GE Energy

Uprate Options for the MS6001 Heavy-Duty Gas Turbine

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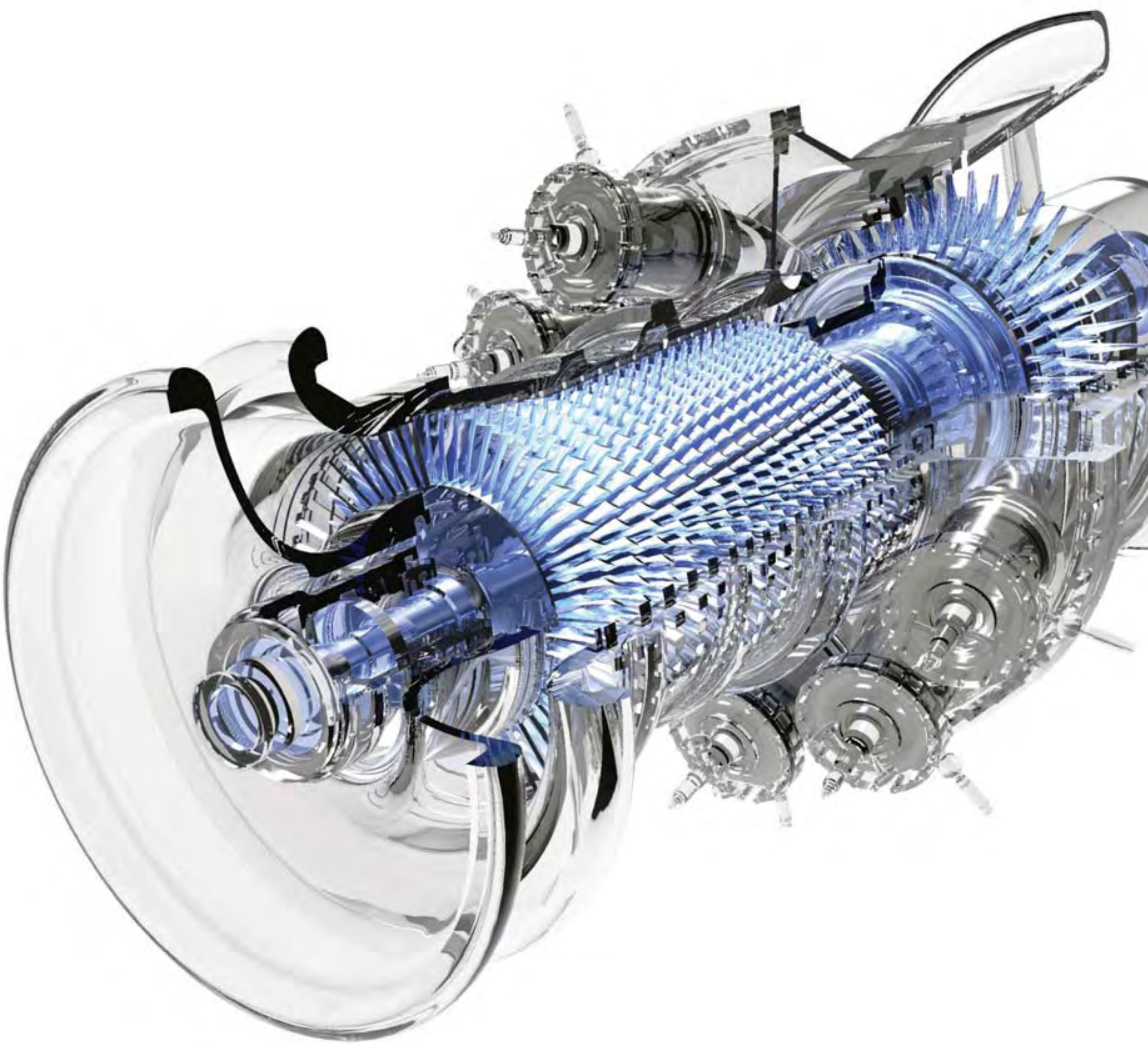

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Note: All values in this GER are approximate and subject to contractual terms.

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Abstract

Since its introduction in 1978, advances in materials, cooling, and design have allowed GE MS6001 turbines to be operated with higher firing temperatures and greater airflows. These advances have resulted in higher turbine output, improved efficiency, better reliability, and increased availability. In addition, recent improvements in combustion technology have made significantly lower emission levels achievable for operators of MS6001 turbines.

The MS6001 heavy-duty gas turbine has undergone a series of uprates since its original introduction into the market in 1978. *(See Figure 1.)* These uprates are made possible by the technology advances in the design of new machines based on information accumulated through millions of fired hours and GE's on-going engineering development programs. This development work has resulted in many improvements that are now available to operators of MS6001 units.

Turbine Model	Ship Dates	Firing Temp. °F/°C	Output† kW	Heat Rate† BTU/kWhr	Exh Flow 10 x 3lb/hr	Exh Temp °F/°C
MS6431A	1978	1850/1010	31.050	11,220	1,077	891/477
MS6441A	1979	1850/1010	31,800	11,250	1,112	901/483
MS6521B	1981	2020/1104	36,730	11,120	1,117	1017/547
PG6531B	1983	2020/1104	37,300	10,870	1,115	1005/541
PG6541B	1987	2020/1104	38,140	10,900	1,117	999/537
PG6551B	1995	2020/1104	39,120	10,740	1,137	1003/539
PG6561B	1997	2020/1104	39,620	10,740	1,145	989/532
PG6571B††	1997	2077/1136	40,590	10,600	1,160	1005/541
PG6581B	2000	2084/1140	41,460	10,724	1,166	1016/546

† ISO with distillate fuel, STD combustor, no inlet or exhaust losses.
†† Available as retrofit only.

Figure 1. Evolution of the MS6001 gas turbine

This document discusses design advances in critical components, and how the latest GE-owned technology can be applied to enhance performance, extend life, and provide economic benefits through increased reliability and maintainability of operating MS6001 turbines. *(See Figure 2.)* It also discusses where the latest technology advances can be applied to enhance the performance, extend the life and provide economic benefits from increased reliability and maintainability of all earlier MS6001 turbines. All of these uprates can be applied as a single project or individually phased in over time.

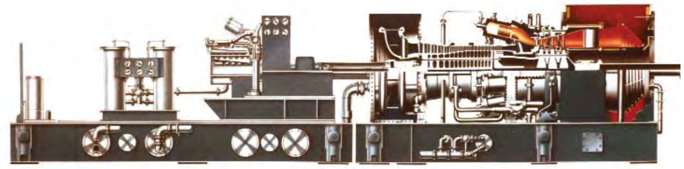


Figure 2. MS6001 simple-cycle, single-shaft heavy-duty gas turbine

Overview

In today's deregulated market, owners/operators of all gas turbines need to improve the performance of their assets. In many cases it can prove economically attractive to modernize and uprate their installed fleet of turbines. This document covers new uprates that have been successfully developed using components engineered for new unit production, or developed for units in operation. The MS6001 gas turbine can be improved in the areas outlined in *Figure 3*. If the gas turbine is installed in a combined-cycle plant, then uprates applied to the turbine can be chosen to enhance the complete plant performance.

Uprates are made possible as a result of GE's underlying design philosophy to maintain interchangeability of components for a given frame size, which can enable components to be installed in earlier vintage units with little or no modifications. Installing the latest technology hardware and taking advantage of the highest

MS6001B Uprate Technology Program

- Increase airflow
- Increase firing temperature
- Performance output and heat rate improvements
- Increase turbine speed
- Reduce parasitic leakage and cooling flows
- Extend inspection intervals
- Improve availability and reliability
- Parts life extension
- Reduce emissions

Figure 3. Overview of available improvements

firing temperatures allows owners and operators to remain competitive in the marketplace. Virtually every key component in the MS6001 series, illustrated in *Figure 4*, has gone through significant design improvements since the first MS6001A was shipped. Buckets, nozzles, shrouds and combustion components have undergone multiple evolutions based on new designs, manufacturing techniques, materials and field experience.

Advanced design technology is usually introduced for new unit production and subsequently applied by an uprate program to customer-operated gas turbines. Many new uprates have been introduced for installed GE-designed heavy-duty gas turbines. These uprates are most applicable to older units, such as the PG6541 configured unit illustrated in *Figure 5*, where the largest gains in output and heat rate improvements can be made.

As illustrated in *Figure 6*, each uprate provides one or more of the following: increased output; improved heat rate and efficiency; improved reliability; reduced maintenance costs; longer inspection

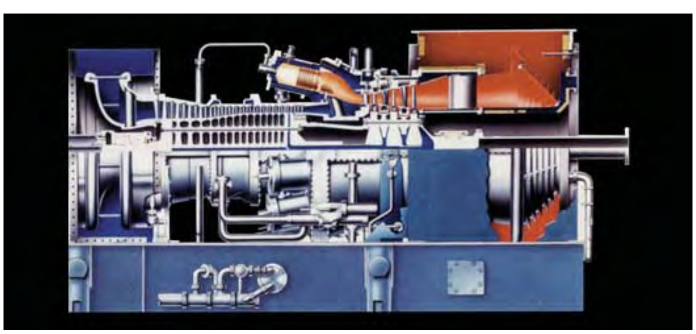


Figure 4. Cross section of MS6001 gas turbine

Typical Older Technology Configuration	
Stage 1 Shroud	310 SS with 'Pumpkin Tooth'
Stage 2 Shroud	Non-Honeycomb Shroud
Stage 3 Shroud	Non-Honeycomb Shroud
Stage 1 Nozzle	FSX-414, Not Improved Cooled
Stage 2 Nozzle	FSX-414 Material
Stage 3 Nozzle	FSX-414 Material
Stage 1 Bucket	GTD-111*, 12 hole, BLE/DS, GT-29* IN+
Stage 2 Bucket	IN-738™, 4 hole, Non-Cutter Tooth Design (see TIL 1203)
Stage 3 Bucket	U500™, Non-Cutter Tooth Design
Inlet Guide Vanes (IGV)	403 SS Material, 84° Maximum Angle
Transition Piece	Hastelloy-X™ Body and Aft-Frame with TBC
Liner	Standard Combustion Design Without TBC
Inner Barrel	Standard Labyrinth Seal Design
Load Gear	5094 RPM Load Gear with 51 MW Limit
Firing Temperature	2020°F
*Based on typical PG6541 model configuration.	

Figure 5. Typical currently installed parts on PG6541 configured machines

intervals; or longer parts lives. Some uprates are based on current production components that are not always unique to older machines, and thus are readily available.

MS6001B Uprate Technology Program

Advanced Technology

- Materials
- Coatings
- Cooling
- Sealing
- Aircraft Engine technology

Providing...

Advanced Performance

- Increased output
- Improved heat rate
- Increased reliability and availability
- Reduced maintenance costs
- Reduced emissions

Figure 6. GE offers advanced technology uprates that provide for the needs of our customers

Affordable Uprates

Uprates can make good investments, with many exhibiting prompt payback for a specific operator. While each turbine application must be evaluated on its own merits, many 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. An example of a +35°F firing temperature increase is illustrated in *Figure 7*.

MS6001B +35°F Uprate Example

- GTD-111 DS, perimeter cooled stage 1 bucket (FS4A)
- Advanced cooled IN-738™ stage 2 bucket (FS4B)
- Improved cooling stage 1 nozzle with chordal hinge (FS2J)
- GTD-222* reduced cooling stage 2 nozzle (FS1P)
- GTD-222 stage 3 nozzle (FS1R)
- HR-120™ stage 1 shroud (FS2Y)
- GTD-450* reduced camber IGVs (pre-1987) (FT4C)
- Uprate transition piece with cloth seals (FR2B)
- Extendor* combustion system (includes TBC coated liners)

Most requirements are part of normal maintenance plan improve performance with uprate parts in place of normal spares

Figure 7. Example of +35°F firing temperature increase

Reduced or Increased Emission Levels After Uprating

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. Individual site requirements and specific emission levels can be provided in an uprate study supplied to GE customers through GE Sales.

Upgraded Control Systems

MS6001 gas turbines have been shipped with Mark* II, Mark IV and Mark V control systems. These systems can be upgraded to the latest Mark VI or Mark VIe control system. Full details of the Mark VI control system can be found in *GER-4193*. Mark VI turbine control system upgrades can offer much improved gas turbine reliability with:

- Digital control
- Triple modular redundancy (TMR)
- Protection against loss of availability of spares

Performance Guarantees and Turbine Degradation

Performance uprates discussed in this GER are based on airflow or firing temperature increases directly related to performance increases, expressed as a percentage (delta) of increase. Quantifying turbine performance degradation can be difficult due to lack of consistent and valid field data. In addition, several variables exist—including site conditions and maintenance characteristics, and operation modes that affect turbine performance and degradation trends. Delta upgrades, providing a performance change, are consistent with or without turbine degradation factors. Absolute performance guarantees must factor in degradation losses to calculate the final expected performance level. Therefore, absolute performance guarantees offered usually appear slightly different than delta percentage changes in order to account for turbine degradation.

Flange-to-Flange Replacement

GE offers replacement of the entire unit, including the compressor, combustor, turbine, and exhaust shipped as a single piece (called flange-to-flange replacement). Customers with older units that desire to install the very latest technologies described here can place orders for a MS6001B flange-to-flange replacement that has pre-installed any/all of the uprate options described herein.

Example Uprates

Figure 8 and *Figure 9* illustrate examples of improvements typical of GE uprates offered for operators of units configured as PG6531, 41, 51 and 61. *Figure 10* and *Figure 11* denote uprates needed whenever firing temperature is increased by +42°F. Units lacking

Gas Turbine Output Improvements	Source Book	Required for 2084°F Tfire	PG6531B	PG6541B	PG6551B	PG6561B
GTD-450 reduced camber IGVs (84 dga)	FT4C	X	1.50			
GTD-222/ GTD-222+ Stage 2 Nozzle	FS1P	X	1.00	1.00		
Stage 2 Honeycomb Shroud	FS2T		0.35	0.35		
Stage 3 Honeycomb Shroud	FS2U		0.25	0.25		
86° IGV Setting	FT4M		0.40	0.40		
5163 RPM Load Gear†	FP4E		1.10	1.10	1.10	0.50
High Pressure Packing Brush Seal	FS2V		0.75	0.75	0.75	0.75
Stage 2 Nozzle Interstage Brush Seal	FS2Z		1.00	1.00	1.00	1.00
Stage 1 Shroud Abradable Coating	FS6A		0.70	0.70	0.70	0.70
Stage 1 Shroud with Cloth Seals	FS2Y	X	1.05	1.05	1.05	1.05
Improved Cooling Stage 1 Nozzle	FS2J	X				
Advanced Aero Stage 3 Bucket and Nozzle	FS4K-L		1.00	1.00	1.00	1.00
Increase Tfire to 2084°F	FT4P	X	3.20	3.20	3.20	3.20
GTD-111 DS Perimeter Cooled Stage 1 Bucket	FS4A	X				
Improved Cooling 6 Hole Stage 2 Bucket	FS4B	X				
IN-738™ Stage 3 Bucket	FS2K	X				
GTD-222/ GTD-222+ Stage 3 Nozzle	FS1R	X				
Uprate Transition Piece with Cloth Seals	FR2B	X				
TBC Liners	FR1G	X				
Total Expected Percentage Output Improvement			**12.30**	**10.80**	**8.80**	**8.20**
† 50 Hz GE supplied load gear						

Figure 8. Examples of available output improvements

Gas Turbine Heat Rate Improvements	Source Book	Required for 2084°F Tfire	PG6531B	PG6541B	PG6551B	PG6561B
GTD-450 reduced camber IGVs (84 dga)	FT4C	X	-0.30			
GTD-222/ GTD-222+ Stage 2 Nozzle	FS1P	X	-0.40	-0.40		
Stage 2 Honeycomb Shroud	FS2T		-0.35	-0.35		
Stage 3 Honeycomb Shroud	FS2U		-0.25	-0.25		
86° IGV Setting	FT4M		0.20	0.20		
5163 RPM Load Gear†	FP4E		-0.07	-0.07	-0.07	
High Pressure Packing Brush Seal	FS2V		-0.50	-0.50	-0.50	-0.50
Stage 1 Shroud Abradable Coating	FS6A		-0.70	-0.70	-0.70	-0.70
Stage 2 Nozzle Interstage Brush Seal	FS2Z		-0.50	-0.50	-0.50	-0.50
Stage 1 Shroud with Cloth Seals	FS2Y	X	-0.45	-0.45	-0.45	-0.45
Improved Cooling Stage 1 Nozzle	FS2J	X				
Advanced Aero Stage 3 Bucket and Nozzle	FS4K-L		-1.00	-1.00	-1.00	-1.00
Increased Tfire to 2084°F	FT4P	X	-0.20	-0.20	-0.20	-0.20
GTD-111 DS Perimeter Cooled Stage 1 Bucket	FS4A	X				
Improved Cooling 6 Hole Stage 2 Bucket	FS4B	X				
IN-738™ Stage 3 Bucket	FS2K	X				
GTD-222/ GTD-222+ Stage 3 Nozzle	FS1R	X				
Uprate Transition Piece with Cloth Seals	FR2B	X				
TBC Liners	FR1G	X				
Total Expected Percentage Heat Rate Improvement			**-4.52**	**-4.22**	**-3.42**	**-3.35**
† 50 Hz GE supplied load gear						

Figure 9. Examples of available heat rate improvements

Gas Turbine Output Improvements	Source Book	Required for 2084°F Tfire	% Change in Exhaust Energy
GTD-450 reduced camber IGVs (84 dga)	FT4C	X	0.90
GTD-222/GTD-222+ Stage 2 Nozzle	FS1P	X	0.50
Stage 2 Honeycomb Shroud	FS2T		-0.20
Stage 3 Honeycomb Shroud	FS2U		-0.20
86° IGV Setting	FT4M		0.70
5163 RPM Load Gear†	FP4E		1.00
High Pressure Packing Brush Seal	FS2V		0.20
Stage 2 Nozzle Interstage Brush Seal	FS2		0.40
Stage 1 Shroud with Cloth Seals	FS2Y	X	-0.30
Improved Cooling Stage 1 Nozzle	FS2J	X	
Advanced Aero Stage 3 Bucket and Nozzle	FS4K-L		-0.50
Increase Tfire to 2084°F	FT4P	X	2.90
GTD-111 DS Perimeter Cooled Stage 1 Bucket	FS4A	X	-
Improved Cooling 6 Hole Stage 2 Bucket	FS4B	X	-
IN-738™ Stage 3 Bucket	FS2K	X	-
GTD-222/GTD-222+* Stage 3 Nozzle	FS1R	X	-
Uprate Transition Piece with Cloth Seals	FR2B	X	-
TBC Liners	FR1G	X	-
Total Change in Exhaust Energy			**6.00**
† 50 Hz GE supplied load gear			

Figure 10. Examples of change in exhaust energy after installed uprates

Components Required for Increase in Firing Temperature to 2084°F (FT4P)	Source Book
GTD-450 IGVs (pre-1987 units)	FT4C
Improved Cooling Stage 1 Nozzle	FS2J
GTD-111 DS Perimeter Cooled Stage 1 Bucket	FS4A
Stage 1 HR 120 Shroud with Cloth Seals	FS2Y
GTD-222/GTD-222+ Stage 2 Nozzle	FS1P
Improved Cooling 6 Hole Stage 2 Bucket	FS4B
GTD-222/GTD-222+ Stage 3 Nozzle	FS1R
IN-738™ Stage 3 Bucket	FS2K
Uprate Transition Piece with Cloth Seals	FR2B
TBC Liners	FR1G
S17 Protection (Counterbore Covers and Operating Restrictions)	

Figure 11. Uprates needed in unit before it can be uprated to 2084°F Tfire

some but not all of the required parts only need to uprate those parts not already uprated in the unit. Note that there exist different rotor speeds for 50 Hz and for 60 Hz applications, due to different load gear ratios. Please contact GE for the performance impact of each design, when uprating with the latest load gear speeds.

History

The MS6001 gas turbine is a single-shaft, two-bearing unit designed for either 50 Hz or 60 Hz power generations. Since its introduction, more than 1000 of these units have been shipped by GE and its manufacturing/business associates. Operating worldwide in both simple-cycle and combined-cycle modes, these gas turbines have proven to be very robust and reliable machines. Many design improvements have been made to bring it to the current AO (Advanced Order) model list definition PG6581B.

As illustrated in *Figure 12*, the MS6001 fleet has historically operated as a base-loaded or cyclic-duty machine, with a small minority of units operating as peakers. Uprates discussed in this document are applicable to improve all three categories of operation.

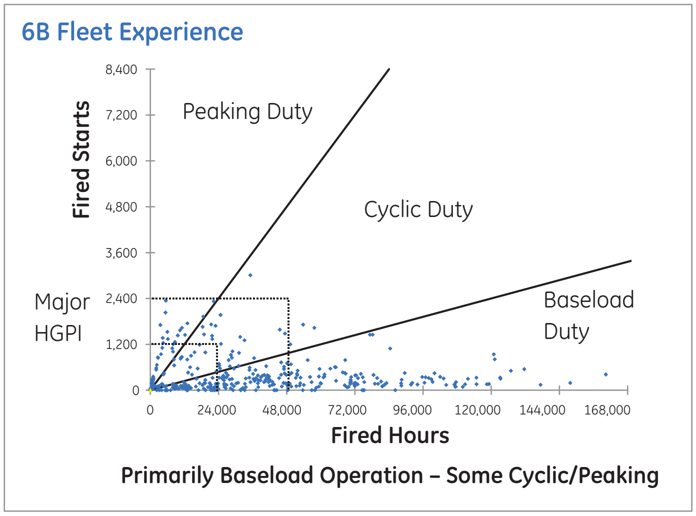


Figure 12. Historical operation of the MS6001 fleet

Virtually every key component in the MS6001 series has gone through significant design improvements since the first MS6001A was shipped in 1978. Buckets, nozzles, shrouds, and combustion components have undergone multiple evolutions based on new designs, improved manufacturing techniques, new materials, and acquired field experience. *(See Figure 13.)*

MS6001 Development

1978

- Introduced by scaling from the successful MS7001E

1987

- Increased airflow and reduced cooling
- GTD-450 high flow IGV
- Blunt leading edge stage 1 bucket
- Universal stage 1 nozzle

1997

- "Advanced technology"
- Speed
- Improved materials; firing temperature
- Improved cooling/sealing

2000

- "PG6581B"
- Speed
- Improved cooling; firing temperature

Figure 13. History of MS6001 gas turbine development

Originally introduced in 1978, the MS6001A gas turbine was scaled from the successful MS7001E gas turbine and had a modest firing temperature of 1850°F. It was upgraded almost immediately (in 1981) to the MS6001B machine with a firing temperature of 2020°F. *Figure 14* illustrates the product line evolution for the MS6001.

The PG6541B rating was introduced in 1987 with several improvements to increase airflow through the gas turbine and reduce cooling and sealing losses, including:

- Blunt leading edge 1st stage buckets
- GTD-450 – high flow IGV (angle 84°)
- Inboard (Universal) 1st stage nozzle.

As illustrated in *Figure 15*, compressor-related secondary flows were re-designed during the evolution of the PG6541B to increase its performance. Note that in *Figure 15*, the frame cooling air exits out two (2) aft ports. (*See also Figure 18*).

In 1995 GE conducted an uprate program for the MS6001 to ensure that it remained a competitive option for owners/operators. This program's main features were:

- Improved cooling and sealing features
- Improved materials
- Increased speed
- Improved turbine aerodynamics
- Increase in firing temperature

The 1997 follow-on Advanced Technology Program brought the MS6001 up to the PG6571B rating. This rating was only available as a retrofit package. In 1999, engineering teams in the US and France combined designs and developed the PG6581B rating, which remains the latest and most current configuration with the highest available firing temperature from GE.

	MS6431(A)	MS6441(A)	MS6521(B)	PG6531(B)	PG6541(B)	PG6551(B)	PG6581(B)
Output	31050 kW	31800 kW	36730 kW	37300 kW	38140 kW	39120 kW	41090 kW
HR	11220 Btu/kWh	11250 Btu/kWh	11120 Btu/kWh	10870 Btu/kWh	10900 Btu/kWh	10740 Btu/kWh	10740 Btu/kWh
Press Ratio	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	12.2
Firing Temp	1850°F	1850°F	2020°F	2020°F	2020°F	2020°F	**2084°F**
Comp Stages	17	17	17	17	17	17	17
Turbine Stages	3	3	3	3	3	3	3
Op Date	1978	1979	1981	1983	1987	1995	2000
Installed Fleet	61A = 9				61B = 894		

Figure 14. Evolution of the MS6001 fleet of A and B models

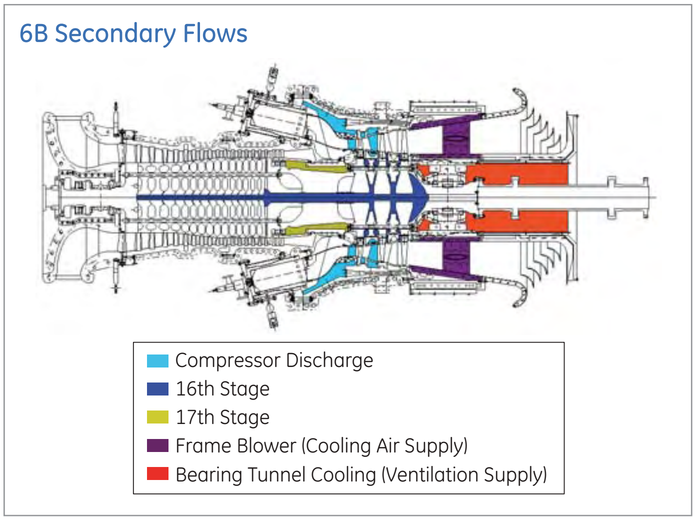


Figure 15. Secondary flows that evolved in MS6001B to increase its performance

PG6581B Model History

In 1997, GE decided to uprate their current production MS6001 PG6551B model to the 5163 RPM turbine speed. Output and efficiency improvements were achieved by:

- Increasing firing temperature to 2084°F/1140°C.
- Reducing leakages in the hot gas path
- Reducing inlet and exhaust pressure losses

These improvements were introduced in three steps to achieve the PG6BEV2 model rating. See *Figure 16* for each of the improved features.

After the acquisition of GE's French engineering team in June 1999, engineering teams in the US and France conjoined ideas and developed the current and latest PG6581B rating. The final configuration of the PG6581B is a uniting of the PG6BEV2 developed in France and the PG6571B that was developed as part of GE's CM&U uprate program in the United States. See *Figure 17* and *Figure 18* for the final PG6581B configuration. The major differences from the PG6571B model are:

- 13th compressor stage extraction for stage 2 nozzle cooling (*See Figure 19*)
- High performance exhaust diffuser (*see Figure 21)*

Re-designing the MS6001 gas turbine achieved an increase of 6% in output and a decrease of 0.6% in heat rate—resulting in improved MS6001 competitiveness in today's deregulated market.

See *Figure 20* for a performance comparison between the PG6561B and the PG6581B models.

Option	6561B	6BEV-	6BEV2
Speed Increase			
Increase in speed to 5163 rpm	X	X	X
Pressure Losses Reduction			
Vertical inlet	X	X	X
High performances exhaust diffuser		X	X
Leakages Reduction			
Outer sealing strips on S1 Nozzle			X
Chordal hinge on S1 Nozzle			X
Braided seal on stage 1 shroud			X
HPP seal improvement (brush seals)			X
Increase in Firing Temperature			
Increase in firing temp. (1140°C)			X
S1 Bucket – GTD-111 DS, turbulators			X
S2 Bucket – GTD-111, turbulators		X	X
S1 Nozzle – Improved cooling			X
S2 Nozzle – New engine			X
13th Stage bleed and improved shroud cooling		X	X
Combustion			
Dry low NOx using natural gas			X
Dry low NOx using distillate			X
Combustion Life Extendor			X

Figure 16. AGT PG6561B/6BEV-/6BEV2 improved features

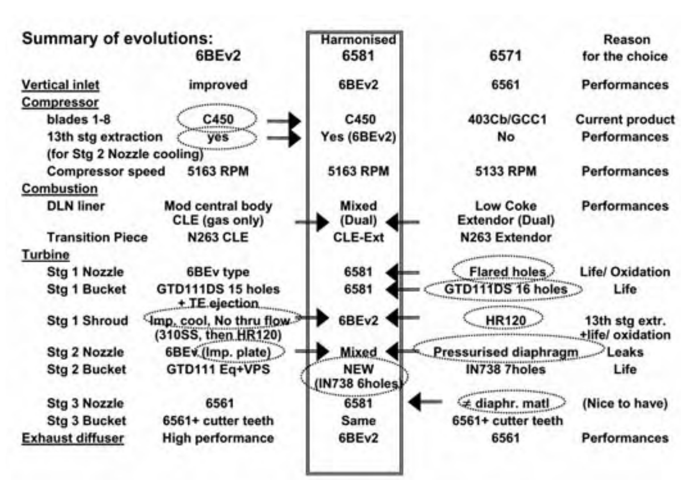


Figure 17. PG6581B configuration 6BEV2 and PG6571B harmonization

6581 Upgraded Components

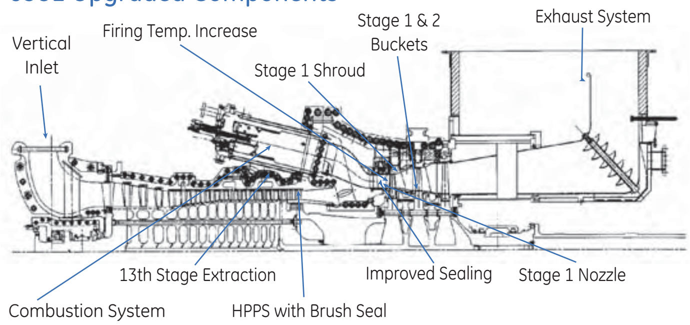


Figure 18. PG6581B upgraded components

Stage 13 Extraction

- **Compressor discharge casing**
  - Bleed belt incorporated into casing

- **Extraction system pipework**
  - Turbine casing: bosses for pipe flange attachment
  - Second stage nozzle cooling with radiation shield

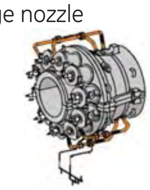


Figure 19. 13th compressor stage extraction for stage 2 nozzle cooling

Performance Data Comparison		
	PG6561B(†)	**PG6581B(††)**
Output	39,640 KW	42,100 KW
Heat Rate (LHV)	11295 kJ/kWh	11227 kJ/kWh
Pressure Ratio	12.03 : 1	12.2 : 1
Exhaust Flow	525 t/h	530 t/h
Exhaust Temp	531°C	548°C

(†) ISO conditions, Methane, STD combustor 4/2.5 inlet/exhaust pressure drop
(††) ISO conditions, Methane, STD combustor, 2.55/2.52 inlet/exhaust pressure drop

Figure 20. Performance data comparison between PG6561B and PG6581B model

PG6581B Improved Exhaust Aft Diffuser

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 subassembly.

The improved aft diffuser installed on PG6581B units includes: improved cooling air circuit; upgraded covers and gaskets for horizontal joints; upgraded forward flex seals; stress relief scallops; turning vane enhancements; improved aft diffuser supports; and improved aft 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.

Note that this larger aft diffuser will not fit inside older vintage MS6001B units due to its increased dimensions.

Exhaust Diffuser

- Improved performances in reducing exhaust pressure losses
- Reduced design change:
  - Same shaft line level and length
  - Same generator interface
  - Same exhaust casing and struts
- Two configurations available
  - Lateral and vertical exhaust

Figure 21. Improved PG6581B aft diffuser

PG6581B Installed Fleet

The first shipment of the newest model PG6581B unit was in September 2000. See *Figure 22* for examples of selected installed 6BEV2 and 6581B units.

Country	Ex Works	Model	Comments
France	5/28/1999	6BEv2	DLN1 (gas only)
Spain	10/14/1999	6BEv2	STD (dual fuel)
Spain	11/18/1999	6BEv2	STD (dual fuel)
France	1/19/2000	6BEv2	DLN1 (gas only)
France	1/31/2000	6BEv2	DLN1 (gas only)
Spain	5/29/2000	6BEv2	STD (dual fuel)
Wisconsin/USA	8/29/2000	6BEv2	DLN1 (dual fuel)
Wisconsin/USA	9/14/2000	6BEv2	DLN1 (dual fuel)
Philadelphia/USA	11/30/2000	6581B	DLN1 (gas only)
Philadelphia/USA	11/30/2000	6581B	DLN1 (gas only)
Philadelphia/USA	11/30/2000	6581B	DLN1 (gas only)
Philadelphia/USA	10/11/2000	6581B	DLN1 (gas only)
Philadelphia/USA	10/11/2000	6581B	DLN1 (gas only)
Philadelphia/USA	10/20/92000	6581B	DLN1 (gas only)
Philadelphia/USA	6/13/2001	6581B	DLN1 (gas only)
Philadelphia/USA	6/26/2001	6581B	DLN1 (gas only)
Philadelphia/USA	7/16/2001	6581B	DLN1 (gas only)
Philadelphia/USA	7/25/2001	6581B	DLN1 (gas only)
Philadelphia/USA	8/21/2001	6581B	DLN1 (gas only)
Philadelphia/USA	9/12/2001	6581B	DLN1 (gas only)
Over 245 PG6581B Units Sold to Date			

Figure 22. Examples of PG6BEV2 and PG6581B units in their respective fleets

Maintenance

The maintenance schedule for MS6001 A/B units is based on publication *GER-3620 (Heavy-Duty Gas Turbine Operating and Maintenance Considerations)*. This advises on the types of maintenance required, the time between maintenance and all the factors that affect maintenance scheduling.

Figure 23 illustrates maintenance intervals for MS6001 units for the different firing temperatures and combustion systems. These intervals are based on the reference condition of gas fuel, no steam or water injection, and base load operation.

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

Summary of Recommended Combustion Inspection Intervals With and Without CL-Extendor*

Frame Size for Combustion Type	6541/51/61B (2042°F)				6571/81B (2077-2084°F)			
	Standard		DLN		Standard		DLN	
Non CL-Extendor								
Fired Starts	800	Service Factor	400	Service Factor	800	Service Factor	400	Service Factor
Factored Hours w/Standard T/P	12,000	Ref	12,000	Ref	NA		NA	
Gas, no inj. (dry)	12,000	1.0	12,000	1.0	NA		NA	
Gas, Ext. L-L (dry)	NA	NA	4,000	3.0	NA		NA	
Gas, w/stm inj.	12,000	1.0	NA	NA	NA		NA	
Gas, w/stm aug.	12,000	1.0	3,000	4.0	NA		NA	
Gas, w/water inj.	6,000	2.0	2,000	6.0	NA		NA	
Dist, no inj. (dry)	8,000	1.5	2,667	4.5	NA		NA	
Dist, w/stm inj.	8,000	1.5	NA	NA	NA		NA	
Dist w/stm aug.	8,000	1.5	NA	NA	NA		NA	
Dist, w/water inj	4,000	3.0	1,333	9.0	NA		NA	
CL-Extendor								
Fired Starts	800	Service Factor	400	Service Factor	800	Service Factor	400	Service Factor
Factored Hours w/Standard T/P†	24,000	Ref	24,000	Ref	NA		NA	Factored
Factored Hours† w/Advanced T/P (gas/dry)	NA		NA		24,000	Ref	24,000	Ref
Gas, no inj. (dry)	12,000	1.0	24,000	1.0	NA	1.0	24,000	1.0
Gas, Ext. L-L (dry)	NA	NA	8,000	3.0	NA	NA	8,000	3.0
Gas, w/stm inj.	24,000	1.0	NA	NA	24,000	1.0	NA	NA
Gas, w/stm aug.	24,000	1.0	6,000	4.0	24,000	1.0	6,000	4.0
Gas, w/water inj.	12,000	2.0	4,000	6.0	12,000	2.0	4,000	6.0
Dist, no inj. (dry)	16,000	1.5	5,333	4.5	16,000	1.5	5,333	4.5
Dist, w/stm inj.	16,000	1.5	NA	NA	16,000	1.5	NA	NA
Dist w/stm aug.	16,000	1.5	NA	NA	16,000	1.5	NA	NA
Dist, w/water inj	8,000	3.0	2,667	9.0	8,000	3.0	2,667	9.0

Notes:
† 24,000 is the goal for CL-Extendor which is expected to be validated from field experience

Figure 23. Maintenance intervals for combustion hardware in MS6001B

Conversions, Modifications, and Uprates

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. *Figure 24* illustrates uprates available to operators of MS6001B units.

Many of the design improvements for components involve a change in the materials used. *Figure 25* lists the composition of many of the gas turbine alloys discussed herein. In addition, the rupture stress for the bucket and nozzle materials is compared in *Figure 26*, illustrating the improvements associated with the new materials developed and offered in uprates. *Figure 27* illustrates

6B Uprate Opportunities

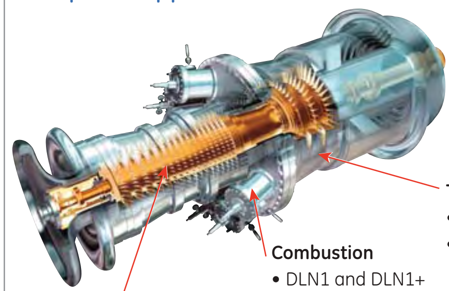


Figure 24. Overview of uprates offered by GE for MS6001B

Component	Nominal Composition (%)											
	Cr	Ni	Co	Fe	W	Mo	Ti	Al	Cb	V	C	B	Ta
Buckets													
U500™	18.5	BAL	18.5	-	-	4	3	3	-	-	0.07	0.006	-
Rene 77™ (U200™)	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
Nozzle													
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
Combustors													
SS309	23	13	-	BAL	-	-	-	-	-	-	0.1	-	-
Hastelloy-X™	22	BAL	1.5	1.9	0.7	9	-	-	-	-	-0.07	0.005	-
N-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	-
Turbine Wheels													
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	-	-
Compressor Blades													
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 25. Compressor and hot gas path turbine alloys

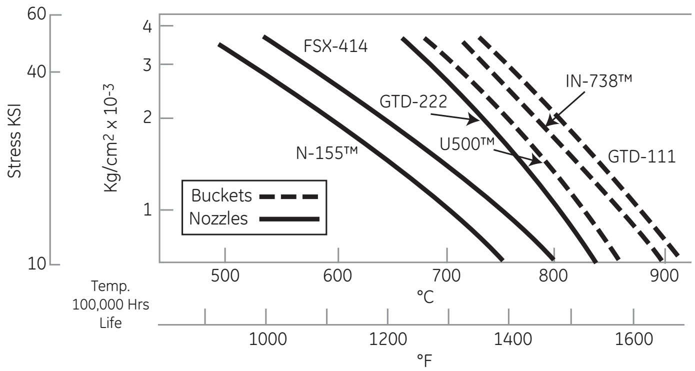


Figure 26. Creep stress rupture comparison of bucket and nozzle materials

how these materials are configured in the MS6001 hot gas path and unit rotor.

Note in *Figure 25* that 403+CB material for increased strength was introduced during 1999, whereas the original MS6001B (and all other models) had installed 403 compressor blades.

The Conversions, Modifications and Uprates (CM&U) program at GE offers a wide range of improvements for the installed fleet of GE turbines (all frame sizes and models). These CM&U improvements are offered as individual uprates, or can be applied in groups or packages. Each uprate is defined by a four-digit uprate code known as a "PED" code. *Figure 28* lists the CM&U uprate codes currently applicable for MS6001 gas turbines.

Uprate Experience

GE has successfully uprated numerous MS6001 units to the PG6571B model rating as illustrated by the MS6001 uprate experience illustrated in *Figure 29*. Many other customers have chosen to install current MS6001 new technology components as single spare part replacements, when their existing older technology components reached the end of their service life. This is done according to the customer's plan to increasing firing temperature when all components needed for the increase have been installed.

The first MS6001B firing temperature uprate to 2077°F/1136°C uprate was successfully completed in spring 1997. Because this was the first uprate of its kind, extensive testing was completed to monitor compressor and turbine performances. Successful testing

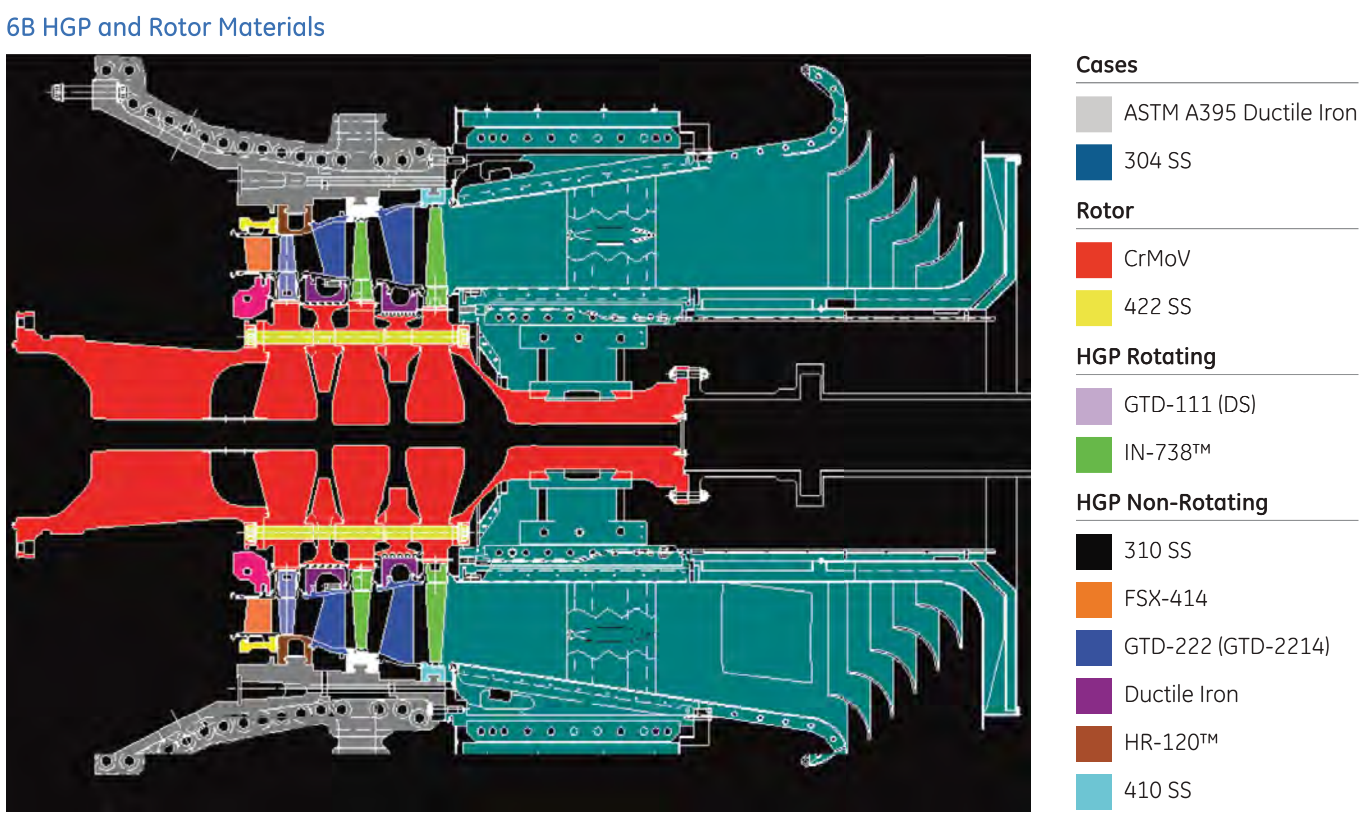


Figure 27. MS6001B hot gas path and rotor materials

Uprate	Description
FA1A	Convert To Gas Fuel Only
FA1S	Gas Fuel Change Study
FA2D	Add Fuel Pump Clutch
FA3D	Convert From Liquid To Dual Fuel
FC4A	Add Compressor Water Wash Off Line
FC4C	Add Turbine Water Wash
FC4D	Install Water Wash Skid
FD3A	Add Inlet Bleed Heat
FF1E	Uprate Turbine Compartment to Dual 100HP Fan
FF1K	ATEX Impact Assessment
FF2A	Add Flexible Pigtails for Fuel Gas
FF2B	Add Flexible Pigtails for Atomizing Air
FF3B	Supply Turbine Relocation Drawings Package
FG1A	Add Water Injection For Gas Or Dual Fuel Units
FG1B	Add Steam Injection for NOx Control in Gas or Dual Fuel Units
FG1C	Add Water Injection For Liquid Fuel Units
FG1F	Add Steam Injection for NOx Control in Liquid Fuel Units
FG2B	Uprate Combustion System to Dry Low NOx 1.0
FG2L	Uprate Combustion System to Dry Low NOx 1.0+
FG2R	E-Class Operational Flexibility
FJ3A	Add Manual Steam Injection For Power Augmentation
FJ3B	Add Automatic Steam Injection For Power Augmentation
FK5K	Replace Exhaust Thermocouples with Uprated Version
FN2E	Add Turbine Bearing Metal Thermocouples
FP1H	Add Dry Diaphragm Load Gear Coupling
FP4D/E	Uprate Speed Increase and Load Gear to 5133 RPM
FR1B	Add Low NOx Combustion Liners
FR1D	Add Uprated Transition Pieces With Nimonic™ Aft Bracket
FR1G	Install Uprated TBC Coated Combustion Liners
FR1T	Add Uprated Breech Loaded Fuel Nozzles
FR1V	Install Extendor Combustion System Retrofit Uprate
FR1W	Uprate Combustion System to Extendor
FR2B	Install Nimonic™ Transition Pieces Uprated for MS6001B
FS1F	Add Compressor Stages 1 - 8 Uprated to GTD-450
FS1P	Install Uprated GTD-222+ Stage 2 Nozzles
FS1R	Uprate Stage 3 Nozzles to GTD-222+
FS2A	Re-Blade Entire Compressor With New Parts
FS2B	Add Uprated Shrouded S17 + EGV1&2 And Counter Bore Covers
FS2J	Add Uprated Stage 1 Nozzles With Chordal Hinge
FS2K	Install Stage 3 Buckets Uprated to IN-738™
FS2T	Uprate Stage 2 Shrouds to Honeycomb Seal
FS2U	Uprate Stage 3 Shrouds Honeycomb Seal
FS2V	Install High Pressure Packing Brush Seal Uprate
FS2Y	Add Uprated Stage 1 Shrouds with HR-120™ and Cloth Spline Seals
FS2Z	Add Interstage Brush Seal Uprate
FS4A	Replace Stage 1 Buckets with Uprated Perimeter Cooled 16-Hole
FS4B	Install Stage 2 Buckets with Improved Cooling
FS4G	Coat Stage 1 Buckets With TBC
FS4K	Replace Stage 3 Nozzles With Advanced Aero Uprate
FS4L	Replace Stage 3 Buckets With Advanced Aero Uprate
FS6A	Apply Stage 1 Shroud Abradable Coating Uprate
FS6E	Coat Stage 1 Nozzle With TBC
FT4C	Add High Flow Reduced Camber GTD-450 Inlet Guide Vanes
FT4M	Increase in IGV Angle to 86-Degrees
FT4L	Uprate Tfire by 35°F
FT4P	Uprate Tfire to 2084°F
FW3W	Counter Bore Plugs per TIL1352-2

Figure 28. Uprates available for MS6001 units

of five units occurred between 1997-1998, giving average performance improvements better than expected. Uprates on differently rated MS6001 units have been completed, including several on the more recent PG6551B and PG6561B models.

GE quotes the +42°F Tfire increase (it was +35°F at the beginning of the MS6001B GE uprate program), and therefore the PG6571B

Description	Region	CM&U Date
PG6001 2077Tf Firing Temperature Uprate – MS6001B	Americas	1997
	Americas	1997
	Americas	1997
	Americas	2001
	Americas	2001
	Americas	2002
	Americas	2002
	Americas	2003
	AIM	2003
	Europe	2003
	Europe	2003
	Europe	2003
	Americas	2003
	Europe	2003/2004
PG6001 2084Tf Firing Temperature Uprate – MS6001B	Europe	2004
	Europe	2004
	Europe	2004
	Asia	2004/2005
	Asia	2004/2005
	Americas	2004/2005
	Asia	2005/2006
	Asia	2005/2006
	Asia	2005/2006
	Asia	2005/2006
	Asia	2006
	AIM	2006
	Asia	2007
	Europe	2008
	Europe	2008
	Europe	2009
	Europe	2009
	Asia	2009

Figure 29. MS6001B full uprate experience list (firing temperature increase of +35°F and +42°F)

(MS6001B CM&U uprate "model") reference firing temperature is now 2084°F, like PG6581B new units.

Customers may order components as individual parts to suit their own turbine component service life, and scheduled overhaul requirements. All uprate parts are interchangeable with existing components and can be integrated into the gas turbine's current configuration. As additional new technology parts are installed at each successive outage, final completion of the uprate can be scheduled and controls modified to achieve the required performance and/or maintenance objectives.

Simple-Cycle Performance CM&U

Many of the following CM&U packages help to improve the overall performance of the simple cycle gas turbine. *Figure 30* and *Figure 31* list the expected delta changes in performance, for each of the CM&U individual modifications. These modifications can be applied one at a time or all together. The improvements indicated in these tables are additive.

Combined-Cycle Performance CM&U

Where the gas turbine is installed in combined-cycle applications, modifying the unit to improve output and heat rate will change the exhaust characteristics of the gas turbine. This results in changes to the steam production and hence to combined-cycle performance.

As a rule, any modification that reduces compressor losses and/or cooling airflow will result in more gas turbine output at a reduced heat-rate, with more energy available in the exhaust. This leads to an improvement in steam production and hence to gains in combined-cycle output and overall efficiency.

Modifications that lead to the turbine section becoming more efficient result in more output and reduced heat rate for the simple-cycle gas turbine, but also result in a reduction in exhaust energy

Gas Turbine Output Improvements	**Source Book**	**Required for +42°F**	**PG6531B**	**PG6541B**	**PG6551B**	**PG6561B**
GTD-450 reduced camber IGVs (84 dga)	FT4C	X	1.50			
GTD-222/GTD-222+Stage 2 Nozzle	FS1P	X	1.00	1.00		
Stage 2 Honeycomb Shroud	FS2T		0.35	0.35		
Stage 3 Honeycomb Shroud	FS2U		0.25	0.25		
86° IGV Setting	FT4M		0.40	0.40		
5163 RPM Load Gear†	FP4E		1.10	1.10	1.10	0.50
High Pressure Packing Brush Seal	FS2V		0.75	0.75	0.75	0.75
Stage 2 Nozzle Interstage Brush Seal	FS2Z		1.00	1.00	1.00	1.00
Stage 1 Shroud abradable coating	FS6A		0.70	0.70	0.70	0.70
Stage 1 Shroud with Cloth Seals	FS2Y	X	1.05	1.05	1.05	1.05
Improved Cooling Stage 1 Nozzle	FS2J	X				
Advanced Aero Stage 3 Bucket and Nozzle	–		1.00	1.00	1.00	1.00
Increased Tfire to 2084°F	FT4P	X	3.20	3.20	3.20	3.20
GTD-111 DS Perimeter Cooled Stage 1 Bucket	FS4A	X				
Improved Cooling 6 Hole Stage 2 Bucket	FS4B	X				
IN-738™ Stage 3 Bucket	FS2K	X				
GTD-222/GTD-222+ Stage 3 Nozzle	FS1R	X				
Uprate Transition Piece with Cloth Seals	FR2B	X				
TBC Liners	FR1G	X				
Total Expected Percentage Output Improvement			**12.30**	**10.80**	**8.80**	**8.20**
† 50 Hz GE supplied load gear						

Figure 30. Delta changes in gas turbine output as a result of each CM&U package

available for steam production. However the net effect on the overall plant in most cases is a small increase in output and a slight reduction in overall heat rate.

GE provides customers with detailed performance calculations for the gas turbine and estimated overall plant performance for specific units receiving specific uprate packages.

Compressor Improvements

The compressor is a 17-stage axial flow type. The compressor rotor is made up of an assembly of compressor wheels and stub shafts connected by through bolts. The 1st stage wheel also includes the rotor stub shaft for the #1 bearing, thrust bearing and the accessory gear coupling.

Originally rows 1-8 were 403+Cb with a NiCd coating and rows 9-17 were 403+Cb without coating. NiCd coating helps prevent corrosion pitting on the blades by combining a tough barrier of nickel with a sacrificial cadmium layer. NiCd coating was replaced by GECC-1*—which provides the same protection as NiCd without the use of cadmium, considered an environmental hazard. Both GECC-1 and NiCd possessed outstanding corrosion resistance in neutral and sea salt environments.

From 1994 to 2000, stages 1-2 used GTD-450 material, stages 3-7 used 403+Cb material with a GECC-1 coating and Stages 8-17 used 403+Cb material without coating. GECC-1 (a GE proprietary corrosion- resistant coating) is an aluminum slurry coating, which has a protective ceramic top layer that provides improved corrosion resistance. The GECC-1 coating can be applied at a GE service shop to existing compressor blading for all stages of the compressor. However, GECC-1 cannot be applied to blades made from GTD-450 stainless steel alloy; no coatings of any kind are recommended or allowed on GTD-450 material.

Gas Turbine Heat Rate Improvements	**Source Book**	**Required for +42°F**	**PG6531B**	**PG6541B**	**PG6551B**	**PG6561B**
GTD-450 reduced camber IGVs (84 dga)	FT4C	X	-0.30			
GTD-222/GTD-222+Stage 2 Nozzle	FS1P	X	-0.40	-0.40		
Stage 2 Honeycomb Shroud	FS2T		-0.35	-0.35		
Stage 3 Honeycomb Shroud	FS2U		-0.25	-0.25		
86° IGV Setting	FT4M		0.20	0.20		
5163 RPM Load Gear†	FP4E		-0.07	-0.07	-0.07	
High Pressure Packing Brush Seal	FS2V		-0.50	-0.50	-0.50	-0.50
Stage 1 Shroud abradable coating	FS6A		-0.70	-0.70	-0.70	-0.70
Stage 2 Nozzle Interstage Brush Seal	FS2Z		-0.50	-0.50	-0.50	-0.50
Stage 1 Shroud with Cloth Seals	FS2Y	X	-0.45	-0.45	-0.45	-0.45
Improved Cooling Stage 1 Nozzle	FS2J	X				
Advanced Aero Stage 3 Bucket and Nozzle	–		-1.00	-1.00	-1.00	-1.00
Increased Tfire to 2084°F	FT4P	X	-0.20	-0.20	-0.20	-0.20
GTD-111 DS Perimeter Cooled Stage 1 Bucket	FS4A	X				
Improved Cooling 6 Hole Stage 2 Bucket	FS4B	X				
IN-738™ Stage 3 Bucket	FS2K	X				
GTD-222/GTD-222+ Stage 3 Nozzle	FS1R	X				
Uprate Transition Piece with Cloth Seals	FR2B	X				
TBC Liners	FR1G	X				
Total Expected Percentage Heat Rate Improvement			**-4.52**	**-4.22**	**-3.42**	**-3.35**
† 50 Hz GE supplied load gear						

Figure 31. Delta changes in gas turbine heat rate as a result of each CM&U package

Since 2000, all PG6581B units are manufactured with stages 1-8 in GTD-450 uncoated material and stages 9-17 in uncoated 403+Cb material. (GEEPE Belfort has been the sole GE manufacturer of new PG6581B units since 2000.) GTD-450 material has shown repeatedly to be as effective or more effective than a coated 403+Cb material in terms of corrosion/erosion protection.

GTD-450 High Flow Reduced Camber Inlet Guide Vanes (FT4C)

Inlet guide vanes are used to control air inlet flow to the compressor during startup and part load operation. (*See Figure 32.*) In 1987 low camber, high flow IGVs were introduced to all GE gas turbines.

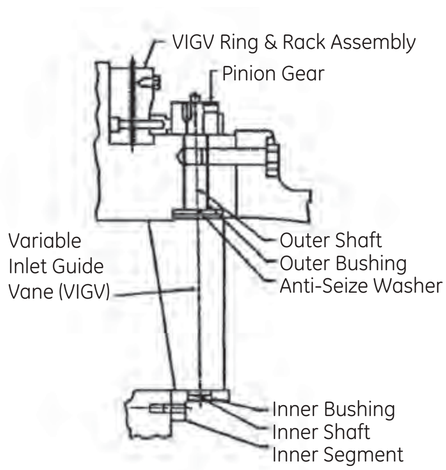


Figure 32. GTD-450 reduced camber high-flow variable IGV arrangement

The high flow IGVs, compared to the previous IGVs with less flow have better output and heat rate due to their redesigned aerodynamics and resultant higher flow. The redesign is made possible by using precipitation hardened martensitic stainless steel that has higher properties than alloy 403 used for the previous IGVs with less flow. *(See Figure 33.)* Material developments include increased tensile strength, improved high cycle fatigue strength, increased corrosion-fatigue strength, and superior corrosion resistance due to higher concentrations of chromium and molybdenum.

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 opened to 84 degrees, can increase power up to 1.5% and decrease heat rate by up to -0.3% while improving corrosion, crack, and fatigue resistances. The low camber design increases the airflow across the IGVs, giving improvements in gas turbine output and reduction in heat rate.

Benefit:

Model	*Change in Output*	*Change in Heat Rate*
MS6001B	*+1.5%*	*-0.3%*

Note: Negative heat rate changes are an improvement.

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.

Increase IGV Angle (FT4M)

In 1995 the IGV angle was increased from 84 degrees to 86 degrees, allowing slightly higher airflow through the gas turbine and giving increased output, but with a slight heat rate penalty (due to compressor efficiency decrease). This uprate requires that the unit has the latest design GTD-450 inlet guide vanes. *(See uprate FT4C.)*

Benefit:

Depending upon current unit configuration, this option may provide up to 0.4% additional output with only a slight penalty (<0.2%) in heat rate.

Increasing IGV angle will require the application of an inlet plenum scroll on single base MS6001 gas turbines. There may be an increase in bushing wear associated with the increase in IGV angle and hence regular inspection is required. *(Refer to TIL 1068-2R1).*

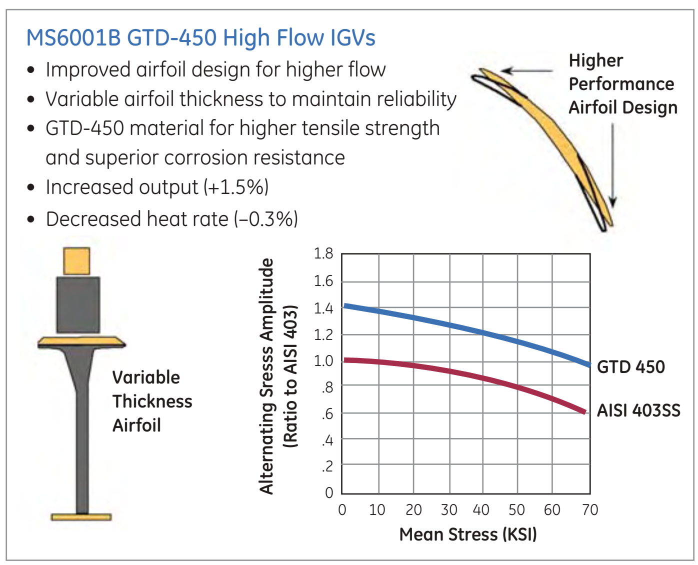


Figure 33. High-flow IGV design improvements with GTD-450 material

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

This modification for MS6001B units involves replacing the stage 1-8 compressor blades and stator vanes with GTD-450 material, uncoated. The GTD-450 material provides high corrosion resistance even when uncoated, and significantly increases the strength of the blades and stator vanes.

Benefit:

GTD-450 stainless steel compressor blades and stator vanes offer high tensile strength, corrosion resistance and crack resistance that will significantly increase the reliability and cycle life of the part.

Replacing the existing stage 1 through stage 8 compressor blades and stator vanes with uncoated GTD-450 material gives the blades and vanes a distinct material advantage. GTD-450 material is a precipitation-hardened, martensitic stainless steel that provides fatigue strength, 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 eight stages because during standard operation this region could be subjected to liquid water, therefore incurring an elevated risk of corrosion.

Shrouded S17 + EGV1&2 and Counter Bore Covers Uprates (FS2B)

A limited number of MS6001B compressor stator 17 and EGV1 vanes have experienced high cycle fatigue or cracking. *(Refer to TIL 1170-2R1)*. Metallurgical analysis of distressed and cracked vanes concluded that high cycle fatigue was the cause of distress. Aerodynamic excitation of stage 17 and EGV stator vanes is due to flow separation that results when the aft end of the compressor is heavily loaded. Aft end compressor loading increases with higher pressure ratios, as well as with lower IGV turndown airflows when operating on temperature control.

Benefit:

This modification significantly increases the strength of these stator assemblies that allows operation under these flow separation conditions. Shrouded compressor stator blade assemblies, counter bore covers, or IGV angle re-scheduling reduce the sensitivity of the structure and prevent blade failure.

A number of operational modes have been identified that further increase the loading on the vanes, which may lead to the distress experienced:

- Operation during periods of cold ambient temperatures
- Operation at reduced load (with closed IGV)
- Operation with water/steam injection for NO_X reduction or power augmentation
- Low BTU gas fuel
- Flow path disturbances from inner barrel counter bores, uncovered.

Counter bores, located at the compressor discharge casing inner barrel split-line, have shown to be significant contributors to the high aerodynamic loading. To reduce the probability of a stator 17 or EGV vane distress, the following configuration modifications may need to be installed with any of the CM&U uprates detailed in this GER:

- New inner barrel counter bore plugs.
- Control system modification to change turbine operating curves. This will limit gas turbine minimum IGV angle operation under certain low ambient and extreme operating conditions.
- GE has designed shrouded stator 17 and EGV vanes to remove risk of blade failure. GEEPE Belfort (the sole GE manufacturer of new PG6581B units since 2000) has manufactured Frame 6B S17 and EGV 1 & 2 shrouded design compressor stator blades since mid-2004.

Analysis of the unit configuration and operating parameters will allow GE to determine if any FS2B modifications are required. GE can supply pre-packaged kits of parts to operators if analysis for a particular unit shows that modifications are needed.

Exit guide vane concerns 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 per *Figure 34* and *Figure 35*. The vanes have 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.

A vane flow incidence (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 place a greater need for installing a shrouded design for a specific unit.

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)

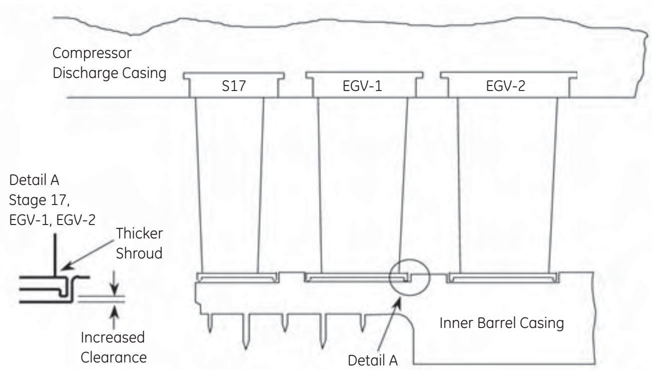


Figure 34. Side view of the three stages of shrouded compressor blades

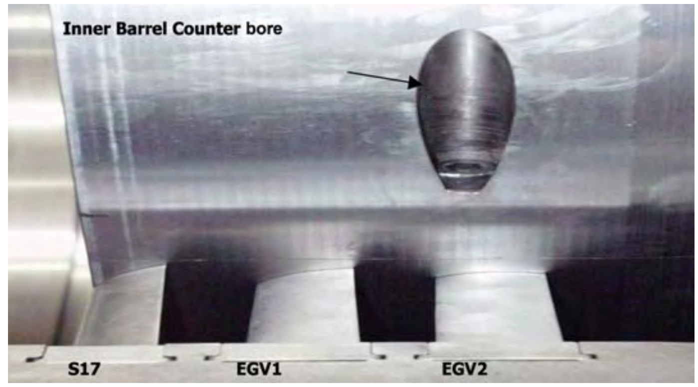


Figure 35. Stator 17 and EGV blade distress locations, and counter bore

Figure 36 illustrates an example of a CM&U analysis for a unit configuration in ambient temperatures from 41°F to 85°F and a maximum IGV angle of 84 degrees. The figure illustrates that shrouded hardware is needed for most ambient temperatures at the utilized IGV angles. Low-cost counter bore cover plugs in the horizontal split-line bolt holes are recommended on most units operating at colder ambient temperature. (Consult with GE Application Engineering for more details.) *Figure 37* shows an example of IGV restrictions placed on a MS6001B DLN1 unit to protect unshrouded stage 17 hardware. The figure also illustrates the impact on gas turbine exhaust flow/temperature, and DLN low emissions turndown.

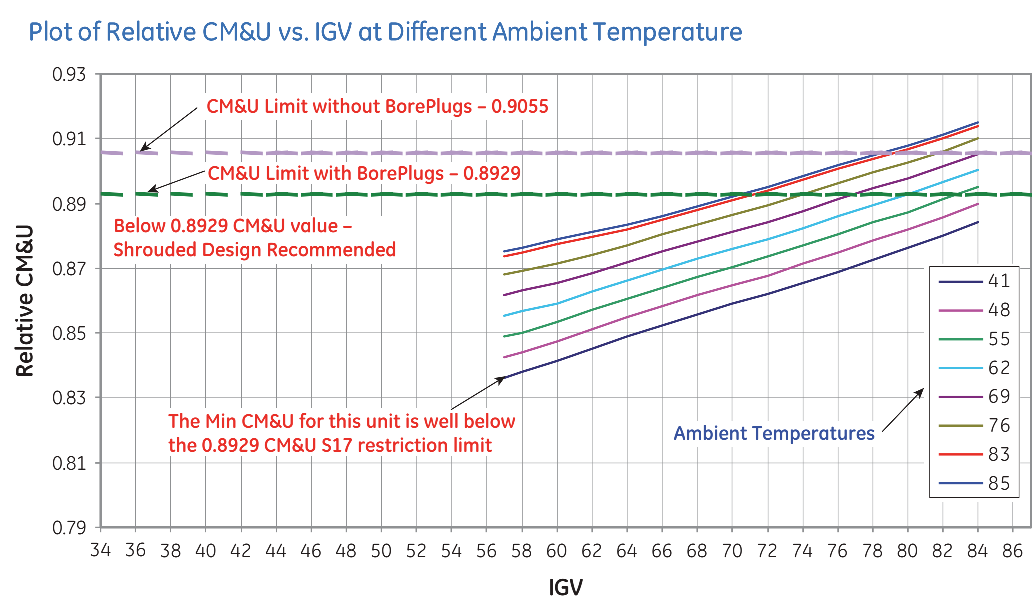


Figure 36. CM&U analysis for a specific unit showing need for shrouded design

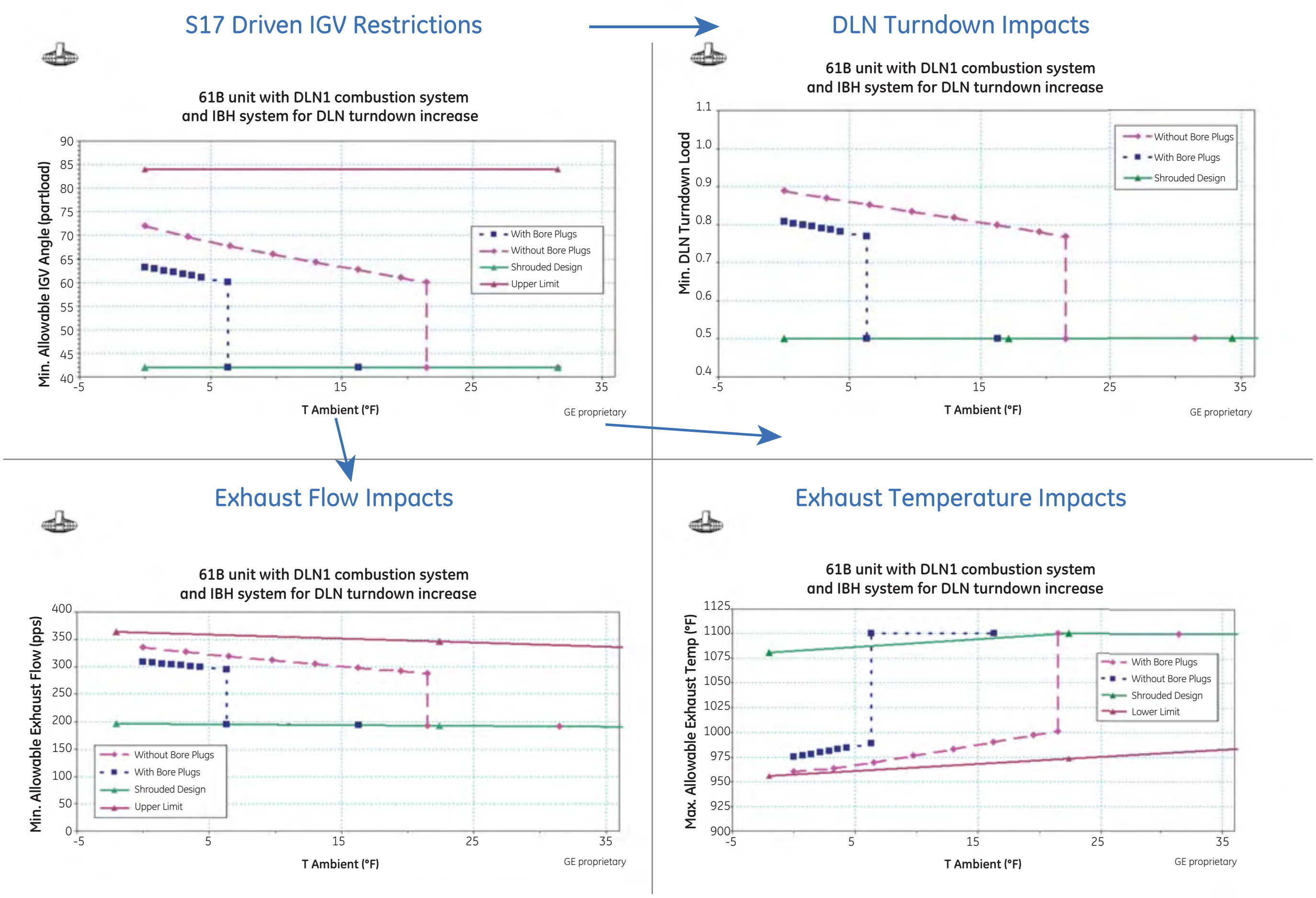


Figure 37. Example of S17 operating restrictions

Inlet Bleed Heat (IBH) for Anti-Icing and DLN Turn-Down (FD3A)

Anti-icing of the inlet compressor bell mouth, inlet guide vanes, and other inlet components is sometimes required by customers for gas turbine applications in cold and humid ambient environments. The approach used to avoid the formation of ice is to bleed hot gas turbine compressor discharge air and re-circulate this air to the inlet to warm the inlet airflow. Inlet bleed heat is also used for DLN emissions control when operating at part load. (*See Figure 38.*)

Benefit:

This system decreases risk of damage to the gas turbine compressor from icing when operating during cold, humid conditions. It also allows for emissions control for DLN operation at part load. Note that the IBH system has significant impact on heat rate increase at less than 75% base load when used for DLN turndown increase.

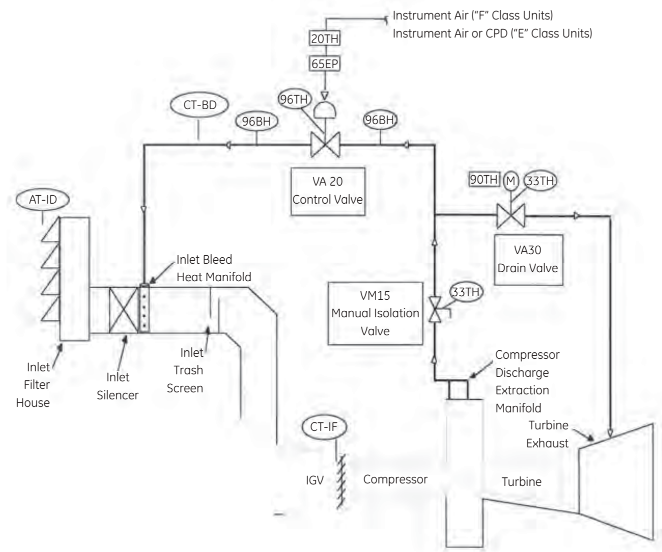
Compressor and Turbine Water Wash Using Skid (FC4A, FC4C, FC4D)

Off-line water wash (FC4A) allows the customer to clean the compressor after the turbine is brought off-line and cooled. Compressor water wash removes contaminants from the compressor by washing with clean water and detergent. The compressor water wash removes dirt and deposits from the compressor sections to increase unit performance.

Off-line 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 wheelspace temperatures are cool, and with the unit at crank speed. For machines burning high-grade liquid fuels or gas, turbine water wash probably is not needed. Compressor water wash (FC4A) should be used in conjunction with turbine wash.

Inlet Bleed Heating

- The inlet bleed heat system is used to bleed off compressor air to increase the compressor surge margin. The compressor bleed air is re-ingested into the inlet to heat the inlet air which increases surge margin
- Anti-icing function when IGVs are closed down
- Emissions control with DLN for part load operation



20TH-1	Control Valve Trip Solenoid	96BH-2	Control Valve Outlet Pressure Transducer
33TH-3	Manual Isolation Valve Open Limit Switch	96TH-1	Control Valve Position Transducer
33TH-4	Drain Valve Closed Limit Switch	AT-ID-1,2,3	Ambient Air Thermocouples
65EP-3	Control Valve Electropneumatic Positioned	CT-BD-1,2,3	Inlet Bleed Heat Flow Thermocouples
90TH-4	Drain Valve Motor Operator	CT-IF-1A, 2A, 3A	Compressor Inlet Thermocouples
96BH-1	Control Valve Inlet Pressure Transducer		

Figure 38. Inlet bleed heat system

A water wash skid (FC4D) is used to supply washing solution. To limit thermal stress, operators should not exceed a limit of 150°F for the difference between the temperature of the wash solution and the temperature in the wheelspace as detected by thermocouples.

Benefit:

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

High Pressure Packing Brush Seal Uprate (FS2V)

To improve overall performance of the gas turbine in both output and heat rate, GE has developed a series of sealing technologies available for retrofit in all the heavy-duty gas turbine frame sizes. Most of these seals are installed in current production models.

Brush seals—comprised of a pack of fine metallic wires (or bristles) held in a frame—are available in two locations on the MS6001 gas turbine. Simple designs have been used for basic sealing applications for a number of years. Recently, advanced designs have become prevalent in aircraft engine and industrial gas turbines. In these applications, brush seals are typically used as replacements or additions to labyrinth seals that are not maintaining their desired sealing levels, especially after a number of transient radial excursions.

The bristles are simply displaced during the excursion and, then, return to their position once the transient condition has passed. Labyrinth seals would rub under similar excursions introducing higher leakages beneath the labyrinth seal. The brush seals also maintain a pressure gradient across the bristle path while minimizing leakage through the bristle pack. A brush seal can easily accommodate misalignment normally not tolerated by labyrinth designs.

The HPP is designed to reduce the leakage of compressor discharge air between the stationary inner barrel and the compressor rotor aft stub shaft into the turbine first-forward wheelspace. The clearance between the seals on the compressor discharge casing/inner barrel and the compressor rotor aft stub shaft controls the flow through this area. Some of this leakage bypass airflow is required for cooling the turbine first-forward wheel-space; however, flows without the brush seals in place are excessive. Controlling this bypass airflow to the minimum levels required for cooling will increase the amount of air available to perform work in the cycle.

The original design was for a labyrinth seal, which can experience severe rubs during some transient operating conditions. Replacing this labyrinth seal with a rub-tolerant brush seal controls the bypass airflow, leading to improved gas turbine performance (output and heat rate). *(See Figure 39.)* Long-term performance

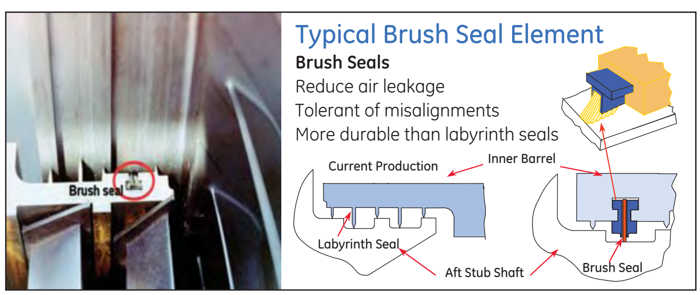


Figure 39. High pressure packing brush seal

degradation is also reduced as the brush seal maintains HPP seal clearances after high numbers of starts/stops and operating hours.

This uprate provides a +0.75% increase in output and improves heat rate by -0.5%. This option consists of replacing the existing labyrinth tooth and seal arrangement with a more 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 the 2003 production year.

Benefit:

Model	*Change in Output*	*Change in Heat Rate*
MS6001 A/B	*+0.75%*	*-0.5%*

Note: Negative heat rate changes are an improvement.

With the conventional labyrinth tooth/land seal packing on the inner barrel, the minimum clearance that can be tolerated is controlled by the expected rotor displacement during transient conditions, and by wheelspace cooling 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 and flex, thereby withstanding rotor excursions and maintain 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 area, the unit is able to sustain initial performance levels over an extended time because the inevitable excursion does not increase the clearance/flow at the seal.

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 and/or component life.

The combustion system—which contains fuel nozzles, liners, transition pieces, X-fire tubes, flame detectors and spark plugs—consists of 10 reverse-flow combustion chambers arranged concentrically around the periphery of the compressor discharge casing. *(See Figure 40.)*

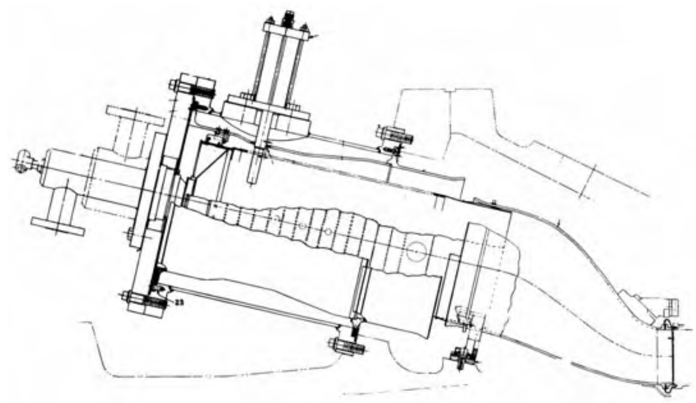


Figure 40. Cross section through combustion system

TBC Coated Combustion Liner Uprate (FR1G)

This uprate applies a thermal barrier coating (TBC) to combustion liners for the MS6001 gas turbine. *(See Figure 41 and Figure 42.)* The uncoated liner metal temperatures will be reduced by applying Hastelloy-X™, a nickel-based alloy introduced for combustion liners in the 1960s. Today, however, a thermal barrier coating (TBC) is also applied. *(See Figure 43.)* The TBC consists of a two-part coating to

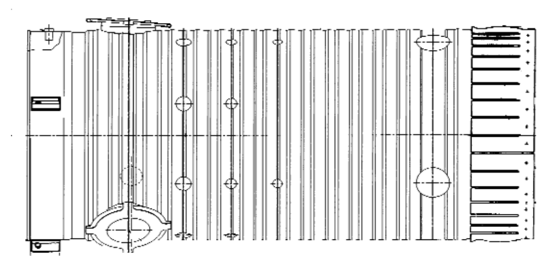


Figure 41. Slot cooled liner with TBC applied

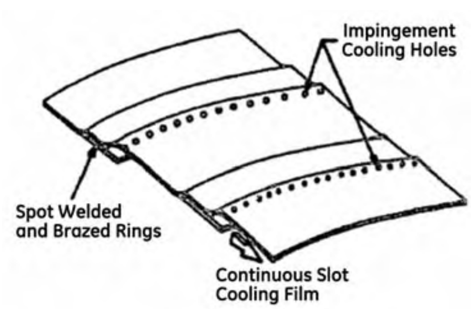
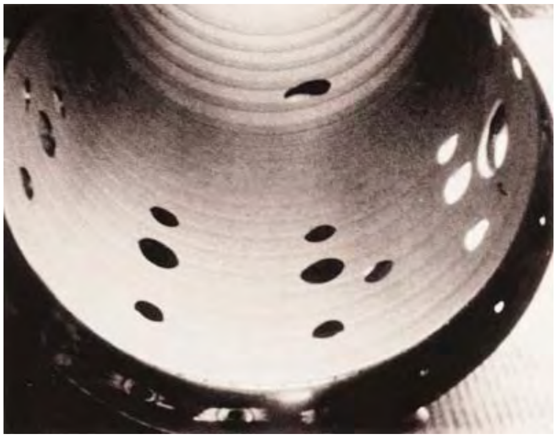


Figure 42. Slot-cooled combustion liner; cutaway view



Liner

Coating Microstructure

Figure 43. Thermal barrier coating

the hot inside surface of the liner. A bond coat is first applied, and then an insulating oxide TBC is applied over the bond coat. This TBC provides a 0.015-inch insulating layer that reduces the temperature of the underlying base material by approximately 100°F, which leads to a reduction in component cracking, an overall reduction in thermal stress, and higher operating strength of material.

Combustion liners are slot-cooled, which provides a uniform distribution of cooling airflow on the inside of the liner body. 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-cooled liner section is illustrated in *Figure 42*. 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.

Benefit:

TBC coated liners are equipped with an insulating layer that reduces the underlying base metal temperature—thus allowing higher temperature conditions, reduced cracking, and an overall reduction in liner thermal stress for less cracking and reduced maintenance.

Uprated Nimonic™ Transition Pieces with Improved Aft Bracket (FR2B)

Transition piece (TP) aft-end creep distortion was a significant concern for MS6001B units that were originally fitted with TPs made entirely of Hastelloy-X™ alloy. TP creep is the time dependent deformation of the transition piece downstream end due to high temperatures and stresses. The creep distortion resulted in aft seal disengagement, causing an undesirable change in gas temperature profile into the turbine. To overcome this concern, Nimonic 263™ end frames replaced the earlier Hastelloy-X™ end frame. The Nimonic 263™ alloy is precipitation-strengthened and nickel-based, with substantially higher creep strength capability than the Hastelloy-X™ alloy. This upgrade became standard for production in late 1995. The Nimonic 263™ end frame upgrade (FR1D) provides a substantial reduction in TP creep as does the TBC applied to the aft end. *(See Figure 44.)*

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 shown in *Figure 44*, significantly reduces the transition piece metal temperatures. The Nimonic™ transition piece maintains the benefits of inner and outer floating seal arrangements used with the stage 1 nozzle interface.

Figure 44. Nimonic™ transition piece showing downstream end coated with TBC

Benefit:

This modification allows for longer Combustion Inspection (CI) maintenance intervals and operation at the increased firing temperature of several available firing temperature uprates. Elimination of the leakage due to a deformed transition piece also offers inspection interval and life extension benefits to the downstream gas path components.

For the even higher firing temperatures associated with Advanced Technology Uprates (FR2B), both the transition piece body and the aft frame are manufactured using Nimonic 263™ material. In addition to the all Nimonic™ material construction. the new design includes a re-designed aft support system, cloth seals, and Extendor features, which are discussed later. *(See Figure 45 and Figure 46.)* Note that Nimonic™ TPs per uprate FR1D are not acceptable for the +35°F or +42°F technology uprates. New TPs per FR2B are required for these uprates. Note that it is not practical to convert old style TPs to the latest FR2B configuration.

The re-designed transition piece per FR2B employs an aft mounting system that attaches directly to the new aft frame instead of the transition piece body. The previous design mounted the aft bracket to the existing Hastelloy-X™ transition piece body, accentuating stresses in this lower strength portion of the assembly and increasing creep deformation rate. The new all Nimonic 263™ design applies aft support loading into a much stronger aft frame—and combined with the stronger body—creep deformation is completely eliminated.

Finally, cloth seals are designed to reduce the leakage between the transition piece and the first stage nozzle and reduce wear rates to further improve inspection intervals and part life. The new cloth type end of the seal employs a sheet metal portion that engages the first stage nozzle same as before and a metal cloth section that engages the TP aft frame seal groove. The flexible cloth section produces more uniform contact with the TP frame grove to limit peak contact loads (lower wear) and improve sealing.

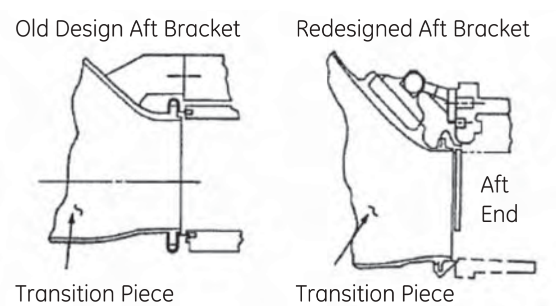


Figure 45. Comparison of old and new forward aft brackets

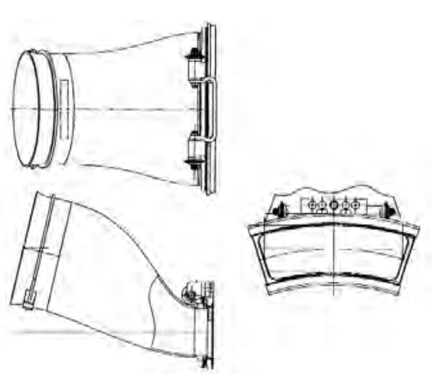


Figure 46. Full Nimonic-263™ transition piece with cloth seals

CL-Extendor Combustion System Uprate (FR1V & FR1W)

All gas turbines require periodic combustion inspections. For any given machine, the duty cycle, the type of fuel used, and the amount of water and steam injected are the key factors in determining the recommended combustion inspection intervals.

What Controls Combustion Inspection Intervals?

- Experience shows that friction-caused wear is a leading contributor to combustion system inspection intervals and repair costs
- Transition piece aft end "creep" limits inspection intervals for older Hastelloy-X™ body with Nimonic™ aft frame but NOT for latest all Nimonic™ TPs

How Does Extendor Increase Intervals?

- Field operation proven "wear-couple" material design
- Configuration change reduces relative motion
- Newly designed combustion components reduce wear interface hours
- Critical clearance control reduces wear interface forces and relative motion
- Can increase the interval between combustion inspections to as much as 24,000 hours (depending on operating conditions)
- Reduces maintenance costs and increases availability

Figure 47. Fundamentals of CL-Extendor combustion system

(See Figure 47.) These factors directly influence the amount of material creep, thermal stress, wear of combustion components, and TBC coating erosion.

The CL-Extendor combustion system increases combustion inspection intervals by significantly reducing combustion component wear. *(See Figure 48 and Figure 49.) Figure 48* provides a summary of the combustion component features included in the MS6001B CL-Extendor combustion systems. *Figure 49* illustrates the increased inspection intervals after installing a CL-Extendor combustion system. *Retrofit CL-Extendor onto Existing Components* (FR1V), and *Purchase New CL-Extendor Components* (FR1W) both apply to the MS6001 gas turbine.

The CL-Extendor's extended inspection interval system is a unification of the earlier Extendor GE product and the CLE product offered by GE's European manufacturing associate, which is now part of GE Energy Products Europe (GEEPE). CL-Extendor takes the best aspects of both products and is available for units with standard diffusion and DLN1 combustion systems.

CL-Extendor extends time between inspection intervals 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.

CL-Extendor can be applied to combustion components by modifying (FR1V) existing hardware at an authorized GE Service Center or by having CL-Extendor features built into (or pre-applied to) new combustion components (FR1W) during the manufacturing process. *(See Figures 50, 51a and 51b.)*

MS6001 CL-Extendor Component Features	Standard Comb	DLN Comb	Trans Piece
Combustion Liners			
Three (3) "Lug" Type Liner Stops		X	
Four (4) Extendor-I Liner Stops	X		
Three (3) Liner Stop Wear Shims		X	
Hardened Fuel Nozzle Collar	X		
Hardened Fuel Nozzle Collar and Anti-Rotation Stop		X	
Wear Coating on Hula Seal	X	X	X
Flow Sleeves/Casings			
Four (4) Extendor-I Flow Sleeve Stops	X		
Three (3) Casing Stops		X	
Fuel Nozzles			
Wear Coating on Gas Tip	X	X	
Transition Pieces			
New Side and Inner and Outer Floating Seals	X	X	X
Body and End Frame Modifications	X	X	X
Replaceable Wear Covers on Forward Supports	X	X	X
Wear Coating on Forward Sleeve (Interior)	X	X	X
Hardened Guide "H" Blocks	X	X	X
Replaceable Wear Strips in End-Frame Slots	X	X	X
Change End Frame to Nimonic™ Material	X	X	X
Class B or C TBC Coating	X	X	X

Figure 48. Technical features of MS6001 CL-Extendor

Combustion Inspection Intervals Fired Hours Limit — Gas Fuel	Dry	Steam (42 NOx ppm)	Water[1] (42 NOx ppm)	Water/BLFN1 (42 NOx ppm)
MS6001B Single Nozzle (Without Extendor)	12,000	8,000	8,000	8,000
MS6001B Standard with Extendor System	24,000	24,000	8,000	12,000
MS6001B DLN System without Extendor System	12,000			
MS6001B DLN with Extendor System	24,000			
MS6001B Transition Piece with Extendor System	24,000	Depends on combustor and diluent		
[1] See FR1T				

Figure 49. Increased inspection intervals for MS6001B gas fuel CL-Extendor

MS6001B Extendor Systems

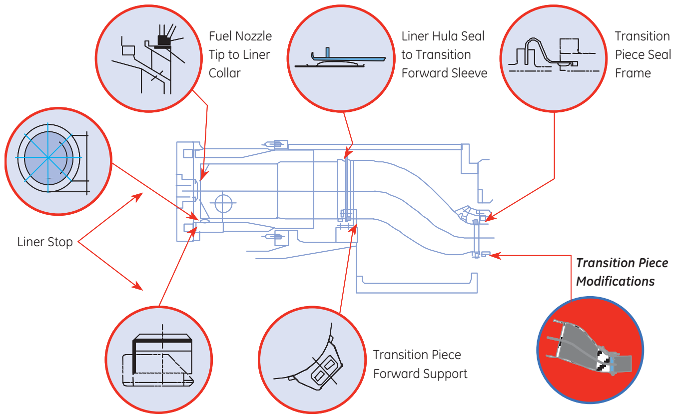


Figure 50. Cross section through CL-Extendor

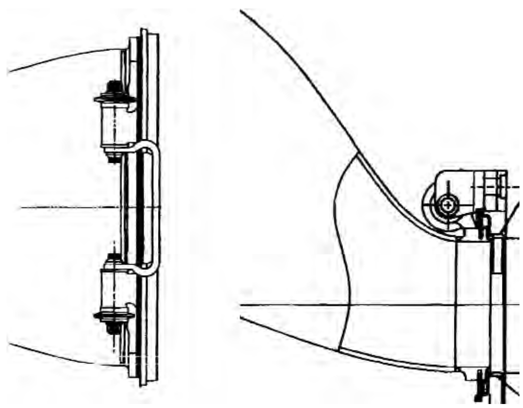


Figure 51a. Aft bracket arrangement on new transition piece

Cloth Side Seal Arrangement:

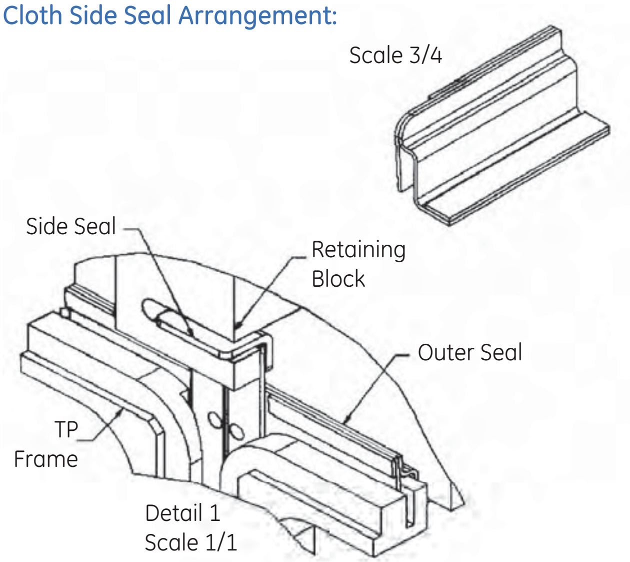


Figure 51b. Cloth seals for transition pieces

The CL-Extendor Uprate Package reduces the effects of wear at the following key interfaces:

- Three wear-coated liner stops mated to three wear-coated flow sleeve stops with reduced clearances to ensure accurate positioning and reduced motion during operation for standard combustion systems
- Three wear-coated liner stops mated to three wear-coated combustion casing stops to ensure accurate positioning and reduced motion during operation for DLN1 combustion systems
- Coating applied on the fuel gas tips and wear-resistant combustion cap collars
- Replacement of male crossfire tubes (STD combustion system)
- Replacement of male and female crossfire tubes (DLN combustion system)
- Wear coatings on the liner-aft hula seals and on the mating ID of the transition piece
- Wear coating on the transition piece bullhorns
- Wear-resistant transition piece fwd H-blocks
- Sacrificial wear strips in end-frame slots
- FR1D: Nimonic-263™ T/P end-frame and Class B TBC applied to the latter 6-8" of the gas path surface *(See Note 1)*
- FR2B New TP cloth seals, side seals and inner and outer floating seals)

Note 1: Standard and DLN combustor systems require the new end frame and TBC coating to reduce or eliminate transition-piece aft frame creep experienced with older design Hastelloy-X™ end frames. Transition-piece end frame creep is a distortion and closing of the discharge end and such closing gradually disengages the inner floating seal until excessive leakage occurs. The Nimonic™ frame material provides substantially greater creep resistance and the Class "B" TBC applied to the inner surface of the transition-piece downstream end reduces the bulk metal temperature.

Note 2: CL-Extendor requires the Nimonic™ end frame and TBC coating to reduce the transition piece aft frame end creep experienced with older design Hastelloy-X™ end frames. Applying CL-Extendor wear features to Hastelloy™ Transition Pieces is not a cost-effective upgrade as end frame creep will not allow extension of CI intervals.

Benefit:

Gas turbine combustion inspection intervals are extended by reducing wear on combustion system components. Customer savings are realized by: reducing frequency of CIs and reducing frequency and extent of repair.

Flexible Pigtails for Fuel Gas (FF2A) or Atomizing Air (FF2B)

The flex pigtails consist of flexible corrugated metal surrounded by a layer of braid reinforcement and a layer of spiral wound armor. The flex pigtails may be used to replace the original rigid pigtails used on both the atomizing air and gas fuel systems of older machines. Gas or atomizing air ring manifolds that were used with rigid pigtails were partially or fully supported by the rigid pigtails. If flex pigtails are employed, support frames for the existing ring manifolds are required.

Benefit:

Flex pigtails allow easier maintenance and higher reliability compared to rigid pigtails that sometimes fail due to vibration and thermal expansion differences between the machine and the manifolds. Of course, care must be used while handling the flex pigtails and while doing maintenance in the turbine compartment to avoid denting or otherwise damaging the flex pigtails during maintenance.

Emissions Mitigation and Compliance

Emission levels are affected when a gas turbine is uprated. There are three main emissions abatement options available for the MS6001B: a Dry Low NO_X combustion system, and steam or water injection. These options are available for new build units, and for retrofitting to the installed fleet. *(See Figure 52.)*

Breech Loaded Fuel Nozzle Uprate (FR1T)

This modification provides the turbine and on-base components for converting a standard shower head water-injection system to a breech-loaded system in which the water is injected through an internal passage of the fuel nozzle (as in the current new unit configuration). This modification applies to dual fuel, gas only or liquid only systems with NO_X abatement by water injection. If the unit is not currently equipped with water injection, refer to uprate FG1A.

Benefit:

The breech-loaded fuel nozzles reduce or eliminate combustion liner cap cracking, extend inspection intervals, and can reduce water injection levels to achieve required NO_X levels.

With the design for the breech-load fuel nozzles, water is injected through a passage concentric to the center oil passage of the fuel nozzle. Water is then discharged as a spray that is just outboard of the oil spray or inboard of the multiple gas jets channeling the water directly into the combustor flame. As a result, the water injection spray does not impinge on the fuel nozzle swirl tip or the combustion cap cowl assembly and thereby reduce or eliminate combustion liner cap cracking. The BLFN nozzle design extends combustion system inspection intervals, decreases repair costs and somewhat reduces the water flow requirements to achieve a specified NO_X level particularly for lower required NO_X levels.

Add Water Injection for Gas or Dual Fuel Units (FG1A)

Water injection works essentially in the same way as steam injection: reducing the flame temperature, which results in lowered nitrogen oxides NO_X emissions. The initial design injected water into the fuel nozzle swirler. This led to water impingement on the combustion liner cap and body, which resulted in thermal shock and increased combustion maintenance. The latest design is a breech-loaded fuel nozzle, where water is injected down into the center of the fuel nozzle, which reduces the risk of water impingement *(See Figure 53.)* Retrofitting water injection will increase the output and the heat rate of the gas turbine. *(See Figure 54.)*

Single Shaft Units		**STD Combustion System Dry Conditions**		**STD Combustion System Water/Steam Injection**		**Dry Low NOx Combustion System**	
Model	Firing Temp °F/°C	Gas –	Dist –	Gas (FG1A/FG1B)	Dist. (FG1C/FG1C/FG1F	Gas (FG2B)	Dist.† (FG2B)
MS6001B	2084/1140	170	328	42/25	65/42	5	65
† With water injection for distillate oil							

Figure 52. NO_x emission levels at 15% O_2 (ppmvd)

Benefit:

This uprate reduces the NO_X emissions level to meet EPA required levels. In addition, a significant increase in power and heat rate will be experienced.

This uprate includes the material necessary to add water injection to a unit. The modification uprate kit includes replacement fuel nozzles containing water injection passages and connections, the water injection skid, instrumentation, manifolding, on-base piping, the fuel flow measurement system, and control changes to operate the NO_X system.

This modification is typically not applicable to dual fuel units without atomized air. *(See uprate FA6B.)* The main benefit of this modification is the reduction of the NO_X emissions level to meet EPA required levels. In addition, an increase in power is experienced.

The water injection system provides water to the combustion system of the gas turbine to limit the amount of NO_X emitted in the turbine exhaust. This limit is site specific and is dictated by the local regulating governmental agency. Applicable Federal, State, or 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 federal standard. Based on these tests, a final control schedule is programmed into the control system that regulates the water injection system.

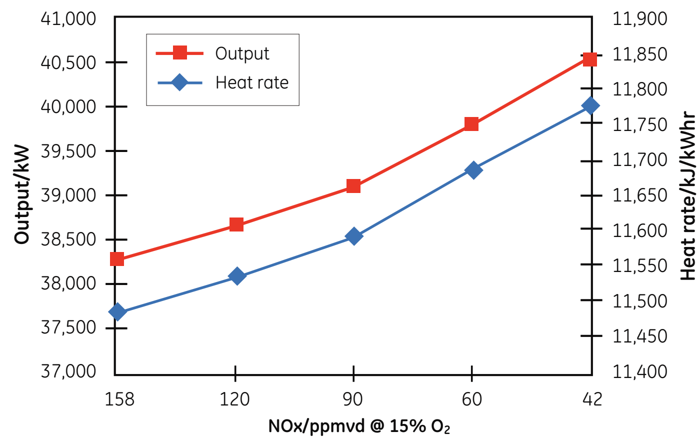


Figure 54. Effects of water injection on gas turbine output and heat rate

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 breech-loaded fuel nozzle was designed. *(See uprate FR1T.)* In this design, the water is injected through an annulus in the center of the nozzle directly into the flame zone. This generally prevents water from impinging on the fuel nozzle or liner cap/cowl assembly. This generally eliminates the cracking of these components observed in the older designs and has allowed increased combustion inspection intervals. The breech-loaded nozzle also allows easy maintenance of the oil side of the nozzle. On units with oil operation, the application of the breech-loaded fuel nozzle requires increasing the pressure ratio of the boost atomizing air compressor (by increasing speed) and/or controls changes for proper ignition.

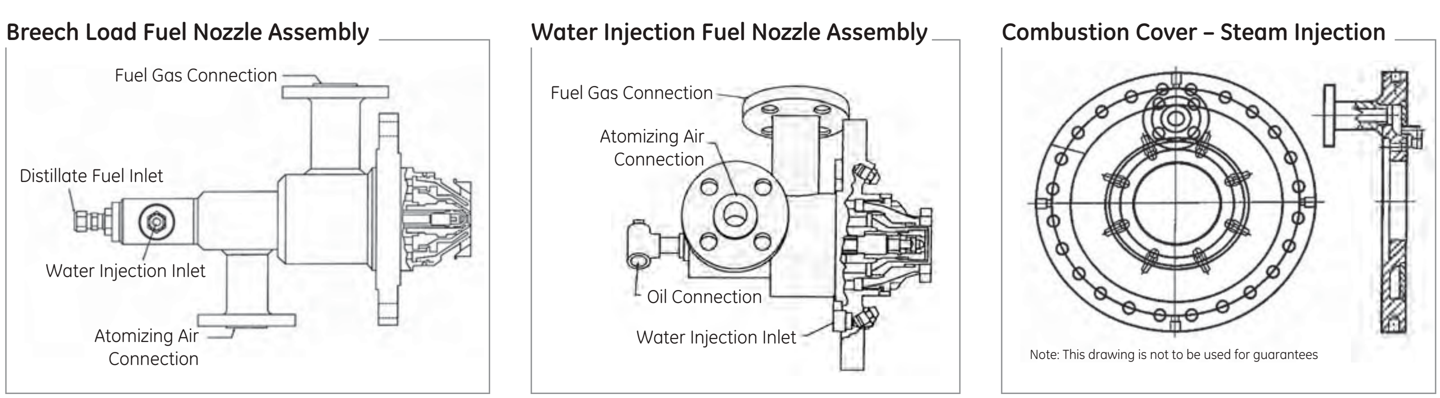


Figure 53. Breech-loaded fuel nozzle as compared to water injection and steam injection

Water Injection for Liquid Fuel Units (FG1C)

This uprate includes the components needed to add water injection to MS6001 gas turbines 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_X system. The water injection system provides water to the combustion system of the gas turbine to limit the amount of nitrogen oxides (NO_X) in the turbine exhaust. In addition to this benefit, an increase in power is experienced.

Benefit:

This uprate reduces the NO_X emissions level to meet EPA required levels. In addition, a significant increase in power and heat rate will be experienced. Note that a Maintenance Factor per GER3620 will reduce the number of actual fired hours between inspections.

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 mist through water spray orifices that are installed in each of the turbine fuel nozzles assemblies. The water is injected into the combustion zones of each combustion chamber.

Typical NO_X with water injection is 42 ppmvd at 15% O_2 with natural gas fuel, or 65 ppmvd with liquid fuel.

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

Steam injection for power augmentation in MS6001 gas turbines 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. *(See Figure 56.)* The power augmentation steam is injected into the compressor discharge airflow for standard combustion. The steam for power augmentation is directly injected in the combustion area through the combustion casing and the flow sleeve for the MS6001B and Frame 7EA DLN1.

As an additional benefit, a portion of the steam reacts in the combustion zone of the combustor, thereby reducing NO_X levels. The modification kit includes the 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.

Benefit:

Model	*Steam Injection* (1)	*Increase in Output* (2)	*Decrease in Heat Rate* (3)
MS6001B	*5.0%*	*+13.8%*	*-5.8%*
MS6001B DLN1 (4)	*5.0%*	*+12.9%*	*-5.7%*
MS6001B DLN1 (5)	*2.8%*	*+6.8%*	*-3.4%*

Notes:

(1) *Percent of Compressor Inlet Air Mass Flow.*

(2) *Estimated simple cycle turbine performance improvement at ISO conditions and steam injection mass flow.*

(3) *Negative heat rate changes are improvement*

(4) *For all the MS6001B DLN1 frame unit models except for PG6581B DLN1.*

(5) *For PG6581B DLN1 the level of the steam injection for power is 2.8%. If customer wants to increase the level of steam injection up to 5.0%, it is mandatory to contact COMBUSTION ENGINEERING to get approval.*

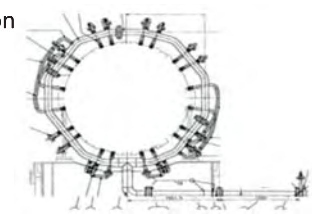
Steam Injection for power augmentation is available for standard and for DLN1 and DLN1+ combustion systems, on gas fuel operation only. *(See Figure 55a and 55b).*

Steam Injection for Power with DLN1+

6B DLN1+ with CPC needed. Same emission guarantees with steam injection.

Features are as per steam injection for standard combustion:

- Steam injection through 20 turbine shell mounted NPT pipe fittings
- Flex tubes connect between external manifold and turbine shell mounted NPT pipe fittings



Steam injection on-base piping

Range of applications:

- Occasional steam user, over fire with steam HGP life debit
- Continuous steam user, combustion transition piece enhanced for steam user with no impact on HGP life

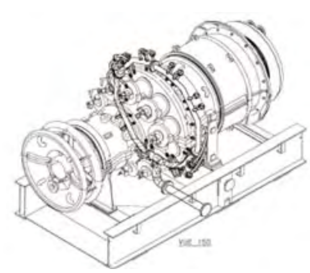
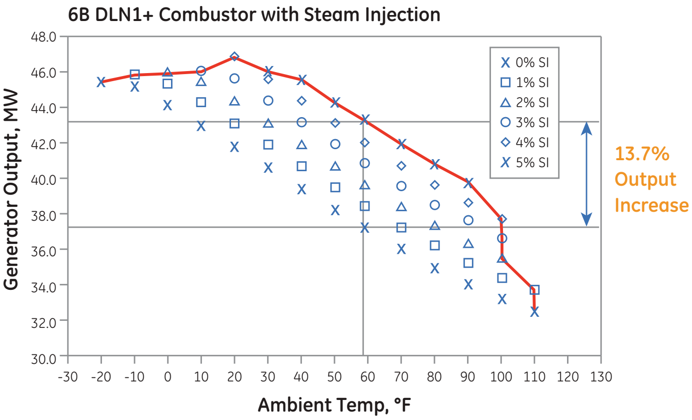


Figure 55a. Steam injection for DLN gas fuel only systems – for power with DLN1+

Steam Power Augmentation Benefits



- Up to 5% (of GT compressor airflow) steam injection capable at base load
- Up to 13.7% GT power increase and 5.7% GT heat rat decrease, at ISO conditions, dry control curve

Figure 55b. Steam injection for DLN gas fuel only systems – power augmentation benefits

Superheated steam is injected into the compressor discharge at a point upstream from the 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.

Steam Injection for NO_X Control in Gas or Dual Fuel Units (FG1B/D) (B=manual, D=automatic)

Steam is injected into the compressor discharge air stream around each of the fuel nozzles to reduce flame temperature, which leads to a reduction in NO_X emissions. *(See Figure 57.)*

The quality of steam for injection must comply with *GEK101944: Requirements for Water/Steam Purity in Gas Turbines*; typical supply conditions of the steam would be 325 psig with a minimum of 50°F superheat. Retrofitting steam injection will increase the gas turbine output and reduce heat rate (improved heat rate).

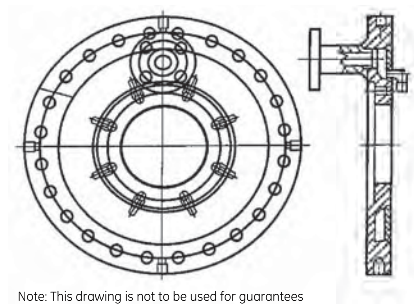
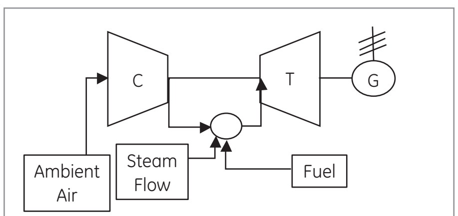
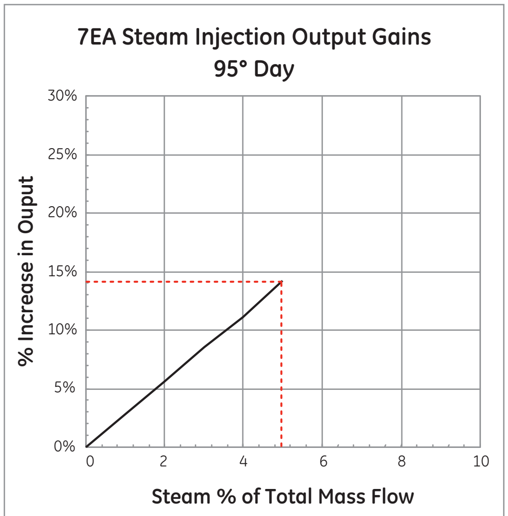


Figure 57. Combustion cover with steam injection nozzles

Steam Injection Technical Description

- Superheated Steam is injected into the compressor exit stream increasing mass flow into the turbines resulting in dramatic power output gains
- Injection of Steam can be done on a continuous operation basis
- Typically not used at less than 59°F ambient for power augmentation





Steam Injection Provides Significant Power Gains

Figure 56. Steam can be used to increase power

(See Figure 58.) The quantity of steam required will depend on the desired NO_X level required, the fuel used, and the ambient conditions.

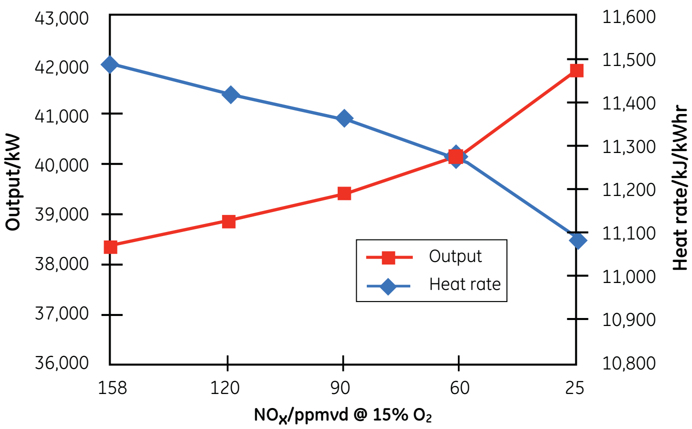


Figure 58. Effects of steam injection on gas turbine output and heat rate

The steam injection provides NO_X 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, serving to lower combustion temperatures thereby reducing NO_X production.

Benefit:

Model	*NO_X (gas)*	*NO_X (distillate oil)*
MS6001B	*25*	*42*

Notes:

Standard combustor with nozzle turbulated design combustion system.

Negative heat rate changes are an improvement

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. *(See FA6B).*

The addition of steam injection for NO_X control system requires increased protective functions. To allow for these additional control functions, all pre-Mark IV+ control systems require an upgrade. Existing Mark IV Simplex or TMR controls must be upgraded to Mark IVe or Mark VIe. Fuel gas flow measurement and a humidity sensor are supplied as part of this package. The standard control system changes provide for improved data logging functions that meet most regulatory agency requirements. Please note that on earlier units without the universal liquid fuel system, a second flow measurement device is required which is not included in this package, but is available as an option.

Uprate Combustion System to DLN1 (FG2B)

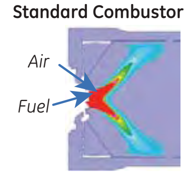
Customers operating MS6001 gas turbines burning gas fuel without diluent supplies for injection purposes may achieve NO_X emission requirements using dry low NO_X combustors (DLN). DLN combustion reduces NO_X emissions without steam or water injection on gas fuel units. This is done by fuel staging, with lean fuel-to-air ratios dependent upon premixing fuel with hot compressor discharge air to yield lower temperature rises across the combustor. *(See Figure 59.)* NO_X control for gas fuel is via the dry low NO_X system, while NO_X control for distillate fuel oil is by lean combustion augmented with a water injection system.

Combustion Fundamentals

Diffusion

- A region of 100% fuel is surrounded by a region of 100% air. The air and fuel diffuse together at the boundary with reaction occurring in the diffusion zone at or near ø = 1
  - Very robust/stable flame
  - Operative over ~2000°F temperature range
  - High NO_X emissions without diluent
  - Low CO emissions

Standard Combustor



Premixed

- Air and fuel are completely mixed upstream of the flame zone. The reaction occurs at the mixture. A premix flame has ø < 1
  - Operable over ~2000° temperature range
  - Can achieve very low NO_X emissions without diluent
  - CO emissions must be considered

DLN1 Combustor

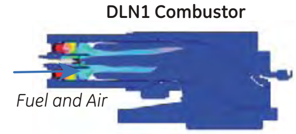


Figure 59. DLN uses a premixture, whereas diffusion flame does not

Benefit

Model	NO_X (gas)	CO (gas)	Diluent	NO_X (distillate)	CO (distillate)	Diluent
MS6001B	25	15	Dry	42	20	Water
MS6001B	15	25	Dry	42	20	Water
MS6001B	9	25	Dry	42	20	Water
MS6001B	5	25	Dry			

Dry Low NO_X (DLN) is a two-stage premixed combustor designed for operation on natural gas. *(See Figure 60.)* The combustor operates by premixing the gas fuel with the air in the first stage, 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 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 NO_X control.

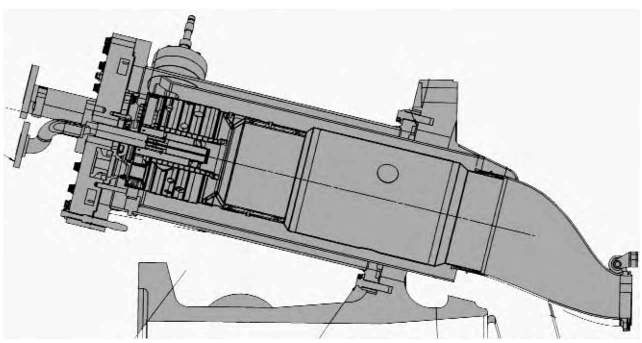


Figure 60. Cross section of DLN1 combustion system

DLN operates at a constant flame temperature, and so has limited turndown in the premix operation mode. A product called "inlet bleed heat" (see uprate FD3A) mixes compressor discharge air with inlet air to extend turndown with DLN premix combustion. Details of the DLN combustion system are given in *GER 3568G: Dry Low NOx Combustion Systems for Heavy Duty Gas Turbines*.

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 61 and Figure 62.)* The DLN combustion system offers lower NO_X emissions levels on gas fuel fired units without the parts life reduction associated with water or steam injection NO_X reduction systems. A typical DLN combustor for the MS6001B is illustrated in *Figure 63* and fuel gas delivery systems (original and current) in *Figure 64 and Figure 65a*.

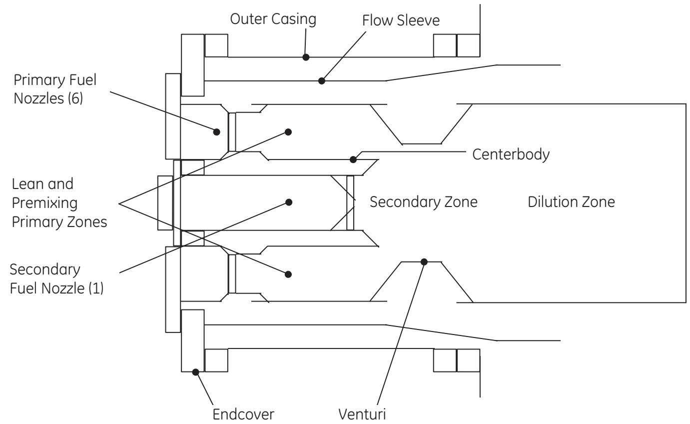


Figure 61. Dry low NOx (DLN) combustor

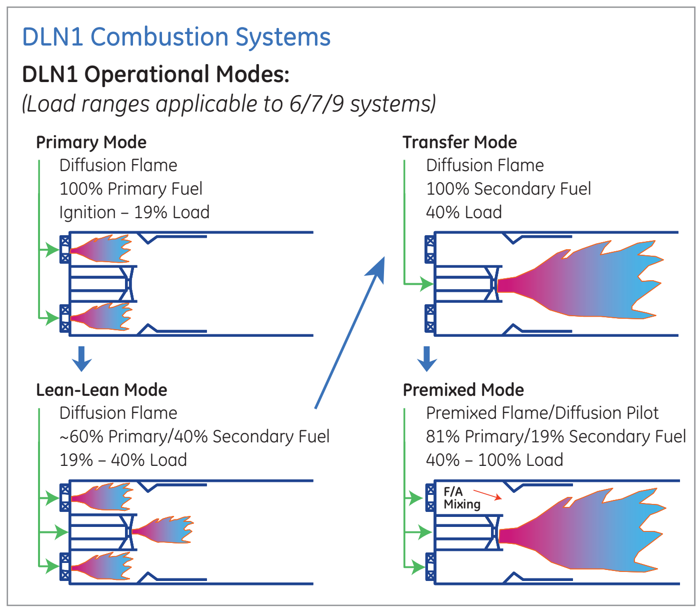


Figure 62. DLN operating modes

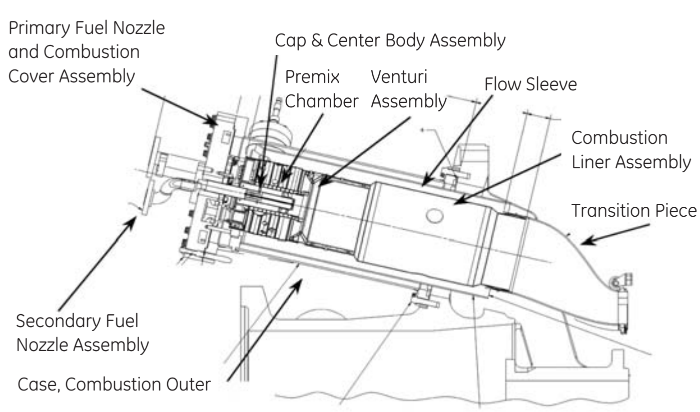


Figure 63. Dry Low NOx combustion system

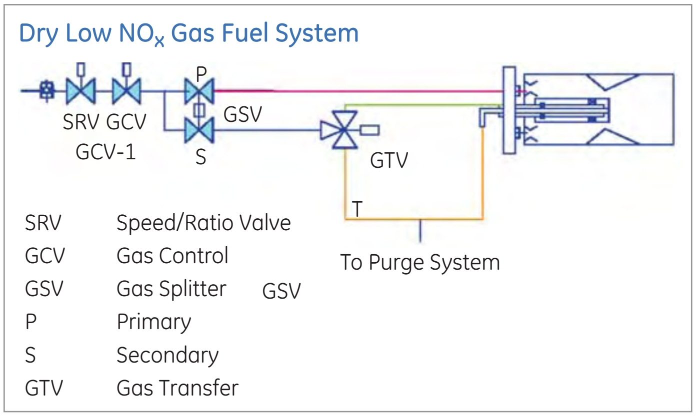


Figure 64. Original MS6001B DLN fuel gas system

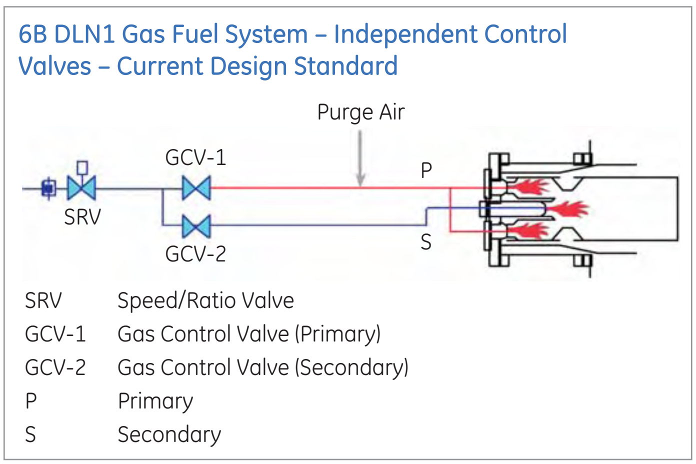


Figure 65a. Current MS6001B DLN fuel gas system

Uprate Combustion System to DLN1+ (FG2L)

The MS6001B DLN product has two designs: DLN1 for 9, 15, or 25 ppm corrected NO_X; and DLN1+ for 5 ppm corrected NO_X. Note that the DLN1+ design is compatible with existing DLN1 end-covers. Currently, DLN1+ is not available for dual fuel units (gas only). DLN1+ is available for all MS6001B units firing at 2020°F and above. It includes new liners, new transition pieces, and new secondary nozzles. For DLN1+, no changes to the turbine repair/replace procedures are expected. *Figure 65b* illustrates the evolution of emissions reduction offered by GE since year 1990.

The building block approach to lower-emissions uprates offered by GE is illustrated in *Figure 65c*. The DLN1+ uprates provide the quickest solution to comply with stringent emissions regulations because it leverages proven experience and provides a platform for future NO_X and CO reductions by allowing a building block approach.

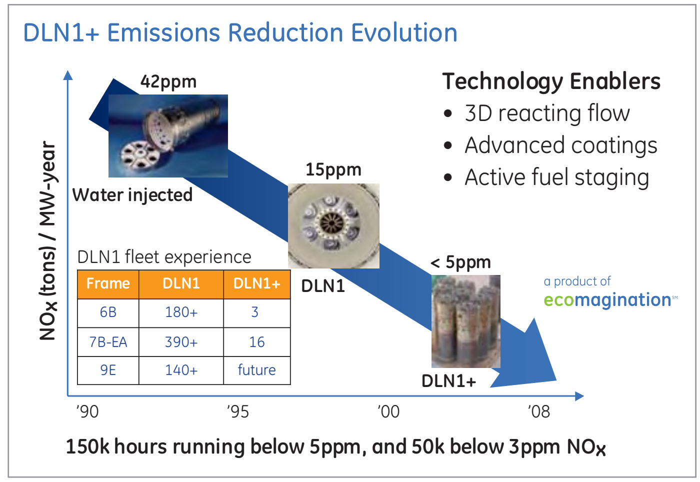


Figure 65b. Evolution of emissions reduction

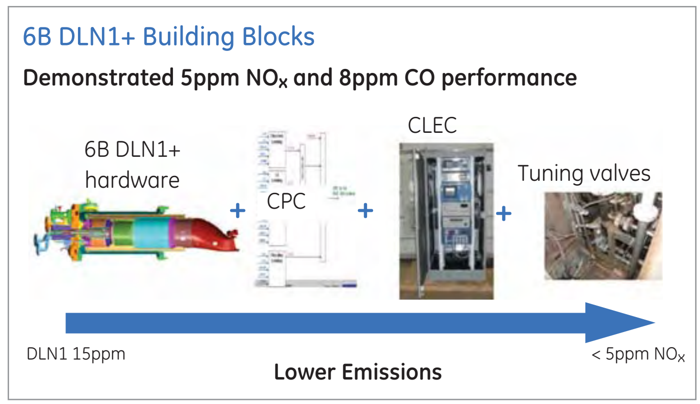


Figure 65c. DLN1+ building blocks

DLN1+ offers many improvements over DLN1. *(See Figures 65d and 65e.)* Among these are:

- Various combinations of hardware and software building blocks allow flexible emissions offerings, depending on the customer's current needs and future requirements. Examples include:
  - The standard 5/25 ppm NO_X/CO guarantee with fuel ambient range of 0°F-120°F requires DLN1+ combustion hardware, DLN1+ controls with corrected-parameter control, and closed-loop emissions feedback. This full DLN1+ technology package also offers a 4/25 ppm NO_X/CO guarantee with ambient range of 10°F to 20°F
  - The DLN1+ combustion-hardware-only package offers a 7/25 ppm NO_X/CO guarantee or 9/9 ppm NO_X/CO guarantee over respective temperature ranges.

- The combustion inspection interval is extended from 8,000 FFH / 50 FFS to 16,000 FFH / 450 FFS. DLN1+ includes wear-resistant Extendor materials and coatings to extend maintenance intervals.
- Proven and patented sealing technology for tighter performance and longer intervals; also used on GE F-Class fleet.
- Equivalent or similar turndown to DLN1 (i.e., 60% or better with inlet bleed heat).

DLN1+ System Advancements

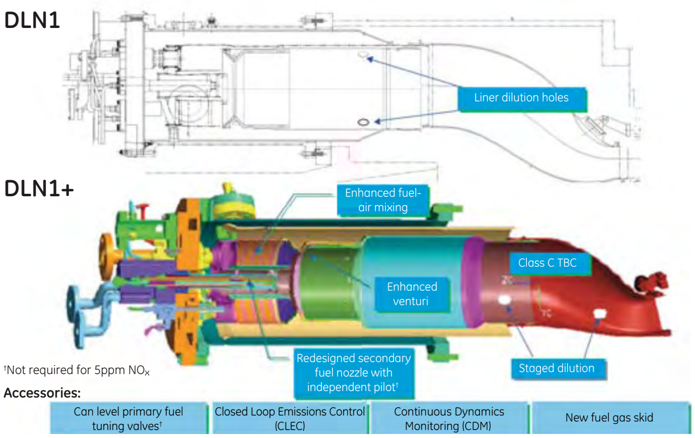


Figure 65d. GE's DLN1+ system improvements

6B DLN1+ Combustion Hardware

- For DLN1 to DLN1+ upgrade liner, transition piece, and secondary (center) nozzle need to be changed
- Hardware designed for 24,000 fired hours and 450 starts
- No impact on turbine durability
- Designed for 6B cycles firing temperatures, 2020 to 2100°F
- Includes all 6B DLN1 CLEX Extendor product features
- Staged dilution moved from liner to TP
- Liner aft end with F-class liner cooling
- TP thermal barrier coating upgraded w/clothseals

Figure 65e. GE's DLN1+ combustion improvements

System advancements that resulted in the current 5 ppm DLN1+ are illustrated in *Figure 66a*. Critical to the operation of the DLN1+ system are the following:

- Enhanced fuel-air mixing
- Independent pilot gas
- Can level primary fuel tuning valves
- Closed Loop Emissions Control
- Dilution staging enhancement

DLN1+ Next Generation <5 ppm NO_x

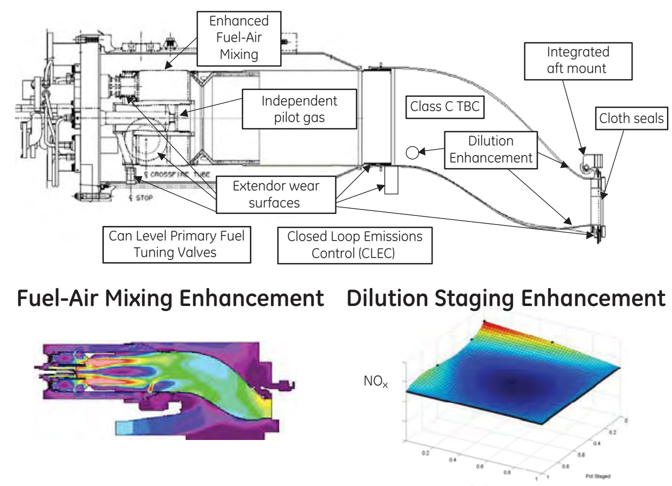


Figure 66a. Significant improvements included in DLN1+

Lean Head End (LHE) Reduced NO_X Combustion Liners (FR1B)

The liner offered in this option is specially designed to reduce NO_X emissions about 10% compared to standard combustion liner. Gas-only and dual fuel (distillate only) versions are available and are intended for short-term use only. Note that dual fuel versions require an atomizing air system.

Benefit:

A benefit of LHE liners is lower NO_X, the value of which depends on the frame size and fuel (gas-only or dual). For simple-cycle dry operation, a 15% reduction of NO_X can be realized.

LHE liners on all machines have a new mixing hole pattern that reduces NO_X. All of these high technology liners have with TBC coating applied to improve life. *(See uprate FR1G for more on TBC application on liners.)* The crossfire tube collars have hard-facing applied (on liners and crossfire tubes) to reduce wear. An option to apply hard facing on the fuel nozzle collars is also available upon request. The application of this liner is limited to dry operation or with water injection for NO_X control.

Fuel Delivery Systems

Convert to Gas Fuel Only (FA1A)

For MS6001B units that are equipped with dual fuel, the conversion to a gas-only fuel system from a dual fuel liquid/gas system is designed to leverage the availability of gas fuel and to simplify the operation and maintenance of the gas turbine. This upgrade addresses the conversion of MS6001B units to gas-only from a gas and distillate dual fuel configuration.

Benefit:

One benefit of converting to a gas-only system is that it eases maintenance and, for some units, may utilize an available, possibly less costly fuel. Gas fuel is a more easily handled fuel and has simplified emission controls.

This modification is for units that are equipped with a dual fuel, liquid and gas 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 are that it eases maintenance and eliminates the power consumption of the atomizing air compressor.

The conversion that is outlined here calls for:

- Modification, not replacement, of the primary and secondary fuel nozzle assemblies
- Elimination of the 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

Fuel Gas Change Study (FA1S)

Changing fuel gas (composition or temperature) has an impact on the performance, emissions and components of the machine. This study will evaluate these impacts and propose the necessary modifications to the machine. Due to commercial or other reasons, it is often desirable to change the fuel gas. If the change in fuel gas composition or temperature (from the original fuel for which the machine was designed) is significant, there may be a considerable impact on the machine performance, emissions and operation. Under this condition, component changes in the gas turbine are required for safe and reliable operation. These component changes may include fuel nozzles, gas control valve, controls and/or the entire fuel system, depending on the magnitude of the fuel change.

Convert from Liquid Only to Dual Fuel (FA3D)

Many gas turbines exist that only have liquid fuel capabilities. This is because 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 backup.

This conversion adds the capability of operating on either liquid fuel or gas fuel according to the economics and availability considerations.

Benefit:

This modification gives customers significant operational flexibility and potential fuel cost savings for some units with the added gas fuel capability.

There is negligible output performance difference expected by adding gas fuel, however, natural gas emissions are lower than liquid fuel emissions. Depending on site-specific conditions, NO_X levels of 42 ppm can be achieved while operating on gas fuel and using water or steam for diluent injection.

DLN1 and 1+ with Extended Fuel Flexibility (FG2R)

GE offers increased fuel flexibility for the MS6001B DLN1 system with only minor changes to the combustion system. GE has updated its MS6001B DLN1 fuel quoting limits for increased capabilities, thereby providing customers with additional value by removing the need for diluents, allowing higher levels of off-gas blending, with reduced emissions. *(See Figure 66b.)*

6B DLN1 Extended Gas Fuel Capability

- DLN1/DLN1+ hardware with extended gas fuel space
  - Hydrogen from 10% up to 32% in volume
  - Ethane from 15% up to 52% in volume
  - Propane from 15% up to 70% in volume
  - Parafins C4+ from 10% up to 40% in volume
- Using DLN1 or DLN1+ hardware
  - For fuel gas H2 content greater than 10%, a modification to the primary fuel nozzles is required to avoid potential fuel leaks outside of the combustion liner
- Gas fuel blending skid

Figure 66b. GE offers uprate to customers needing to burn off-gases

The gas fuel quoting limits have been extended for some operators to allow the use of up to 30% hydrogen (H2), 60% ethane (C2H6), 70% propane (C3H8) and 40% paraffin (C4+). This offering applies to MS6001B customers having the opportunity to burn off gases, usually available in refineries, chemicals or other oil and gas activities.

The main benefits to MS6001B customers using DLN1 or converting their combustion system to DLN1 are:

- Use of off-gas, which is usually less expensive than natural gas, as a primary fuel.
- Use of off-gas as a back-up fuel
- Avoiding the use of steam for NO_X control, as the DLN1 system using off-gas provides emissions below 25 ppm NO_X and 25 ppm CO
- DLN1 system provides extended combustion intervals compared to standard combustion with steam or water injection

Typical new quoting limits are illustrated in *Figure 66c*.

Frame	6B DLN1	6B DLN1+	7E/EA DLN1+	9E DLN1
Hydrogen (in. vol.)	32%	32%	30%	26%
Ethane (in vol.)	52%	52%	45%	33%
Propane (in vol.)	70%	70%	59%	60%
Parafins C4+ (in vol.)	40%	55%	34%	25%

Figure 66c. Typical gas fuel quoting limits

This offering is available only with gas fuel configuration, and does not apply for dual fuel. Please contact GE for further information on hardware configurations, emissions, accessory system requirements, maintenance, and more.

Summary

DLN1/DLN1+ with extended fuel capability

- Meets stricter NOx/CO regulations than standard combustion
- Reduces operating costs by burning cheaper fuels than expensive natural gas
- Improves gas turbine efficiency by converting a DLN1 combustion system

- Eliminates water usage cost by converting to a dry system
- Reduces maintenance costs by converting to a dry system

Figure 66d. Benefits of extended fuel capability

Hot Gas Path Improvements

The MS6001B machine has a three-stage turbine. The first two stages are air-cooled, with the 3rd stage un-cooled. *(See Figure 67.)* It is an assembly of three turbine wheels, wheel spacers and the aft stub shaft, all connected with through bolts.

Figure 67. Cross-section through turbine shell

Perimeter Cooled 16-Hole Stage 1 Bucket (FS4A)

The original stage 1 buckets (S1B) were made of IN-738™ material, a precipitation-hardened, nickel based superalloy with 13 cooling holes. IN-738™ material was the standard material for S1B on all frame sizes in the early 1980s.

The S1B was upgraded in 1987 with the introduction of equiaxed, nickel-based superalloy GTD-111 material, GT-29 coating, 11 cooling holes, and a blunt leading edge (BLE) airfoil section. Equiaxed GTD-111 material was introduced because it had 20°C improved creep rupture strength and was more resistant to low cycle fatigue than IN-738™ material. GTD-111 also has high corrosion resistance compared to other superalloys. 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.

Several design changes to the buckets have been made since 1989. First, an additional cooling hole was added to reduce bulk metal temperature (with 12 cooling holes) and GT-29 IN Plus* coating was applied. This coating is a vacuum plasma spray, with an aluminide coating on the internal (IN) cooling-hole passages and on the bucket exterior (Plus). This coating provided hot corrosion protection and high temperature oxidation resistance.

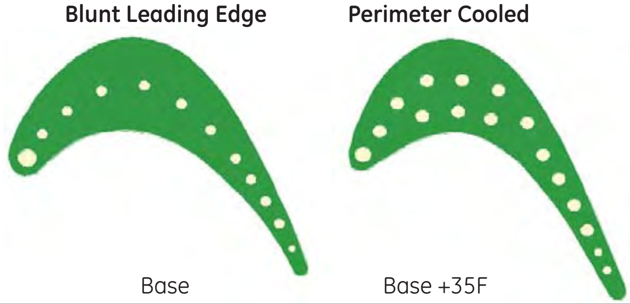
Directionally solidified (DS) GTD-111 buckets were introduced in the mid-1990s. DS GTD-111 material possesses an oriented grain structure that runs parallel to its major axis and contains greatly reduces transverse grain boundaries. The elimination of the transverse grain boundaries results in additional creep and rupture strength. This improved material extends the life of the buckets.

In 1997, the coating was changed to GT-33* IN material. GT-33 material is a vacuum plasma applied coating that offers an increased resistance to cracking. "IN" refers to an aluminide coating on the internal cooling hole passages (no exterior aluminide Plus coating). The over-aluminide coating, designated by the "Plus" was discontinued due to its propensity to crack and allow risk of crack propagation into the bucket metal surface. GT-33 IN material is GE's new standard coating for stage 1 buckets; however GT-29 IN Plus material is still available and sometimes recommended when combusting very highly corrosive fuels. For further information on bucket materials and coatings, see *GER-3569: Advanced Gas Turbine Materials and Coatings*.

Currently produced MS6001 buckets are DS GTD-111 material with GT-33 IN coating and 16 cooling holes. The perimeter-cooled stage 1 bucket incorporates several design improvements to allow for operation at the higher firing temperature associated with the MS6001B Advanced Technology Uprate. *(See Figure 68.)* The new bucket-cooling scheme includes a series of 16 radial cooling holes located around the "perimeter" of the bucket. Thirteen of the cooling holes include "turbulators" on the internal surfaces of the cooling

6B Advanced Technology Stage 1 Bucket

Blunt Leading Edge | **Perimeter Cooled**



Tf	Base	Base +35F
Material	DS GTD-111	DS GTD-111
Coating	GT-29 IN+	GT-33 IN+
Cooling	12 smooth holes	3 smooth/13 turb. holes
	Meanline	Perimeter
Shank	Radial ECM	Hollow core

- Use existing DS GTD-111 material (nickel-based alloy material) and coating technology
- New bucket profile
- Turbine Aerodynamic analysis undertaken for new engine operating conditions
- Enhanced cooling configuration:
  – 16 turbulated cooling holes
- Analyzed for operation with both Standard and DLN combustors

Figure 68. Stage 1 bucket GTD-111 perimeter-cooled by 16 holes

holes (from 0% to 80% of the bucket span) to increase the efficiency of heat transfer from the bucket metal to the cooling air. The turbulators are STEM (Shaped Tube Electrochemical Machining) drilled. The buckets also incorporate a cored or hollow shank that more effectively provides air to the 16 cooling holes. This feature allows for more consistent control of the quantity of cooling air and reduces the risk of cooling holes becoming plugged during operation.

Benefit:

The turbulated cooled design increases bucket cooling to allow more cooling air to reach the leading edge and significantly reduces thermal gradients and cracks along the leading edge. The improved materials extend the life of the buckets at the higher firing temperatures.

In addition to the improvements in cooling, the new 16-hole bucket has a new airfoil profile. The new airfoil profile is designed with heat transfer characteristics appropriate for operation at the higher firing temperature of the MS6001B Advanced Technology Uprate. This included thinning of the leading edge and rotating the airfoil hub sections aimed at improving the aerodynamic efficiency. GTD-33 IN material is now the standard S1B coating for B and E class gas turbines. Similar to GT-29 IN material, it is also a vacuum plasma spray coating, but offers increased resistance to cracking. *Figure 69* summarizes the advances made in these 16-hole perimeter cooled buckets.

TBC Coated Stage 1 Buckets (FS4G)

Upon special request from a customer, thermal barrier coating (TBC) can be applied to new and in-service stage 1 turbine buckets to extend bucket life and increase maintenance intervals.

Benefit:

According to design predictions and field experience, TBC has the potential to increase bucket life from three hot gas path intervals to four for any particular operator. There is no emissions impact from this upgrade.

These buckets have a dense vertically cracked (DVC) TBC patented by GE that is believed to have advantages compared to third-party coating applications due to the following:

- GT-33 bonding coat is believed to have advantages compared 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 than any third-party product
- Extensive GE lab data, Global Research Center studies, and design engineering modeling have been used to insure the enhanced application, thickness, composition, and product performance of DVC TBC applied by GE.

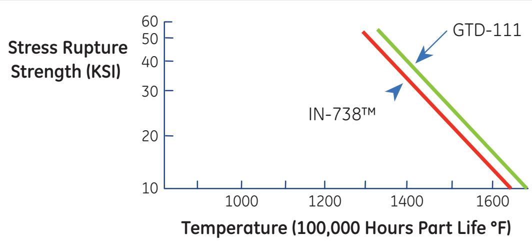
Coating first stage buckets with DVC TBC increases hot gas path parts life and maintenance intervals at a very minor

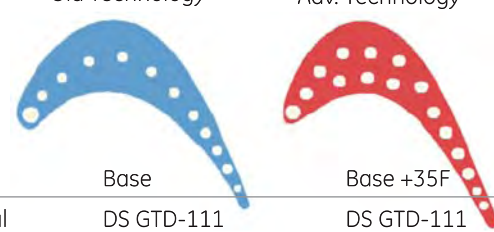
MS6001B Advanced Technology Uprates

Turbine Section: GTD-111 Stage 1 Buckets

Features:

- **DS GTD-111 material**
  - Improved rupture strength and reduces high cycle fatigue
- **GT-29 IN Plus/GT-33 incoat coating**
  - Improved corrosion and oxidation resistance
- **Turbulated cooling circuit**
  - Improved cooling





	Blunt Leading Edge Old Technology	Perimeter Cooled Adv. Technology
Tf	Base	Base +35F
Material	DS GTD-111	DS GTD-111
Coating	GT-29 IN+	GT-33 IN+
Cooling	12 smooth holes	3 smooth/13 turb. holes
	Meanline	Perimeter
Shank	Radial ECM	Hollow core
314B7162G013 (typical)		**314B162G021 (typical)**

Figure 69. Summary of advances made for perimeter-cooled first stage bucket uprate FS4A

debit (-0.66%) to performance and heat rate (+0.45%). Based on fleet leader data and extensive testing, it has been determined that 32,000 hour inspection intervals may be obtained with potential for 96,000 hour total life. 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 these will need to be considered on a unit-by-unit basis. *(See GER-3620).*

Upgraded Stage 2 Buckets (FS4B)

The stage 2 bucket (S2B) has undergone several design changes since its introduction. It was originally made from IN-738™ material with four radial smooth cooling holes and no coating. *(See Figure 70.)* TIL 1203-1R1 advises inspection requirements of these buckets. All 4-hole buckets are to be replaced at or before 48,000 hours of operation.

In 1997 with the announcement of the Advanced Technology Uprate for the MS6001B, a new 7-cooling-hole design was introduced. Five of seven holes were turbulated from 40% to 70% of their span to improve cooling of the bucket—leading to reduced bulk metal temperatures, even at the higher firing temperature.

The current S2B design incorporates several design improvements to allow for operation at the higher firing temperature associated with the MS6001B Advanced Technology Uprate and the available firing temperature increase in PG6581B. *(See Figure 71.)* The material for the new stage 2 buckets continues to be IN-738™ material; however, the bucket now has six radial cooling holes—four of which are turbulated from 40% to 70% of their span. *(See Figure 72.)* New airfoil geometry has been utilized which allows improved cooling to the trailing edge of the bucket.

Both the 7-hole and 6-hole S2B include "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. Cutter teeth have been included on all stage 2 MS6001 buckets manufactured since late 1995.

Benefit:

The improved cooled stage 2 buckets for MS6001B possess an improved cooling design that provides more effective cooling of the stage 2 bucket. The improved cooling allows the bucket to be used at the higher firing temperature associated with the 2084°F uprate.

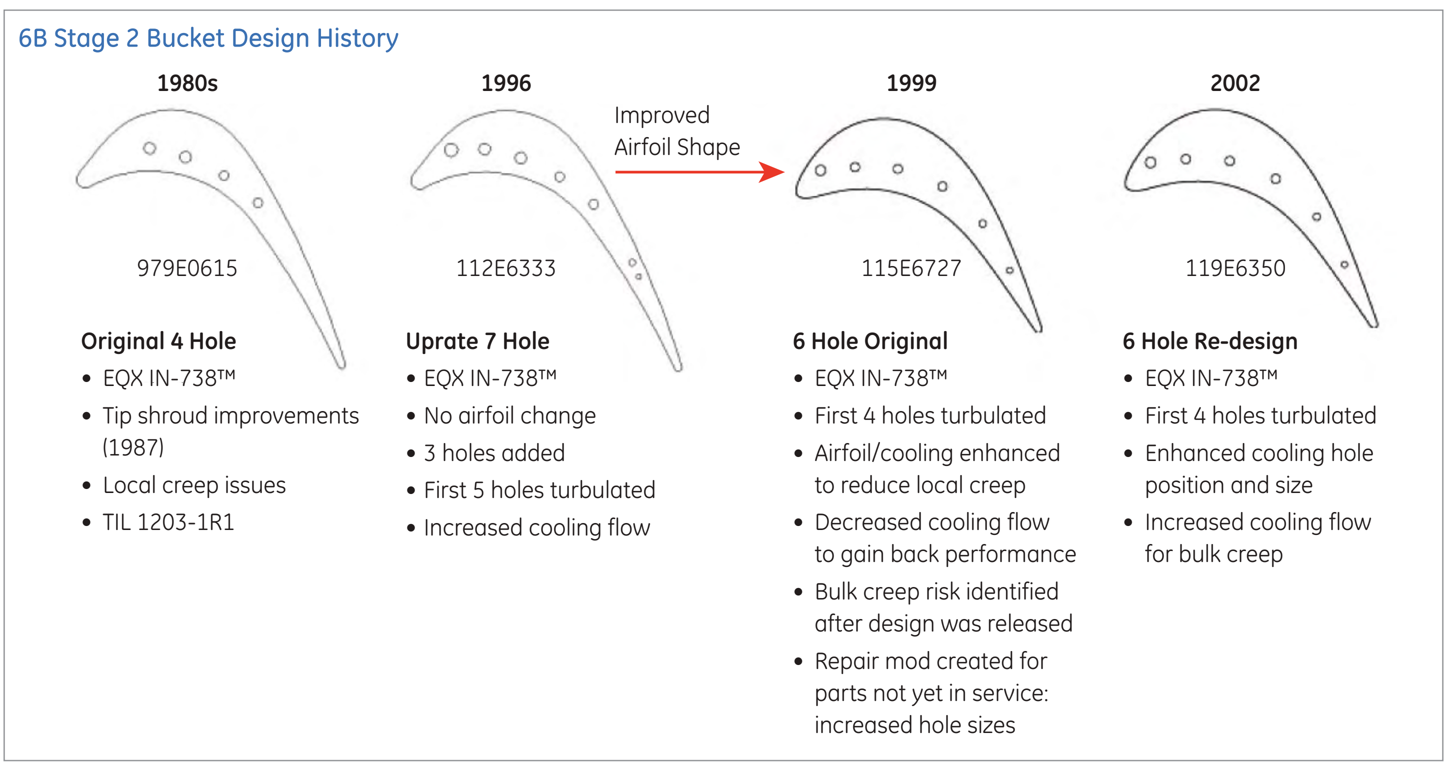
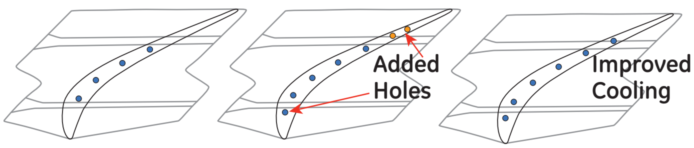


Figure 70. Evolution of MS6001B stage 2 buckets

MS6001B Second Stage Bucket



	Original	+35F Uprate	2084°F Uprate
Aero	Baseline	Baseline	Baseline
Material	IN-738™	IN-738™	IN-738™
Coating	None	None	None
Cooling	4 Smooth holes	2 Smooth (nearest TE)	2 Smooth (nearest TE)
	Meanline	5 Turbulated (40 to 70%) Meanline	4 Turbulated (40 to 70%) Meanline
			*Complies with TIL-141171

Figure 71. Stage 2 bucket used in machines fired at 2084°F as compared to previous

- Nickel base alloy material
- Enhanced cooling of airfoil
- Contoured tip shroud for creep life improvement

Figure 72. Stage 2 buckets with improved, six-hole cooling

Uprated Stage 3 Bucket IN738™ (FS2K)

The stage 3 bucket has undergone improvements in design, manufacturing, materials, and processes, as illustrated in *Figure 73*.

The latest stage 3 bucket design is made out of IN-738™ material instead of U-500™ material. The IN-738™ material offers superior hot corrosion resistance in comparison to U-500™ material and also has outstanding strength at the high uprate temperature. GE also offers an optional chromide coating for applications where fuel related corrosion is expected or has been experienced.

Benefit:

This modification improves the third-stage buckets parts lives for uprated higher firing temperatures.

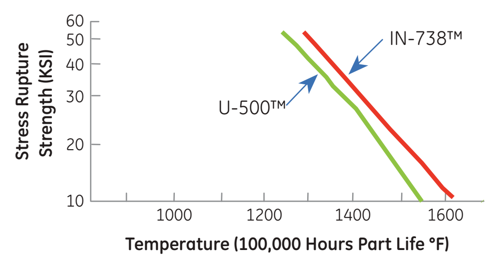
The new stage 3 bucket designs also include "cutter teeth" on the bucket tip shroud rails. These are designed to cut a slot in the

Turbine Section-Stage 3 Rotated Buckets

IN-738™ Stage 3 Bucket

Features

- New bucket material
- Rotated bucket profile
- New shroud tip design
- Cutter teeth



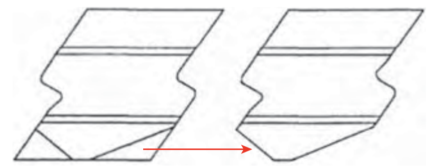
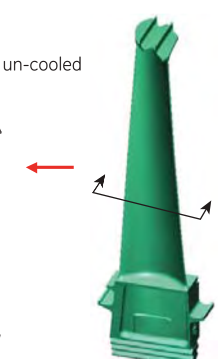


Figure 73. Improved stage 3 buckets

honeycomb seal material on the stage 3 shroud block with no metal transfer to the bucket. This will allow new shroud blocks with honeycomb seals to be installed (refer to FS2U). Since 1996, all new MS6001B stage 2 and 3 buckets have been manufactured with cutter teeth on the bucket tip rails. For the MS6001B, the IN-738™ uprated bucket is dimensionally interchangeable with the existing bucket, except the material change from U-500™ material to IN-738™ material. The IN-738™ bucket does NOT have the rotated airfoil, as illustrated in *Figure 74*.

6B Stage 3 Bucket Evolution

- Airfoil shape unchanged
- Shroud scalloped early on (1970s)
- Original U500™ material
- +35°F Tfire uprate S3B (1996)
  - IN-738™ material
  - Cutter teeth added
- Optional chromide coating



7EA Stage 3 Bucket Shroud Profile History

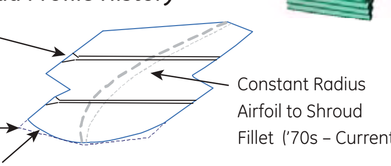


Figure 74. Evolution of stage 3 bucket for the MS6001 gas turbine

Uprated Stage 1 Nozzle With Chordal Hinge (FS2J)

The original material used for the first stage nozzle and still used today is the FSX-414 cobalt-based superalloy, which has excellent oxidation, hot corrosion, and thermal fatigue resistance. It requires inspection during the hot gas path inspection (HGPI@24,000 hrs), and is weld-repairable, which allows the nozzle to be refurbished and returned to service.

There have been several generations of the stage 1 nozzle (S1N). A universal S1N was installed in the MS6001 gas turbine in 1987, which allowed operation on residual fuels (ash bearing fuels) as well as fuel gas and distillate oil.

The universal S1N has been modified to be capable of replacing nozzles based on the older universal nozzle design, as well as pre-universal nozzles operating on either conventional or heavy fuel. First time application of the universal nozzle will require a new nozzle support ring. The key modifications include these improvements:

- Nozzle sidewall cooling
- Airfoil trailing edge film cooling holes
- New impingement hole pattern on the core plug
- New pressure side cooling hole pattern
- Improved inner segment spline seals
- Improved sidewall seal
- Addition of a nozzle inner sidewall improved hinge rail.

The major design change incorporated into the improved cooling, stage 1 nozzle is the addition of a more efficient film-cooling pattern. This new design incorporates a sidewall cooling hole pattern that has been relocated to promote better coverage of the most commonly distressed area on the nozzle sidewall, as determined by computer modeling and operational histories. The improved coverage pattern is achieved on current production nozzles by replacing the pressure side film holes with film cooling slots as illustrated in *Figure 75*.

The new slots are spaced more closely together and are combined with new cooling holes to the inter-vane space on the nozzle outer sidewall. The resulting improvement in exit conditions significantly increases the cooling efficiency of the airflow to the sidewall areas—without increasing the overall airflow requirement.

The hinge design originates from proven aircraft engine technology applied to today's heavy-duty gas turbines. The improved seal is created on the support lug with a new straight improved seal ridge. This results in an improved seal at the S1N / support ring interface. This seal eliminates the potential leak path due to warping and distortion sometimes associated with the older curved support lug after it disengaged during operation. This straight improved seal requires a re-designed shorter tangential slot on the inner sidewall support lug. This new seal—coupled with the offset of the support lug—combines to create a 'hinging' action downstream from the retaining ring along the radial plane of the nozzle. Improved inner segment sidewall spline seals reduce leakage between nozzle segments.

Benefit:

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. Also, there is reduced nozzle distress at the sidewall by improved sidewall cooling and sealing design.

Improved Cooling FSX-414 Stage 1 Nozzle

- New nozzle design made from the FSX-414 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

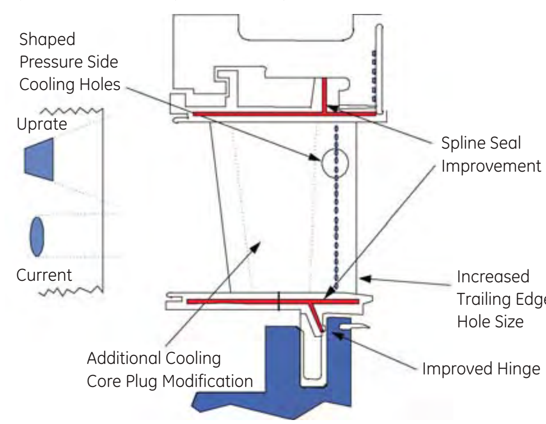


Figure 75. Stage 1 nozzle showing cooling and sealing modifications

The chordal hinge nozzle introduced in 1994 is the result of two major design changes maintaining the philosophy of burning both clean 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 76*. 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.

Turbine Section

Chordal Hinge Stage 1 Nozzle

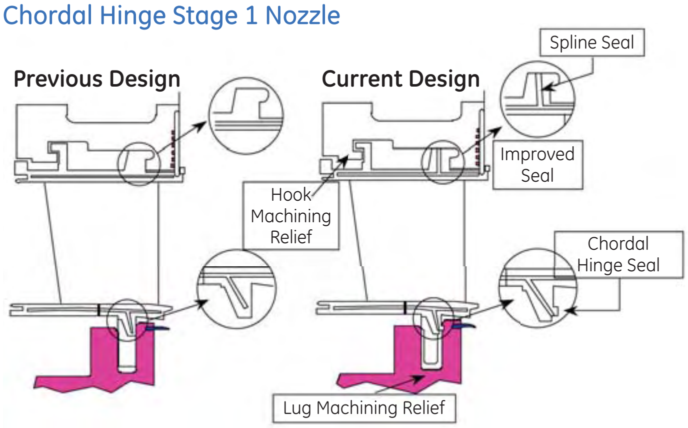


Figure 76. Stage 1 nozzle improved sidewall sealing with chordal hinge

As firing temperatures have increased during the development of the MS6001B, the nozzle metal incurred higher temperatures, causing oxidation and erosion to occur on the sidewalls. To reduce oxidation and erosion, cooling effectiveness was increased. The overall cooling effectiveness was improved by relocating some of the holes and re-shaping some of the holes into slots, as illustrated in *Figure 77*.

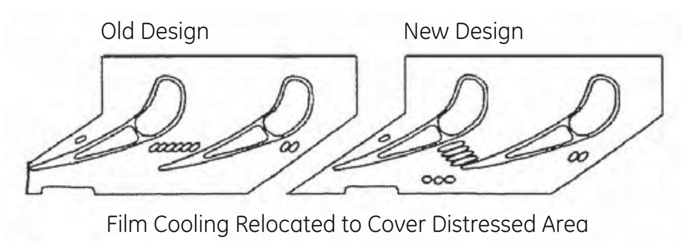


Figure 77. Stage 1 nozzle improved cooling outer sidewall film cooling

When the chordal hinge nozzle was introduced, the original 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 78.)* More recently, the tangential pin hardware has been eliminated because field inspections have

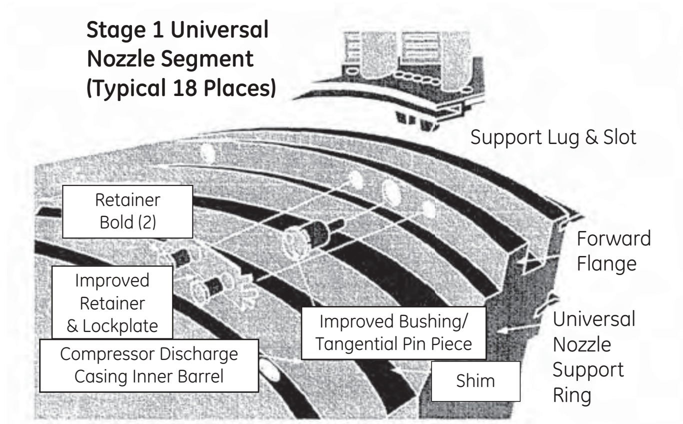


Figure 78. First stage nozzle improved inner sidewall tangential support

indicated that the nozzle does not require this redundant tangential support. This elimination simplifies the design and eliminates the potential for gas path object damage that could result from improper assembly. In addition to eliminating the hardware, the forward flange on the support ring has been eliminated. *(See Figure 79.)* These design modifications make the universal nozzle and the chordal hinge nozzle interchangeable with no support ring modifications required.

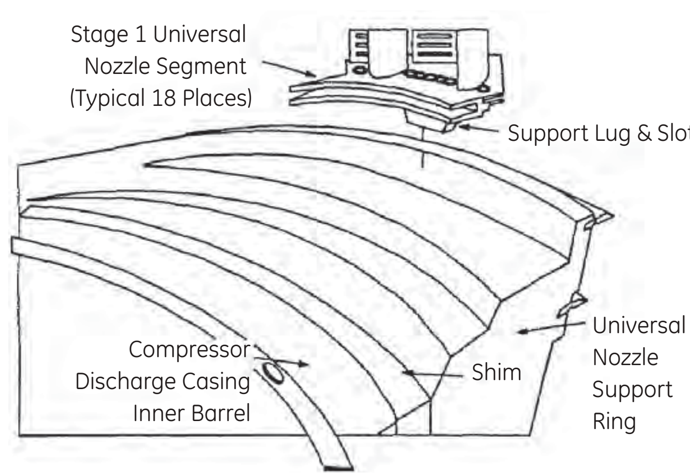


Figure 79. First stage nozzle and support ring with no tangential hardware

TBC Coating for Stage 1 Nozzle (FS6E)

Stage 1 nozzles can be coated with thermal barrier coating (TBC). The TBC can be applied to the leading edge, pressure side and outer wall of the stage 1 nozzle. *(See Figure 80.)* The TBC coating on E-Class stage 1 nozzles helps protect the nozzle metal from oxidation and contaminants.

Benefit:

- *Oxidation resistance for the nozzle metal*
- *Reduced susceptibility to surface fouling for the nozzle metal*
- *Sustained unit operating performance*
- *Due to reduced metal temperatures the following are obtained: prolonged component life; increased durability; and increased maintenance intervals*

TBC reduces heat transfer (increasing part durability), improves erosion resistance (3X greater in laboratory testing), and reduces surface fouling of the nozzle metal surface.

Enhanced Thermal Barrier Coating

eTBC, an advanced three layer coating system consisting of:

- Bond coat
- Porous class TBC
- 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 can yield performance

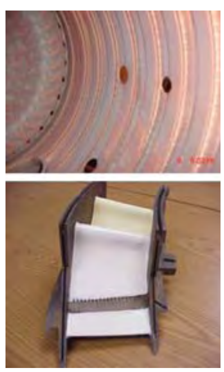


Figure 80. Stage 1 nozzle with TBC

GTD-222+ Stage 2 Nozzle Uprate (FS1P)

The second stage nozzle (S2N) design, originally fabricated from FSX-414 material, has been replaced by a newer nozzle design, fabricated from creep-resistant GTD-222+ material. FSX-414 nozzles are subject to downstream creep deflection due to the combination of gas loading and metal temperature exceeding the FSX-414 long-term creep strength of this cantilevered design. Experience combined with analysis has shown that units operating with FSX-414 stage 2 nozzles require frequent repair to restore the nozzle axial position and unit clearances due to this creep deflection.

The latest GTD-222+ nickel-based superalloy significantly reduces downstream deflection compared to FSX-414 material. *(See Figure 81.)* The overall dimensions of the GTD-222+ nozzle remain unchanged from the previous design and are applicable as either an uprate, or a replacement part for units with the older nozzle. The new FS1P nozzle increases performance over superseded nozzles, and a brush seal is also available to further increase performance. *(See uprate option FS2V.)*

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

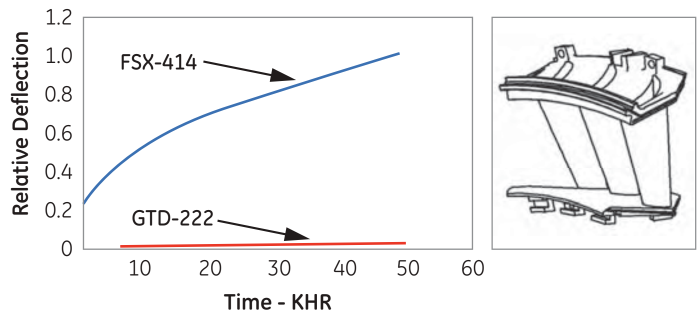


Figure 81. Stage 2 nozzle creep deflection comparison

The new GTD-222+ second stage nozzle is coated with an aluminide coating to resist high temperature oxidation resistance. Other modifications include changes to the second stage nozzle's internal core plug. Core plug modifications allow more efficient distribution of cooling air and reduced nozzle-cooling requirements. *(See Figure 82.)*

Current Stage 2 Nozzle Design

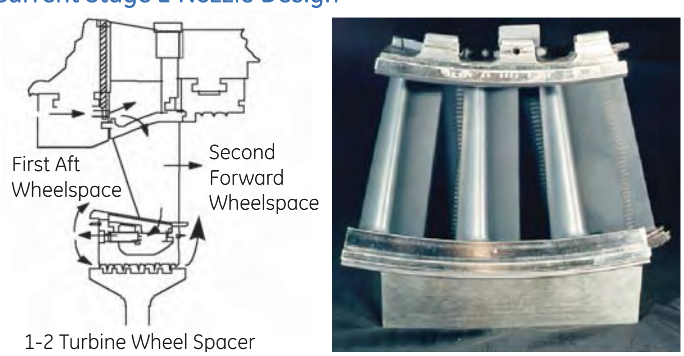


Figure 82. Stage 2 nozzle cooling airflow

New tuning pins associated with this uprate and modifications to the first stage shroud blocks that include smaller cooling air orifices—in combination with core plug modifications—further reduce cooling air requirements and result in gas turbine performance improvements.

There are two configurations of S2N diaphragms referred to as "pressurized" and "non-pressurized" designs. *(See Figure 83.)* The pressurized design nozzle was shipped between 1998 and 2002. All subsequently shipped S2Ns are the non-pressurized design. S2Ns shipped before and after 1998 to 2002 were/are non-pressurized. It was found that customers experienced high 1AO wheelspace temperature concerns with the pressurized design, as referred to in TIL 1243-2. As illustrated in *Figure 84*, GE offers an uprate option to convert pressurized S2N to non-pressurized S2N. Evolution of the stage 2 nozzles is illustrated in *Figures 83–85*.

Benefit

Model	*Output*	*Heat Rate*
MS6001 A/B	*+1.0%*	*-0.4%*

Note:

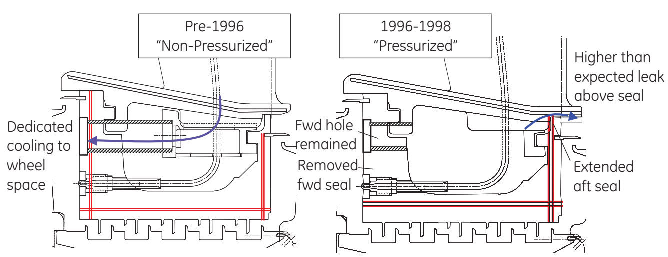
The GTD-222+ second stage nozzle significantly reduces nozzle downstream stream creep deflection. Performance improvements can only to be expected on those machines currently equipped with air-cooled second stage nozzles, but it is not guaranteed. Negative heat rate changes are improvement

Reducing the nozzle cooling flow yields an increase in output power. *(See Figure 85.)* The MS6001 will see an increase in output of approximately +1.0% with new tuning pins in conjunction with the GTD-222+ stage 2 nozzle. For those existing MS6001 stage 2 nozzles that are not air cooled, installing this air cooled stage 2 nozzle would result in an output loss of approximately -1.0% due to the air extracted from the system for cooling airflow.

GE developed a brush seal for the stage 2 nozzle diaphragm based on the success of the high-pressure packing and No. 2 bearing brush

6B Stage 2 Nozzle Diaphragm Evolution (up to 1998)

Background: S2N Diaphragm converted to "pressurized" in 1996 by removing airbox and modifying sealing arrangement to encourage forward leakage.

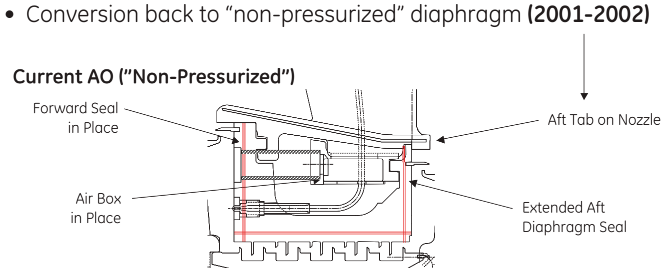


Issue: Conversion to "pressurized" diaphragm increased leak across aft side of diaphragm resulting in decreased flow to the forward wheel space (1AO). Several units experienced elevated 1AO temperatures as well as 1AO high temperature alarms as a result.

Figure 83. The S2N currently has returned to the non-pressurized design

Corrective Action: 6B Stage 2 Nozzle Diaphragm

- TIL 1243-2 issued to inform users **(1998)**:
  - Higher than expected aft diaphragm leak and associated high wheel space temps (1AO)
  - Modifications (if required):
    - Install smaller shroud tuning pins
    - Decrease aft leakage gap by weld-building up aft nozzle hook surface (field mod.)
- Material added to aft end of nozzle sidewall (new parts) to reduce aft leakage **(1998)**
- Conversion back to "non-pressurized" diaphragm **(2001-2002)**

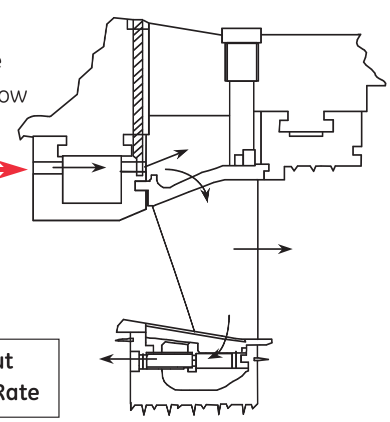


Current S2N Utilizes Best Features from Previous Designs

Figure 84. Uprate option is available to convert pressurized diaphragm to non-pressurized

- Improved creep resistance
- Improved nozzle vane cooling
  - Redesigned core plug
- Improved performance
  - Reduced cooling air flow

Reduced cooling flow controlled by tuning pin



1%	**Increased Output**
0.4%	**Improved Heat Rate**

Figure 85. Design changes and reduced airflow in non-pressurized stage 2 nozzle

seals. (See 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 from the first aft to the 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 nozzle core plug via the plenum formed between the outer sidewall of the nozzle and turbine shell. Cooling air flows through the nozzle core plug and some of the air exits the nozzle via the trailing edge cooling holes while the remainder of the cooling airflows into the cavity between the diaphragm and the nozzle. Cooling air also flows to the first aft wheelspace and through the diaphragm/spacer seal (inner stage packing) to the second forward wheelspace.

This GTD-222+ nozzle includes an aluminide coating for increased high temperature oxidation resistance. It can be further enhanced by adding TBC offering increased resistance to thermal fatigue, resulting in life extension and improved maintenance intervals. *(See uprate option FS6E.)*

GTD-222+ Stage 3 Nozzle Uprate (FS1R)

The third stage nozzle (S3N) was redesigned to essentially eliminate the downstream nozzle deflection. Similar to the S2N, GTD-222+ material has replaced the FSX-414 material due to its superior creep strength.

The original stage 3 nozzle, like the stage 2 nozzle, experienced tangential deflection caused by creep. To reduce creep and decrease tangential deflection, three design changes were made. *(See Figure 86.)* First, the chord length was increased to reduce overall airfoil stress levels. Secondly, an internal airfoil rib, similar to the one for the stage 1 nozzle, was added to provide additional stability and increase the component's buckling strength. In 1992, the material was changed from FSX-414 material to GTD-222+ material. Unlike the stage 2 nozzle, an aluminide coating is not necessary due to lower temperatures always typical of stage 3. Since this nozzle is not air-cooled, there is no performance benefit like the stage 2 nozzle [and no performance detriment]. Dimensionally, the GTD-222+ nozzle for stage 3 is interchangeable with the existing FSX-414 nozzle for stage 3.

Benefit:

One advantage of GTD-222 third-stage nozzle GTD-222+ is to eliminate the nozzle downstream creep deflection, a key life-limiting factor. The re-design and change of material for the third stage nozzle reduces stress levels and increases creep life.

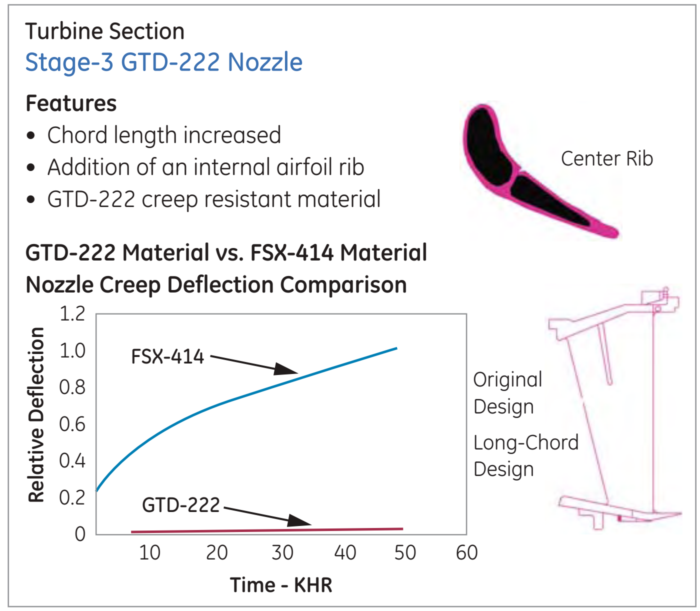


Figure 86. Improved stage 3 nozzle

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.

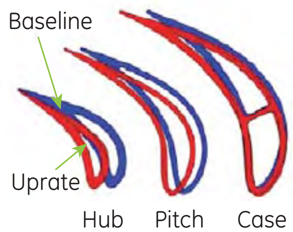
Advanced Aero Stage 3 Nozzle (FS4K) and Bucket Uprates (FS4L)

Always striving to increase performance of MS6001 units, GE has developed new stage 3 buckets and nozzles with an advanced aerodynamic airfoil shape. The latest stage 3 bucket design is made out of GTD-741* material instead of IN-738™ material, and offers similar hot corrosion resistance and outstanding strength at the high uprate temperature.

These new advanced aero S3Bs and S3Ns are best installed together in an aerodynamically coordinated pair to obtain the performance benefits illustrated in *Figure 89*.

FS4K Advanced Nozzle. To improve output and decrease heat rate, the advanced aero third stage nozzle is re-designed with improved airfoil aerodynamics. *(See Figure 87.)* This improved design gives

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 87. Advanced aero stage 3 nozzle

additional performance benefits when used in combination with the advanced aero stage 3 bucket, FS4L, as described in *Figure 88*. The uprate includes the third stage nozzle and diaphragm, plus required hardware.

The third stage nozzle was aerodynamically re-designed to improve aerodynamic performance. 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 existing GTD-222+ nozzle. The latest stage 3 nozzle design is also made of GTD-222+ material. On those units that are not already equipped with GTD-222+ material or advanced aero nozzle, the installation of the new design third stage nozzles provides an excellent time to install replaceable wheelspace thermocouples. *(See uprate FK5C.)*

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

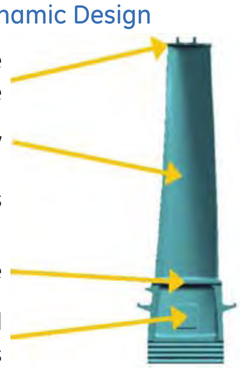


Figure 88. New stage 3 bucket design

FS4L Advanced Bucket. This modification replaces the existing stage 3 buckets with an advanced aerodynamic, re-designed stage 3 bucket with an improved airfoil, see *Figure 88*. This improved design allows for additional performance benefits, as illustrated in *Figure 89*, when used in combination with the advanced aero stage 3 nozzle in FS4K. The improved airfoil design on the advanced aero stage 3 bucket has a "high efficiency" airfoil that is significantly thinner from hub to pitch, and has a closed airfoil throat to reduce stage losses and improve efficiency.

Installation of Both Parts Provides the Greatest Benefit

Provides Significant Improvement in Output and Heat Rate

Part	S/C Output	S/C Heat Rate	Exhaust Energy
New S3B/New S3N, Hot Day, 100F/38C, Guarantee Pt	+0.7%	-0.7%	-.035%
New S3B/New S3N, ISO Day, 59F/15C, Reference Only	+1.0%	-1.0%	-0.50%
New S3B/New S3N, Cold Day, 0F/ -18C, Reference Only	+1.2%	-1.2%	-0.70%

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

Figure 89. Performance benefit when the advanced aero Stage 3 bucket and nozzle are combined on the same unit. (Note: Negative heat rate changes are an improvement)

The advanced aero bucket is dimensionally interchangeable with the existing bucket. The advanced aero stage 3 bucket is made of IN-738™ material, 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 90.)* 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 blocks, with no metal transfer to the bucket. This allows new shroud blocks with honeycomb seals to be installed. *(See uprate FS2U.)*

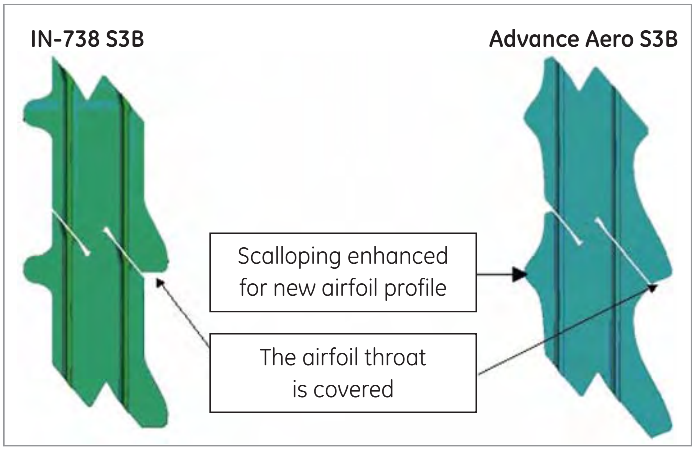


Figure 90. Advanced aero stage 3 bucket tip shroud

Uprated Stage 1 Shroud HR-120™ with Cloth Spline Seals (FS2Y)
There are several design improvements made on the stage 1 shrouds (S1S), as illustrated in *Figure 91*. The original material has been changed from 310SS to HR-120™ material. The new material has both higher inherent material strength and more favorable time at temperature characteristics. Note that HR-120™ stage 1 shrouds with cloth spline seals and the S2N cooling path do not apply for 6581 units with 13th stage S2N cooling.

The new shroud design 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. New spline seals replace the original pumpkin teeth design. This dramatically reduces the leakage of compressor discharge air into the hot gas path, resulting in improved turbine performance. A new flexible "W" seal is also fitted between the S1S and S1N retaining ring. After a period of service or after overhaul/repair, the S1N may be slightly distorted. The flexible "W" seal accommodates for this distortion and again prevents leakage of CD air into the HGP.

The improved stage 1 shrouds are made of a one-piece design from Haynes HR-120™ material, a solid solution strengthened iron-nickel-chromium alloy that improves low cycle fatigue life and allows operation at higher 2084°F firing temperatures. *(See Figure 92 and Figure 93.)* Reduced leakage associated with this design increases performance and lowers heat rate.

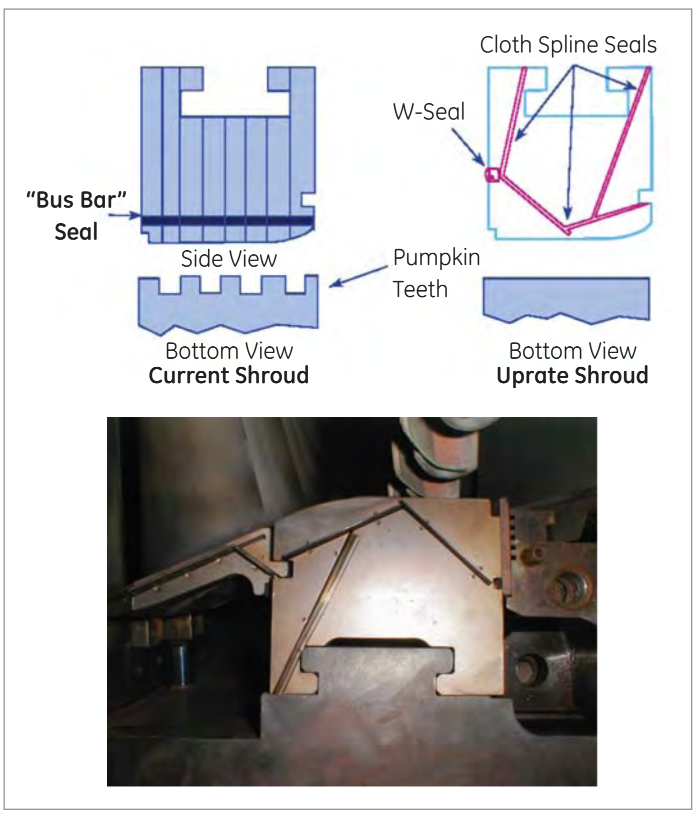


Figure 91. Improved stage 1 shrouds with cloth spline seals

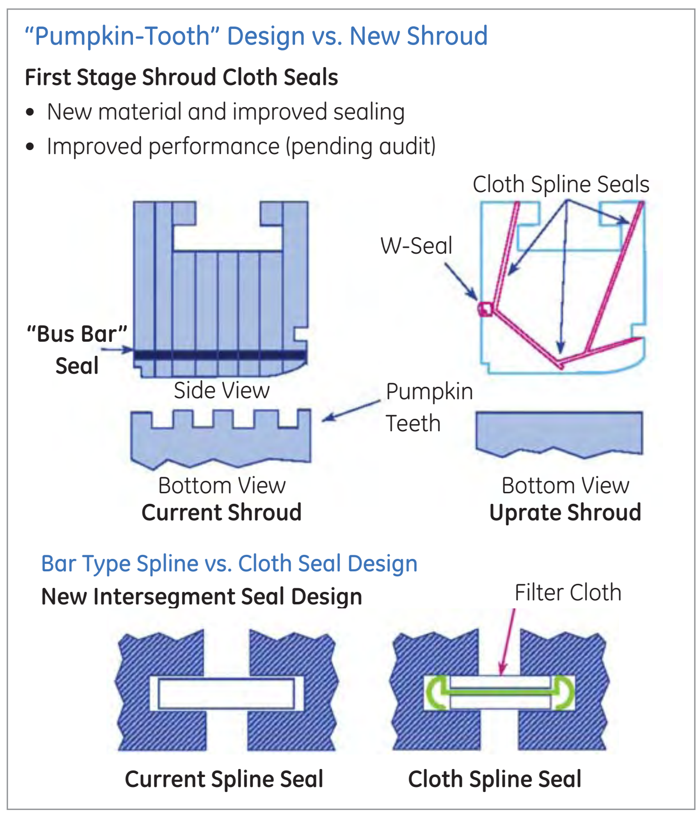


Figure 92. First stage shroud with cloth seals FS2Y

Benefit:

Model	*Output*	*Heat Rate*
MS6001 A/B (Note A)	*+1.05%*	*-0.45%*
MS6001 A/B (Note B)	*+0.3%*	*-0.15 %*

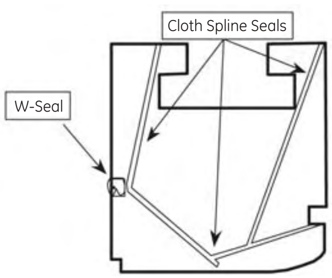
Notes:

A: The current production 6B PG6581 units ship with an HR-120™ stage 1 shroud with pumpkin teeth for intersegment sealing. The HR-120™ stage 1 shrouds with intersegment cloth seals cannot be supplied as a replacement due to differences in the stage 2 nozzle-cooling scheme. The PG6581 model uses stage-13 compressor extraction air for stage 2 nozzle cooling, which is different from the older cooling scheme routing compressor discharge air through the stage 1 shroud to the stage 2 nozzle. At this time, there is not a plan to incorporate an HR-120™ stage 1 shrouds design with intersegment cloth seals on new 6B units.

B: For MS6001 units, HR-120™ stage 1 shrouds with metallic spline seals have been in production for a number of years. However, HR-120™ stage 1 shrouds with the superior cloth spline seals are currently the standard advanced technology offering. Customers with the HR-120™ stage 1 shroud with metallic spline seals can convert to the cloth seal version to obtain the additional performance improvement of the new seal (+0.30% output and -0.15% heat rate).

C: Negative heat rate changes are an improvement.

Advanced Shroud Seal Configuration



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™ Material

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

Figure 93. HR-120™ improved stage 1 shroud

Spline Seal Arrangement (GE Exclusive Design): The new cloth seal arrangement illustrated in *Figure 93* 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™ Material: 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. *(See Figure 93.)* The new stage 1 shroud material provides a 3X improvement in low cycle fatigue 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.

Turbine Sealing Improvements

Stage 1 Shroud Abradable Coating Uprate (FS6A)

The stage 1 shroud blocks can be coated with an abradable coating on the inner circumference. *(See Figure 94.)* The abradable coating is designed to wear away (in the event of a bucket tip rub) without removing any bucket tip material. It allows tighter clearances between the bucket and shroud, therefore yielding performance improvements.

Clearances between static and rotating components allow the combustion gas to leak past the airfoil section of the buckets. These clearances are influenced by transient thermal growth, rotor alignment, rotor sag, and turbine shell out-of-roundness. The abradable coating compensates for these factors to reduce the required clearance. This reduces bucket tip leakage, which leads to an improvement in turbine section efficiency.

Figure 94. Stage 1 shrouds coated with abradable coating

Prior to application of the abradable coating, the shroud block is grit-blasted to remove the 7-mil of hard coating typically applied by the shroud block manufacturer. The abradable coating is a 47-mil layer of GT-50 coating comprised of CoNiCrAlY alloy with polyester, and is suitable for use with a non-tipped blade that does have a hard/abrasive tip coating. The net result is a 40-mil clearance reduction.

The abradable coating on the Stage 1 shroud blocks gives +0.7% increased output power and an improved heat rate of –0.7%. Abradable coating addresses performance benefits by clearance reduction, even under conditions of rotor misalignment and casing out of roundness. *(See Figure 95.)*

Benefit:

Model	*Output*	*Heat Rate*
MS6001B	*+0.7%*	*-0.7%*

Note: Negative heat rate changes are an improvement.

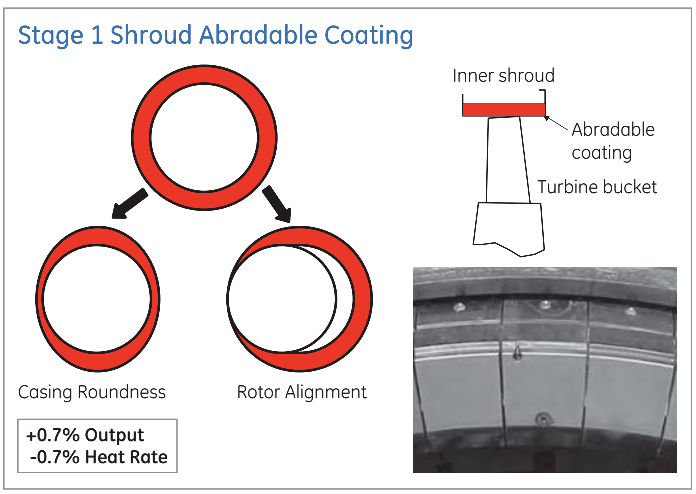


Figure 95. Abradable coating increases performance when rotor is not 100% aligned or casing is out of round

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

Honeycomb seals are designed to reduce leakage associated with hot gases that flow around the tips of the buckets—thereby improving both heat rate and output. In the past, clearances between the bucket shroud tips and the casing shrouds were set based upon expected transients that tend to close (and open) the clearances. The clearance had to be large enough to allow these transients to occur without permitting contact between the bucket tip and the shroud. As a result, the steady-state running clearance was typically larger than it needed to be from an efficiency standpoint.

To provide relatively tight clearances during steady-state operation, honeycomb seals allow contact between the bucket tip and the casing shrouds. Strips of honeycomb material made of a high-temperature, oxidation-resistant alloy are brazed between the teeth on the casing shrouds. “Cutter teeth” on the leading edge of the shrouded 2nd and 3rd stage bucket tip rails act to “cut” the honeycomb material away when contact occurs during transients. This produces steady-state running clearances that are—on an absolute basis—no larger than the difference between the steady state and the transient clearances. The effective clearance is actually tighter than the absolute clearance since the resulting groove in the honeycomb provides a tighter labyrinth seal than could be obtained with solid materials. Honeycomb shrouds also reduce performance degradation by maintaining tighter clearances throughout the life of the shroud. *(See Figure 96.)*

Honeycomb seals are designed to reduce bucket tip leakage, resulting in an improved heat rate and output. As a minimum, 50% of the buckets in a given row will need cutter teeth to ensure proper performance of the honeycomb material and achieve a +0.35% increase in output with a –0.35% decrease in heat rate for stage 2, and 0.25% increase in output with a –0.25% decrease in heat rate for stage 3.

Benefit:

Model	*Output*	*Heat Rate*
MS6001 A/B Stage 2	*+0.35%*	*-0.35%*
MS6001 A/B Stage 3	*+0.25%*	*-0.25%*

Note: Negative heat rate changes are an improvement.

Honeycomb allows contact between the bucket tip and casing shrouds during transient operation and provides relatively tight clearances during steady-state operation. *(See Figure 97.)* 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). Installation of honeycomb shrouds requires buckets with cutter teeth. As mentioned, current production stage 2 and 3 buckets have cutter teeth.

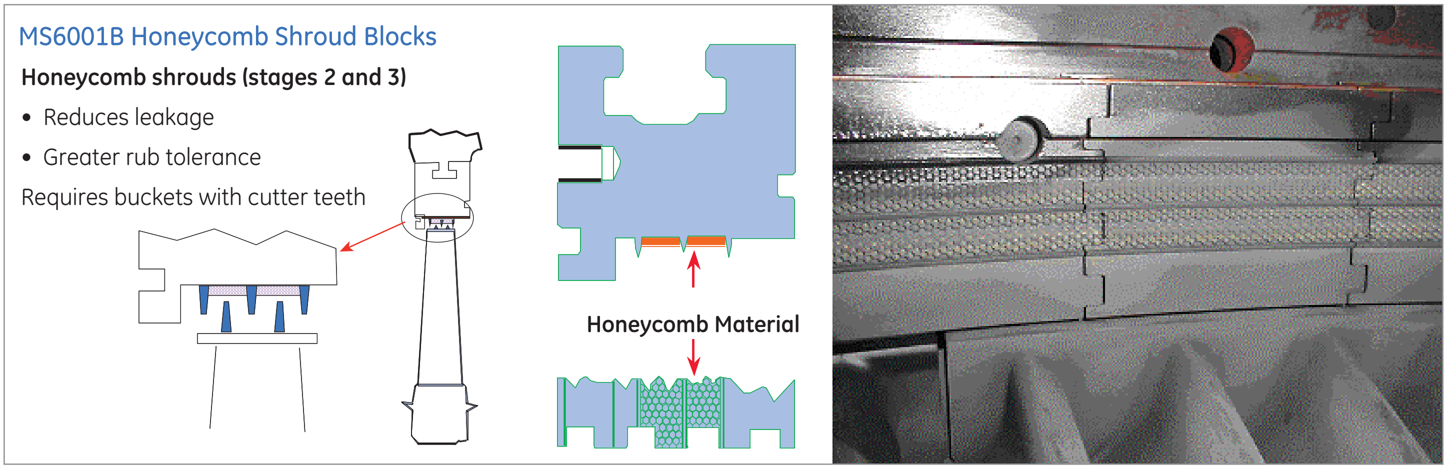


Figure 96. Stage 2 shroud with honeycomb sealing

Stage 2 Nozzle Interstage Brush Seal Uprate with New Diameter Diaphragm Purge Holes and New S13 Extraction Orifices (FS2Z)

The 2nd stage nozzle/diaphragm assembly contains a radial high-low labyrinth seal that reduces flow leakage across the diaphragm and the turbine rotor from stage 1 aft into stage 2 forward wheelspace. The interstage brush seal further reduces this leakage and hence reduces the cooling air (purge air) flow requirements into the stage 1 aft wheelspace. *(See Figure 98.)*

Reduction of cooling airflow losses allows more air to flow through the combustion system, thereby improving overall gas turbine performance. Cooling airflow to the 2nd stage forward wheel space will be reduced, but this flow is currently larger than required.

Benefit:

Model	*Output*	*Heat Rate*
MS6001 A/B	*+1.0%*	*-0.5%*

Note: Negative heat rate changes are an improvement.

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 wheelspace area. When added to a unit, the interstage brush seal further reduces this leakage. *(See Figure 99a.)* 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.

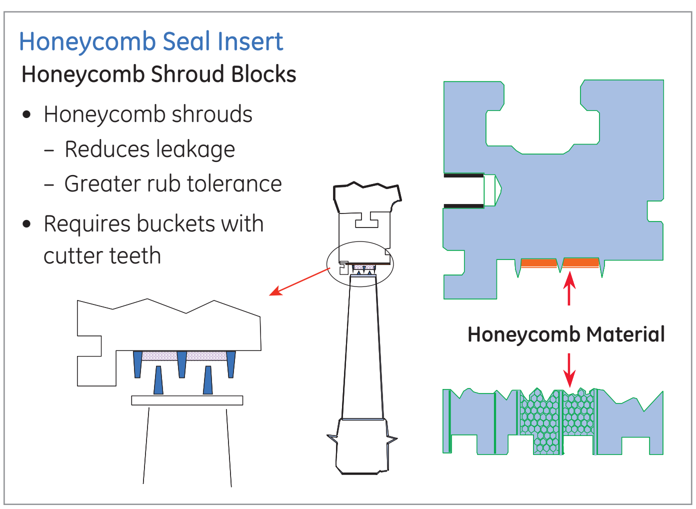


Figure 97. Stage 2 honeycomb inner shroud design

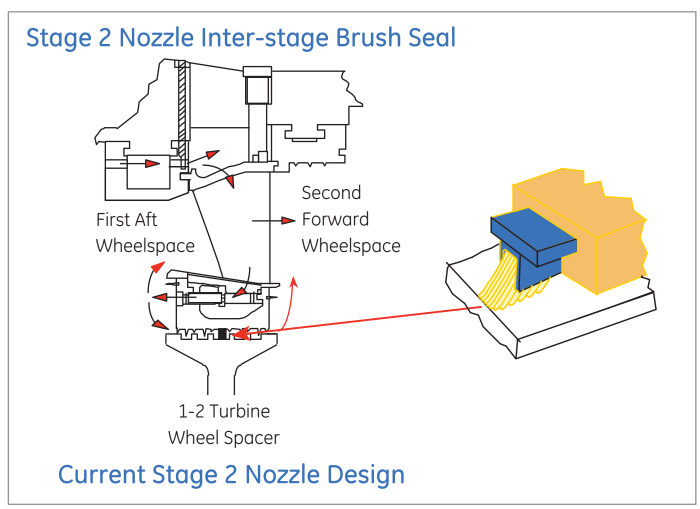


Figure 98. Stage 2 nozzle interstage brush seal

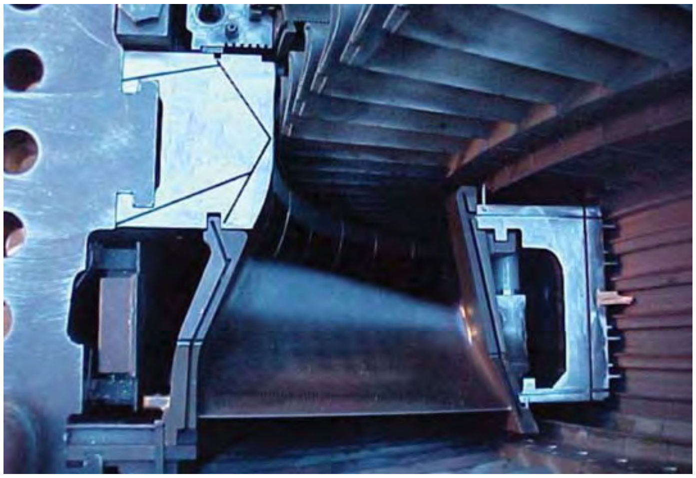


Figure 99a. Installed interstage brush seal

In testing, the sealing efficiency of a single brush is found to be 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 wheelspace area.

Turbine Uprate Packages

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

Operational Flexibility (OpFlex*) Package for DLN1 (FG2R)

The E-class OpFlex Enhancements Package utilizes Corrected Parameter Control (CPC) to expand the low-emissions operating envelope and enhance the operational flexibility of MS6001B gas turbines with DLN1 combustors. The package includes: Extended Turndown, which significantly improves cold-day low emissions turndown capability; Autotune which eliminates the need for periodic combustor re-tunes to maintain low-emissions; and Low-NO_X Variable Peak, which provides multiple peak loading options including full, variable, and low-NO_X peaking capability.

The E-class OpFlex Enhancements Package provides the following benefits:

- *Extended Turndown* significantly reduces the amount of fuel consumed to operate at minimum low-emissions load during cold ambient conditions. This can improve the economics to remain on-line during off-peak market conditions, reduce shutdown and start-up costs, and the need for turbine maintenance associated with cyclic operation. Current maximum low-emissions turndown is approximately 60% load. With Extended Turndown, it is estimated that a MS6001B with a 15 ppm NO_X DLN1 system, can maintain CO (<25 ppm) emissions capability down to as low as 50% of base load at ambient temperatures as low as ~0°F. Low-NO_X (<15 ppm) operation can be maintained down to as low as 45% load, at ambient conditions of ~40°F and below. Actual turndown capability is unit-specific, and is a function of DLN combustion system design and hardware, site conditions, initial combustor tuning settings, etc.
- *Autotune* reduces fuel costs by eliminating the need for periodic manual DLN1 combustor tuning (and the associated turbine operation) needed to ensure low emissions and stable combustor operation across the full range of ambient conditions. Autotune also improves operator confidence that turbine operation can be maintained within emission limits, and may also provide increased performance by enabling operation closer to emissions limits, without increasing the risk of exceeding limits.
- *Low-NOx Variable Peak* provides improved peaking flexibility, including greater flexibility to manage the maintenance factor impact of peak firing. Operators can select from among the following OpFlex peaking modes:
  - *Low-NOx Peak:* To achieve maximum output possible while maintaining low NO_X emissions levels (assuming the unit is currently NO_X and CO compliant), to provide increased output on hot humid days, when demand for peaking power is at a premium
  - *Variable Peak:* To achieve specific megawatt output set-point defined by the operator or by Automatic Generation Control (AGC)
  - *Maximum Peak:* To achieve maximum capability, up to 100°F above base-load firing temperature, to provide increased output on hot humid day, while maintaining NO_X emissions below approximately 25 ppm

GE Mark V (Rev B), Ve, VI, or VIe controls are currently required for this modification. The unit Continuous Emissions Monitoring System (CEMS) must be adequate for interface to the control system. For operation with the Mark V control system, the unit must be configured for gas only operation. It is assumed that the candidate unit for modification is a gas-only unit with a Mark V (Rev B) panel. If these assumptions are incorrect, additional scope will be required. Sufficient I/O must be available in the control panel. A copy of the M6B file (Unit 1 directory for Mark V) for each unit to be uprated is required from the site. Based on review of the control system configuration additional scope may be required.

The E-class OpFlex Enhancements Package provides the following performance improvements:

- Extended Turndown combines CPC control with revised Inlet Bleed Heat scheduling to enable low-emissions operation down to lower load levels, in cold, dry ambient conditions. Currently maximum low-emissions turndown is approximately 60% load. With Extended Turndown, it is estimated that, for a MS6001B with a 15 ppm DLN1 system, low-CO (<25 ppm) operation can be maintained down to as low as 50% of base load at ambient temperatures as low as ~0°F. Low-NO_X (<15 ppm) operation can be maintained down to as low as 45% load, at ambient conditions of ~40°F and below. Actual turndown capability is unit-specific, and is a function of DLN combustion system design and hardware, site conditions, initial combustor tuning settings, etc.
- Autotune may provide increased performance by enabling operation closer to emissions limits, without increasing the risk of exceeding emissions limits. *(See Figure 99b.)* Low-NO_X Variable Peak provides:
  - Up to 6 percent increased output with low NO_X emissions on hot humid days, when demand for peaking power is at a premium (typically below 15 ppm NO_X for the MS6001B with DLN1).

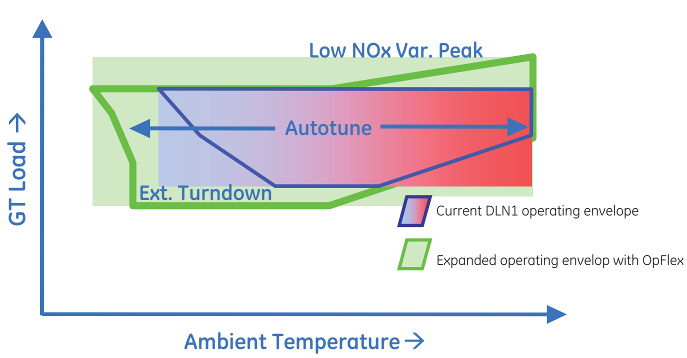


Figure 99b. Expansion of DLN1 low-emissions operating envelope with OpFlex Package

  - Up to 7.5 percent increased output with the maximum +100°F peak fire on hot humid days, while maintaining NO_X emissions below approximately 25 ppm
  - Flexibility to vary the amount of peaking between base load and the maximum +100°F, as selected by the operator or by AGC
  - Flexibility to manage the maintenance factor impact of peak firing

Firing Temperature Uprate +35F (FT4L)

This modification will increase the base firing temperature of any MS6001 by an additional +35°F. This uprate involves changing the majority of the hot gas path components to current production, new unit Advanced Technology configuration. With the firing temperature uprate, there are several pieces of hardware that are required and some that are options. The objective of this uprate is to improved performance, increased reliability and availability, and reduced maintenance costs.

Benefit:

Model	*Output*	*Heat Rate*
MS6001 A/B	*+5.0%*	*-1.4%*

Note:

Figures shown assume that all the required uprates in the following list are installed. Negative heat rate change is an improvement.

The following are the needed and optional advanced technology components for a +35°F firing temperature increase. Included are optional items available as part of the complete advanced technology uprate to achieve maximum performance improvement. If more information is required for a specific component, please refer to the appropriate sourcebook article or contact GE Application Engineering.

- GTD-111, Directionally Solidified, Perimeter Cooled, Blunt Leading Edge Stage 1 Buckets (FS4A)
- Improved Cooling Stage 1 Nozzle with Chordal Hinge and Spline Seals on Inner Segment (FS2J)
- HR-120™ Stage 1 Shroud Blocks with improved Spline Sealing (FS2Y)
- IN-738™ Stage 2 Buckets with Advanced Cooling, Scalloped Shroud Tips and Cutter Teeth (FS4B)
- GTD-222 Stage 2 Nozzle with reduced cooling flow (FS1P)

- IN-738™ Stage 3 Buckets with Scalloped Interlocking Shroud Tips and Cutter Teeth (FS2K)
- GTD-450 Reduced Chamber IGVs (Pre-1987) (FT4C)
- GTD-222 Stage 3 Nozzle (FS1R)
- Slot cooled liners with TBC (FR1G)
- Nimonic-263™ Transition Pieces with TBC (FR2B)
- Firing Temperature Increase +35°F (FT4L)

The FT4L uprate provides improved heat rate and increased output due to the increase in firing temperature and the reduction in turbine wheel space cooling flow. Estimated performance improvements will vary depending on the present machine unit configuration.

Firing Temperature Uprate to 2084F (FT4P)

With the introduction of the MS6001B in 1981, the firing temperature for the MS6001 was stated as 2020°F. After performance data collection and analysis by GE performance engineers of a wide selection of PG6541 gas turbines and after re-modeling of the GE firing temperature calculation program, it was determined that the true firing temperature reference of these units was 2042°F. In 1996, the stated MS6001B firing temperature reference was changed from 2020°F to 2042°F, to reflect these correct findings.

When GE offered the +35°F firing temperature uprate, this referred to +35°F above the true firing temperature reference of 2042°F, which provides Advanced Technology Uprate gas turbines with an uprated firing temperature of 2077°F. There has been some confusion in sales literature which quotes +35°F above the older temperature of 2020°F (actually 2042°F) for an uprate to 2055°F (actually 2077°F). The true firing temperature is correctly stated as 2077°F after the +35°F uprate.

Benefit:

Current Production models (PG6581B) have a slightly higher true firing temperature reference of 2084°F. This higher firing temperature is now available for all earlier models provided that the components listed in Figure 10 and Figure 11 are installed. An additional output increase of 0.2% is achieved over the 2077°F firing temperature.

Figures 8–11 list the sourcebook uprates and associated codes required to increase firing temperature to 2084°F, as well as for advanced seals and other optional uprates that can be installed. Some items such as steam for power augmentation require a CM&U proposal from GE Application Engineering before output and heat rate can be quoted. The PG6571B model was only available as a retrofit package. All MS6001 gas turbines shipped before 1999 can be uprated to 2084°F by including many of the sealing modifications discussed above, a speed increase, and new HGP components which allow the unit to operate at the new 2084°F firing temperature.

Rotor Speed Increase (FP4D/E)

GE introduced a speed increase for the MS6001 in 1995, to increase the mass airflow through the turbine and hence increase output. This increased the speed from 5104 rpm to 5133 rpm. More recently a further speed increase to 5163 rpm was introduced.

Benefit:

MS6001 gas turbines are suitable for this increase in speed, giving a 0.5% increased output (5133 to 5163), providing that the new perimeter-cooled S1Bs and the 6- or 7-hole S2Bs are fitted. To achieve this uprate, the complete load gearbox is normally replaced.

PG6581B Performance Improvement Option Packages

Performance improvement options are available for PG6581B units. The following CM&U performance value packages (described earlier) have been recently introduced as an optional Performance Improvement Package (PIP) for additional improvement in Gas Turbine performance. See *Figure 100* for performance improvement values of an example PIP.

- Advanced Aero Stage 3 buckets and Nozzles (FS4K & FS4L)
- Stage 1 Shroud Abradable Coating (FS6A)
- Stage 2 Nozzle Interstage Brush Seal (FS2Z) with new S2N diaphragm purge holes diameter and new S13 extraction orifices

Unit Rotor Interchangeability Studies

Operators are likely to eventually desire a spare rotor, especially for MS6001B units.

GE Application Engineering provides any MS6001B operator with a rotor interchangeability study upon a request placed with our Sales

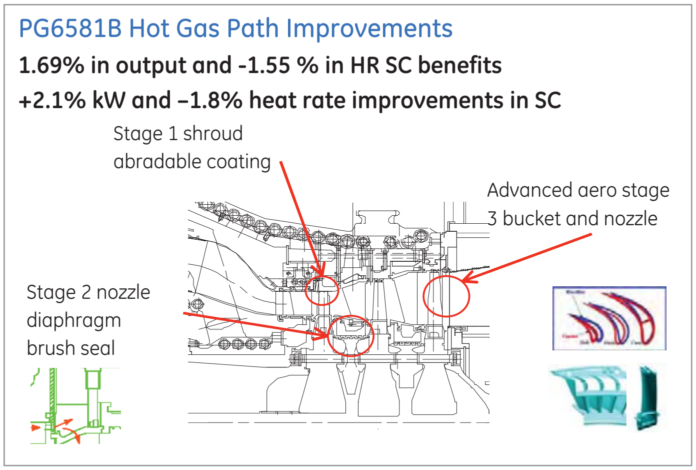


Figure 100. Example of Performance Improvement Package (PIP)

or Commercial Teams. These studies include: compressor forward stub shaft; turbine distance piece; turbine aft stub shaft, and S14 row blading.

As illustrated in *Figure 101*, the compatibility of putting a new or refurbished MS6001B rotor into an existing unit is situated at three locations:

- The compressor forward stub shaft design: undercut or not in the shaft adjacent to the current active thrust face
- The turbine aft shaft wheel design: groove width for journal bearing #2 dimension
- S14 row blading axial position on PG6518B units is modified compared to PG6561B and older units to allow S13 air extraction for S2N cooling.

Compartment and Exhaust Improvements

Turbine Compartment Dual 100HP Fan Uprate (FF1E)

This modification 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.

Benefit:

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 CO2/Halon pressure actuated spring release latch. This latch is operated by

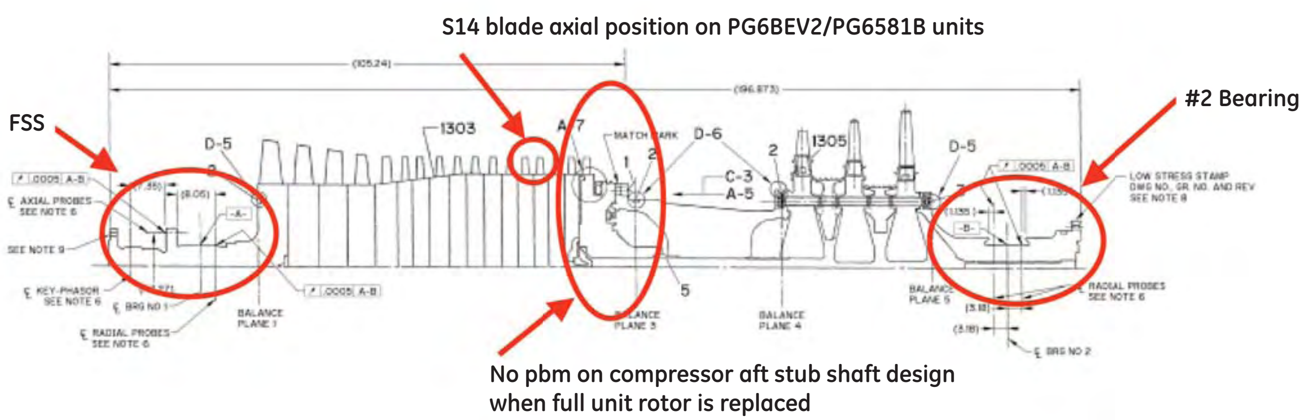


Figure 101. Critical locations to be considered when evaluating the suitability of a rotor for installation

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 CO2 latch are bolted to the fan outlet and shipped as a unit. It should be noted that the CO2 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.

Replaceable Exhaust Thermocouples Uprate (FK5K)

Two options are now available for replacement exhaust thermocouple kits: Option I (see FK5B) is the existing extended (or long-lead) design; and Option II (see FK5K) is a newer short-lead design. The long-lead design is a one-piece thermocouple/lead, terminating in junction boxes located outside the load compartments that are away from the high temperatures that can affect old design thermocouples. 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.

Benefit:

There are distinct benefits associated with the long-lead or extended exhaust thermocouples. They reduce the rate of thermal deterioration for longer life, they provide greater reliability and they offer a capital cost alternative to the newly designed short-lead exhaust thermocouple. The mineral insulation and metallic sheath also provide superior protection against high temperature insulation breakdown, grounds and shorts.

The long-lead or extended exhaust thermocouples reduce the rate of thermal deterioration and therefore have longer life. They provide greater reliability and offer a lower life-cycle-cost alternative to the short-lead exhaust thermocouple. The mineral insulation and metallic sheath also provide superior protection against high temperature insulation breakdown, grounds, and shorts.

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. But, 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.

Corrosion and Heat Resistant Uprated Inlets and Exhaust Systems

GE offers uprated Corrosion and Heat Resistant Original Equipment Manufacturer (CHROEM*) for inlets and exhausts. *Figures 102–105* illustrate the blue colored inlet and exhaust systems offered: exhaust frame and aft diffuser; enclosures and houses; plenums; stacks; silencers; ducts; and expansion joint. Over time, exhaust plenums experience hot flanges and outer skin concerns. Excessive

CHROEM Gas Turbine Inlet & Exhaust Systems

Corrosion and Heat Resistant Original Equipment Manufacturer (CHROEM) products include:

- Corrosion and heat protection
- Acoustic protection systems
- Other items related to this area of the turbine

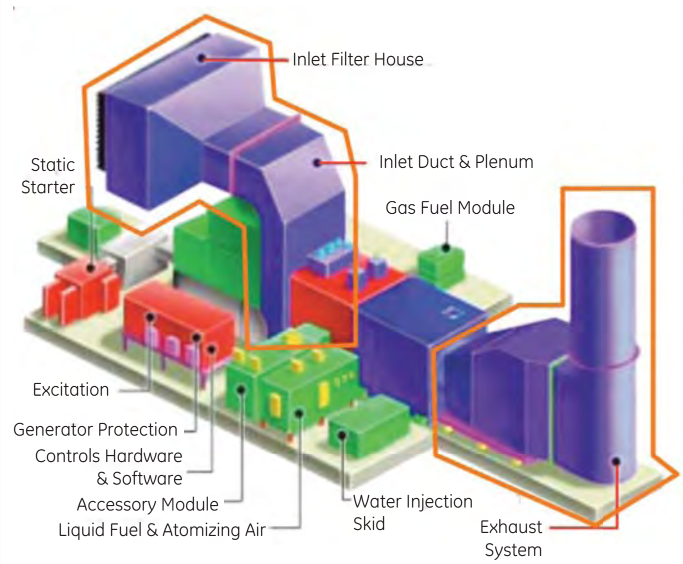


Figure 102. CHROEM stands for Corrosion and Heat Resistant Original Equipment Manufacturer

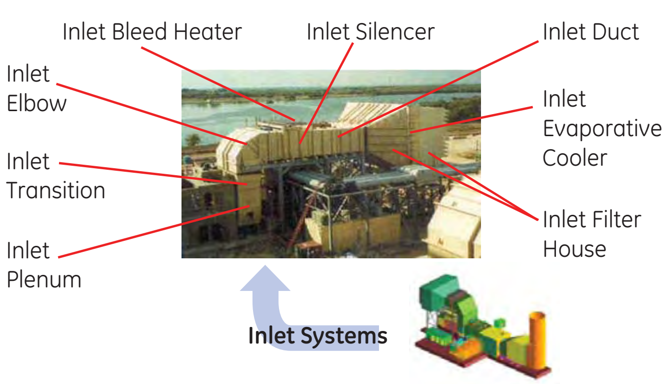
CHROEM Product Focus

- Inlet filter house (A040)
- Inlet system (A041)
  - Inlet plenum (MLI 1612)
  - Inlet silencer (MLI A054)
  - Inlet system (MLI 0809)
- Exhaust system (A042)
  - Exhaust system (MLI A066, A071, A096, A097)
  - Exhaust plenum (MLI 1625)
  - Exhaust silencer (MLI A086)
  - Exhaust frame (MLI 0706, 0718)

Figure 103. CHROEM products available from GE

thermal movement contributes to destruction of control cables and severe turbulence that can cause liner damage. To ensure that customers have access to high quality gas turbine exhaust plenums, GE offers retrofit re-designed CHROEM exhaust plenums as part of its product offerings. *(See Figure 106.)*

Areas of the Gas Turbine Covered by CHROEM Inlet Systems



Inlet Systems
- Plenum
- Silencers
- Ductwork

Inlet Filter House
- Filters
- Media
- Cooling

Figure 104. CHROEM products for inlets

Areas of the Gas Turbine Covered by CHROEM Exhaust Systems

Exhaust Systems
- Frames
- Diffusers
- Plenums
- Silencers
- Ductwork
- Stacks
- Expansion joints

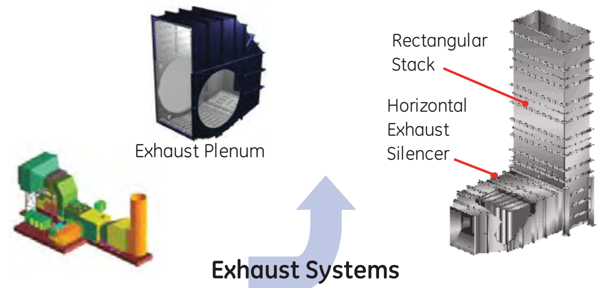


Figure 105. CHROEM products for exhaust

The re-designed plenums can 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. These advancements reduce thermal stress gradients, and thereby lead to longer plenum life. External wall temperatures are greatly reduced, leading to lowering of temperature in the adjoining compartments and therefore increased reliability. *(See Figure 107.)*

MS6001B Plenum Assembly

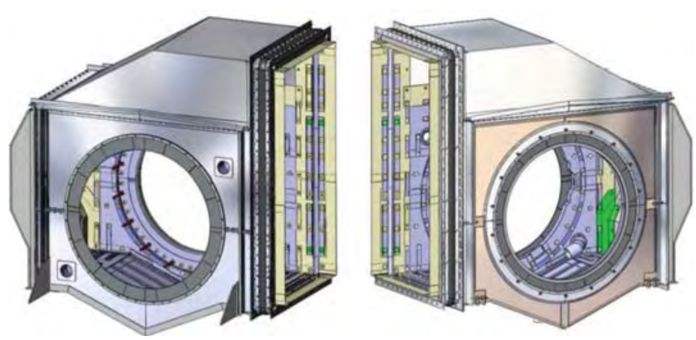


Figure 106. Improved CHROEM exhaust plenum

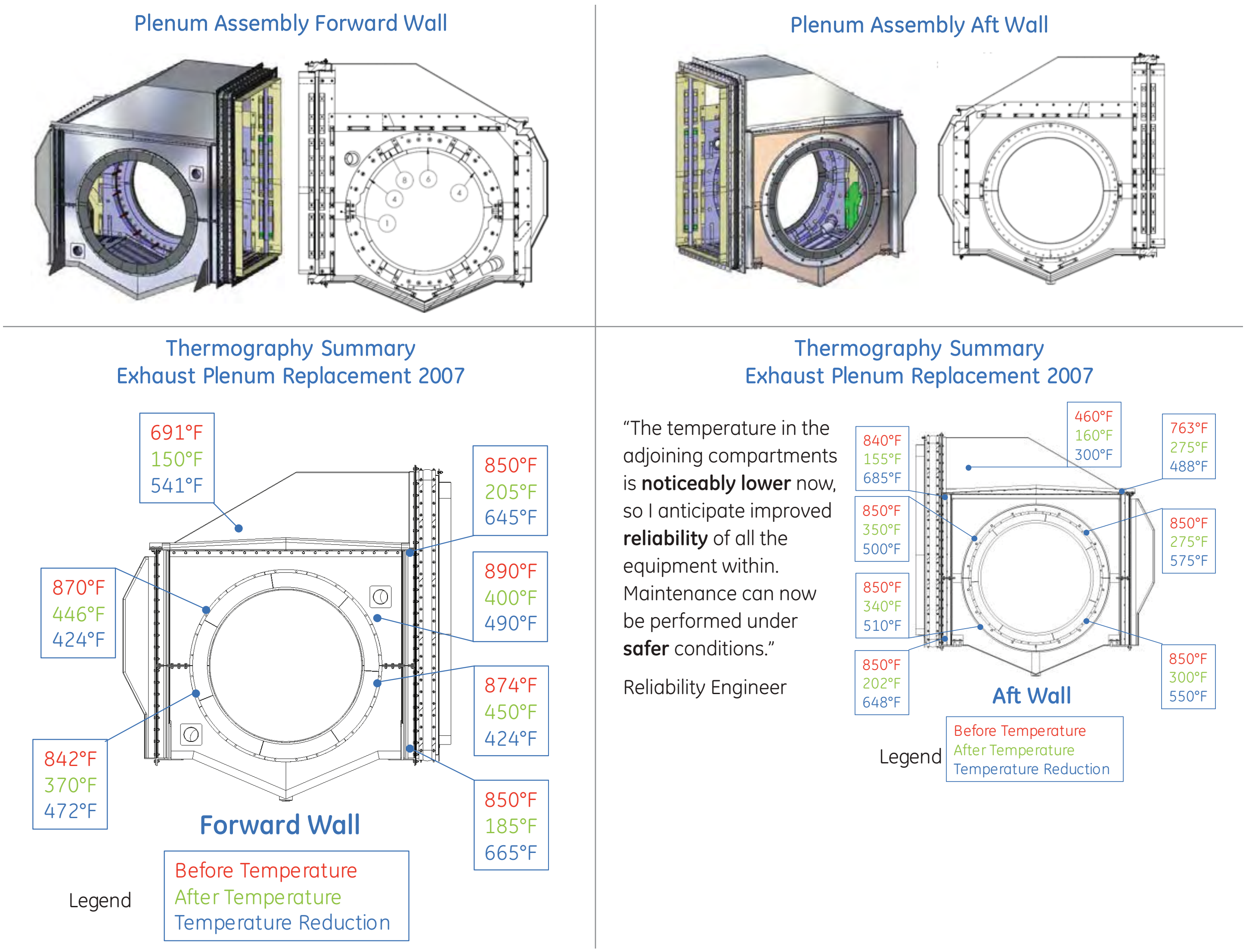


Figure 107. The advanced CHROEM designs offered by GE are measured to greatly lower the wall temperature of exhaust plenum

Summary

GE has uprate packages available for all MS6001 gas turbines in the field. These uprates can be done during scheduled outages on a piece-meal basis or all at the same outage, depending on when the currently installed hardware life is due to expire.

GE is pleased and freely available to provide detailed technical proposals for owners of MS6001 gas turbines, and to establish performance and/or reliability improvements for those specific turbines at our customer's sites. If the gas turbine is installed in Combined Cycle (CC), Cogen, or Combined Heat and Power (CHP), then GE can also advise on impact to the steam cycle resulting from installation of uprates described in this document.

- GE Energy has advanced technology uprate packages available to uprate all MS6001 heavy-duty gas turbines to improve their performance, efficiency, and reliability
- Uprates are available to increase maintenance intervals and reduce repairs.
- Rotor and/or parts interchangeability studies are available
- Impact on steam cycle can be provided by GE upon request
- Performance guarantees are available upon request

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