</b>	<b>-3.0</b>	<b>-2.9</b>	<b>-2.4</b>	<b>-2.2</b>

Figure 76. Frame 9 uprate options heat rate decreases.

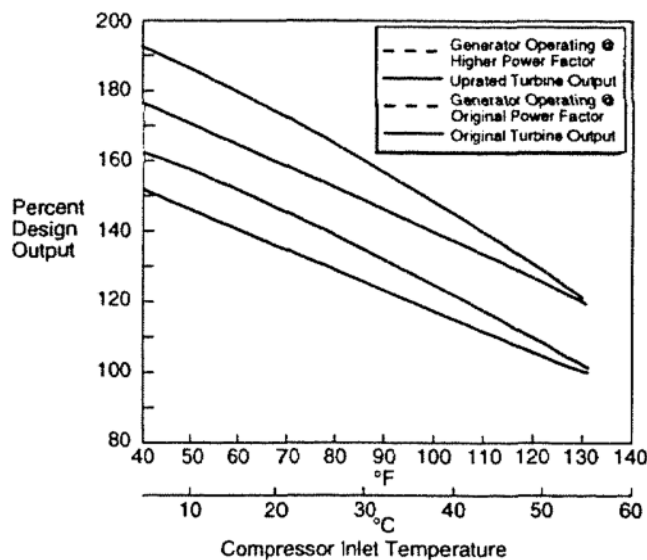


Figure 77. Typical MS9001B to E uprate performance study.

- **Stage 1 Nozzles.** This nozzle has only 2 vanes per segment, which decrease the thermal stresses, making it less vulnerable to fillet cracking. This nozzle also has the improved hinge, improved sidewall sealing, and improved sidewall cooling. (Reference FS2J.)
- **Stage 1 Shrouds.** New stage 1 shrouds are required to accommodate the new stage 2 nozzle.
- **Stage 2 Buckets.** The stage 2 bucket is now air-cooled, made of GTD-111 and coated with IN Plus, and has a scalloped tip shroud. In option 2, the cooling holes in this bucket are plugged. (Reference FS2F.)
- **Stage 2 Nozzles.** This nozzle is now air-cooled and made of GTD-222+ with an over aluminide coating. (Reference FS1P.)
- **Stage 3 Buckets.** The material and design of this bucket have been improved. (FS2K)
- **Stage 3 Nozzles.** This nozzle has an increased chord length and is now made from GTD-222+. (Reference FS1R.)
- **Stage 3 Shrouds.** New stage 3 shrouds are required to accommodate the new stage 3 buckets.
- **GTD-450 Inlet Guide Vanes.** The high flow inlet guide vane has a reduced camber design to increase airflow. (Reference FT6B.)
- **Combustion System.** In order to utilize the TBC-coated

slot-cooled liners and Nimonic 263™ transition pieces, new combustion cans, flow sleeves, and crossfire tubes are required. The new combustion system provides more effective cooling allowing for higher firing temperatures. The 9B was introduced with the “parallel” combustion system meaning that the liners were parallel to the turbine rotor. When the 9E was introduced, the combustion system was modified to the “canted” system where the liners are installed at an angle to the turbine rotor. The latest design 9E has a canted arrangement that utilizes a longer transition piece than in the canned arrangement. Both the canned and the canted arrangements use the same liner. When uprating the 9B combustion hardware, the 9E slot-cooled liner is used, however the 9E transition piece is incompatible. A new Nimonic 263™ transition piece was designed for this specific application. The 9B and the 9E Nimonic 263™ transition pieces are not interchangeable.

- **Extensor Wear Kit.** The Extensor wear kit decreases combustion component wear and increases combustion inspection intervals by reducing the relative movement and associated wear of the parts in the combustion system. (Reference FR1W.)
- **Exhaust Frame Modification and Exhaust Frame Blowers.** Exhaust frame cooling is accomplished by two 100 hp motor driven centrifugal blowers. (Reference FS2D.)
- **Inner Barrel Bore Plugs.** The unplugged cooling circuit tuning holes can be plugged to decrease the cooling airflow across the inner barrel high-pressure packing. (See Figure 78.)

#### Increase MS9001E to 2020°F Firing Temperature (FT6C)

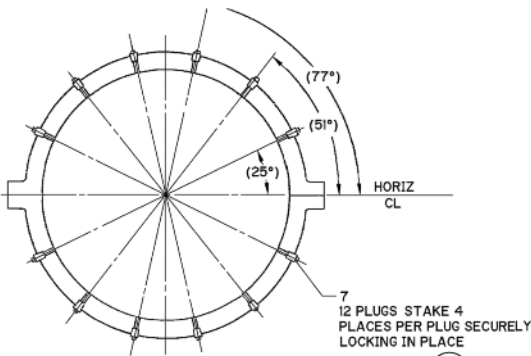
This uprate package is designed for MS9001E units with firing temperatures below 2020°F. This package is based on installing the latest technology components into older machines. The uprates required for the firing temperature increase are listed in Figure 71. An engineering review of the current turbine configuration should be provided to determine the uprates required for Tf increase. The performance improvement is derived from the increase in firing temperature as well as improved component designs. Depending on the original configuration of the unit, the increase in output ranges from +6.4% to +10.4%, while the heat rate decreases from -1.2% to -1.6%, (including optional items for advanced technology uprate).

# CDC boreplugs

## Inner Barrel Bore Plugs

The inner barrel/compressor discharge casing includes a number of machined holes, which allow for tuning of the amount of compressor discharge flow to the first forward wheel space. The number of open/plugged holes varies depending on the configuration of the unit. Field testing has confirmed that all of these holes may be plugged without significantly impacting first forward wheelspace temperature.

The reduction in flow results in a performance improvement (+0.4% output and -0.2% heat rate).



**+0.40% : Output**  
**-0.20% : Heat Rate**

Figure 78. Bore plugs are used to fine-tune cooling air to the first wheel space.

The benefits of this Model 9E uprate are:

Original Tf	1955°F	1985°F	2000°F
Output	10.4%	7.8%	6.4%
Heat Rate	-1.6%	-1.3%	-1.2%

Figure 75 and Figure 76 provide the performance gains associated with each of the components as well as the entire uprate package. Again, it is important that the turbine/generator be evaluated to determine if the current load equipment can withstand the increase in output associated with this uprate.

The design improvements associated with the MS9001E components include:

- **Stage 1 Buckets.** This bucket is now made of GTD-111 with the IN Plus coating, has the blunt leading edge design, and is turbulated cooled. (Reference FT6J.)
- **Stage 3 Nozzles.** This nozzle has long chord length and is now made from GTD-222+. (Reference FS1R.)
- **GTD-450 Inlet Guide Vanes.** The high flow inlet guide vane has a reduced camber design to increase airflow. (Reference FT6B.)

- **TBC Coated Slot-Cooled Liners.** TBC coated slot-cooled liners are required as a part of this uprate. The latest design liners are thick-walled liners that are TBC Coated. The customer has the option of having the existing thin-walled liners coated with TBC or purchasing the new thick-walled TBC coated liners. The thick-walled liners can withstand a firing temperature of 2055°F.
- **Nimonic Transition Pieces.** Nimonic 263™ transition pieces are required for this uprate. These transition pieces increase maintenance intervals and increase hot gas path life.
- **Extendor Wear Kit.** The Extendor wear kit decreases combustion component wear and increases combustion inspection intervals by reducing the relative movement and associated wear of the parts in the combustion system. (Reference FR1W.)
- **Inner Barrel Bore Plugs.** The unplugged cooling circuit tuning holes can be plugged to decrease the cooling airflow across the inner barrel high pressure packing, this increases output.
- **Exhaust Frame Blowers.** Exhaust frame cooling is accomplished by two 100 HP motor driven centrifugal blowers. (Reference FS2D.)

## Increase MS9001E to 2055°F Firing Temperature (FT6Y)

This uprate package is designed for MS9001E units with firing temperatures below 2055°F. This package provides the advanced technology components to increase the firing temperature of an earlier vintage MS9001E to 2055°F, the highest firing temperature available on an MS9001E.

The benefits of this uprate are:

- Increase in output ranging from 5.1% to 15.5%, depending on the original configuration of the unit, while the heat rate decrease ranges from –2.2% to –3.0%, (including optional items for advanced technology uprate)

The hardware required for a given unit varies depending on its current turbine configuration. An Applications Engineering review is conducted to define the balance of components required for the uprate of any specific unit.

The increase in output associated with the uprate is dependent upon the original configuration of the unit. *Figure 75* and *Figure 76* provide the performance gains associated with each of the individual components as well as the entire uprate package. Again, it is important that the turbine/generator be evaluated to determine if the current load equipment can withstand the increase in output associated with this uprate.

The items listed in *Figure 79* need to be configured on the unit for a firing temperature increase to 2055°F:

- **Stage 1 Buckets.** GTD-111 material, directionally solidified, equiaxed, 11-hole turbulated cooled GT-33 IN Plus coating.
- **Stage 2 Buckets.** GTD-111 material with advanced cooling (6 cooling holes), scalloped shroud tips, and cutter teeth.
- **Stage 3 Buckets.** IN-738™ material with scalloped and interlocking shroud tips with cutter teeth.
- **Stage 1 Nozzles.** FSX-414 material, improved cooling with chordal hinge, and spline seals on inner segment.
- **Stage 2 Nozzles.** GTD-222+ material with reduced cooling flow, non-pressurized.
- **Stage 3 Nozzles.** GTD-222+ material. This nozzle has an increased chord length and is now made from GTD-222+.
- **Stage 1 Shrouds.** One-piece design, HR-120 material with improved spline sealing.

### MS9001E 2055°F Uprate Requirements

• GTD-111 Equiaxed BLE Stage 1 Bucket	FT6J
• 2 Vane Chordal Hinge Stage 1 Nozzle	FS2J
• GTD-111 Air-Cooled Stage 2 Buckets	FS2F
• GTD-222 Reduced Cooling Stage 2 Nozzle	FS1P
• IN-738 Stage 3 Bucket	FS2K
• GTD-222 Stage 3 Nozzle	FS1R
• HR-120™ Improved Stage 1 Shroud Blocks	FS2Y
• GTD-450 Reduced Camber IGVs	FT6B
• Nimonic-263™ Transition Pieces, TBC Coating	FR1U
• Thick Slot-Cooled Liners with TBC	FR1U
• Exhaust Isotherm Temp Limit Upgrade, Exhaust Frame Upgrade/100 HP Blowers	FS1W/FS2D
• Inner Barrel Bore Plugs	FS2S

Most requirements are part of normal maintenance plans.  
Improve performance with uprate parts in place of normal spares.

**Figure 79.** Requirements for uprate to 2055°F.

- **Stage 3 Shroud Cooling Air Modification.** Addition of 5th compressor stage extraction piping for supplying cooling air between the turbine case and stage 3 shrouds.
- **Combustion System.** The latest design combustion system is referred to as a “canned” arrangement and replaces the “canted” arrangement. The “canted” arrangement is easily identified because the combustion covers bolt directly to the wrapper without the external combustion casing “cans.” For units with a firing temperature less than 2055°F, the combustion system remains as the “canted” arrangement, which features full Nimonic 263™ “long” transition pieces and “thick-walled” slot-cooled liners, both of which are TBC coated. The longer transition piece moves the liner out thus requiring the outer cans. This requires modifications to fuel gas piping (for single gas units), or requires fuel oil, fuel purge and atomizing air piping (for dual fuel units). Units equipped with false start drain piping require drains for the new, lower half combustion cans.
- **Exhaust Frame Blowers.** Exhaust frame cooling is accomplished with two 100 hp motor-driven centrifugal blowers.
- **Inner Barrel Bore Plugs.** The unplugged cooling circuit tuning holes can be plugged to decrease the cooling airflow across the inner barrel high pressure packing.

- **Inlet Guide Vanes.** GTD-450 material (PG9151E units and earlier do not have GTD-450 high flow inlet guide vanes) with reduced camber design to increase airflow.
- **Inner Barrel Counter Bore Covers.** IGV angle restrictions might also be necessary. (Reference FS2B.)
- **Temperature Control Curve.** Modification for firing temperature increase.

## Compartment and Exhaust Improvements

### Turbine Compartment Dual 100 HP Fan Uprate (FF1E)

This modification for MS9001B and E units involves adding two centrifugal ventilation fans, enclosed in box-type casings and driven by AC motors, to the top of the turbine compartment. The fans provide ventilation by drawing air up through several ducts in the turbine and accessory compartments and exhausting it to atmosphere through a horizontal discharge. A dual vent fan arrangement is used to supply symmetrical airflow throughout the turbine compartment.

The benefits of this uprate are:

- Additional cooling to the turbine compartment
- Dual vent fan configuration symmetrically extracts hot air away from the turbine, reducing part degradation caused by thermal fatigue

This modification provides additional cooling to the turbine compartment. The dual vent fan configuration symmetrically extracts hot air away from the turbine, thereby reducing part degradation caused by thermal fatigue. Two holes need to be cut in the existing turbine compartment roof to accommodate the new vent fans. Appropriate lagging or struts must also be added to the existing turbine compartment roof to support the weight of the new equipment.

The ventilation fan assemblies supplied with this uprate have externally-mounted motors. Each motor is mounted atop the fan enclosure in the ambient environment. This design helps maintain the expected fan motor life by removing the fan motors from the hot air discharge path.

Each vent fan assembly employs a damper housing. The damper blades are held in a normally open position with a CO<sub>2</sub>/Halon pressure actuated spring release latch. This latch is operated by

the fire-extinguishing agent. When the fire protection system is activated, the latch releases and the damper blades close by gravity. The damper housing and CO<sub>2</sub> latch are bolted to the fan outlet and shipped as a unit. It should be noted that the CO<sub>2</sub> latch could be mounted on either side of the vent fan damper.

New motor starters and circuitry changes to the motor control center are included in this uprate. These changes allow the fans to be operated from the existing control unit. Other options that can be incorporated into this uprate include limit and differential pressure switches, as well as back draft dampers.

### Upgrade to 100 HP Exhaust Frame Motor Bowers (FS2D)

For MS9001E units, cooling of the turbine exhaust casing and frame is accomplished by motor-driven blowers. These fans are mounted externally to the turbine. The replacement kit includes 100 HP exhaust frame blowers, interconnection piping arrangement modifications, motor control center modifications, and exhaust frame cooling circuit tuning. The current design exhaust frame is cooled with two motor-driven centrifugal blowers. The 100 HP exhaust frame blowers reduce the temperature of the frame thereby reducing cracking to provide a durable exhaust frame.

The benefits of this uprate are:

- Exhaust frame blowers help to reduce temperature of the frame
  - Helping to reduce cracking and general repair costs
  - Providing a durable exhaust frame

Upgrading the exhaust frame blowers is applicable to units with the modern design exhaust frame that can use but do not yet have 100 HP blowers. All 9E units have the modern design.

The recommended design for combined cycle machines is 100 HP exhaust frame blowers for 9E units. For simple cycle, the recommended design is 30 HP blowers for 9E units. Simple cycle units generally have lower horsepower blowers because the gas path pressure is relatively low for simple cycle. However, for simple cycle units, an upgrade to exhaust frame blowers with 100 HP rating may be required to obtain the elevated exhaust temperature capability needed to get the full benefit of a 2055°F firing temperature increase.

Reference FS1W for a modification kit for 9E units that contain the latest enhancements and recommended plenum upgrades. For 9B units, reference FS1W for the exhaust frame blower addition/upgrade and exhaust frame upgrade.



### Replaceable Wheel Space Thermocouples Uprate (FK5C)

Intended for MS9001B units, the removable wheel space thermocouples modification provides thermocouples that can be replaced upon failure without removing the turbine shell. The new thermocouples are also extended which provides greater reliability by moving the termination junction from the turbine compartment to outside of the compartment. The modification includes all wheel space thermocouples, necessary hardware, and on-base junction boxes.

The extended externally replaceable wheel space thermocouples increase turbine availability through a reduction in down time. The reliability of the thermocouple increases with the increased shielding and removal of the termination point from the turbine compartment.

### Replaceable Exhaust Thermocouples Uprate (FK5K)

Two options are now available for replacement exhaust thermocouple kits:

- Option FK5P Connector Design
- Option FK5K Short-Lead Design

The connector design exhaust thermocouples have head design that reduces the likelihood of damage from improper applied torque or wiring; and special torque wrenches are no longer required for installation. This design also eliminates the need to replace the thermocouple from radiation shield to junction box, and eliminates mechanical destruction of TC due to over-tightening of Swagelok fitting. It also provides for more positive bottoming of TC in the radiation shield, thereby reducing breaking of the TC tip. It has reduced installation time and reduced wear/tear due to its quick disconnect arrangement.

The short-lead thermocouple splits the thermocouple device and the thermocouple wiring that goes to the outside junction box into two parts. This makes the first connection point at the thermocouple head instead of at the junction box. The modification kits for either the long lead or the short lead include the frame size specific number of thermocouples, special tools, and all the necessary hardware to install the modification.

The short-lead exhaust thermocouple provides a more positive bottoming of the thermocouple in the radiation shield. The flex leads are not as susceptible to damage from shipping, handling, and installation. However, the biggest advantage is eliminating the need to replace the thermocouple from the radiation shield to the junction box because the lead (thermocouple cable) and the

thermocouple device are two separate parts. For a thermocouple failure, the thermocouple is disconnected and removed at the radiation shield, the cable is left in place, and then the new thermocouple is inserted and reconnected. This significantly reduces the labor hours to replace an exhaust thermocouple.

### Exhaust Frame Uprate (FS1W)

For MS9001B and E units, the exhaust frame diffuses high temperature exhaust gas through the exhaust plenum. The frame consists of an inner forward diffuser, an outer forward diffuser, an aft exhaust diffuser, and a turning vane sub-assembly. (See *Figure 80*.)



**Figure 80.** Improved exhaust frame.

This modification package includes the following as appropriate: improved cooling air circuit; increased exhaust frame blower capacity; upgraded covers and gaskets for horizontal joints; upgraded forward flex seals; stress relief scallops; turning vane enhancements; improved aft diffuser supports; and improved after diffuser stress relief. These modifications improve exhaust frame cooling, reduce general repair costs, and address load tunnel over-temperature issues by reducing exhaust gas leakage.

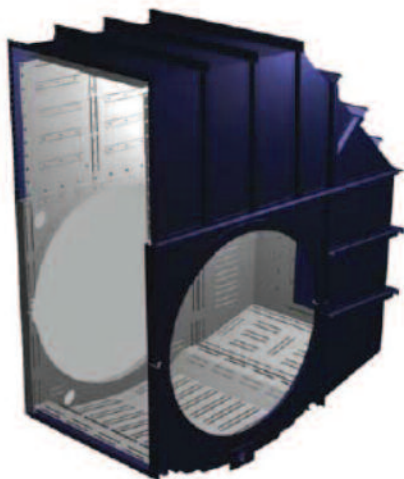
The benefits of this uprate are:

- Enhanced exhaust frame for MS9001B and E units (FT6X, FT6Y) firing temperature uprates
- Enhanced exhaust frame cooling
- Reduced repair costs
- Reduced exhaust gas leakage (addressing load tunnel over-temperature issues)



### Advanced Exhaust Plenum Uprate (FD4K)

To ensure that customers have access to high quality gas turbine exhaust plenums, GE Energy makes retrofit, re-designed exhaust plenums part of its product offerings. (See *Figure 81*.) Over time, exhaust plenums experience hot flanges and outer skin problems. Excessive thermal movement contributes to destruction of control cables and severe turbulence that can cause liner damage.



**Figure 81.** Improved exhaust plenum.

The re-designed plenums include: drainable liner floor with optional jacking port; double sealed wing door; cool shell and cool flange; designed to be installed with the turbine rotor and aft diffuser in place (not removed); and an internal floating liner design.

### Summary

GE has advanced technology uprate packages available to uprate MS9001B and E gas turbines. These advanced uprate technology packages provide significant savings derived from reduced maintenance, improved efficiency, higher output, better reliability, and life extension. Regulatory requirements may necessitate the need for emission controls due to changes in emission levels when uprating the gas turbine, and modifications are available to significantly reduce emissions. Today's technology and enhanced production components allow customers to bring their aging turbines back to better-than-new condition based upon these offerings.

- GE Energy has advanced technology uprate packages available to uprate all MS9001 Heavy-Duty Gas Turbines to improve their performance, efficiency, and reliability
- Uprates are available to increase maintenance intervals and reduce repairs

*\* Mark V, Mark I, Mark VI, Extendor, GT-29, GT-29 IN, GT-29 IN Plus, GT-29 Plus, GTD-111, GTD-222, GTD-222+, GTD-241, GT-33, GT-33 IN, GTD-741, Plasmaguard, and ETBC are trademarks of General Electric Company. Hastelloy-X™ is a trademark of Cabot Corp.*

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## List Of Figures

- Figure 1. MS9001E Simple-cycle single-shaft heavy duty gas turbine.
- Figure 2. Benefits of uprates offered.
- Figure 3. NO<sub>x</sub> emissions levels at 15% O<sub>2</sub>.
- Figure 4. MS9001 E-Class performance history.
- Figure 5. Gas turbine alloys.
- Figure 6. Creep stress rupture comparison of bucket and nozzle materials.
- Figure 7. Uprates available for 9B and 9E units.
- Figure 8. GTD-450 reduced camber high-flow variable IGV arrangement.
- Figure 9. Design improvements with GTD-450 high flow IGVs.
- Figure 10. HPP brush seal.
- Figure 11. Brush seals for #2 bearing.
- Figure 12. Side view of the three stages of shrouded compressor blades.
- Figure 13. CM/U analysis for a specific unit showing need for shrouded design.
- Figure 14. Improved slot-cooled liner versus original louvered liner.
- Figure 15. Thermal barrier coating.
- Figure 16. Slot-cooled combustion liner; cutaway view.
- Figure 17. MS9001E combustion system comparison.
- Figure 18. Comparison of old and new transition piece aft brackets.
- Figure 19. Nimonic 263™ transition piece.
- Figure 20. Nimonic 263™ transition piece illustrating downstream aft end coated inside only with TBC.
- Figure 21. Areas of combustion system that are Extendorized.
- Figure 22. Extendor technology lengthens maintenance intervals.
- Figure 23. Modifications for 9E Extendor.
- Figure 24. Increased inspection intervals for 9E Extendor.
- Figure 25. MS9001 E-Class dry low NO<sub>x</sub> combustion system.
- Figure 26. Dry low NO<sub>x</sub> combustor.
- Figure 27. Fuel-staged DLN operating modes.

- Figure 28. MS9001EA Dry Low NO<sub>x</sub> combustion system.
- Figure 29. DLN fuel system.
- Figure 30. New stage 1 buckets have material and design improvements.
- Figure 31. Types of bucket coatings.
- Figure 32. Sharp and blunt leading edge bucket designs.
- Figure 33. MS9001E stage 2 air-cooled bucket.
- Figure 34. Scalloping of bucket shroud.
- Figure 35. Final configuration of bucket shroud.
- Figure 36. Improved stage 2 bucket.
- Figure 37. Non air-cooled GTD-111 buckets have better creep properties.
- Figure 38. Improved stage 3 buckets.
- Figure 39. Machining required on stage 3 shroud.
- Figure 40. Comparison of 9B and 9E stage 1 nozzles.
- Figure 41. Cracked stage 1 nozzle.
- Figure 42. Stage 1 nozzle airfoil pressure-side-film cooling modification.
- Figure 43. Stage 1 nozzle airfoil pressure-side-film cooling.
- Figure 44. Stage 1 nozzle improved sidewall sealing with chordal hinge.
- Figure 45. Stage 1 nozzle improved cooling outer sidewall film cooling
- Figure 46. First stage nozzle improved inner sidewall tangential support.
- Figure 47. First stage nozzle and support ring with no tangential hardware.
- Figure 48. Improvements in upgraded stage 1 nozzle for 9B and 9E units.
- Figure 49. Stage 1 nozzle with enhanced TBC.
- Figure 50. Design changes and reduced airflow in non-pressurized stage 2 nozzle.
- Figure 51. Long and short chord nozzle design comparison.
- Figure 52. Nozzle creep deflection comparison.
- Figure 53. Reduced cooling flow gives increased output.
- Figure 54. Benefits of GTD-222+ nozzles as compared to FSX-414 nozzles.
- Figure 55. Improved stage 3 nozzle.
- Figure 56. Advanced Aero Stage 3 Nozzle.
- Figure 57. New stage 3 bucket design.
- Figure 58. Performance benefit when Advanced Aero Stage 3 Bucket and Nozzle are combined on same unit.
- Figure 59. Advanced Aero Stage 3 Bucket.
- Figure 60. First stage shroud with cloth seals FS2Y.
- Figure 61. HR-120™ Improved Stage 1 Shroud.
- Figure 62. Stage 1 shrouds coated with abradable coating.
- Figure 63. Abradable coating increases performance when rotor is not 100% aligned or casing is out of round.
- Figure 64. Stage 2 shroud blocks with honeycomb and stage 2 buckets with cutter teeth.
- Figure 65. Shroud block with honeycomb sealing.
- Figure 66. 7EA stage 2 honeycomb inner shroud design.
- Figure 67. 7EA stage 2 brush seal inner diaphragm design.
- Figure 68. Installed interstage brush seal.
- Figure 69. RCA of cracking at third stage hook fit.
- Figure 70. MS9001E component design improvement examples.
- Figure 71. MS 9001 E-Class uprate options.
- Figure 72. Uprating a 9B to a 9E.
- Figure 73. Uprating a 9B to a 9E.
- Figure 74. Uprating a 9B to a 9E.
- Figure 75. Frame 9 uprate options output increases.
- Figure 76. Frame 9 uprate options heat rate decreases.
- Figure 77. Typical MS9001B to E uprate performance study.
- Figure 78. Bore plugs are used to fine-tune cooling air to the first wheel space.
- Figure 79. Requirements for uprate to 2055°F.
- Figure 80. Improved exhaust frame.
- Figure 81. Improved exhaust plenum.







